SOUTH AFRICA TEXAS ARIZONA CALIFORNIA COLORADO

RENEWABLE ENERGY GRID INTEGRATION STUDY TOUR

NOVEMBER 10–22, 2013

DELEGATION FROM Eskom

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SOUTH AFRICA TEXAS ARIZONA CALIFORNIA COLORADO
RENEWABLE ENERGY GRID INTEGRATION STUDY TOUR

ITINERARY

AUSTIN, TEXAS	
SUNDAY, NOVEMBER 10, 2013	
10:00am	Delegation arrives in Austin, TX (AUS) on Delta 201/Delta 1868 via Atlanta. Delegates will proceed through customs in ATL and are greeted by BCIU at the airport in Austin.
10:30am	Departure for the Omni Austin Hotel, 700 San Jacinto Blvd, Austin, TX.
4:00pm	BCIU Orientation Meeting & Dinner, Eddie V's, 301 E. 5th Street, Austin, TX.
MONDAY, NOVEMBER 11, 2013	
8:30am	**Lower Colorado River Authority (LCRA)**, 3505 Montopolis Drive, Austin, TX
10:30am	**Austin Energy**, 721 Barton Springs Rd, Austin, TX
2:00pm	**Electric Reliability Council of Texas (ERCOT)**, 800 Airport Drive, Taylor, TX 76574
TUESDAY, NOVEMBER 12, 2013	
7:00am	Delegation departs from Austin, TX for Houston, TX via bus.
HOUSTON, TEXAS	
10:30am	**Clean Line Energy**, 1001 McKinney Street, Suite 700, Houston, TX
12:30pm	**EDP Renováveis**, 808 Travis St #700, Houston, TX
2:45pm	**GE,** location TBC
5:30pm	**Networking Reception "U.S. Investment and Export Opportunities in South Africa's Independent Power Projects"**, Marriott Houston Energy Corridor, Petroleum Grill, 16011 Katy Freeway, Houston, TX
WEDNESDAY, NOVEMBER 13, 2013	
9:15am	Delegation departs from Houston, TX (IAH) on United 4650 to Tucson, Arizona.
TUCSON, ARIZONA	
11:00am	Delegation arrives in Tucson, Arizona (TUS). Departure for Lunch.
2:30pm	**First Solar Avra Valley Solar Generating Station Site Visit**, Avra Valley, 9602 N. Garvey Rd, Marana, AZ, 85653.

*As of November 8, 2013

SOUTH AFRICA

TEXAS ARIZONA CALIFORNIA COLORADO

RENEWABLE ENERGY GRID INTEGRATION STUDY TOUR

5:30pm	Departure for the Hilton Tucson East, 7600 East Broadway, Tucson, AZ.

THURSDAY, NOVEMBER 14, 2013

8:30am	**Areva and Tucson Electric Power (TEP)**, 4350 East Irvington Road, Tucson, AZ 85714

PHOENIX, ARIZONA

12:00pm	**First Solar**, PV National Control Center, 3740 S. Signal Butte Rd., Mesa, AZ, 85212
1:00pm	Drive to **First Solar Headquarters**, 350 West Washington Street, Suite 600, Tempe, AZ 85281
1:30pm	**First Solar**, Lunch and Presentations
3:30pm	**ABB/PowerOne**, 350 West Washington Street, Suite 600, Tempe, AZ
7:11pm	Delegation departs from Phoenix (PHX) on Delta 4740 to Los Angeles, California (LAX).

SOUTHERN CALIFORNIA

7:39pm	Delegation arrives in Los Angeles, California (LAX). Departure for the Costa Mesa Marriott, 500 Anton Blvd, Costa Mesa, CA.

FRIDAY, NOVEMBER 15, 2013

9:00am	**Business Briefing** at the Costa Mesa Marriott, 500 Anton Blvd, Costa Mesa, CA.
12:00pm	**ABB, Inc.**, Costa Mesa Marriott
2:30pm	**Black & Veatch**, Costa Mesa Marriott

SATURDAY, NOVEMBER 16, 2013

Free time for site seeing & shopping in Los Angeles, California.
Entertainment options provided in the delegate handbooks.

SUNDAY, NOVEMBER 17, 2013

Free time for site seeing & shopping in Los Angeles & San Diego, California.
Entertainment options provided in the delegate handbooks.

1:00pm	Delegation departs from Costa Mesa, CA for San Diego, CA via bus.
3:30pm	Delegation arrives at the San Diego Marriott Gaslamp Quarter Hotel, 660 K Street, San Diego, California.

MONDAY, NOVEMBER 18, 2013

10:30am	**San Diego Gas & Electric and Sempra Energy**, 8326 Century Park Ct, San Diego, CA
6:55pm	Delegation departs from San Diego (SAN) on Southwest 458 to Sacramento (SMF).

SACRAMENTO, CALIFORNIA

8:30pm	Delegation arrives in Sacramento, CA. Departure for the Hilton Sacramento Arden West, 2200 Harvard Street, Sacramento, CA.

*As of November 8, 2013

SOUTH AFRICA — TEXAS ARIZONA CALIFORNIA COLORADO
RENEWABLE ENERGY GRID INTEGRATION STUDY TOUR

TUESDAY, NOVEMBER 19, 2013	
9:00am	**California Energy Commission**, 770 L Street, Sacramento, CA
1:00pm	**Sacramento Municipal Utility District (SMUD)**, 6301 S Street, Sacramento, CA
4:00pm	**California ISO (CASIO)/Utility Variable Generation Group**, 250 Outcropping Way, Folsom, CA
WEDNESDAY, NOVEMBER 20, 2013	
8:00am	Delegation departs from Sacramento, California (SMF) on Southwest 599 to Denver, CO.
DENVER, COLORADO	
11:20am	Delegation arrives in Denver, Colorado. Depart for the Sheraton Downtown Denver Hotel, 1550 Court Place, Denver, CO.
THURSDAY, NOVEMBER 21, 2013	
9:00am	**National Renewable Energy Laboratory (NREL)**, 1617 Cole Boulevard, Golden, CO
FRIDAY, NOVEMBER 22, 2013	
10:00am	**RES-Americas,** Cedar Point Wind Farm Site Visit, Limon, CO
2:30pm	**Western Area Power Administration (WAPA),** 12155 W Alameda Pkwy, Lakewood, CO
SATURDAY, NOVEMBER 23, 2013	
10:20am	Delegation departs from Denver, CO on Delta 1578 via Atlanta to Johannesburg.

*As of November 8, 2013

USTDA
United States Trade and Development Agency

AN OVERVIEW

USTDA PROGRAMS AND ACTIVITIES

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The U.S. Trade and Development Agency (USTDA) helps companies create U.S. jobs through the export of U.S. goods and services for priority development projects in emerging economies. USTDA links U.S. businesses to export opportunities by funding project planning activities, pilot projects, and reverse trade missions while creating sustainable infrastructure and economic growth in partner countries.

USTDA Programs

USTDA's promotes economic growth in emerging economies by facilitating the participation of U.S. businesses in the planning and execution of priority development projects in host countries. The Agency's objectives are to help build the infrastructure for trade, match U.S. technological expertise with overseas development needs, and help create lasting business partnerships between the United States and emerging market economies.

USTDA advances these objectives through its two key programs, the International Business Partnership Program and the Project Development Program.

The International Business Partnership Program

In support of the National Export Initiative, USTDA launched the International Business Partnership Program (IBPP) designed to connect foreign buyers with U.S. manufacturers and service providers in order to open new export markets and commercial opportunities around the world for U.S. companies through the following activities:

Reverse Trade Missions

As part of the IBPP, USTDA increased its investment in reverse trade missions, which bring foreign buyers to the United States, pending upcoming procurements, in order to observe the design, manufacture and demonstration of U.S. products and services that achieve their development goals. These strategically planned missions also present excellent opportunities for U.S. businesses to establish or enhance relationships with prospective overseas customers.

Conferences and Workshops

USTDA organizes worldwide conferences and workshops to connect U.S. firms with foreign project sponsors. These sector or project-specific events are designed to showcase U.S. goods, services and technologies to foreign buyers. U.S. firms also have the opportunity to meet one-on-one with overseas project sponsors. These events also provide U.S. companies with an understanding of U.S. government programs and the role they can play in supporting increased exports, from advocacy support to export financing options.

NEI NATIONAL EXPORT INITIATIVE www.export.gov

USTDA Supports the NEI's mission as a member of the President's Export Promotion Cabinet

AN OVERVIEW

USTDA PROGRAMS AND ACTIVITIES

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Project Development Program

USTDA provides grants directly to overseas sponsors who, in turn, select U.S. companies to perform Agency-funded project development activities. An overseas sponsor is a local entity, public or private, with the decision-making authority and ability to implement a project. USTDA's priority sectors include: clean energy and energy efficiency, transportation, and information and communications technology.

Key project development program activities include:

Feasibility Studies and Pilot Projects

USTDA-funded and U.S.-led feasibility studies link foreign project sponsors with U.S. businesses at the critical early stage when technology options and project requirements are being defined. These studies provide the comprehensive analysis required for major infrastructure investments to achieve financing and implementation. In some cases, export opportunities depend on a demonstration of the U.S. seller's goods, services or technologies in the foreign buyer's setting. USTDA-funded pilot projects demonstrate the effectiveness of commercially proven U.S. solutions and provide the analysis, evaluation, and empirical data needed for potential foreign projects to secure funding.

Technical Assistance

USTDA advances economic development in partner countries by funding technical assistance that supports legal and regulatory reform related to commercial activities and infrastructure development, the establishment of industry standards, and other market-opening activities. These technical assistance programs facilitate favorable business and trade environments for U.S. goods and services.

Training Programs

In support of U.S. businesses, USTDA also provides training for foreign decision makers to support the sale of U.S. equipment and services overseas. Training can take place in either the United States or host country and it typically focuses on technology or regulatory requirements in order to give project sponsors a better understanding of U.S. capabilities and expertise related to a procurement.

Supporting Small Businesses

USTDA has served as a catalyst for U.S. small businesses to expand their international markets. The Agency partnered with the Small Business Administration (SBA) to increase small business participation in USTDA-sponsored events in order to raise their profile with international buyers, which has yielded significant results. Additionally, USTDA draws extensively on the expertise of small consulting and engineering firms across the country to provide a variety of services related to project definition and evaluation.

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USTDA by the Numbers

73:1 For every $1 invested in its programs, USTDA has generated $73 in U.S. exports

$45.8 Billion Since its establishment, USTDA's programs have contributed to over $45.8 billion in U.S. exports

USTDA
U.S. Trade and Development Agency

CLEAN ENERGY IN SUB-SAHARAN AFRICA

PROMOTING ECONOMIC DEVELOPMENT AND COMMERCIAL COOPERATION

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USTDA's reverse trade missions (RTM) are the mainstay of its International Business Partnership Program (IBPP). Created in 2010 in response to President Obama's National Export Initiative, the IBPP is USTDA's signature program for linking the U.S. private sector to foreign buyers. These visits are carefully planned to enable foreign decision makers to meet with U.S. businesses and to observe the manufacture, and demonstration of U.S. goods and services that can help them achieve their development goals. These RTMs also include meetings with financial institutions to observe financing options and technical and regulatory bodies that can assist with strengthening the project sponsor's technical capacity.

Through feasibility studies, technical assistance and pilot projects, USTDA's Project Development Program helps overseas project sponsors identify technological solutions and various sources of financing for priority infrastructure projects.

African Clean Energy Solutions Initiative

The centerpiece of USTDA's clean energy strategy in sub-Saharan Africa is the African Clean Energy Solutions (ACES) Initiative. Focus areas of the initiative include: (1) supporting power generation using clean energy sources; (2) modernizing transmission and distribution grids; and (3) promoting energy efficiency and demand-side management. Under this initiative, USTDA has contributed to developing clean energy projects with partner agencies. Intergovernmental initiatives include:

The U.S.-Africa Clean Energy Development and Finance Center (CEDFC) is an initiative by USTDA, the Overseas Private Investment Corporation (OPIC) and the Export-Import Bank of the United States to provide a coordinated approach to clean energy project development in sub-Saharan Africa. CEDFC is providing U.S. and sub-Saharan African energy project developers with a centralized means to identify and access U.S. government support for their clean energy export and investment needs.

The U.S.-Africa Clean Energy Finance Initiative (ACEF) is an innovative financing mechanism developed by USTDA, the U.S. State Department, and OPIC. The initiative aligns USTDA's project planning expertise and OPIC's financing and risk mitigation tools in new ways, to support private sector investment and increase support for U.S. businesses and exports in sub-Saharan Africa's clean energy sector.

These interagency initiatives, along with USTDA's regular energy portfolio, are in direct support of President Obama's Power Africa initiative, which will add more than 10,000 MW of cleaner, more efficient electricity generation capacity across the continent.

Doing Business In Africa

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Transmission and Distribution

Access to a stable electricity supply is a critical driver of sub-Saharan Africa's economic growth. In Ghana, USTDA funded a feasibility study for Ghana Grid Company (GRIDCo) to determine the technical and economic viability of expanding Ghana's electricity transmission network with a new 330 kilovolt power transmission line. When implemented, the project will create nearly 150 miles of new transmission linkages in southwest Ghana, stabilizing electricity supply in the sub-region and bringing access to electricity to areas previously disconnected from the national grid.

In Nigeria, USTDA funded an RTM to connect senior management of Nigeria's newly privatized distribution companies with U.S. companies that provide equipment and services in the electricity distribution sector, with a focus on loss reduction and smart grid technologies, as well as policies, regulations, financing mechanisms and management structures that can support the implementation of smart grid infrastructure in Nigeria.

Southern Africa Solar Power Initiative

Southern Africa has some of the highest potential for solar power generation. Through a series of RTMs, a technical workshop, and project planning activities, USTDA is fostering partnerships between the United States and Southern Africa in the sector. The first RTM of the initiative took place in January 2013, and included delegates representing public sector and financing organizations from Southern Africa. The delegates participated in meetings with U.S. government and private sector representatives, and visited technology labs and solar power plants across the country, including Solar Reserve's Crescent Dunes Solar Energy Project, and AREVA's Kimberlina Solar Power Plant in California, as well as First Solar's Silver State North Solar Project in Nevada.

The first RTM was followed by a workshop in South Africa, in May 2013 highlighting regional solar projects and initiatives, U.S. solar technologies, and policies, standards and financing mechanisms that can support innovation and sustainability in the solar power sector. U.S. participants included, General Electric and PricewaterhouseCoopers. A second RTM recently concluded in September 2013, focusing on the development of business-to-business partnerships by including private sector representatives from Southern Africa's solar power sector. The RTM included meetings with Bechtel and Parsons Brinckerhoff as well as a site visit to Ivanpah Solar Electric Generating System, owned by NRG Energy, Google, and BrightSource Energy.

Geothermal

Geothermal reserves in East Africa's Rift Valley have the potential to significantly increase the region's generation capacity. In Kenya alone, the World Bank estimates 10,000 megawatts in geothermal potential. To help capitalize on this potential, USTDA provided technical assistance to Kenya's Geothermal Development Company (GDC). The grant provided capacity training to GDC personnel, assisted in the development of feed-in tariffs supporting geothermal power generation, and established evaluation criteria for potential sector investment partners in these efforts.

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The U.S. Trade and Development Agency (USTDA) advances sustainable infrastructure and economic growth in emerging economies by funding project planning activities, pilot projects, and U.S. study tours. USTDA activities promote the use of U.S. goods and services for priority development projects that help build the infrastructure for trade.

USTDA Programs

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USTDA advances these objectives through its two key programs, the International Business Partnership Program and the Project Development Program.

U.S. study tours are the mainstay of USTDA's International Business Partnership Program (IBPP). Created in 2010, the IBPP is USTDA's signature program for linking U.S. technologies and expertise to priority development projects. These visits are carefully planned to enable overseas project sponsors to meet with U.S. businesses, technical experts, policymakers, and financiers that can help them achieve their development goals. These study tours also provide delegates with an opportunity to tour industrial development sites in the United States and to observe the manufacture and demonstration of state-of-the-art technologies first-hand.

Through feasibility studies, technical assistance, pilot projects and other forms of project planning assistance, USTDA's Project Development Program helps overseas project sponsors identify technological solutions and sources of financing for priority infrastructure projects.

USTDA in Sub-Saharan Africa

USTDA places a high priority on sub-Saharan Africa, working with qualified project sponsors to facilitate the implementation of priority infrastructure and development projects.

USTDA focuses its activities in strategic sectors that offer the greatest opportunity for developmental and commercial impact. These strategic sectors include clean energy, transportation, and telecommunications. Other sectors of interest include agribusiness and water.

The following page provides a representative sample of USTDA initiatives and activities in the region.

*Representatives from East Africa's transport sector participated in a USTDA-funded East Africa Railway **Modernization** Study Tour. The study tour included site visits and meetings with industry experts in Washington, D.C., Chicago, IL, Denver, CO, and Erie, PA.*

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USTDA IN SUB-SAHARAN AFRICA

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Clean Energy

U.S.-Africa Clean Energy Development and Finance Center (CEDFC): CEDFC, an initiative by USTDA, the Overseas Private Investment Corporation (OPIC) and the Export-Import Bank of the United States (Ex-Im Bank), provides a coordinated approach to developing and financing clean energy projects in sub-Saharan Africa.

Electricity Company of Ghana (ECG) Smart Grid Applications Feasibility Study: This feasibility study for ECG is evaluating the critical aspects of a smart grid applications project in southern Ghana, providing recommendations for a system that will address business process planning and decision making, while helping to bring sustainability to ECG's infrastructure.

Aviation

South Africa Aviation Initiative: This initiative supports the growth of safe, reliable aviation services in South Africa through the development of critical human capacity resources and closer professional and commercial partnerships between the U.S. and South African aviation sectors. Under the initiative, USTDA is funding a series of U.S. study tours, training programs, and project planning activities for key stakeholders from South Africa's aviation sector in partnership with the U.S. private sector.

Rail

Southern Africa Regional Rail Initiative: Through this initiative, USTDA is supporting the development of rail linkages and regional integration in Southern Africa. The initiative commenced with a technical workshop in Johannesburg. Subsequent activities will include study tours to familiarize regional stakeholders with innovative locomotive, signaling, and other rail sector technologies and services.

U.S. East Africa Railway Modernization Study Tour: This study tour allowed delegates from the Rift Valley Railways and the Government of Uganda to discuss industry best practices with U.S. rail sector experts and explore financing options with Ex-Im Bank and OPIC for priority projects in the sector.

Telecommunications

Khayelitsha and Mitchells Plain Digital Inclusion: USTDA has partnered with the City of Cape Town to assess options for expanding internet services in Khayelitsha and Mitchells Plain. When implemented, the new network will connect Khayelitsha and Mitchells Plain to Cape Town's existing fiber optic network and increase access to affordable, reliable telecommunications.

Contact us for more information:

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Blair Mersinger - Special Projects Manager
Chris Giglio - Project Analyst Contractor
Meredith Schuessler - Project Analyst Contractor
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ELECTRICITY TRANSMISSION AND DISTRIBUTION

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Recent Activities

USTDA sponsored a visit to the United States for senior officials from the Vietnam National Power Transmission Corporation (NPT) to connect them with U.S. electric power transmission technology providers. Having identified $5 billion worth of upgrades and investments that are needed for their network, NPT delegates had the opportunity to visit U.S. power transmission companies and equipment manufacturers as well as meet with consulting companies that could assist with service capabilities and construction management.

Shortly after the RTM, NPT and GE signed a memorandum of understanding to work together on a pilot to install GE's relay system on NPT's network. Thus far, NPT has purchased $11 million worth of GE equipment, and NPT and GE are currently working with the U.S. Export-Import Bank to purchase additional equipment valued at $36 million.

Delegates from NPT tour Georgia Power's substation facility

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eThekwini Smart Metering Feasibility Study in South Africa

In order to address concerns over South Africa's declining electricity reserve margin, USTDA awarded a grant to eThekwini Municipality to support the rollout of advanced electricity metering, or smart meters. USTDA's assistance promotes the application of innovative U.S. technologies that will enable South African electricity distributors to integrate energy-intensive users into a smart metering system.

Demand Response System Pilot Project in China

In support of the U.S.-China Energy Cooperation Program's efforts to open China's market to U.S.-manufactured technologies as the country continues to develop its energy infrastructure, USTDA funded a feasibility study and pilot project on the implementation of a smart grid demand response management system for the China State Grid Electric Power Research Institute (SGEPRI). U.S. companies provided the equipment for the pilot, and the results will assist SGEPRI in designing a national smart grid implementation strategy.

CESC Smart Grid Feasibility Study in India

USTDA is funding a feasibility study grant to CESC Ltd. for the implementation of smart grid technologies and practices across their electricity supply and distribution network in Kolkata, India. The study would develop requirements and specifications for a smart grid implementation roadmap for CESC and would address a range of improvements, including integrating smart meters and automated meter reading into CESC's distribution system.

Eastern Transmission Line Feasibility Study in Ghana

USTDA is funding a feasibility study to assist the Ghana Grid Company Limited, a state-owned power transmission company, in determining the technical and economic viability of reinforcing Ghana's electricity transmission network with new power transmission lines. The new lines would makes the electrification of unserved rural communities more affordable and accessible in the northern and eastern regions of Ghana.

Smart Grid Applications in Power Distribution in Turkey

USTDA is providing funding for a feasibility study that will introduce upgraded control systems and smart grid technology to the Başkent Elektrik Company in Turkey. The study will include a gap analysis, strategy proposal, estimate of investment requirements, and system integration recommendations for this newly privatized company.

Smart Grid Regulatory Framework Project in Mexico

USTDA is providing a grant to the Comisión Reguladora de Energía to provide technical assistance that will outline the key components of a regulatory framework to support smart grid deployment in Mexico.

Contact us for more information:

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U.S. Africa Clean Energy Finance (US-ACEF) Initiative

US-ACEF is an innovative, collaborative financing mechanism aligning U.S. government resources in new ways to catalyze significant private sector investment primarily focused on African clean energy infrastructure. The three main partners under the program are the U.S. Department of State, USTDA, and the Overseas Private Investment Corporation (OPIC). Under the four-year, $20 million program, USTDA will leverage its project planning expertise to support activities both eligible for and currently in OPIC's pipeline for private-sector transactions. The program will help ensure that otherwise technically and financially sound projects are implemented, rather than falling short because of lack of funding for critical "last mile" activities.

Eligibility Checklist

- Do you intend to apply for OPIC financing and/or insurance for purposes of financing and/or insuring the project?

  US-ACEF funds are intended for the purpose of leveraging USTDA's project planning expertise to support OPIC's existing and future pipeline of deals. Projects funded through US-ACEF must therefore intend to apply for OPIC financing and/or insurance as well meet OPIC's eligibility criteria.

- Is the proposed project in an US-ACEF eligible country?

  Please review the list of US-ACEF Eligible Countries

- Does the proposed project satisfy US-ACEF additionality criteria?

  US-ACEF funding will be considered additional if it achieves one or more of the following objectives:

  (i) ***Fills funding gap****: US-ACEF provides support for essential project development costs that the client or other financial partner does not otherwise have the financial resources to cover.*
  (ii) ***Project acceleration****: US-ACEF support will accelerate the project's development process by helping to meet the project development costs in a manner that improves the probability of financial close.*
  (iii) ***Attracts private sector participation****: US-ACEF funding will enable the project to meet a key milestone that will bring previously uncommitted private investors to the table to help finance the project.*
  (iv) ***Barrier removal****: US-ACEF funds address a barrier that would otherwise prevent USTDA from funding project preparation assistance and?or may prevent OPIC from providing financing and/or insurance to the project.*

- Does the proposed project qualify as a "Clean Energy Investment"

  Clean energy activities eligible for US-ACEF funding support include, but are not necessarily limited to, the following areas: wind, solar, geothermal, hydropower, biomass and other sustainable sources of energy, which will reduce carbon emissions, improve access to electricity for remote populations and support economic growth. "Clean energy investment" is defined as investment, including financing and insurance, that ***(a)*** *promotes the sustainable use of renewable energy technologies or energy efficiency technologies, or that* ***(b)*** *supports other efforts to reduce, mitigate, and/or sequester emissions of greenhouse gases, with the exception of activities that* *enable nuclear power, gas, coal and oil production, transmission, distribution, direct use, or the generation of electricity with these fuels. US-ACEF will also support projects that promote energy efficiency, including electricity grid loss mitigation activities, energy efficiency building solutions, and other investor-driven activities that mitigate the need for new power generation.*

- Do you satisfy relevant OPIC criteria?

  Review OPIC criteria

- Do you satisfy relevant USTDA criteria?

  For U.S. Business
  For Project Sponsors

Applying

USTDA encourages applicants to contact USTDA at USACEF@USTDA.gov PRIOR to submitting an application

View application instructions

U.S. Trade and Development Agency

Connecting U.S. companies with export opportunities overseas

PRESS RELEASE
September 11, 2013

MEDIA INQUIRIES:
Thomas Hardy | (703) 875-4357

USTDA SUPPORTS ROOFTOP SOLAR PROJECT IN WESTERN CAPE, SOUTH AFRICA

Facilitating South Africa's transition to clean energy

CAPE TOWN – Today, the U.S. Trade and Development Agency (USTDA) awarded a grant to the Green Cape Sector Development Agency NPC (Green Cape), serving on behalf of the Western Cape Government's (WCG) Department of Transport and Public Works, to evaluate the feasibility of implementing a large-scale rooftop solar photovoltaic project in Cape Town's central business district.

The grant will fund a review of the Western Cape's solar irradiation, the WCG's electricity needs, and solar photovoltaic and energy storage technologies, and will develop a design for the project and financing options. U.S. Consul General Erica Barks-Ruggles and Green Cape CEO Francois du Plessis signed the grant at the U.S. Consulate General in Cape Town, with WCG's Minister for Transport and Public Works Robin Carlisle witnessing.

"The U.S. Embassy is pleased to partner with Green Cape and the Western Cape Provincial Government in facilitating the uptake of clean energy in South Africa," said Consul General Erica Barks-Ruggles. "Green economy initiatives like these create jobs while improving our environment."

"Our vision at Green Cape is for the Western Cape to become the base for renewable energy and related green economy businesses, which will be the driver of growth and job creation in South Africa. This solar rooftop project is one of the many reasons why Green Cape was established in 2010," said Green Cape CEO Francois du Plessis.

"We are trusting that our ongoing involvement in strategic projects such as this will entrench our role in ensuring that the barriers to the growth of the green economy in the Western Cape are minimized and that the Western Cape becomes the investment destination of choice for businesses involved in the African Green Economy."

Minister Carlisle commented that "Through our Public Works Green Economy Steering Committee, the Western Cape Government is dedicated to fulfilling our 110% Green commitments through the promotion of clean energy and energy efficient solutions at government buildings. We will continue to employ measures that reduce electricity consumption and thereby reduce carbon emissions, make use of our own renewable energy generation (through rooftop PV solar), and ensure that government buildings embrace whatever green and sustainable practices are feasibly available.

"We have committed to ensure that all new Western Cape Government buildings are at least 4-star Green Building Council rated, with the new Khayelitsha Shared Services Centre (currently under construction) enjoying the Province's first 5-star rating. The work that this grant is to facilitate will ultimately go a long way to help achieve the Western Cape Government's goal of reducing electricity consumption in all provincial buildings in the CBD and 3 hospitals by 15% by mid-2014."

The opportunity to conduct the USTDA-funded feasibility study will be competed on the Federal Business Opportunities (FBO) website. A link to the FBO announcements will be posted to USTDA's website at www.ustda.gov. Interested U.S. firms should submit proposals according to the instructions in the FBO announcements.

# # #

The U.S. Trade and Development Agency helps companies create U.S. jobs through the export of U.S. goods and services for priority development projects in emerging economies. USTDA links U.S. businesses to export opportunities by funding project planning activities, pilot projects, and reverse trade missions while creating sustainable infrastructure and economic growth in partner countries.

U.S. Trade and Development Agency
1000 Wilson Boulevard, Suite 1600
Arlington, Virginia 22209
Phone: 703.875.4357 • Fax: 703.875.4009
Website: www.ustda.gov

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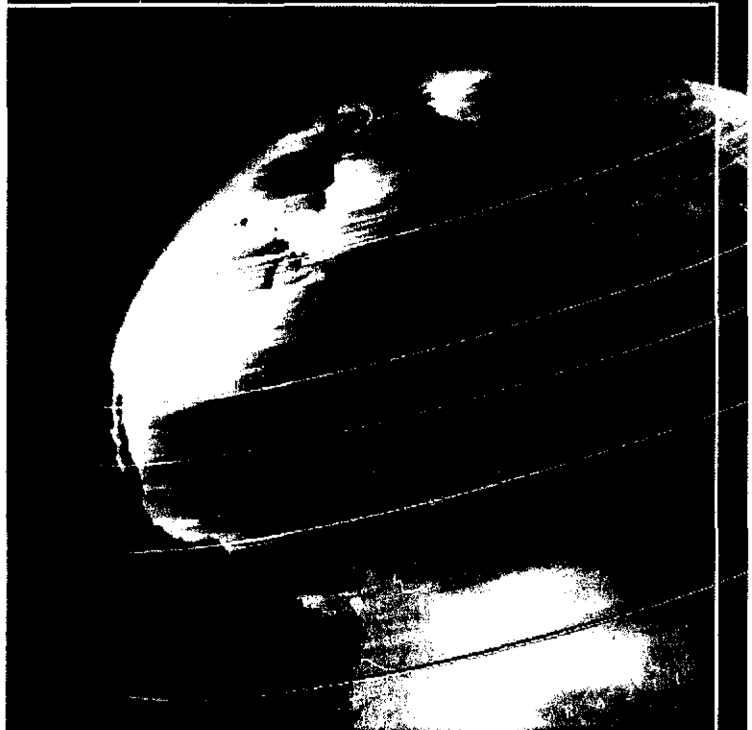
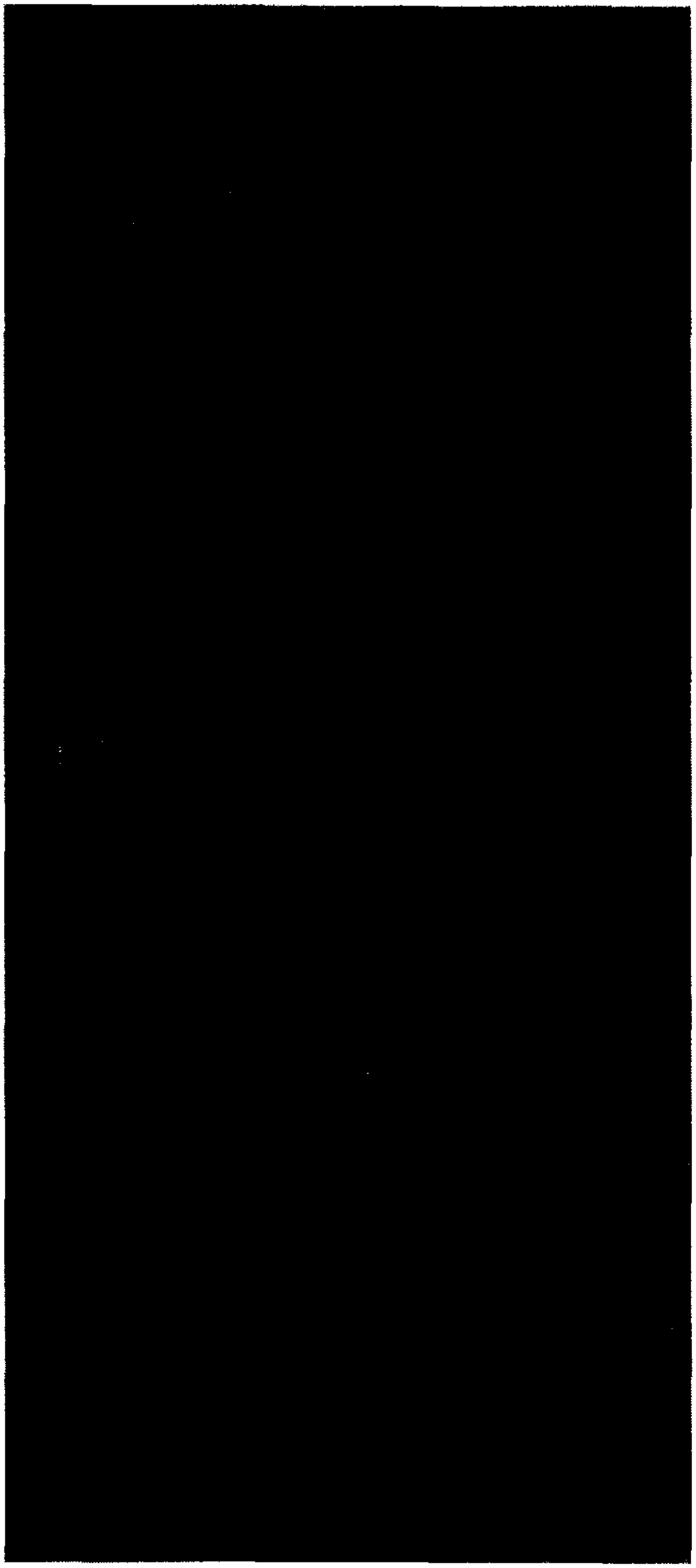


U.S. TRADE AND DEVELOPMENT AGENCY

Project Sponsor Information



Recognizing that trade and private sector growth are catalysts for development, the U.S. Trade and Development Agency (USTDA) helps project sponsors in developing and middle-income countries to establish the infrastructure and environment necessary for economic growth to occur. By providing access to U.S. expertise in the planning and development of priority projects and capacity-building activities, USTDA facilitates partnerships between project sponsors and U.S. firms that contribute to the achievement of important development goals.

What is USTDA?

USTDA is an independent U.S. Government foreign assistance agency that is funded by the U.S. Congress.

What are USTDA's objectives?

Our aim is to advance economic development in developing and middle-income countries by providing foreign project sponsors with access to U.S. technology and expertise.

What types of projects does USTDA support?

USTDA provides grant funding for the planning of projects that support the development of modern infrastructure and an open trading system.

While USTDA activities span a wide variety of sectors, many focus on clean energy and power, transportation, information and communications technology, environmental infrastructure and services, and healthcare.

On what eligibility factors are USTDA grants based?

USTDA evaluates projects primarily based on:

- Their priority to the project sponsors and the countries where they are located and their likelihood of receiving implementation financing or, in the case of USTDA's trade capacity building work, advancing trade liberalization efforts; and
- Whether they offer mutual economic benefit for the host country and the United States, including opportunities for commercial cooperation with U.S. firms, thereby supporting U.S. jobs.

With whom does USTDA work?

USTDA provides grants directly to foreign project sponsors.

A foreign project sponsor is the local entity with the decision-making authority and ability to implement a project. The sponsor may be a government institution at the national, state/provincial, or local level, or it may be a local private sector company.

USTDA is open for business in more than 100 nations around the world.

What types of activities does USTDA support?

USTDA accomplishes its mission by funding: 1) trade capacity building and sector development; and 2) project definition and investment analysis.

Trade capacity building and sector development assistance supports the establishment of industry standards, rules and regulations, market liberalization and other policy reform. Project definition and investment analysis involves activities that support large capital investments related to overseas development.

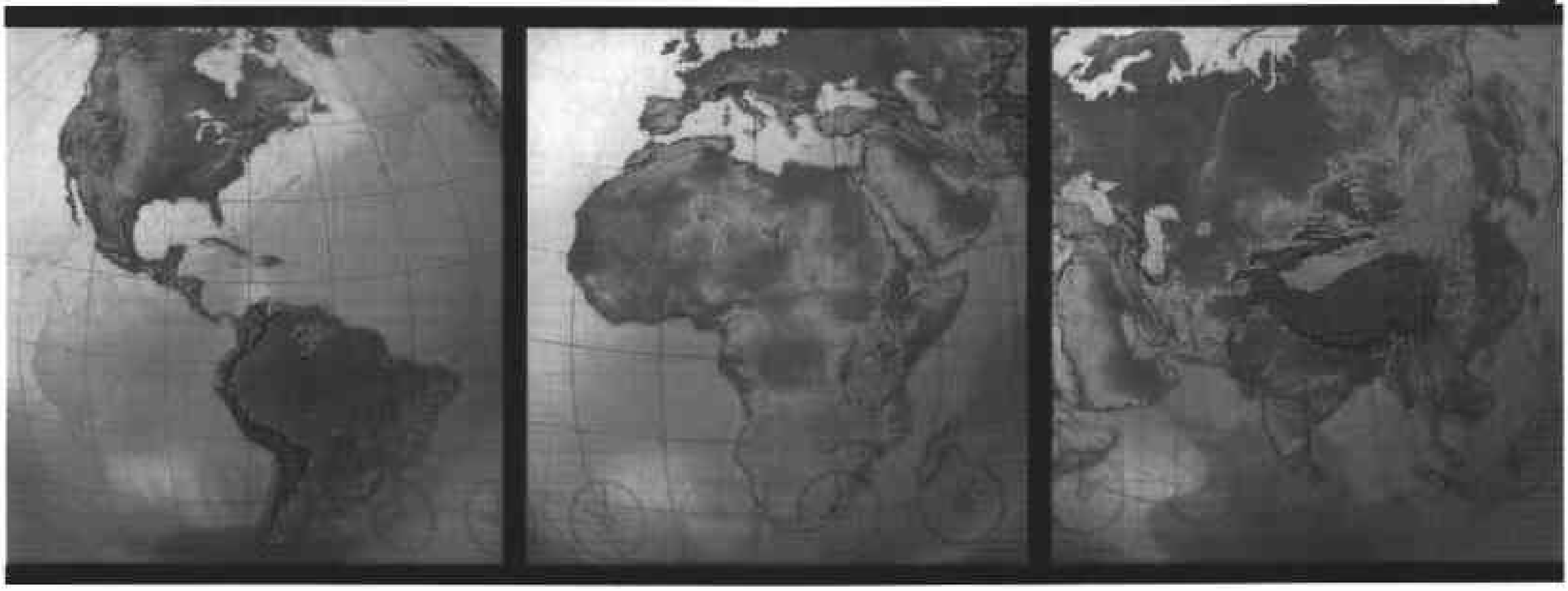
Trade Capacity Building and Sector Development

SECTOR DEVELOPMENT TECHNICAL ASSISTANCE

USTDA provides technical assistance to help with the development of sector strategies, industry standards, and legal and regulatory regimes. This assistance helps to create a favorable business and trade environment. Transportation safety and security are particularly important sectors for USTDA's technical assistance work.

TRAINING

USTDA provides training for foreign decision-makers in economic sectors where there are opportunities for the sale of U.S. equipment and services. The training is normally focused on technology or regulatory issues and is designed to give project sponsors a better understanding of U.S. experience and capabilities. Training can be conducted in the United States and/or in the host country.



TRADE AND INDUSTRY ADVISORS

Foreign government entities may obtain USTDA grants for trade and industry advisors. These advisors are typically located in ministries or municipalities, where they can help with capacity building activities relevant to trade regulations, standards or the import of technology and additional expertise.

Project Definition and Investment Analysis

FEASIBILITY STUDIES

USTDA provides grants for overseas infrastructure project planning assistance, such as feasibility studies. These studies evaluate the technical, financial, environmental, legal, and other critical aspects of infrastructure development projects that are of interest to potential lenders and investors.

ORIENTATION VISITS

Orientation visits bring foreign project sponsors to the United States to observe the design, manufacture, demonstration and operation of U.S. products and services that can potentially help them to achieve their development goals.

WORKSHOPS AND CONFERENCES

USTDA organizes workshops, conferences and technical symposia worldwide. These events are sector or project oriented and connect overseas project sponsors with U.S. firms and entities that supply project finance, technology and industry expertise that may be useful in project implementation.

PROCUREMENT ASSISTANCE

To promote project transparency and integrity, USTDA provides grants to assist in the establishment and oversight of international project procurement activities. Support can take the form of developing appropriate bidding procedures, assisting in the evaluation of technical proposals, and identifying potential suppliers or bidders.

How is a project brought to USTDA for consideration?

If you are developing a project or initiative that you would like USTDA to consider for possible grant funding, you should begin by:

1. Contacting the appropriate USTDA Regional Director or Country Manager for your region (see *How Do I Contact USTDA?*); or,

2. Communicating with the commercial or economic officer, or USTDA representative, at the U.S. Embassy in your country.

To formally initiate USTDA consideration of a project, a project sponsor should direct a request to USTDA. In cases where a specific U.S. company has been identified as a partner or preferred supplier on the project, the U.S. company submits a separate, detailed proposal to USTDA. There is no set deadline for projects to be considered.

How does the approval process work?

USTDA's due diligence review of a proposal involves two steps. First, USTDA staff conducts an internal review to determine whether the proposal represents an appropriate opportunity for USTDA support. Second, proposals that satisfy this internal analysis are then independently assessed by USTDA-funded definitional mission and desk study consultants. Because of the high demand for USTDA funding, not all proposals that meet USTDA funding criteria can be supported.

How does the grant process work?

If USTDA approves funding, it signs a Grant Agreement with the foreign project sponsor (the Grantee). The Grantee then signs a contract with the U.S. company it has selected, usually on a competitive basis, to carry out the USTDA-funded activity. Both the Grant Agreement and the contract contain the terms of reference that outline the parameters of the activity.

What are the responsibilities of the Grantee?

The Grantee is responsible for managing the USTDA-funded activity, including the review of invoices, and providing some limited administrative support.

Who pays the U.S. contractor?

The Grant Agreement is signed by USTDA and the Grantee. The U.S. contractor works under its contract with the Grantee and submits its invoices to the Grantee. Once the Grantee is satisfied with the work product, the invoices are approved and forwarded to USTDA, which then pays the contractor directly.

Do USTDA Grants have to be repaid?

USTDA funds are grants, not loans. Grantees are not required to repay USTDA for the grants they receive.

How much money is available?

Each year, USTDA funds approximately 125 grant activities. The average USTDA grant is $400,000.

This 47.5 megawatt power plant was constructed in the Aydin-Germencik geothermal field in Turkey by the Gurmat Energy Investment and Trade Company, a private Turkish company, following the findings of a USTDA-funded feasibility study. The plant, which became operational in May 2009, is providing an important renewable energy source to further Turkey's economic growth.

Where is USTDA located?

USTDA is active in every region of the world. The agency is headquartered in the Washington, D.C. area, in Arlington, Virginia. In addition, USTDA has representatives in South Africa and Thailand to promote the agency's program throughout Sub-Saharan Africa and Asia.

What other U.S. Government Agencies can I contact?

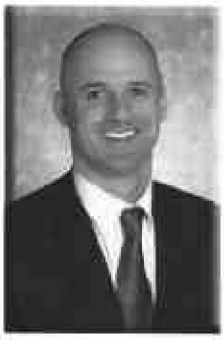
- U.S. & Foreign Commercial Service
  www.usatrade.gov
- U.S. Department of State
  www.state.gov
- Office of the U.S. Trade Representative
  www.ustr.gov
- Overseas Private Investment Corporation
  www.opic.gov
- Export-Import Bank of the United States
  www.exim.gov
- U.S. Agency for International Development
  www.usaid.gov
- Millennium Challenge Corporation
  www.mcc.gov

HOW DO I CONTACT USTDA?

More information about USTDA is available at ***www.ustda.gov***. General inquiries about USTDA's program can be made by calling (703) 875-4357, sending a fax to (703) 875-4009 or an e-mail to ***info@ustda.gov***, or completing the Contact Form on USTDA's website.

To contact USTDA's program staff, send an e-mail to your region of interest:

- East Asia:
  East_Asia@ustda.gov
- Europe and Eurasia:
  Europe_Eurasia@ustda.gov
- Latin America and the Caribbean:
  LAC@ustda.gov
- Middle East and North Africa:
  MENA@ustda.gov
- South and Southeast Asia:
  South_Southeast_Asia@ustda.gov
- Sub-Saharan Africa:
  Africa@ustda.gov



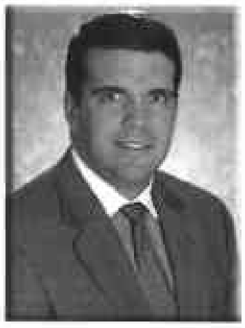
PAUL MARIN

Paul Marin serves as the Regional Director for Sub-Saharan Africa at the U.S. Trade and Development Agency (USTDA), where he is responsible for developing the agency's strategies and assistance activities throughout the region.

Previously, Mr. Marin served as USTDA's Assistant Director for Policy and Program, a role in which he advised program staff on the formulation of foreign assistance activities and worked to improve program-related operational efficiency and product quality.

In his career at USTDA, Mr. Marin served briefly as the Acting Regional Director for Latin America and the Caribbean and was responsible for managing the agency's Southeast Asia and Southeast Europe portfolios. Prior to joining USTDA in 1998, he contributed to the development of U.S. commercial policy in the Balkans while working in the Market Access and Compliance division of the Commerce Department's International Trade Administration.

Mr. Marin's 15-year career in international trade and development started soon after earning his Bachelor's degree from Bucknell University and his Master's degree from the Johns Hopkins School of Advanced International Studies.



THOMAS R. HARDY

Thomas R. Hardy is the Director for Congressional Affairs and Public Relations at the U.S. Trade and Development Agency (USTDA). As a member of Director Leocadia Zak's senior management team, Mr. Hardy oversees the agency's outreach to Capitol Hill, the business community and press to amplify the success USTDA achieves through its commercially oriented foreign assistance program. Prior to this assignment, Mr. Hardy served as the Chief of Staff of USTDA. Since his arrival at USTDA in 2001, he has also served as the Country Manager for China, the Agency's largest program, and West Africa where he brought a trade policy background that led to a more active program in support of the African Growth and Opportunity Act.

Prior to joining USTDA, Mr. Hardy served as an advisor to Commissioner Thelma J. Askey at the U.S. International Trade Commission.

After attending California State Polytechnic University at San Luis Obispo, Mr. Hardy worked at the Trade Subcommittee of the Committee on Ways and Means in the U.S. House of Representatives, where he assisted in the development of trade legislation.

Diana Rossiter

Ms. Rossister serves as Director of the Program Evaluation Office. Ms. Rossiter leads a department responsible for evaluating the results of USTDA's funding commitments. She provides analytic advice to USTDA's senior leadership and staff on all aspects of the Agency's program, in order to inform critical decision-making with the ultimate goal of identifying where the Agency's program is most effective. Prior to this role, Ms. Rossiter began her career at USTDA in the program office, where she served as Country Manager for Southeast Asia and Pakistan. In this role, she managed a multi-million dollar portfolio of infrastructure projects throughout the region. By successfully connecting U.S. companies with foreign project sponsors, Ms. Rossiter helped identify technologies and services to solve development challenges abroad. She has significant experience developing projects in collaboration with multi-lateral development banks, private industry, and foreign stakeholders, as well as coordinating on policy-projects associated with APEC, ASEAN, WTO and Free Trade Agreements.

Prior to serving in the U.S. government, Ms. Rossiter worked at an international private bank in Denver, Colorado where she managed the bank's compliance as well as business development. Ms. Rossiter earned a Master's Degree in Global Finance, Trade, and Economic Integration from the Josef Korbel School of International Studies at the University of Denver, and a Bachelor's degree from Roanoke College.

Michael J. DeRenzo

Michael J. DeRenzo currently serves as the Country Manager for Southern Africa at the U.S. Trade and Development Agency (USTDA). In this capacity, he is responsible for business development, project preparation and evaluation, and supervision of USTDA activities in Southern Africa. Prior to joining the Sub-Saharan Africa team, Mr. DeRenzo was a Project Analyst in the Europe and Eurasia region at USTDA.

Mr. DeRenzo holds a Master's degree in International Commerce and Policy from the George Mason School of Public Policy and a Bachelor's degree in Economics and Political Science from Rutgers University. Mr. DeRenzo was the recipient of the 2008 David Ricardo Trade Award, which is given for exceptional ability, involvement, and promise in the fields of international commerce and policy.

JASON NAGY

Jason Nagy is the Africa Business Development Manager, based in Johannesburg, South Africa, for the U.S. Trade and Development (USTDA). Prior to this, Mr. Nagy served as USTDA Country Manager for South Asia and as a Project Analyst, Contractor for USTDA's Sub-Saharan Africa regional program.

Prior to USTDA, he served as Program Specialist for the Member of the Board of Directors at the Export-Import Bank of the United States responsible for the Bank's sub-Saharan Africa business development efforts.

Mr. Nagy has a master's degree in international affairs from American University with concentrations in international economic policy and international business. His bachelor's degree is in political science and journalism from Indiana University.

LCRA FY 2014 Business and Capital Plans

ENERGY • WATER • COMMUNITY SERVICES

LCRA Mission Statement

The Lower Colorado River Authority (LCRA) provides reliable, cost-effective electric, water and other public services of value and is a responsible steward of the river and the basin's natural resources. LCRA is a Texas conservation and reclamation district operating with no taxing authority.

LCRA Vision

We will manage the river and lakes to provide a safe and reliable water supply for the lower Colorado River basin.

We will provide reliable energy and other public services to our customers and our region.

We will manage our lands and the river to preserve the resources of which we are stewards.

We will provide the services in a cost-effective manner, using sound business practices, and in collaboration with our customers and communities to enhance the economic health and well-being of our region.

The New LCRA – A Culture of Continuous Improvement

Improved Structure

The Lower Colorado River Authority (LCRA) has changed substantially in a short amount of time. LCRA previously was divided into five separate business units - each with its own goals and support functions. Positions were duplicated in different groups and the structure didn't lend itself to collaboration. A major reorganization eliminated redundant structures and streamlined the company with shared support groups. The fiscal year (FY) 2014 Business Plan calls for about 500 fewer positions than there were two years ago. The vast majority of those positions were eliminated by not filling open jobs and offering employees the option of participating in two voluntary severance programs (VSP). The result is that LCRA shed more than 20 percent of its positions since Becky Motal became general manager on July 2, 2011.

The two charts below show the change from the FY 2012 Business Plan to the FY 2014 Business Plan in the number of positions and total base pay at LCRA. There have been significant decreases in both areas.

Today, LCRA is a more cost-effective organization with two clear goals - to save money and find water. The same goals exist across the company, and collaboration is a matter of course. LCRA has created a culture of continuous improvement to meet the challenges ahead.

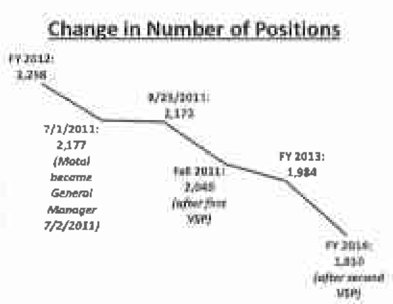
Improved Approach to Talent

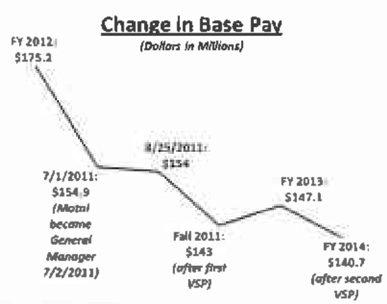
Not only has LCRA's structure changed – talent is now accessed across the organization. Previously, LCRA's systems and processes made it difficult for employees to move into new roles or across departments. Today's LCRA has made it easy for employees to take on new opportunities and new challenges in different roles and different departments. Employees whose titles haven't changed also are getting chances to learn something new as the company increases cross-training and implements new technical and leadership training programs. Employees now have more opportunity to grow their careers and have taken on new responsibilities with excellent results. This diversification of talent encourages new ideas and approaches to meeting LCRA's strategic goals.

Looking Ahead

Continuous improvement means that LCRA will continue to look for better and more cost-effective ways to work and structure the organization and retool as circumstances and situations change.

LCRA is poised to continue achieving its goals with a talented group of people in place who have a passion for public service. LCRA has already accomplished several objectives under the goals of saving money and finding water. It has held down costs in areas across the company and taken the first steps to meet the goal of adding 100,000 acre-feet of additional firm water supply by FY 2017. LCRA will continue to focus on the goals set out in this Business Plan through FY 2014 and beyond.





About LCRA

- **LCRA is governed by a 15-member Board of Directors appointed by the governor and confirmed by the Texas Senate.** LCRA is accountable to its customers and a number of stakeholders, including the Texas Legislature that created it. The Board chair is selected by the governor and communicates regularly with state policymakers and stakeholders. LCRA's energy, water and public services activities fall under a variety of state, federal and local regulatory authorities. As a public entity, LCRA conducts its business and sets policies in open meetings and is subject to public information laws.
- **LCRA is a wholesale provider of electricity and raw water.** LCRA provides reliable services at the most economical cost possible and plans for long-term power generation, transmission and water-supply needs. LCRA also has responsibilities to provide certain public services as spelled out in its enabling legislation.
- **LCRA neither collects nor receives taxes but must operate on the rates and fees it charges for its services.** Most of LCRA's revenues come from its electric generation and transmission operations.
- **A small portion of LCRA's electric and water revenues helps fund its public service activities.** This enables LCRA to carry out these services that have been authorized or mandated in LCRA's enabling legislation. These services include community development, parks and recreation, land conservation and public safety on waters and lands managed by LCRA, they do not generate enough revenues to cover their costs. Because LCRA has no taxing authority and does not receive state appropriations, it uses a small portion of its electric and water revenues to pay for these services. LCRA's enabling statute and related laws allow LCRA to fund these activities in this manner.
- **Two LCRA-related organizations pay taxes.** While LCRA, as a political subdivision of the state, is exempt from paying state and local taxes, the LCRA energy affiliate and nonprofit transmission affiliate pay state and local sales and property taxes. GenTex Power Corporation, which owns the Lost Pines 1 Power Project in Bastrop County, and LCRA Transmission Services Corporation, which owns and develops all LCRA-related transmission operations and infrastructure, through December 2012 have paid more than $163.5 million in state and local taxes since they first had taxable activity – GenTex in 1999 and LCRA Transmission Services Corporation in 2002. Additionally, LCRA projects that these affiliates will pay more than $100 million in taxes over the five-year plan period.
- **LCRA Transmission Services Corporation works with other transmission providers, distribution providers and electric generators** to provide reliable and cost-effective electric transmission services in Central Texas and throughout the Electric Reliability Council of Texas region.

Generation

Generation

LCRA combines both fuel and nonfuel rates into a time-of-use pricing structure This pricing structure is designed to recover LCRA's reasonable and necessary costs of providing services to all wholesale customers while ensuring the long-term financial health of LCRA Each customer pays the same price for energy based on when it is used (more for peak times such as summer afternoons, less for off-peak times such as the middle of the night)

Fuel Rate

Covers costs including

- Fuel (natural gas and coal) used to generate electricity
- Managing and transporting fuel to power plants and fuel storage facilities
- Purchased power
- ERCOT market settlement
- Labor for fuel-related activity, power sales and purchases, and risk management

LCRA adjusts the fuel rate periodically to reflect changing fuel, fuel transportation and purchased power costs

Nonfuel Rate

Covers costs including

- Labor for nonfuel-related activity
- Operations and maintenance, including hydroelectric operations
- Debt service, debt service coverage, and debt retirement
- Assigned enterprise costs
- Contributions to Public Service Fund
- Other nonfuel costs

Financial Summary

In FY 2014, the generation revenue requirement of $697 1 million is $152 million, or 18 percent, lower than the FY 2013 budget This decrease reflects a fuel revenue decrease of $145 2 million and a nonfuel revenue decrease of $6 8 million For the FY 2016 to FY 2018 horizon, fuel revenue increases are primarily a product of projected higher market prices for fuel. Nonfuel revenue increases for FY 2015 and FY 2016 are the result of increasing operations and maintenance expense and debt

service attributed to projected capital spending in generation

Operating expenses in FY 2014 of $425 7 million are $145 3 million, or 25 4 percent, lower than the FY 2013 budget, and debt service payments of $171 7 million are $7 6 million, or 4.6 percent, greater than the FY 2013 budget Nonfuel operations and maintenance expenses stayed relatively flat compared to the FY 2013 budget Fuel expense and purchased power decreased $145 2 million, due primarily to changes in LCRA s market load obligation related to generation customers who have breached and defaulted under their Wholesale Power Agreements with LCRA Changes in debt service payments throughout this Business Plan horizon reflect the structure of the long-term debt associated with LCRA capital spending Additionally, debt service coverage is included in the nonfuel revenue requirement to achieve a targeted 1 25x debt service coverage level Projected capital expenditures for FY 2014 are $157 8 million and $260 2 million over the five-year plan period

LCRA will continue long-term generation resource planning to analyze and improve LCRA s competitive position in the ERCOT system While investments in projects like the replacement of the Thomas C Ferguson Power Plant increase nonfuel revenue requirements management believes this investment helps LCRA improve its competitive position over the long term, as the new plant is anticipated to burn less fuel, produce fewer emissions and require fewer near-term maintenance outages

Generation and Affiliates Financial Summary, FY 2013 - FY 2018[1]

(Dollars in Millions)	Budgeted	Projected	Forecast			
	FY 2013	FY 2014	FY 2015	FY 2016	FY 2017	FY 2018
Revenues						
Nonfuel Revenues	$ 358 4	373 8	379 2	384 8	312 5	331 4
Fuel Revenues	468 5	323 3	319 2	330 0	388 6	414 6
Subtotal Fuel and Nonfuel Revenues	826 9	697 1	698 3	714.8	70[illegible] 0	746 0
Revenues Deferred for Debt Paydown	[illegible]	0 0	[illegible]	[illegible]	[illegible]	[illegible]
Total Revenue	849 1	697 1	698.3	714.8	701 0	746 0
Expenses						
Net F&PCR and Affiliate Fuel Expenses	[illegible]	323 3	[illegible]	[illegible]	[illegible]	[illegible]
Total Nonfuel Operations and Maintenance	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Total Wholesale Power / Affiliate Expense	571 0	425 7	425 8	450.5	487 9	533.2
Net Operating Margin	278 1	27[illegible] 4	272 6	264 3	203 [illegible]	212.8
Add Interest Income	0 1	0 3	0 5	3 3	6 6	7 6
Less Assigned Enterprise Expense	25 5	31 7	35 3	36 8	37 4	38 1
Public Service Fund - Generation	24 7	26 4	26 1	26 7	27 2	27 9
Net Revenues Available for Debt Service	[illegible]	214 7	211 7	204 2	145.0	154 5
Less						
Revenues Deferred for Debt Paydown	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Coverage Adjustments (GenTex)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Adjusted Net Revenues Available	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Total Debt Service	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Debt Service Coverage	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Net Revenue After Debt Service	4[illegible] 7	43 1	45 7	41 9	29 7	31 4
Less						
Operating Reserves	0 0	0 0	0.9	6.5	12 0	9 0
Assigned Enterprise Capital	3 6	3 8	1 8	2 7	3 9	2 0
Revenue Funded Capital	38 1	39 3	33 6	[illegible]1 5	13 8	20 5
Restricted for Capital/Debt Retirement	0 0	0 0	9.4	21 1	0 0	0 0
Net Cash Flow	0 0	0 0	0.0	0.0	0 0	0 0
Capital Expenditures						
Revenue Funded	38 1	39.3	33.6	11 5	13 8	20 5
Debt Funded	241 4	111 1	0 0	0.0	12.3	5 3
Third Party / Proceeds Funded	0 0	7.5	5.4	0.0	0 0	0 0
Total Capital	$ 278 5	157 8	[illegible]	[illegible]	26 1	25 8

[1] Includes affiliate GenTex Power Corporation

Transmission

Transmission

LCRA's Transmission Services provides regulated transmission, transformation and metering services required by LCRA Transmission Services Corporation (LCRA TSC). Transmission Services also provides unregulated engineering, construction, project management, maintenance and other services to external customers

Transmission Rates and Revenues

LCRA TSC is regulated by the Public Utility Commission of Texas (PUC). Accordingly, the PUC administers the rate-making and rate-approval processes for LCRA TSC and all other transmission service providers (TSPs) in ERCOT

Transmission Rate

The PUC establishes rates for 37 ERCOT TSPs based on prior expenses. The rate-making process requires the TSP to provide the PUC with a transmission cost of service (TCOS) – the actual, historical cost of owning, operating, maintaining and financing its transmission facilities for a recent 12-month period. The PUC scrutinizes the TCOS expenses and must find them "reasonable and necessary" for them to be recoverable costs

Transmission rates are determined by dividing the TSP's approved TCOS by the "4CP" in effect at the time of the TCOS filing. The 4CP, or four-month coincident peaks, is the average of the peak ERCOT electrical demands (measured in kilowatts) during the most recent June, July, August and September calendar months. The PUC averages these four ERCOT system peaks each year to establish a 4CP for the following calendar year

Dividing LCRA TSC's most recently approved TCOS (March 8, 2012, PUC order) by the ERCOT 4CP in effect at the time of filing produces the current LCRA TSC transmission rate of $4 67

The ERCOT "postage stamp rate" refers to the sum of all TSP rates. LCRA TSC accounts for about 15 percent of the total rate

Billing Unit

The 4CP is also the billing unit for transmission service in ERCOT. Each of the 81 distribution service providers (DSPs) in ERCOT pays each TSP an amount based on the TSP's rate multiplied by the DSP's portion of the previous summer's 4CP. DSPs use their retail rates to pass these transmission costs through to each end-use electric customer in the ERCOT region.

Each month every DSP pays LCRA TSC an amount equal to 1/12 of the DSP's portion of the ERCOT 4CP times the LCRA TSC transmission rate (currently $4 67)

Rate Increases

LCRA TSC is continuing to seek rate increases as needed to recover its costs of investing significant capital in new transmission facilities. LCRA TSC has two options provided by the PUC to increase rates 1) interim capital additions (ICA) or 2) TCOS rate filing. An ICA is an expedited transmission rate process that is limited to recovery of capital investment and taxes on new assets placed into service. The PUC awards interim rates for an ICA, and the process usually takes less than three months

LCRA TSC's Share of ERCOT Transmission Rate

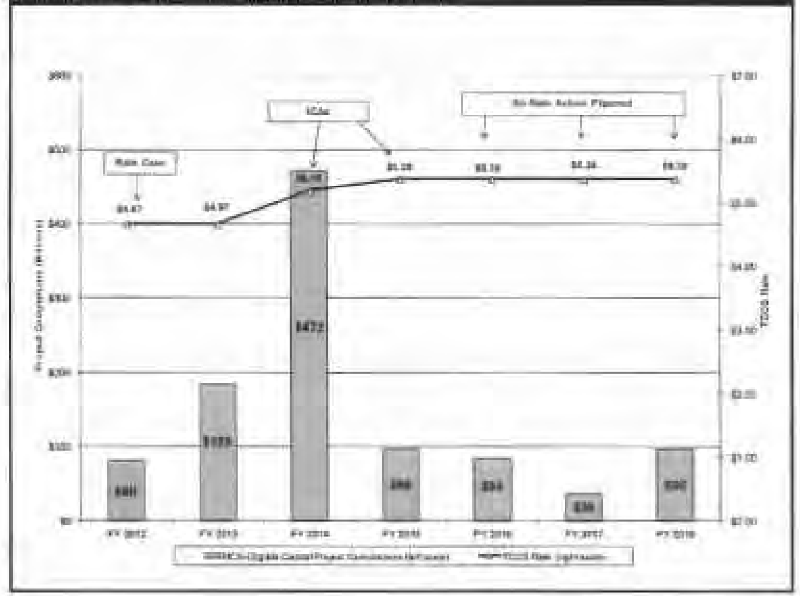
Transmission Service Provider (TSP)	Annual Transmission Rate	% of Total
Oncor Electric Delivery	$9.99	32%
LCRA TSC	$4.67	15%
CenterPoint Energy	$3 95	13%
AEP Texas Central	$2 06	7%
San Antonio City Public Service	$1 62	5%
Brazos Electric Cooperative	$1 51	5%
Austin Energy	$1 00	3%
AEP Texas North	$0 96	3%
Texas Municipal Power Agency	$0 66	2%
Other TSPs	$4 52	15%
Total ERCOT Transmission Rate	**$30.95**	**100%**

A TCOS rate case filing is the PUC process for establishing or changing rates by filing a detailed historical accounting, including updates of a recent year's operating, tax and debt service costs. TCOS rate cases typically require eight months or more to complete

LCRA TSC plans two interim rate increases during the five-year plan period in order to recover ongoing investment in Competitive Renewable Energy Zones (CREZ) and other transmission system improvements

The first of these interim rate increases will incorporate debt service on the Big Hill-to-Kendall project, which will be LCRA TSC's largest 345-kilovolt transmission line construction project both in terms of length and lifetime budget. After these interim capital additions filings are completed, LCRA TSC has no plans for additional rate increases for the remainder of the five-year planning horizon and will manage costs to achieve this goal. See the chart below for the FY 2014 to FY 2018 forecast of LCRA TSC rate actions and the resulting rate increases that are assumed in this Business Plan

Forecast for LCRA TSC Capital Project Completions and Impact on Transmission Cost of Service (TCOS) Rate



Financial Summary

The FY 2014 Business Plan continues LCRA TSC's mission to provide safe, reliable and cost-effective transmission services while investing in new facilities to serve needs across ERCOT

LCRA TSC projects collecting $338 5 million in FY 2014 for the provision of regulated transmission, transformation and metering services. This represents an increase of $20 3 million, or 6 4 percent, from the FY 2013 budget. In addition to regulated revenues, LCRA is budgeting $7 4 million in revenues from unregulated services

Total expenses of $90 million for FY 2014 increase by $6 5 million (7 8 percent), compared to FY 2013's budget The primary drivers for the increase are base pay increases, pension costs property taxes and the capital charge (LCRA TSC's share of transmission minor capital and enterprise capital)

Transmission Services expects to spend $503 8 million on capital projects over the coming five-year period This includes $492 7 million in LCRA TSC capital and $11 1 million for unregulated minor capital

Over the next five years, LCRA TSC plans to bring approximately $784 million in new transmission system facilities into service, including approximately $329 million in support of the PUC's CREZ initiatives

Transmission Financial Summary, FY 2013 - FY 2018

(Dollars in Millions)	Budget - Projected		Forecast			
	FY 2013	FY 2014	FY 2015	FY 2016	FY 2017	FY 2018
LCRA Transmission Services Corporation						
Revenues	$ 318.2	338 5	364.3	373 1	378.9	384.7
Operations and Maintenance	78 1	84 1	89 3	92 6	95.0	99.0
Net Operating Margin	240 1	254.4	275 0	280 6	283 9	285.7
Transmission Customer Services						
Revenues	6 8	7 4	7 6	7 6	7.6	7 6
Operations and Maintenance	5 5	5 9	6 0	6 0	6 0	6 0
Net Operating Margin	1 4	1 6	1 6	1 6	1 6	1 6
Total Transmission Services						
Revenues	325.0	345 9	371 9	380 8	386.5	392 3
Operations and Maintenance	83 5	90 0	95 4	98 6	101 0	105 0
Net Operating Margin	241 4	256 0	276 6	282 2	285 5	287 3
Add Interest Income	0.1	0.2	0 3	2.0	4 1	4 7
Less Assigned Enterprise Expense	26 7	35 1	37 3	38.9	39 6	39 2
Public Service Fund	9.7	10.4	11.2	11.4	11.6	11.8
Net Revenues Available for Debt Service	205.0	210.8	228.4	233.8	238.5	241.0
Debt Service	148.7	160.8	174.8	177.4	175.8	170.1
Debt Service Coverage	1.38x	1.31x	1.31x	1.32x	1.36x	1.42x
Net Revenue After Debt Service	56.3	50 1	53.6	56.5	62.7	71.0
Less						
Operating Reserves	11.3	12 7	14 0	7 9	4 0	1 9
Assigned Enterprise Capital	6 4	5 0	3 8	3 8	3 3	2 0
Revenue Funded Capital	41 0	35 4	39 3	49 2	60 2	72 4
Plus						
Amortization of Enterprise/Minor Capital [1]	2 4	3 0	3 7	4 4	4 9	5 4
Net Cash Flow	0 0	0 0	0.0	0.0	0 0	0.0
Capital Expenditures						
Revenue Funded [2]	40.0	35 4	39 3	49 2	60.2	72 4
Debt Funded	240 3	115 9	92 2	12 0	11.4	15.6
Third Party / Proceeds Funded	14 6	0 0	0.0	0 0	0.0	0.0
Total Capital	$ 294.8	151 3	131 6	61.2	71 7	88.0

[1] In FY 2012 Transmission Services will begin funding minor capital and its share of Enterprise Capital with current year revenues, but will include an amortization of the amount in each year to recover in rates

[2] The Transmission Services Consolidated Capital table includes LCRA TSC capital spending and spending for Transmission Services Minor Capital which is used by LCRA TSC and Transmission Customer Services.

Executive Summary

Some information about generation capital projects included in the Capital Plan is considered confidential and has been removed from this version of the document.

LCRA Board of Directors approval of this Capital Plan authorizes the initiation of all recommended projects at their individually stated lifetime budgets as shown in the plan The plan includes 67 new recommended projects with lifetime budgets totaling $191 5 million, which if approved, will be added to the $1 5 billion in lifetime budgets previously approved by the Board

Board approval of this plan also authorizes the proposed $372 million budget for fiscal year (FY) 2014 capital spending, which includes $79 million for recommended projects and $293 million for projects that the Board has previously approved

Capital spending anticipated in FY 2014 is $115 million (45 percent) higher than the FY 2014 projection from last year's Capital Plan

Over the coming five-year period (FY 2014 to FY 2018) the LCRA Capital Plan forecasts recommended, approved and future capital project spending of about $1 1 billion to respond to growth, reliability environmental and regulatory compliance, and other public service needs in LCRA's service area Considering only recommended and approved project spending of $554 million over the five-year planning horizon, approximately 66 percent will be for projects that the Board has previously approved

FY 2014 - FY 2018 Capital Spending for Recommended, Approved and Future Projects LCRA Total (Including Austin Energy and the City of San Marcos' Share) (Dollars in Thousands)

Status	FY 2013	FY 2014	FY 2015	FY 2016	FY 2017	FY 2018	5-Year Total	Lifetime
Recommended Projects		79 048	92 271	12 446	910	934	185,609	191 450
Approved Projects		292,946	42 586	18,296	7,947	6,362	368,137	1,505,778
Subtotal Recommended and Approved		371 994	134 857	30 742	8,857	7 296	553,746	1 697,228
Future Projects		-	162,409	130 858	147,008	120 985	561 260	696 590
Total FY 2014 Capital Plan		371,994	297,266	161,600	155,865	128,281	1 115 006	2 393 818
Less Partners Share		11,061	6,210	3,603	1,249	346	22,468	37 877
LCRA Share		360,933	291,056	157,997	154 616	127 935	1,092 538	2 355 941
Comparison to Previous Plan								
Total FY 2013 Capital Plan (with partners)	601,764	257,413	171,425	124,356	108 453		1,263,411	2,421,396
Difference*	n/a	114 581	125,841	37 244	47 412	n/a	(148 405)	(27 578)

[illegible]

LCRA developed this Capital Plan in accordance with LCRA Board Policy 304 – Financial Planning Policy and LCRA Transmission Services Corporation (LCRA TSC) Board Policy T304 – Financial Planning Policy These policies direct LCRA staff to submit annually for Board approval a plan describing the projects required during the upcoming five-year time period

The plan presents projects based on one of three status designations

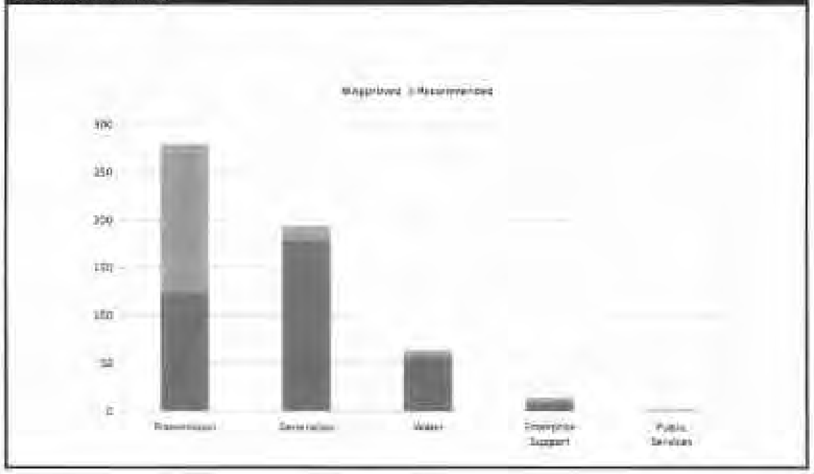
- **Recommended** projects have been reviewed by management and are recommended for Board approval
- **Approved** projects have been previously approved by the Board
- **Future** projects may be recommended for Board approval in the next five years

Future projects are not submitted for Board approval at this time and are included in this document only for strategic planning purposes Future projects are shown in Appendix A and, except where specifically noted, are excluded from the tables and graphs in this document.

Capital Spending Across LCRA

As the chart below shows, LCRA's electric operations will account for the bulk of the $554 million in capital spending for recommended and approved projects (including Austin Energy and the City of San Marcos share) over the next five years Transmission and generation projects will account for $280 million (50 percent) and $194 million (35 percent) of the LCRA total, respectively Water projects will total $64 million (12 percent) Enterprise support projects will total $14 million (3 percent) and public services, with capital spending of $3 million, will account for less than 1 percent of the anticipated capital spending for recommended and approved projects during the coming five years

LCRA
Five-Year Capital Spending by Business Area
(Dollars in Millions)



Transmission Projects

The LCRA Capital Plan includes all capital projects approved separately in the LCRA TSC Capital Plan by the LCRA TSC Board of Directors It also includes transmission minor capital purchases not owned by LCRA TSC and therefore not included in the LCRA TSC Capital Plan The transmission projects address transmission electric system reliability requirements, respond to ERCOT system needs, meet projected area load growth, respond to existing customer needs, and connect new generators to the LCRA TSC electric system

Transmission recommended and approved projects total $151 million in FY 2014 and $280 million over the next five years through FY 2018 This total does not include future projects listed in Appendix A

FY 2014 LCRA TSC Recommended Projects

- **Avery Ranch-to-Jollyville Transmission Line Upgrade** – Increase the capacity of the transmission line and associated terminal equipment between the Avery Ranch and Jollyville substations in Williamson County This project is required to meet reliability performance requirements of the transmission network Recommended completion is June 30, 2015
- **Bastrop West-to-Sim Gideon Transmission Line Overhaul** – Perform inspections and replace deteriorated wood poles and structures, crossarms and braces on the 6 8-mile 138-kilovolt (kV) transmission line in Bastrop County to maintain the safe and reliable operation of the transmission network Recommended completion is June 30, 2014
- **Battery Replacements Substation Upgrade** – Replace existing battery banks at the Plum Substation in Fayette County and the Marion Substation in Guadalupe County, and replace the battery bank and battery charger in the Red Rock Substation in Bastrop County This project is required to maintain the safe and reliable operation of the transmission network Recommended completion is June 30, 2014
- **Bevo Substation Addition** – Construct transmission facilities to provide a transmission point of interconnection with South Texas Electric Cooperative at its new Bevo Substation located in Dimmit County This project is required to meet reliability performance requirements of the transmission network Recommended completion is Dec. 2, 2014
- **Bluebonnet-to-Wyldwood Transmission Line Overhaul** – Perform inspections and replace deteriorated wood poles and structures, crossarms and braces on the 2.4-mile 138-kV transmission line in Bastrop County This project is required to maintain the safe and reliable operation of the transmission network Recommended completion is June 30, 2014
- **Buchanan-to-Burnet Transmission Line Overhaul** – Perform inspections and replace deteriorated wood poles and structures, crossarms and braces on the 11 4-mile 69-kV transmission line in Burnet County This project is required to maintain the safe and reliable operation of the transmission network. Recommended completion is June 30, 2014
- **Circuit Breaker Operator Upgrades – Substation Upgrade** – Replace three circuit breaker operators at the Zorn Substation in Guadalupe County This project is required to maintain the safe and reliable operation of the transmission network Recommended completion is June 30, 2014
- **Circuit Breaker Replacements – Phase 2 – Substation Upgrade** – Replace two 138-kV circuit breakers at the Ferguson Substation in Llano County and the Hunt Substation in Kerr County, and replace one 15-kV circuit breaker at the Marion Substation in Guadalupe County This project is required to maintain the safe and reliable operation of the transmission network Recommended completion is June 30, 2014
- **Circuit Switcher Replacement Program** – Phase 7 – **Substation Upgrade** – Replace existing underrated circuit switchers at the Bastrop City Substation in Bastrop County, Paleface Substation in Travis County and Verde Creek Substation in Kerr County This project is required to increase the reliability of the substation equipment Recommended completion is June 30, 2014
- **Clear Fork Power Transformer Addition** – Add a new power transformer to the Clear Fork Substation in Caldwell County to meet customer-projected load additions Recommended completion is June 30, 2015

- **Control House Replacements – Substation Upgrade** – Replace deteriorated control houses at the Luling Magnolia and Magnolia Mercer substations in Caldwell County. This project is required to increase the reliability of substation equipment. Recommended completion is June 30, 2014.
- **Cuero Hydro-to-Hochheim Transmission Line Overhaul** – Perform inspections and replace deteriorated wood poles and structures, crossarms and braces on the 10.7-mile 69-kV transmission line in Caldwell, Dewitt and Gonzales counties. This project is required to maintain the safe and reliable operation of the transmission network. Recommended completion is June 30, 2015.
- **Dimmit Substation Addition** – Construct a new substation to provide a transmission point of interconnection with American Electric Power at its new Dimmit Substation located in Dimmit County. Recommended completion is March 30, 2014.
- **Eckert-to-Sandstone Mountain Transmission Line Overhaul** – Perform inspections and replace deteriorated wood poles and structures, crossarms and braces on the 23-mile 69-kV transmission line in Gillespie and Llano counties. This project is required to maintain the safe and reliable operation of the transmission network. Recommended completion is June 30, 2014.
- **Elroy-to-Mendoza Transmission Line Overhaul** – Perform inspections and replace deteriorated wood poles and structures, crossarms and braces on the 12.9-mile 138-kV transmission line in Caldwell and Travis counties. This project is required to maintain the safe and reliable operation of the transmission network. Recommended completion is June 30, 2014.
- **Elroy-to-Wolf Lane Transmission Line Overhaul** – Perform inspections and replace deteriorated wood poles and structures, crossarms and braces on the 3.8-mile 138-kV transmission line in Caldwell and Travis counties. This project is required to maintain the safe and reliable operation of the transmission network. Recommended completion is June 30, 2014.
- **Flatonia Power Transformer Addition** – Add a new power transformer to the Flatonia Substation in Fayette County to meet customer-projected load additions. Recommended completion is June 30, 2014.
- **Fort Mason-to-Gillespie Transmission Line Overhaul** – Perform inspections and replace deteriorated wood poles and structures, crossarms and braces on the 14.2-mile 138-kV transmission line in Gillespie County. This project is required to maintain the safe and reliable operation of the transmission network. Recommended completion is June 30, 2014.
- **General Additions** – Required but unplanned system improvements to accommodate load increases, failed equipment, substation reliability enhancement and changing system conditions as they occur through June 30, 2014.
- **Geronimo Substation Upgrade** – Provide a transmission point of interconnection at the Geronimo Substation in Guadalupe County connecting transmission facilities owned by Guadalupe Valley Electric Cooperative. This project is required to meet reliability performance requirements of the transmission network. Recommended completion is June 30, 2014.
- **Harwood Substation Upgrade** – Increase the reliability of substation equipment at the Harwood Substation in Gonzales County. This project is required to maintain the safe and reliable operation of the transmission network. Recommended completion is June 30, 2014.
- **Henne Substation Upgrade** – Increase the reliability of substation equipment at the Henne Substation in Comal County. This project is required to maintain the safe and reliable operation of the transmission network. Recommended completion is June 30, 2014.
- **Highway 46 West Circuit Breaker Addition** – Add four 138-kV circuit breakers at the Highway 46 West Substation in Comal County. This project is required to improve the reliability of transmission service to loads that exceed 20 MW during peak loading conditions. Recommended completion is June 30, 2015.
- **Highway 46 West Power Transformer Addition** – Provide necessary metering equipment to support New Braunfels Utilities' new power transformer at the Highway 46 West Substation located in Comal County. Recommended completion is June 30, 2014.

- **Kenedy Switch-to-Guadalupe Transmission Line Upgrade** – Increase the capacity of the transmission lines and associated terminal equipment between the Kenedy Switch and Cuero substations, and construct a new Guadalupe Substation. This project will take place in Karnes and DeWitt counties. This joint project between LCRA TSC, Guadalupe Valley Electric Cooperative and American Electric Power is required to meet reliability performance requirements of the transmission network. Recommended completion is June 30, 2015.
- **Kenedy Switch-to-Nixon-to-Seguin Transmission Line Upgrade** – Increase the capacity of the transmission lines and associated terminal equipment between the Kenedy Switch, Nixon and Seguin substations, and construct a new substation to provide a transmission point of interconnection with Guadalupe Valley Electric Cooperative at LCRA TSC's new Deer Creek Substation. This project will take place in Karnes, Gonzales and Guadalupe counties. This joint project of LCRA TSC, American Electric Power, South Texas Electric Cooperative and Guadalupe Valley Electric Cooperative is required to meet reliability performance requirements of the transmission network. Recommended completion is June 30, 2016.
- **Kokernot Substation Addition** – Provide necessary metering and remote terminal unit equipment to support Guadalupe Valley Electric Cooperative's power transformer at its new Kokernot Substation located in Gonzales County. Recommended completion is June 30, 2014.
- **Laguna-to-Naval Base Transmission Line Overhaul** – Perform inspections and replace deteriorated wood poles and structures, crossarms and braces on the 3.1-mile 69-kV transmission line in Nueces County. This project is required to maintain the safe and reliable operation of the transmission network. Recommended completion is June 30, 2014.
- **Marshall Ford-to-Lago Vista Transmission Line Upgrade** – Increase the capacity of the transmission line and associated terminal equipment between the Marshall Ford and Lago Vista substations in Travis County. This project is required to meet reliability performance requirements of the transmission network. Recommended completion is June 30, 2015.
- **McNeil-to-Marshall Ford Transmission Line Upgrade** – Rebuild transmission lines and associated terminal equipment between the McNeil and Marshall Ford substations in Travis County. This project is required to meet reliability performance requirements of the transmission network. Recommended completion is June 30, 2015.
- **Menger Creek Transmission Line Addition** – Add a second circuit from the Menger Creek Tap to the Menger Creek Substation, and add three 138-kV circuit breakers at the Menger Creek Substation in Kendall County. This project is required to improve the reliability of transmission service to loads that exceed 20 MW during peak loading conditions. Recommended completion is June 30, 2014.
- **NERC Substation Upgrades** – Add cyber and intruder security equipment at eight 345-kV substations to comply with new North American Electric Reliability Corporation standards. Recommended completion is March 31, 2014.
- **Nopal Substation Addition** – Construct the new LCRA TSC Gillett Tap on the LCRA TSC Nixon-to-Kenedy Switch 138-kV transmission line. This tap will provide a new transmission point of interconnection for Guadalupe Valley Electric Cooperative's new transmission line constructed to serve at its new load-serving Nopal Substation. This project is located in Gonzales and DeWitt counties. Recommended completion is June 30, 2015.
- **Plum-to-Flatonia Transmission Line Upgrade** – Increase the capacity of the transmission lines and associated terminal equipment between the Plum and Flatonia substations in Fayette County. This project is required to meet reliability performance requirements of the transmission network. Recommended completion is June 30, 2014.
- **Seawillow Substation Addition** – Construct facilities and provide necessary equipment to connect a new Bluebonnet Electric Cooperative load-serving substation to the LCRA TSC Lockhart-to-Luling 138-kV transmission line in Caldwell County. Recommended completion is June 30, 2014.

- **Swiftex Circuit Breaker Addition** – Add two 138-kV circuit breakers at the Swiftex Substation in Bastrop County. This project is required to improve the reliability of transmission service to loads that exceed 20 MW during peak loading conditions. Recommended completion is June 30, 2014

- **Wolf Lane-to-Wyldwood Transmission Line Overhaul** – Perform inspections and replace deteriorated wood poles and structures, crossarms and braces on the 5.6-mile Wolf Lane-to-Wyldwood 138-kV transmission line in Bastrop County. This project is required to maintain the safe and reliable operation of the transmission network. Recommended completion is June 30, 2014

FY 2014 Unregulated Transmission Recommended Project

- **Minor Capital – Transmission Services** – Purchase fleet vehicles, heavy equipment and tools for use in providing regulated transmission services to LCRA Transmission Services and unregulated customer service

FY 2014 Capital Plan Approved and Recommended Projects
LCRA Transmission Services Corporation
(Dollars in Thousands)

Project Name	Contingency	FY 2014	FY 2015	FY 2016	FY 2017	FY 2018	5-Year	Lifetime
Recommended								
Avery Ranch - Jollyville Transmission Line Upgrade	5%	236	1,724	-		-	1,960	1,960
Bastrop West - [illegible] Transmission Line Overhaul	10%	687			-	-	687	687
Battery Replacements Substation Upgrade	2%	215			-	-	215	215
[illegible] Substation Addition	4%	282	1,345		-	-	1,627	1,627
Bluebonnet - Wyldwood Transmission Line Overhaul	10%	430		-			430	430
[illegible] - Bastrop Transmission Line Overhaul	10%	445			-	-	445	445
Circuit Breaker Operator Upgrades - Substation Upgrade	2%	410			-	-	410	410
Circuit Breaker Replacements Phase II - Substation Upgrade	2%	[illegible]	-	-	-	-	[illegible]	[illegible]
Circuit Switcher Replacement Program Phase VII - Substation Upgrade	2%	604	-	-	-	-	604	604
Clear Fork Power Transformer Addition	2%	[illegible]	[illegible]		-	-	[illegible]	[illegible]
Control House Replacements - Substation Upgrade	2%	530			-	-	530	530
[illegible] Hydro - [illegible] Transmission Line Overhaul	10%	117	6,465	-	-	-	6,582	6,582
[illegible] Substation Addition	6%	1,459	-	-	-	-	1,459	1,459
[illegible] - Sandstone Mountain Transmission Line Overhaul	10%	3,000	-	-	-	-	3,000	3,000
Elroy - Mendoza Transmission Line Overhaul	10%	292	-	-	-	-	292	292
Elroy - Wolf Lane Transmission Line Overhaul	10%	425	-	-	-	-	425	425
Flatonia Power Transformer Addition	2%	1,059				-	1,059	1,059
Fort Mason - Gillespie Transmission Line Overhaul	10%	[illegible]	-	-	-	-	[illegible]	[illegible]
General Additions - Transmission Services Corporation - FY 2014	0%	4,000					4,000	4,000

FY 2014 Capital Plan Approved and Recommended Projects
LCRA Transmission Services Corporation
(Dollars in Thousands)

Project Name	Contingency	FY 2014	FY 2015	FY 2016	FY 2017	FY 2018	5-Year	Lifetime
Recommended								
Geronimo Substation Upgrade	2%	331	-	-			331	331
Harwood Substation Upgrade	2%	215	-	-		-	215	215
Henne Substation Upgrade	2%	333		-		-	333	333
Highway 46 West Circuit Breaker Addition	[illegible]	82	1,452				1,534	1,534
Highway 46 West Power Transformer Addition	2%	5	82	-		-	87	87
Kenedy Switch - Guadalupe Transmission Line Upgrade	[illegible]	1,167	22,996	-			[illegible]	[illegible]
Kenedy Switch - Nixon - Seguin Transmission Line Upgrade	8%	6,546	19,401	11,560		-	37,507	37,507
Kokernot Substation Addition	2%	287	-	-		-	287	287
Laguna - Naval Base Transmission Line Overhaul	10%	8,618	-				8,618	8,618
Marshall Ford - Lago Vista Transmission Line Upgrade	[illegible]	383	7,663	-	-	-	[illegible]	[illegible]
McNeil - Marshall Ford Transmission Line Upgrade	9%	681	19,406	-	-		20,087	20,087
Menger Creek Transmission Line Addition	7%	4,145	-	-	-	-	4,145	4,145
NERC Substation Upgrades	10%	660	-	-	-	-	660	660
Nopal Substation Addition	[illegible]	[illegible]	[illegible]				3,426	3,426
Pluin - Flatonia Transmission Line Upgrade	10%	8,811	-				8,811	8,811
Seawillow Substation Addition	[illegible]	5,000	-	-			5,000	5,000
Swiftex Circuit Breaker Addition	2%	791		-			791	791
Wolf Lane - Wyldwood Transmission Line Overhaul	10%	[illegible]		-	-		[illegible]	[illegible]
Recommended Subtotal		55,988	85,681	11,560			153,229	153,229

FY 2014 Capital Plan Approved and Recommended Projects
LCRA Transmission Services Corporation
(Dollars in Thousands)

Project Name	FY 2014	FY 2015	FY 2016	FY 2017	FY 2018	5-Year	Lifetime
Approved							
Airline - Laguna - Naval Base Transmission Line Upgrade	189				-	189	347
Altair - Nada Transmission Line Upgrade	[illegible]					[illegible]	[illegible]
Bakersfield Substation Addition	862					862	6,089
Big Hill - Kendall Transmission Line Addition	[illegible]	-	-	-	-	[illegible]	[illegible]
Big Hill Substation Addition	745					745	28,360
Blumenthal Substation Addition	[illegible]	[illegible]	[illegible]	4,714	[illegible]	[illegible]	[illegible]
Buttercup - Whitestone Transmission Line Upgrade	99	-		-	-	99	121
Canyon Power Transformation Addition	[illegible]	-	-	-	-	[illegible]	72
Clear Fork (Maxwell) Substation Addition	2,564	-	-	-	-	2,564	3,064
Clear Springs Substation Upgrade Project	[illegible]	-	-	-	-	[illegible]	[illegible]
CTEC Buchanan - Pitsburg Transmission Line Upgrade	2,727					2,727	3,401
Cushman - Highway 123 Transmission Line Addition	10,794	[illegible]	-	-	-	12,902	17,632
E C Mornhinweg Substation Addition	[illegible]	1,971	1,203	-		7,674	9,692
Elgin - Sim Gideon Transmission Line Upgrade	[illegible]	-	-	-	-	2,916	3,361
Flatonia - Yoakum - Gartner Road Transmission Line Upgrade	303	-	-	-	-	303	20,425
Georgetown Circuit Breaker Addition	[illegible]		-		-	[illegible]	[illegible]
Georgetown - Rivery Transmission Line Upgrade	1,332	-		-	-	1,332	1,642
Gillespie - Eckert Transmission Line Upgrade	[illegible]					[illegible]	[illegible]

FY 2014 Capital Plan Approved and Recommended Projects
LCRA Transmission Services Corporation
(Dollars in Thousands)

Project Name	FY 2014	FY 2015	FY 2016	FY 2017	FY 2018	5-Year	Lifetime
Approved							
Glidden - Colorado - Nada Transmission Line Upgrade	4,928	-	-			4,928	8,457
Goldthwaite Substation Upgrade	220					220	[illegible]
Kendall Auto Upgrade	226	-	-	-	-	226	25,426
Kendall Substation Upgrade	9,000	-	-	-		9,000	[illegible]
Kerrville Stadium - Raymond F Barker Transmission Line Upgrade	5,985	3,750	-		-	9,735	11,235
Kerrville Travis Circuit Breaker Addition	1,096	305				1,401	[illegible]
Lehigh Power Transformation Addition	39		-		-	39	44
Lockhart - Luling Transmission Line Upgrade	1,032					1,032	[illegible]
Mico Substation Addition	2	2	2	805	-	811	838
Mobile Transformer Low-Side Hookup Switches Substation Upgrade	264	-	-	-	-	264	[illegible]
Mockingbird Substation Addition	706		-	-	-	706	1,411
North McCamey Autotransformer Addition	362		-		-	362	[illegible]
North McCamey Substation Upgrade	5	-	-			5	2,659
Protection System Upgrades - FY 2012 Substation Upgrade	1,593	72				1,665	[illegible]
Protection System Upgrades - FY 2013 Substation Upgrade	474		-	-	-	474	1,374
RTU Additions Substation Upgrade	38		-			38	777
Salem Autotransformer Replacement Project	6,379			-	-	6,379	8,641
Salem Substation Upgrade Project	5,851					5,851	[illegible]

FY 2014 Capital Plan Approved and Recommended Projects
LCRA Transmission Services Corporation
(Dollars in Thousands)

Project Name	FY 2014	FY 2015	FY 2016	FY 2017	FY 2018	5-Year	Lifetime
Approved							
Sattler Power Transformation Addition	68	-	-	-	-	68	77
Sherwood Shores Circuit Breaker Addition	2	[illegible]	[illegible]			[illegible]	[illegible]
SOCC Energy Management System Upgrade III	2,437	1,046	-		-	3,483	7,727
Southern 69kV Loop Substation Upgrade	967	777	-	-	-	1,744	[illegible]
Switch Replacement - Phase II Substation Upgrade	259	-	-	-	-	259	703
Switch Replacements Substation Upgrade	977	440	431	-		[illegible]	[illegible]
Transmission Easements Project - FY 2006 - Transmission Line Upgrade	500	-	-			500	3,375
Transmission Line Easement Enhancement Program - FY 2013 Transmission Line Upgrade	1,441	-	-	-	-	1,441	[illegible]
Trans-Rupter Upgrades Substation Upgrade	399	-	-		-	399	421
Warda - Giddings Transmission Line Upgrade	2,099	-	-	-	-	2,099	2,501
Weimar Substation Upgrade	354	-	-		-	354	595
Approved Subtotal	[illegible]	[illegible]	6,541	[illegible]	[illegible]	[illegible]	[illegible]
Total LCRA TSC Recommended and Approved	148,795	99,220	18,101	5,019	5,423	277,058	767,997

FY 2014 Capital Plan Approved and Recommended Projects
Unregulated Transmission and Total Transmission
(Dollars in Thousands)

Project Name	Contingency	FY 2014	FY 2015	FY 2016	FY 2017	FY 2018	5-Year	Lifetime
Recommended								
Minor Capital - Transmission Services	0%	2,565	-	-	-	-	2,565	2,565
Total Transmission Recommended and Approved		151,382	98,220	18,101	5,019	3,022	275,423	279,862

Appendix: FY 2014 Capital Plan Future Projects
LCRA Transmission Services Corporation
(Dollars in Thousands)

Project Name	FY 2014	FY 2015	FY 2016	FY 2017	FY 2018	5-Year	Lifetime
Bellville North Circuit Breaker Addition	-	-	-	950	-	950	950
Boerne Cico - Comfort Transmission Line Upgrade	-	-	370	5,397	-	5,767	5,767
Cedar Park West CCN Transmission Line Addition	-	370	895	1,345	1,975	4,785	10,465
Chappell Hill Substation Addition	-	-	2,443			2,443	2,443
Colton Circuit Breaker Addition	-	-	-	950	-	950	950
Concan Substation CCN Transmission Line Addition		381	1,202	3,427	9,346	14,756	59,300
Cuero Power Transformer Upgrade	-	1,146	-	-	-	1,146	1,146
Cypress Creek Circuit Breaker Addition	-	1,097	-	-		1,097	1,097
FM 250 (NBU) Substation Addition	-	73		-	-	73	73
Garfield Cut-In (AE IA) Substation Addition		-	-	-	3,600	3,600	3,600
General Additions - Transmission Services Corporation Future	-	4,000	4,000	4,000	4,000	16,000	16,000
Hallettsville - Hallettsville City Transmission Line Addition		-	-	363	4,992	5,355	5,355
Hays Energy Substation		2,835	-	-	-	2,835	2,835
Leander - Round Rock Transmission Line Addition		1,284	1,924	14,505	22,247	39,960	39,960
Lockhart - Seguin Split Sub and Transmission Line Addition	-	381	1,202	3,427	9,346	14,756	59,300

Appendix: FY 2014 Capital Plan Future Projects
LCRA Transmission Services Corporation
(Dollars in Thousands)

Project Name	FY 2014	FY 2015	FY 2016	FY 2017	FY 2018	5-Year	Lifetime
Miller Substation Addition		87				87	87
Menger Creek T1 Power Transformer Upgrade	-	-	-	-	2,000	2,000	2,000
Menger Creek T2 Power Transformer Addition	-	-	-	-	2,000	2,000	2,000
Merrelltown Substation Addition	-	-	2,831	-	-	2,831	2,831
Minor Capital - TSC - Future	-	-	350	350	350	1,050	1,050
Mountain Home Substation Addition	-		-	-	73	73	73
Paige Circuit Breaker Addition	-	-		-	950	950	950
Pflugerville South Substation Addition	-	-	-	3,234	-	3,234	3,234
Santa Clara Substation Addition	-	-	281	-	-	281	281
Swiftex Power Transformer Upgrade	-	-	-	2,000	-	2,000	2,000
Transmission Line Overhauls	-	16,677	32,595	22,728	11,721	76,721	78,712
Twin Buttes Autotransformer Addition	-	-	-	2,050	7,886	9,936	9,936
Total LCRA TSC Future	-	29,231	41,033	64,718	80,086	215,626	320,394

Appendix: FY 2014 Capital Plan Future Projects
Transmission
(Dollars in Thousands)

Project Name	FY 2014	FY 2015	FY 2016	FY 2017	FY 2018	5-Year	Lifetime
Minor Capital - TSBU - Future	-	2,678	2,000	2,000	2,000	8,678	8,678

Austin Energy Guiding Principles

- Vision Statement
  - "We want Austin to be the most livable community in the country."
- Mission Statement
  - "To provide clean, affordable, reliable energy and excellent customer service."
- Resource Strategy
  - Austin Energy will first seek renewable energy and conservation solutions to meet our customers' new energy needs…

Resource Strategy through 2020

- Renewable Generation
  - 35% Renewable Energy
  - 200 MW of Solar Energy
- Energy Efficiency
  - 15% energy efficiency and conservation
  - 800 MW of peak demand reductions
- Carbon Reduction
  - 20% below 2005 levels

Austin Energy Efficiency Programs

- Green Building

  Leading the transformation of the building industry to a more sustainable future

  - Ratings for Residential, Multifamily and Commercial New construction and major renovations
  - Energy efficiency and green building consulting services
  - Integrated design energy modeling incentives
  - Energy Code advancement

Austin Energy Efficiency Programs

- Residential Rebates (Existing Construction)
  - Home Performance with Energy Star
  - Low interest loans
  - Refrigerator recycling
  - AC efficiency program
  - Low Income Weatherization
- Multifamily Rebates (Existing Construction)
  - Prescriptive Rebates for AC, Solar Screens, Lighting, and Insulation
  - Performance based rebates (Better Buildings)

Austin Energy Efficiency Programs

- Commercial Rebates (new and existing construction)
  - AC/Chillers and cooling equipment
  - Lighting efficiency
  - LED exterior lighting
  - Thermal energy storage
  - Custom incentives
  - Small business direct installation program

Current Demand Response Programs

- Load Cooperative Program
  - Voluntary C&I program
  - Utilizes e-mail/pager/text notifications
  - Pays incentive compared to baseline
- Power Partner Thermostat Program
  - Residential and small business
  - Direct load control
  - Utilizes one-way radio broadcast
  - Free programmable thermostat

Current Demand Response

- Goals:
  - Reduce AE peak demand
  - Reduce AE demand during ERCOT 4CP
  - Reduce energy usage at times of high SPP
  - Reduce overall cost to customers
- Operates June - September (Summer weekdays)
- Events are ~ 2 hrs. long (up to 3 hrs.)
- Usually operate Load Coop and Power Partner thermostats at the same time

Load Cooperative Program

- Manual Demand Response delivering ~4.5 MW
- Payment of $1.25/kWh during event
- AE utilizes EPO for notifications and settlement
- Notification is one hour before event
- About 77 current meters enrolled
- Challenges
  - Access to low cost, reliable IDR data
  - Requires knowledgeable customers

Current Thermostat DR Program

Free Thermostats

- One-way communication
- Radio Signal Controlled
- "Top Down": AE contracts with a vendor to provide thermostats, installation, maintenance & customer call center
- ~95,000 thermostats installed

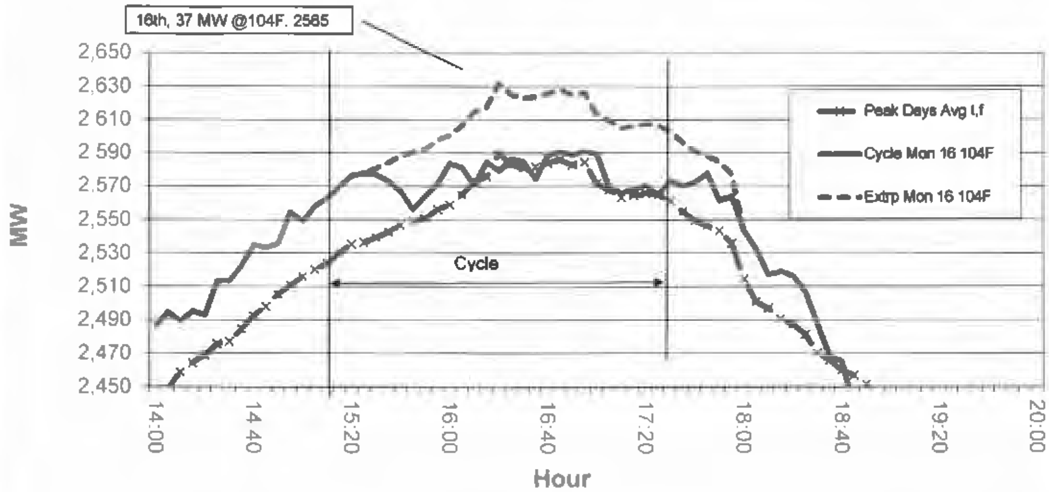
Results

- 10 to 15 events per year
- Provides 10-40 MW of demand side management

AE Challenges with Current Model

- One-way communication: radio controlled devices
- Manual Opt-Out Process: "Needs Improvement"
- Unclear of how many units continue to function properly
- AE measures whole-system effects and subtracts C&I
- Doesn't integrate with other AE programs
- Not adopted by HPwES contractors
- Technology falling behind the industry
  - Large touch screens
  - Adaptive algorithms for energy savings
  - Web and smart phone based programming

Sample Cycling Session (August 2010)



Power Partner Thermostat Program

- Current DR Thermostat business model
  - Traditional utility sponsored program
  - Utility procures all product and installation
  - Utility markets program to customers
  - Utility assumes risk for long term performance
- New DR Thermostat business model
  - Customer choice program through enrollment
  - Leverages customer owned thermostats
  - Vendor and utility marketing
  - Multiple installation channels
  - Can reduce utility financial risk

Future: Residential & Small Commercial

Programmable Communicating Thermostats

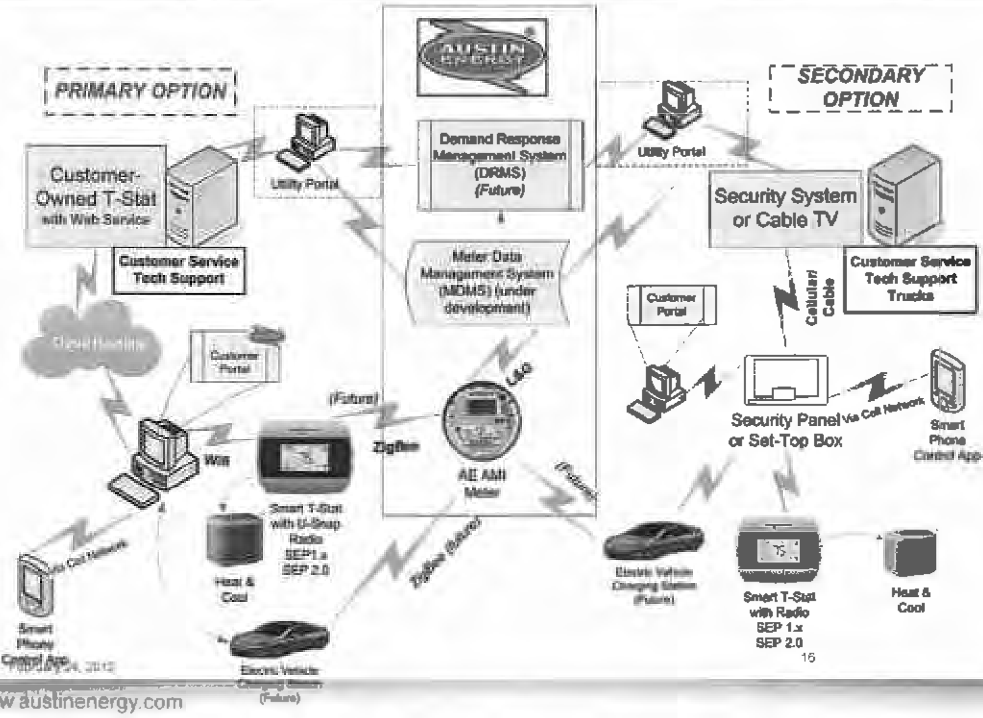
- Customers receive rebates for enrolling in the DR program with an approved thermostat
- Multiple thermostat options from different markets: DIY, HVAC Contractor, Service Companies (i.e.: cable or security)
- Cloud Based Control & Confirmation (2-way)
- Thermostat vendors receive rebates for providing AE direct access to thermostat devices via a "Utility Portal"
- "Bottom Up": Vendor provides thermostats, installation, maintenance & customer call center to customers

- Pilot 2012- Launch 2013
- Future Ability to expand to other devices: car chargers, pool pumps, hot water heaters, etc...
- Future ability to utilize DRMS to aggregate Utility Portals

"Bottom Up" Retail Vendor Model

- No direct purchase by utility
  - Customer or Bundled Service Provider funds product, installation and portal access
  - Utility pays for customer' s enrollment, portal access, and participation
- Participating vendors agreement (portal providers)
  - Utility and portal provider enter into no cost agreement
  - Payment for ongoing utility portal access technically from customer
  - Portal provider agrees to provide API to DRMS
- Customer Participation Agreements
  - Agreement to allow utility DR curtailments
  - Requests their vendor to provide utility access for DR
  - Customer assigns some incentive directly to utility portal provider
- Multiple market channels
  - DIY - Customer Purchase (Home Improvement stores and on-line purchase)
  - HVAC Contractors
  - Bundled Service Providers
    - Cable/Satellite/cellular and broadband providers
    - Home Security companies

Business Model Diagram



Current roadmap

- Maintain legacy system
- Signed vendor agreements (3 current agreements)
- Began deployment in April 2013 (currently ~ 2,000 units)
- Continue expansion with current vendors
- Pilot and test DRMS (test curtailments have begun)
- Perform Measurement and Verification
- Phase-in of additional Participating Retail Vendors
- Market and integrate into other incentive programs
- Implement additional customer performance incentives
- Incorporate into energy codes and rating systems

Where we are today

Company	Thermostats	Where to Buy One	Where to Enroll It
Alarm.com	Radio Thermostat CT100 Radio Thermostat CT80 Radio Thermostat CT30 Trane ComfortLink Control	https://www.alarm.com/get_started/finddealer_zip.aspx	www.alarm.com/login.aspx
ecobee	ecobee Smart ecobee Smart Si	Local HVAC Contractors [illegible]	[illegible]
Filtrete	Filtrete 3M-50	Select Home Depot stores	[illegible]
Nest	1st Generation Nest Learning Thermostat 2nd Generation Nest Learning Thermostat	Best Buy, Home Depot, Lowe's, [illegible] the Apple Store, [illegible] and Nest Certified Installers [illegible]	[illegible]
Nexia Home Intelligence	American Standard AccuLink Remote Thermostat American Standard Silver XM Thermostat Trane ComfortLink Control Trane XL624 Control	Trane dealers (http://www.trane.com/residential/find-a-dealer/) American Standard Air dealers (www.americanstandardair.com/pages/dealerresults.aspx?Code=78756) www.nexiahome.com	[illegible]
Radio Thermostat	Radio Thermostat CT80 (WiFi) Radio Thermostat CT30 (WiFi)	Amazon.com [illegible]	[illegible]

A City of Austin Program

For more information, please call 512-482-5346 or email powerpartnerthermostats@austinenergy.com.

Longer Term: 1-Stop Control Platform

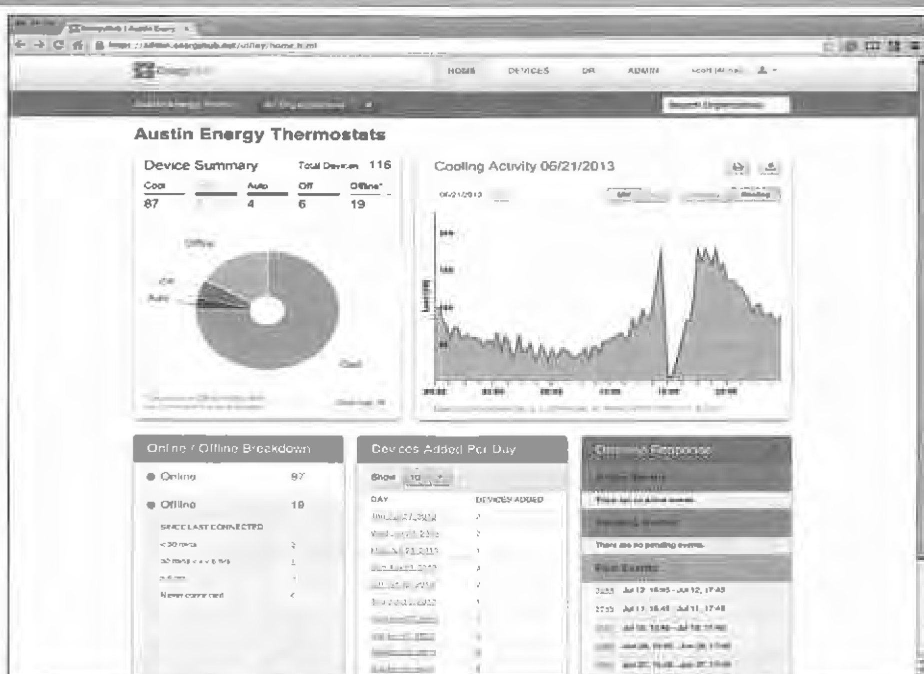
Demand Response Management System (DRMS)

- Short Term: Multiple DR Platforms
  - Maintain Current Legacy System
  - Phase-in of Multiple Participating Retail Vendors
- Longer-Term:
  - One DRMS Platform controls multiple control systems, eventually all M&V data (interval runtime, other data) into MDMS
  - Integrate other monitoring & control (EV Chargers, other end uses)
  - Utilize DRMS for C&I DR expansion

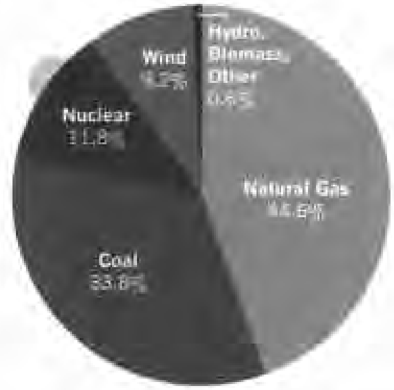
Additional Program Options

- Integrate thermostat portal with energy usage
- HVAC Contractor portal to facilitate maintenance agreements
- HVAC unit remote diagnostics
- Efficiency rebate and HVAC tune-up M&V
- Other messaging and notification
- Promotion/Integration with TOU rates

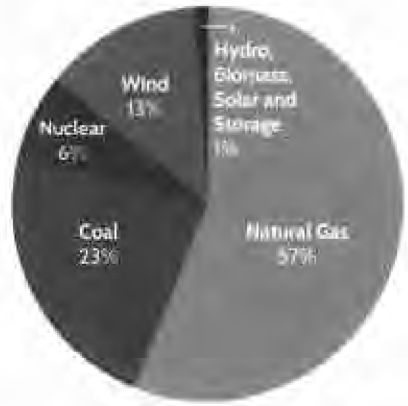
Screen shot of Utility Dashboard



ERCOT Quick Facts



Energy Use 2012



2012 Generation Capacity

At a glance

- 85% of Texas load
- 23 million consumers
- Competitive-choice customers: 73% of load
    - 6.7 million electric-service ID's (premises)
- 40,530 circuit miles of high-voltage transmission:
    - 9,249 miles of 345 kV and 19,565 miles of 138 kV
- 550 generating units
- >74,000 megawatts (MW) capacity for peak demand
    - One megawatt of electricity can power about 200 Texas homes during periods of peak demand.
- Record peak demand: 68,305 MW (Aug. 3, 2011)
- Energy used in 2012: 324 billion kilowatt-hours
    - A nearly 3 percent decrease compared to 2011
- Market size: About $34 billion
- Market participants: >1,100 active entities that generate, move, buy, sell or use wholesale electricity

What we do

The Texas Legislature restructured the Texas electric market in 1999 by unbundling the investor-owned utilities and creating retail customer choice in those areas, and assigned ERCOT four primary responsibilities:

- System reliability – planning and operations
- Open access to transmission
- Retail switching process for customer choice
- Wholesale market settlement for electricity production and delivery

State of the Grid

Transmission Investment and Development

- $7.9 billion in transmission added since 1999
- 9,302 circuit miles of transmission improvements since 1999
- 6,900 circuit miles of transmission planned
- $8.9 billion under development in five-year plan;
    - ~$5-7 billion to support 18,000 MW of wind

Generation Development

- 47,000 MW new generation added since 1999
    - 137 older units decommissioned
- 8,145 MW generation committed for the future (with transmission contract and air permit)
- 40,600 MW of active generation requests under review, including more than 20,000 MW of wind (December 2012)

Wind Generation

- Wind capacity: 10,407 MW
    - Most of any state in the nation
- Wind generation record: 9,481 MW (Feb. 9, 2013)
    - 27.8 percent of the 34,082 MW load at the time

Retail Service Switches to Competitive Retailers

- 61% of residential load (December 2012)
- 80% of small commercial load (December 2012)
- 181 certified competitive retail electric providers

Advanced Meters and Demand Response

- 6.1 million advanced meters
    - 94.2 percent of ERCOT load settled with 15-minute interval data
- >1,950 MW in demand response resources, including:
    - Load resources (mostly large industrial) ~1,200 MW
    - Emergency response service (commercial and industrial) ~550 MW
    - Utility load management programs
- Additional economic demand response, voluntary public responses to conservation requests and more

ERCOT Governance

ERCOT Board of Directors

Craven Crowell
Chair
(unaffiliated)

Judy Walsh
Vice Chair
(unaffiliated)

Jorge Bermudez
(unaffiliated)

Shannon Bowling
Cirro Energy
(independent retail electric provider)

Andrew Dalton
Valero Energy Corporation
(industrial consumer)

H.B. "Trip" Doggett
President and
Chief Executive Officer,
ERCOT (ex-officio)

Mark Dreyfus
Austin Energy
(municipal utility)

Nick Fehrenbach
City of Dallas
(commercial consumer)

Michehl Gent
(unaffiliated)

Sheri Givens
Office of Public Utility Counsel
(residential consumer, ex-officio)

Kevin Gresham
E.ON Climate & Renewables
(independent generator)

Clifton Karnei
Brazos Electric Cooperative
(cooperative)

Donna Nelson
Chair, Public Utility Commission
(ex-officio, non-voting)

Karl Pfirrmann
(unaffiliated)

Scott Prochazka
CenterPoint Houston
(investor-owned utility)

Jean Ryall
CCNG, Inc.
(independent power marketer)

Segment Alternates

Jeff Brown
Shell Energy North America
(independent power marketer)

Mark Carpenter
Oncor Electric Delivery
(investor-owned utility)

Michael Matlock
ENCOA
(independent retail electric provider)

Mike Packard
South Texas Electric Cooperative
(cooperative)

Carolyn Shellman
CPS Energy
(municipal)

Vacant
(independent generator)

ERCOT Officers

H.B. "Trip" Doggett
President and Chief Executive Officer

Betty Day
Vice President of Business Integration

Jerry Dreyer
Vice President and Chief Information Officer

Bill Magness
Vice President and General Counsel

Charles B. Manning, Jr.
Vice President, Human Resources, and Chief Compliance Officer

Mike Petterson
Vice President, Finance and Treasury

Mark Ruane
Vice President, Credit and Enterprise Risk Management

Kent Saathoff
Vice President, Grid Operations and System Planning

Board, Stakeholder Process

The ERCOT Board of Directors has general overall responsibility for managing the affairs of ERCOT, including approval of the budget and capital spending priorities, approval of revisions to ERCOT protocols and guides, and endorsement of major new transmission recommendations.

ERCOT's 16-member "hybrid" board includes five independent (or unaffiliated) members; three consumer segment representatives (industrial, commercial and residential); the ERCOT CEO; the Public Utility Commission (PUC) chairman (nonvoting), and six representatives from each of the industry segments – investor-owned utilities (or transmission owners), municipally-owned utilities, cooperatives, generators, power marketers and retail electric providers.

Under the Board's oversight, ERCOT's stakeholder process is responsible for developing policies, procedures and guidelines for power grid coordination, reliability and market operations.

Six standing committees and subcommittees supported by numerous working groups and task forces function within the stakeholder process.

PUC, Legislative Oversight

ERCOT is unique because its electricity grid is not synchronously connected outside of the state. Because of its separateness, ERCOT is primarily regulated by the Public Utility Commission of Texas (PUC) and the Texas Legislature, not federal authorities. The PUC approves the ERCOT system administration fee and has general oversight authority, including the ability to order audits.

For most purposes, ERCOT, like the PUC, is accountable to the Texas Legislature and its jurisdictional committees. For federal reliability standards, ERCOT is accountable to the Texas Reliability Entity, the North American Electric Reliability Corporation, and the Federal Energy Regulatory Commission.

The Electric Reliability Council of Texas (ERCOT) manages the flow of electric power to approximately 23 million Texas customers – representing 85 percent of the state's electric load and 75 percent of the Texas land area. As the Independent System Operator for the region, ERCOT schedules power on an electric grid that connects 40,500 miles of transmission lines and more than 550 generation units. ERCOT also manages financial settlement for the competitive wholesale bulk-power market and administers customer switching for 6.7 million premises in competitive choice areas. ERCOT is a membership-based 501(c)(4) nonprofit corporation, governed by a board of directors and subject to oversight by the Public Utility Commission of Texas and the Texas Legislature.

POWER ACROSS TEXAS

Issue Brief: Texas Electric Grid Management and Power

The Texas Electric Grid:

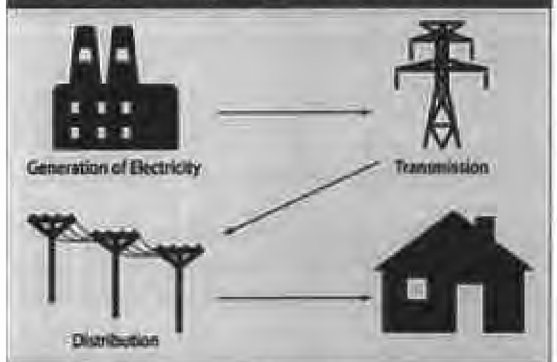
The electric grid can be simplified as: Generation → Transmission (high voltage wires) → Distribution (local wires) → Customer

In reality, the grid is far more complicated, both technically and organizationally.

The **Federal Energy Regulatory Commission** (FERC) oversees some aspects of the US electric grid, particularly transmission, but has very limited authority over most of Texas (ERCOT, which is an electrical "island" mostly isolated from the rest of the US grid).

The **North American Electric Reliability Corporation** (NERC) develops reliability standards under authority from FERC. In Jan. 2013, NERC asked ERCOT to report, by April 30, ERCOT's plan to address its projected capacity shortfall and declining reserve margin.

How Electricity Flows To Its Users

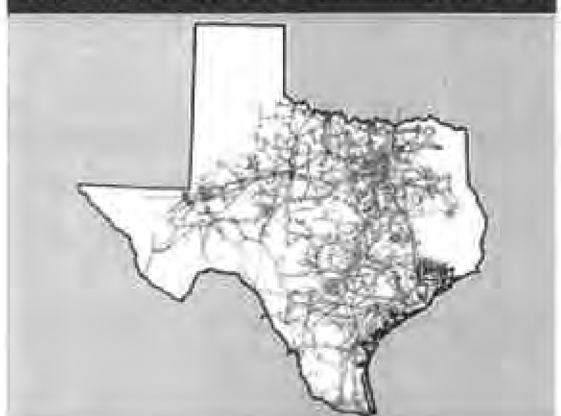


Source: Energy Information Administration

The **Public Utility Commission** of Texas (PUC) oversees some aspects of the electric markets subject to competition in ERCOT (about 60% of Texas residents), has very limited authority over electric cooperatives and municipal electric utilities, and has jurisdiction over rates and services of the remaining traditionally regulated investor-owned utilities.

The **Electric Reliability Council of Texas** (ERCOT) manages power flow for most of Texas (75% of land area, 85% of electric load, 23 million customers, 40,500 miles of transmission lines, and over 550 generation units). As independent system operator, ERCOT also performs financial settlement for the competitive wholesale bulk-power market and administers retail switching for 6.7 million premises in competitive choice areas. ERCOT's system planning functions include reviews of transmission providers' proposed lines, generation interconnection studies, five-year plans, and long-term (10- and 20-year) system assessments. ERCOT is a nonprofit corporation subject to oversight by the PUC and the Texas Legislature.

The ERCOT Electric Transmission Grid



Source: Electric Reliability Council of Texas

The **Texas Reliability Entity** (TRE) monitors and enforces compliance with NERC reliability standards and develops regional standards. The TRE is a nonprofit corporation subject to FERC and NERC oversight, along with PUC oversight regarding the TRE's monitoring / reporting on compliance with ERCOT protocols by ERCOT and by market participants.

Blackouts vs Brownouts:

A blackout is a complete power outage. A brownout is a reduction in voltage that causes lights to dim (a partial power loss). A rolling blackout is an intentional series of temporary power outages in limited areas; this rotation is a last resort effort to prevent a wider system blackout.

Major Outages:

Texas has only had two major generation-related outages in the last 20 years: the rolling blackouts of April 2006 (high electric demand due to high heat) and February 2011 (extreme cold, numerous generator outages). Texas also experiences outages during severe storms, such as Hurricane Rita in 2005, but these outages are generally due to damaged distribution lines and are geographically isolated.

Outage Prevention:

Outages can be avoided or lessened in many ways, such as:

- Reserve margin (percentage of available generation capacity greater than forecasted peak demand): currently set at 13.75% for planning purposes, with a goal of no more than one generation-related outage every ten years
- Economic responses such as construction of new generation when the projected capacity level goes below the target reserve margin or when electricity prices increase
- Reserve (/ancillary) services: ERCOT pays certain generators to be available to run if needed (capacity payments)
- Individual customer demand reduction (voluntarily or for payment by ERCOT)
- Coordination of maintenance for generation and transmission
- Communications among ERCOT and providers of generation, transmission
- Sufficient transmission interconnection and reliability standards

Storm-related outages can be minimized by efforts such as tree cutting, line maintenance, and "storm hardening."

Five Questions to Consider:

1. What are the benefits and disadvantages of having mostly state jurisdiction in the ERCOT area while having federal wholesale/ transmission jurisdiction in the non-ERCOT areas?
2. How should Texas balance the value of reliable service with the cost of outage prevention?
3. What enforcement authority does NERC have over ERCOT?
4. What techniques and technologies would enhance ERCOT's ability to shave aggregate peak use for grid management?
5. Would proposed transmission tie projects such as Tres Amigas, Southern Cross, Texas-Mexico, etc. improve ERCOT grid management?

Resources for Further Reading

- **ERCOT State of the Grid Report (Dec. 2012):** (http://www.ercot.com/content/news/presentations/2012/2012%20ERCOT%20State%20of%20the%20Grid_Web.pdf)
- **ERCOT Grid Information:** (http://www.ercot.com/gridinfo/)
- **Sunset Advisory Commission July 2011 report on ERCOT and the PUC:** (http://www.sunset.state.tx.us/82ndreports/puc/puc_FR.pdf)
- **Texas Reliability Entity:** (http://www.texasre.org)
- **Texas Department of Public Safety webpage on ERCOT blackout prevention & emergency procedures:** (https://www.txdps.state.tx.us/dem/temo/archives/2012/Vol59No5/articles/article2.htm)

This Power Across Texas Issue Brief was published on March 19, 2013

COMPETE

Electricity Competition Drives Innovation and Consumer Benefits

THE TEXAS COMPETITIVE ELECTRICITY MARKET: BENEFITTING CONSUMERS

ABOUT ERCOT

The Electric Reliability Council of Texas (ERCOT) manages the flow of electric power to 23 million Texas customers -- representing 85% of the state's electric load. As the independent system operator for the region, ERCOT schedules power on an electric grid that connects 40,500 miles of transmission lines and more than 550 generation units. ERCOT is a membership-based nonprofit corporation, governed by a board of directors and subject to oversight by the PUC of Texas and the Texas Legislature. ERCOT's members include consumers, cooperatives, generators, power marketers, retail electric providers, investor-owned and municipal-owned electric utilities.

THE TEXAS MARKET BENEFITS CONSUMERS

- The ERCOT wholesale market performed competitively in 2012.
  Potomac Economics: "2012 State of the Market Report," June 2013

- The ERCOT-wide load-weighted average real-time energy price was $28.33 per MWh in 2012, a 47 percent decrease from $53.23 per MWh in 2011. The decrease was primarily driven by more moderate weather and much lower natural gas prices in 2012.
  Potomac Economics: "2012 State of the Market Report," June 2013

- In 2012 Texas residential and commercial / industrial electric markets ranked #1 in competitive markets in North America – for the sixth year in a row -- in the Annual Baseline Assessment of Choice in Canada and the United States (ABACCUS). Texas was the only market that ranked "excellent" for both residential and commercial markets in 2012.
  Distributed Energy Financial Group

THE TEXAS MARKET BENEFITS THE ENVIRONMENT

- ERCOT has more than 10,400 MW of commercial wind power capacity – the most in the nation -- with the addition of 372 MW in December, 2012. Wind power comprised 9.2 percent of total energy used in the ERCOT region in 2012, compared to 8.5 percent in 2011.
  ERCOT press release

- On February 9, 2013 ERCOT set a new wind power record, with wind generation providing 9,481 MW of power at 7:08 p.m.
  ERCOT press release

nationalgrid

CLEAN LINE ENERGY PARTNERS

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NATIONAL GRID BECOMES AN INVESTOR IN CLEAN LINE ENERGY

(January 28, 2013) – National Grid (LSE: NG; NYSE:NGG) and Clean Line Energy Partners LLC (Clean Line) today confirmed the closing of National Grid's previously announced $40 million investment in Clean Line, effective January 25, 2013. The investment was subject to various state and federal regulatory approvals which have subsequently been obtained. Clean Line is a leader in the development of long distance, high voltage direct current (HVDC) transmission projects to move renewable energy to market. National Grid is one of the largest investor-owned energy companies in the world, with extensive experience building, owning and operating large HVDC electricity transmission interconnectors and transmission networks in the US and the UK. National Grid shares Clean Line's vision of enabling a cleaner energy future by investing in transmission projects that facilitate the development of renewable energy resources.

Under the terms of the transaction, Clean Line will use proceeds from the National Grid investment to advance the development of its four HVDC transmission projects that will connect onshore wind energy resources in the mid-west United States to communities and cities with demand for low-cost, clean power.

The investment in Clean Line is consistent with National Grid's long term strategy of developing and operating high quality energy infrastructure. Around 10% of National Grid's investments over the next eight years are expected to be outside its existing regulated activities in the UK and northeastern USA.

Lazard acted as financial advisor to Clean Line for this transaction. Grid America, a subsidiary of National Grid USA, will make the investment in Clean Line with corporate funds; the transaction is separate from National Grid's existing regulated businesses in the US and the UK. Under the terms of the transaction, National Grid will have the ability to acquire a significant ownership stake in Clean Line's HVDC projects. The funds associated with ZBI Ventures and the Houston-based Zilkha family will maintain their existing equity stakes in the company.

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About National Grid:

National Grid (LSE: NG; NYSE:NGG) is an electricity and natural gas company that connects consumers to energy sources through its networks. The company is at the heart of one of the greatest challenges facing society – to create new sustainable energy solutions for the future and develop an energy system that underpins economic prosperity in the 21st century.

In Great Britain, National Grid runs the gas and electricity systems and delivers gas and electricity across the country.

In the US, National Grid delivers electricity to more than 3 million customers in Massachusetts, New York and Rhode Island. It manages the electricity network on Long Island under an agreement with the Long Island Power Authority (LIPA), and owns over 4,000 megawatts of contracted electricity generation, providing power to over one million LIPA customers. It is the largest distributor of natural gas in northeastern U.S., serving more than 3 million customers in New York, Massachusetts and Rhode Island.

For more information please visit: www.nationalgridus.com.

About Clean Line Energy Partners:

Clean Line's mission is to connect abundant, renewable energy resources to areas that have a high demand for clean, reliable energy. Clean Line is developing a series of long distance, high voltage direct current transmission projects to move renewable energy to market. For more, information please visit www.cleanlineenergy.com.

About ZBI Ventures:

ZBI Ventures is a wholly-owned subsidiary of Ziff Brothers Investments, the private investment firm of the New York-based Ziff family. ZBI Ventures focuses primarily on private equity investments in the energy and energy-related sectors.

GRAIN BELT EXPRESS CLEAN LINE

GRAIN BELT EXPRESS CLEAN LINE July 2013

PUBLIC OPEN HOUSE

The purpose of this Public Open House is to:

- Introduce the Grain Belt Express Clean Line
- Share our transmission line routing process
- Seek your feedback to help us refine potential routes

JOBS

LOCAL GROWTH

CLEAN AIR

$2 BILLION INVESTMENT IN TRANSMISSION

$7 BILLION IN NEW WIND FARM INVESTMENTS

5000+ CONSTRUCTION JOBS

500+ OPERATIONS JOBS

MANUFACTURING JOBS

LOCAL BUSINESS PARTNERSHIPS

PROPERTY TAX REVENUES

PROJECT OVERVIEW

The Grain Belt Express Clean Line is an approximately 750-mile overhead, direct current transmission line that will deliver low-cost, renewable energy from western Kansas to Missouri, Illinois, Indiana, and states farther east. Similar to the trains that carry grain harvested in the Midwest to markets, the Grain Belt Express Clean Line will move wind energy from its source in the grain belt of the country to markets with strong demand for low-cost, clean power.

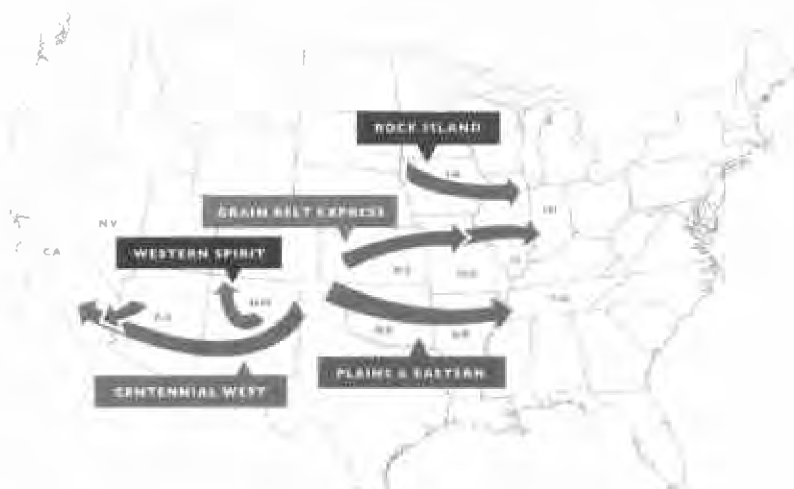
CLEAN LINE ENERGY

The Challenge

The United States has some of the best renewable energy resources in the world; however, the transmission infrastructure does not exist to transport the energy generated from these resources to communities that need the power. Clean Line Energy is working to address this challenge.

The Clean Line Energy Solution

Clean Line Energy is developing long-haul transmission lines to connect abundant renewable energy to communities that need it. The Grain Belt Express Clean Line will deliver low-cost, clean, renewable energy to communities in Missouri, Illinois, Indiana, and states farther east.



CLEAN LINE
ENERGY PARTNERS

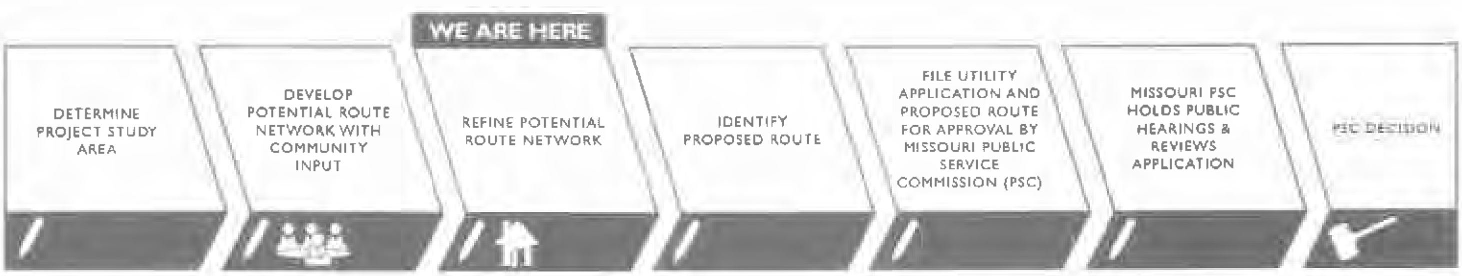
ROUTING A TRANSMISSION LINE

Grain Belt Express Clean Line is developing the transmission line route in a way that attempts to minimize impacts on existing land use and natural and cultural resources. The Grain Belt Express Clean Line team is gathering a wide range of information through agency coordination, public outreach, existing geographic information sources, and field reconnaissance to inform the route planning process. The route planning process takes into consideration routing factors, such as:

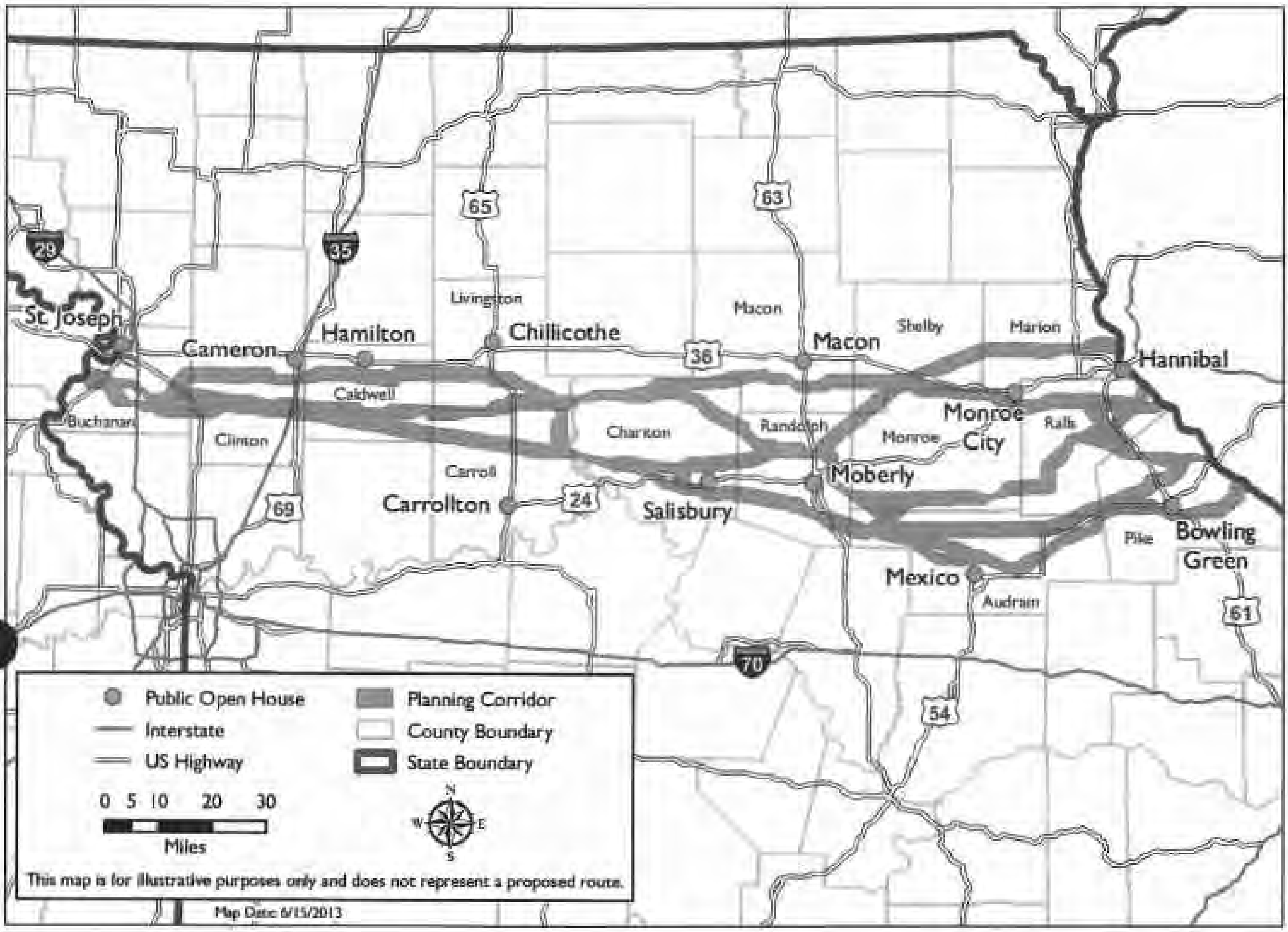
- Residences
- Agricultural lands
- State and federal lands
- Recreational areas
- Water resources
- Known cultural resources
- Schools
- Airports/airstrips
- Churches
- Sensitive habitats and protected species
- Community feedback
- Engineering constraints

With input from local officials, conservation organizations, state and federal agencies, and other stakeholders, potential routes have been identified for the Grain Belt Express Clean Line transmission project in Missouri. Because the potential routes are subject to change, landowners with property within a "planning corridor" around each potential route were invited to attend Public Open Houses to provide feedback.

MISSOURI ROUTING PROCESS



CURRENT NETWORK OF POTENTIAL ROUTES



WHAT'S NEXT AFTER THE PUBLIC OPEN HOUSES?

The feedback we receive at the Public Open Houses will help the Grain Belt Express team refine the potential routes for the transmission line and ultimately select a proposed route to file for approval with the Missouri Public Service Commission. Landowners will be notified if their property is along the proposed route.

Detailed maps of the potential routes and informational materials are available on the project website. In addition to submitting a comment card at the Public Open Houses, landowners and other interested parties can submit comments via the Grain Belt Express Clean Line website and the hotline number.

FREQUENTLY ASKED QUESTIONS

How do I submit feedback on the potential routes in Missouri?

Please submit feedback on the maps or your comment card, on the project website, or by calling the hotline number.

Where can I find the aerial maps shown at the Public Open Houses?

Please visit the project website to view the aerial maps that are available at the Public Open Houses.

Why High Voltage Direct Current (HVDC)?

The Grain Belt Express Clean Line will utilize HVDC transmission, an established technology that is ideal for moving large amounts of power over long distances. HVDC transmission lines use a narrower right-of-way than equivalent alternating current transmission lines and lose less power along the way.

Who will pay for the Grain Belt Express Clean Line?

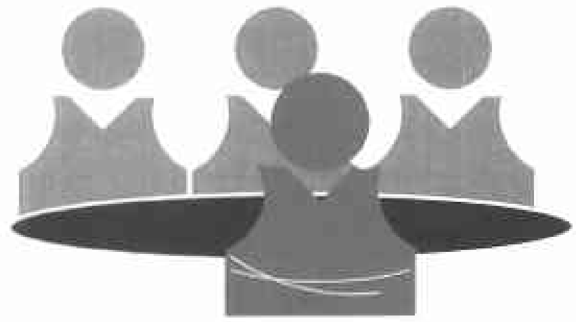
Grain Belt Express intends to privately finance the development and construction of the project and sell transmission capacity to renewable energy generators in Kansas and to utility customers in Missouri, Illinois, Indiana, and states farther east that choose to buy the renewable energy.

When will construction begin?

The timeline of the project is intertwined with the regulatory processes in each state the project will traverse. After Grain Belt Express receives the appropriate approvals from each state utility commission, Grain Belt Express will begin acquiring easements, surveying, environmental permitting, and signing up customers. Construction will take two to three years and could begin as soon as 2016. Grain Belt Express is committed to using qualified, local vendors to assist in constructing the transmission line.

Where should I submit my business information to be considered for the construction of the project?

Construction will not begin for several years. However, we are always seeking businesses that would like to provide services during the construction of the Grain Belt Express Clean Line. If you are interested in submitting your business information, please visit: www.grainbeltexpresscleanline.com.



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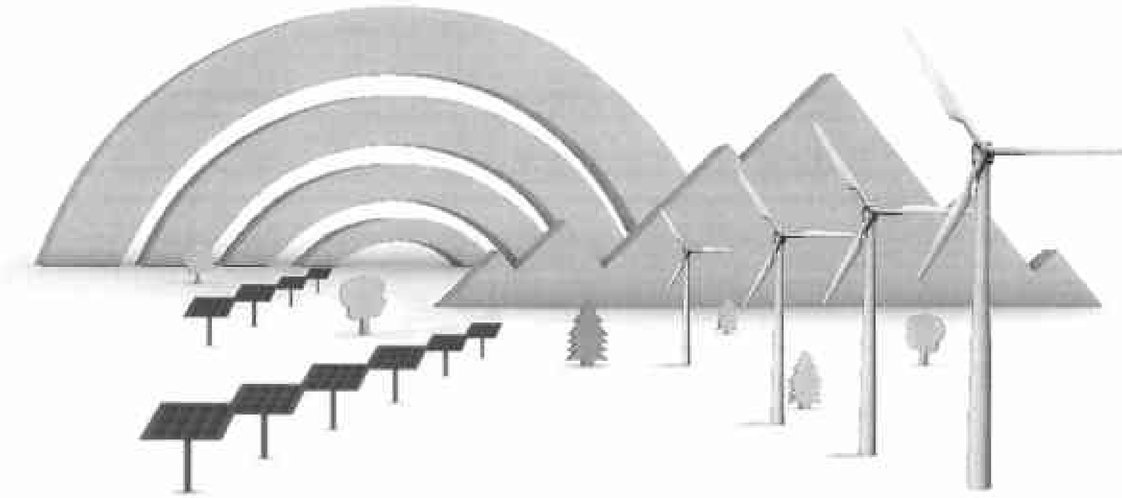
CLEAN LINE
ENERGY PARTNERS

edp renewables



renewable energy myths and truths

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RENEWABLE ENERGY – MYTHS AND TRUTHS

INTRODUCTION

The renewable energy story has been unfolding as a constant oscillation between supporters and sceptics. Environmental promoters have passionately idealised renewables as a silver bullet solution that will solve once-and-for-all air and water pollution, environmental degradation, and the climate change problem. Meanwhile, opponents have regarded renewables as an unattainable utopia, pigeonholed it as a "black sheep" of the electricity sector, and, most recently, pointed at government support of renewables as a major driver of the public deficit.

EDP Renewables believes that renewable energy represents an important part of the energy mix and plays a critical role in a robust 21st century economy. Renewables offer a solid business case, and we are prepared to put our money behind the industry. Moreover, we strongly believe that promoting renewable energy is good for the economy, good for the environment, and good for society today and tomorrow.

This is not just rosy rhetoric. Our business and industry analysts have taken a hard look at the data, and we are reaffirmed in our belief that we are on the right side of energy history.

Find out why...

WHY PROMOTE RENEWABLE ENERGY?

Key arguments resound in favour of promoting renewable energy:

- By investing in renewable energy, countries reduce their energy dependency by enhancing their security of energy supply and minimizing their exposure to potential volatility in fuel prices.
- Promoting a shift from conventional fossil fuels to renewable energy is one of the most effective and feasible near-term ways of mitigating climate change (even if renewables alone cannot resolve this complex problem).
- The reality is that the world economy must install new electricity generation capacity to fuel its growth and to replace old fossil-fired plants that are subject to retirement. Renewable energy is an environmentally-friendly and competitive option for new capacity investments. Renewable energy has a much shorter construction time, enabling a fast and flexible response to the growing demand.

Investing now in renewable energy secures a better world for future generations by providing them with a fully-amortized, clean, and cheap generation.

THE RENEWABLE ENERGY DEBATE

There are several persistent myths about renewable energy, especially with respect to climate change and economic competitiveness. Unfortunately, these myths have penetrated public opinion and are influencing the political landscape around the world. We would like to shed some light on this debate and set the record straight on some of the key issues.

CLIMATE CHANGE AND ENVIRONMENTAL CONCERNS

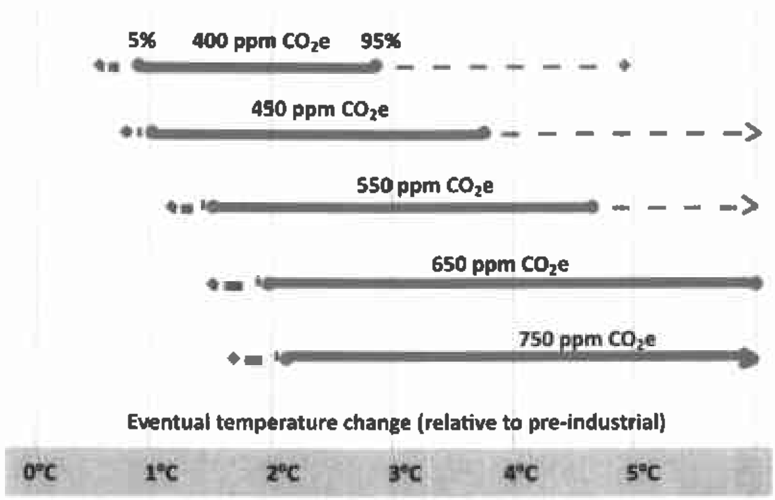
MYTH 1

Global temperature rise due to climate change can still be avoided if an ambitious mitigation effort takes place at the global level.

TRUTH

Global temperature rise is a current reality: the scientific community concurs that a temperature rise of at least 2°C is unavoidable even with the most ambitious mitigation policies, and the world should therefore put in place adaptation measures to minimize the damage that will be caused by this temperature rise.

Probability distribution of temperature rise for differing CO2e concentrations



Sources: Stern review, 2007; Stern lecture, 2012

Note: ppm CO_2e: Concentration of CO_2 emissions is measured in ppm (parts per million), which implies the number of parts of CO_2 found in one million parts of a particular gas, liquid, or solid. Contributions to climate change, whether they cool or warm the Earth, are often described in terms of the radiative forcing or imbalance they introduce to the planet's energy budget. Now and in the future, anthropogenic carbon dioxide is believed to be the major component of this forcing, and the contribution of other components is often quantified in terms of "parts-per-million CO_2-equivalent" (ppm CO_2e), or the increment/decrement in carbon dioxide concentrations which would create a radiative forcing of the same magnitude.

As a rough approximation:

- 450 ppm distribution centered around +2ºC; 20% chance of being greater than +3ºC
- 550 ppm: 50/50 chance of 3ºC
- 650 ppm: 50/50 chance of 4ºC
- 750 ppm: 50/50 chance of 5ºC

MYTH 2

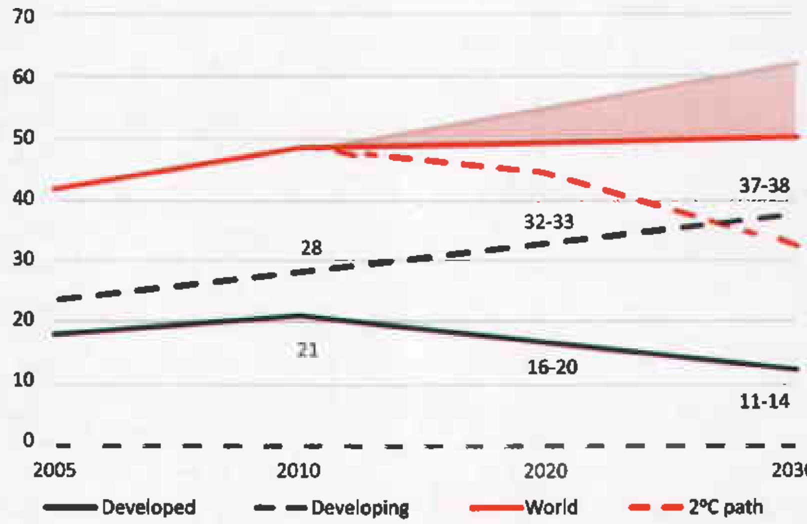
If greenhouse gas emissions could be capped at their current level, the global temperature will not rise above 2°C.

TRUTH

Much more aggressive measures are required at this point.

Prospects for world emissions based on current ambitions, targets and plans

Gton CO_2e



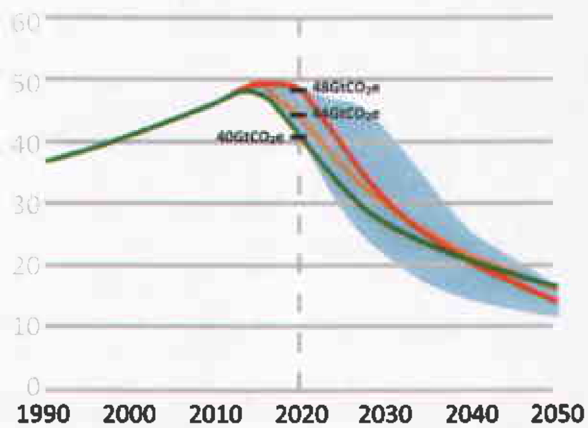
Sources: UNEP, 2011; Stern lecture, 2012

To ensure that temperatures do not rise above 2°C the following conditions need to be fulfilled:

1. Global greenhouse gas emissions must peak **<u>below</u> 50Gton /year <u>before</u> 2020.**
2. Emissions must reach **half the 1990 levels by 2050.**

Global GHG emissions

Gton CO_2e



Sources: Bowen and Ranger, 2009; Stern lecture, 2012

Energy currently accounts for 2/3 of the total greenhouse gas emissions, it is therefore **imperative to address this sector as a clear priority in mitigating climate change.**

MYTH 3

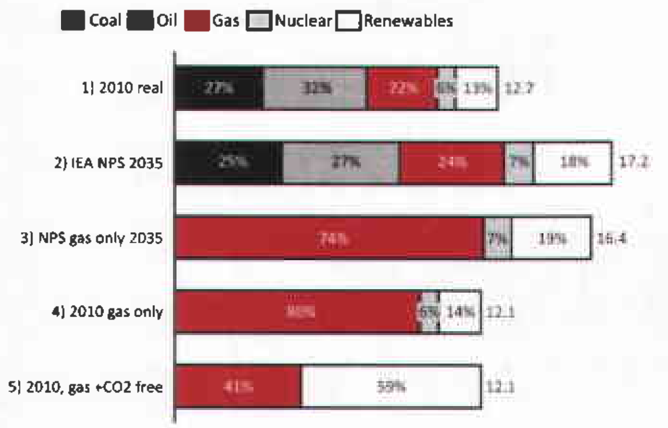
Climate change can be mitigated without promoting renewable energy – natural gas is THE solution to climate change.

TRUTH

Even a massive switch to natural gas without renewable energy would not be enough to cap the temperature rise at 2°C. Energy efficiency and renewable energy are necessarily going to be major components of future energy strategy if we want to respect the 2°C limit.

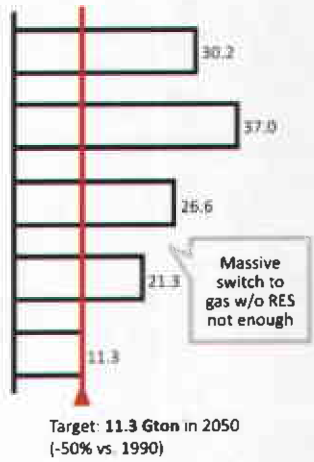
Primary energy mix

Gtoe, %



CO2 emissions

Gton CO2



Note: Scenario 3 considers the same final energy consumption of scenario 2 (2035)

Note 2: Scenarios 4 and 5 consider the same final energy consumption of scenario 1 (2010)

Sources: IEA, WEO 2012; BP Statistical Review; DPE Analysis

MYTH 4

Renewable energy's "green" image is highly overrated and there are numerous environmental issues caused by renewable energy projects.

TRUTH

While some renewable energy projects such as onshore wind farms may adversely affect natural habitats, negative impacts are normally avoided or mitigated during the environmental permitting process.

The key environmental advantages of wind energy over conventional technologies are many:

- Pollution-free: wind energy emits no harmful SOx, NOx, or mercury pollution, protecting valuable air and water resources;
- No carbon emissions, which means it helps to address climate change problem;
- Preserves land for wildlife (wind energy can co-exist peacefully and abundantly with most wildlife);
- Water conservation (there is virtually no water used for wind generation, conserving the vital resource).

However, we recognise that there are some legitimate environmental concerns that renewable energy developers must proactively address, such as:

- *Noise pollution* – this is minimised by placing turbines at a sufficient distance from residential houses and by regularly inspecting turbines to ensure they are in proper working order

- *Visual impact* – this is an undeniable reality of wind energy in particular, but it is also addressed at the permitting stage. Some mitigating measures may be introduced in collaboration with landscape and design experts.
- *Wildlife impact, particularly on birds* – this is a key focus of the environmental studies carried out during the development phase. Furthermore, rigorous analysis is carried out with respect to each and every potentially endangered species, whether avian or terrestrial.
- Potential environmental impact during the manufacturing process, particularly with respect to solar photovoltaic.

Most of these issues are also present (even to a greater degree) in other forms of electricity generation.

CONCERNS ABOUT THE COMPETITIVENESS OF THE RENEWABLE ENERGY

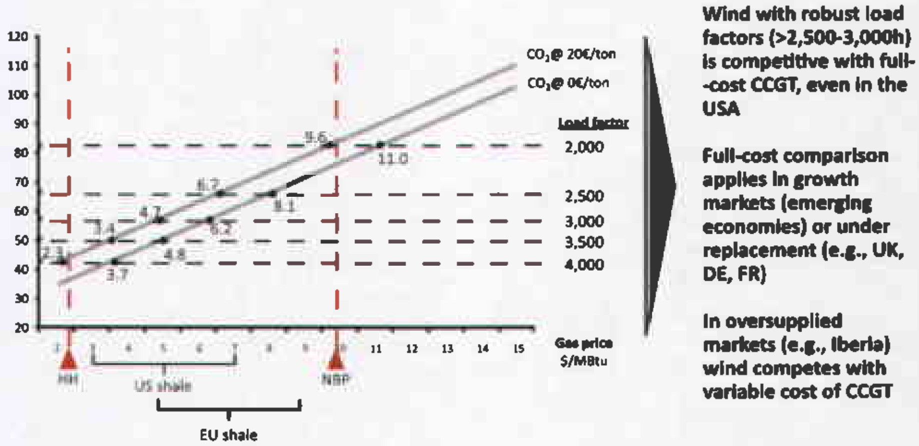
MYTH 5

Renewable energy is much more expensive than fossil fuel generation and will always rely on public subsidies to be competitive.

TRUTH

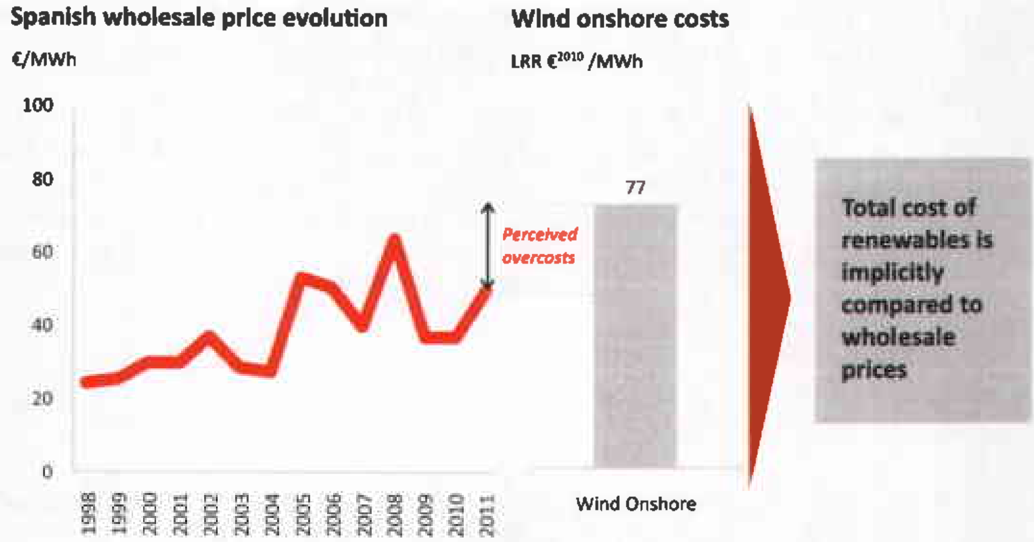
Onshore wind with robust load factors (>2,500 – 3,000 h) is already competitive with new full-cost Combined Cycle Gas Turbine (CCGT) technology, even in the USA.

Comparison of levelized cost of CCGT vs Wind
€/MWhe, 2012



Note: It is assumed 4,000 hours of CCGT working hours

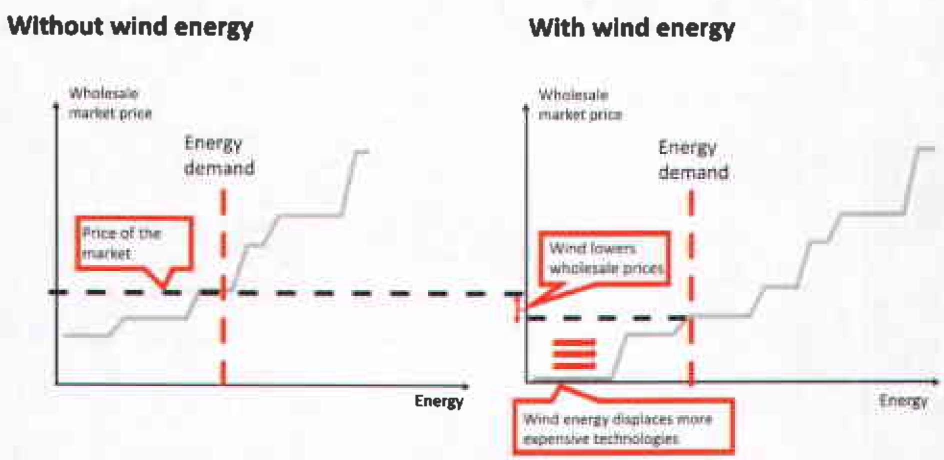
However, renewable energy is **perceived as being expensive** because the total cost of renewable energy is implicitly compared to wholesale prices of existing power plants.



However, this is not a fair comparison:

- Wholesale prices of most existing facilities do not account for the initial capital investment of the facility, as the investment has already been partially or fully amortized.
- Some conventional technologies are not covering their costs with wholesale price and therefore are not sustainable just with receiving this price.
- In some cases, conventional technologies receive additional revenue besides wholesale price, including capacity payments and payments for ancillary grid-support services.
- Renewables actually contribute to lowering wholesale prices, creating a benefit for the system that is not attributed to them.

With wind farms offering their energy at zero cost market price goes down



In the Iberian market, wind energy reduces wholesale prices between ~4 and 8 €/MWh

- The environmental / social costs ("external costs", such as GHG emissions, nuclear waste treatment and risk, re-settlements etc) of some conventional technologies are currently not fully internalised so we cannot yet talk about a level playing field for renewable energies.

MYTH 6

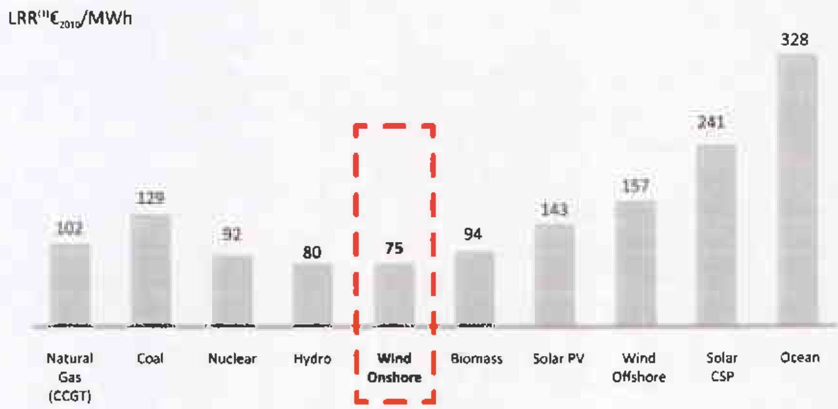
All renewable energy technologies face extremely high total costs and suffer the same competitiveness handicap with respect to conventional technologies.

TRUTH

Not all renewables are the same.

Some technologies (such as onshore wind, biomass and solar PV) are mature from a technological standpoint and competitive from a cost perspective. Therefore, these technologies are perfectly suitable for wide deployment.

Technology total cost benchmark



When total costs are considered, onshore wind is at the same level of cost as new conventional generation (even when back-up costs are included)

(1) Levelized required revenue

Indeed, it is a fact that, in several countries, mature renewables are already competitive when compared to other power generation technologies. For instance, in Brazil, the latest renewable capacity tenders set PPAs (Power Purchase Agreements) for wind farms at lower prices than those set for conventional thermal capacity.

Another example of this situation occurs in Portugal, where the feed-in tariff established by the tender for new wind power licenses was set around 70 €/MWh, which is inferior to the current total costs of a CCGT.

Other renewable technologies (such as solar CSP, ocean current, tidal, and to some extent offshore wind) are still not technologically mature and are not yet competitive from a cost perspective. It can be argued that these technologies should not be widely deployed until their technological maturity and costs reach a critical point. The development of these technologies should be fostered through R&D and carefully controlled installation rates. However, the relative immaturity of these technologies should not cloud the viability and cost-competitiveness of the mature technologies listed above.

MYTH 7

Given the current economic crisis and fiscal austerity context, it is not justified to pursue a low-carbon agenda, which implies significant private and public investment today and will yield benefits only in the long-run.

TRUTH

Not all countries are living under a fiscal austerity context. We believe there are two distinct "regions":

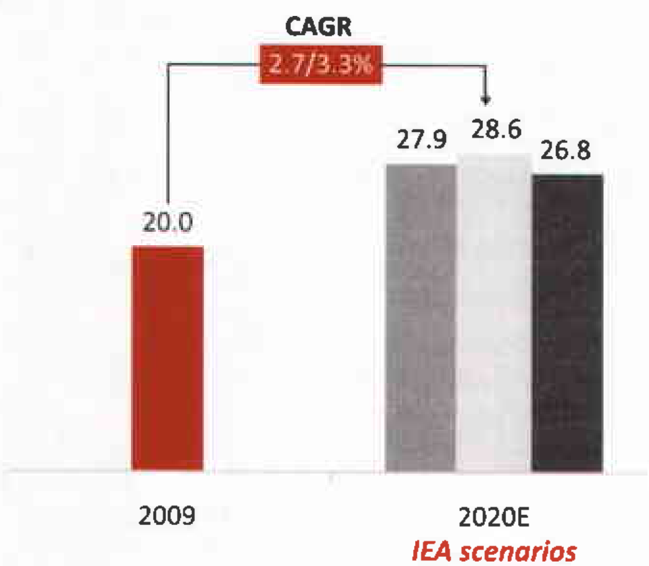
1. Countries with fiscal austerity and economic crisis with electricity demand decrease or stagnation (eg. some European countries)
2. Countries with significant economic and electricity demand growth (majority of non-OECD countries)

With respect to the first group of countries, which are suffering the negative impact of the economic crisis, we would like to point out the following:

The electricity sector is not playing a short-term game; we are creating today the electricity system for the next 20 years. Given the current macro-economic context, in certain countries we are witnessing a decline in electricity demand, which unexpectedly "helps" to achieve the renewable energy targets (defined as % of final consumption) set by national governments. Hence, it is easier to justify a certain slowdown in the deployment of new power generation facilities notwithstanding the importance of the industrial clusters that were locally created to support renewables growth. However, there is a need to invest today in new generation capacity to replace retired plants and to install additional capacity with the view of future recovery. It is important that the decisions that are taken today with respect to new generation capacity are based on long-term considerations and allow for a "no regrets" scenario that enables future low-carbon economic growth.

Global electricity demand growth – 2009 vs. 2020

10^3 TWh, electricity generation



IEA scenarios

Also we should not forget the contribution of renewables to GDP growth through job creation, improvement of countries' trade balance (due to reduced imports of oil and gas) and lower pool prices.

Finally, given the anticipated adverse economic consequences of global climate change, we simply cannot afford not to proactively address the issue in the electricity sector.

MYTH 8

The political discourse about the creation of "green jobs" as an important benefit of the investments in renewable energy is empty talk, as all the economic benefits go to foreign manufacturers.

TRUTH

While it is true that wind turbines and solar panels are sometimes sourced from foreign manufacturers who do not accrue economic benefits to the local economy and do not create "green jobs" at the local level, many of those foreign manufacturers have facilities in the country where the renewable energy is located and employ citizens of that country.

Additionally, there are important local economic benefits generated by the renewable energy projects:

- Development phase studies conducted by local biologists, surveyors, and engineers (including various environmental, technical, geological and other studies)
- Hundreds of construction jobs
- Permanent high-paying operation, maintenance, and technical jobs on-site
- Ongoing local road repairs/improvements
- Tax payments at the local and state level

These and other less visible benefits do favour the local, regional, and national economies.

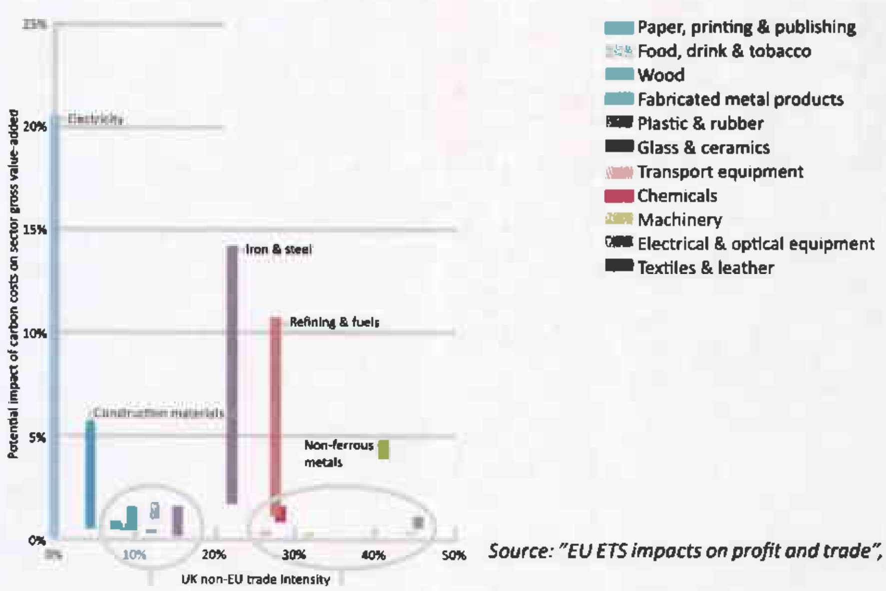
Moreover, those countries that start developing expertise in the sector with great future potential (such as renewable energy) and take leadership in technological race early on in the process, gain a competitive advantage and knowhow that create a strategic niche for their national industries at the global level and eventually lead to growth creation "at home."

MYTH 9

By promoting low-carbon technologies and penalising conventional technologies for emitting CO_2, the economic blocks such as the European Union are losing their competitiveness, especially in the absence of a global climate change agreement.

TRUTH

The CO_2 cost impact (both direct and indirect - through power prices) is material only for non-EU trade-exposed industrial sectors, which account for 1-2% of the EU's GDP.



Source: "EU ETS impacts on profit and trade", The Carbon Trust

Compensation mechanisms exist to offset the negative impact, such as 100% free allowances for direct CO_2 costs and financial compensation for electricity price increases.

Several studies show that impact is likely to be <1% in production, employment and competitiveness.

In some cases, industries even profit from renewable energy – renewables may depress power prices, in some countries industrial consumers are exempted from renewables' overcost, CO_2 allowances may be over-allocated and marketable, and/or companies/industries may have the ability to pass through the costs.

MYTH 10

Greater penetration of renewable energy leads to higher electricity prices for residential consumers.

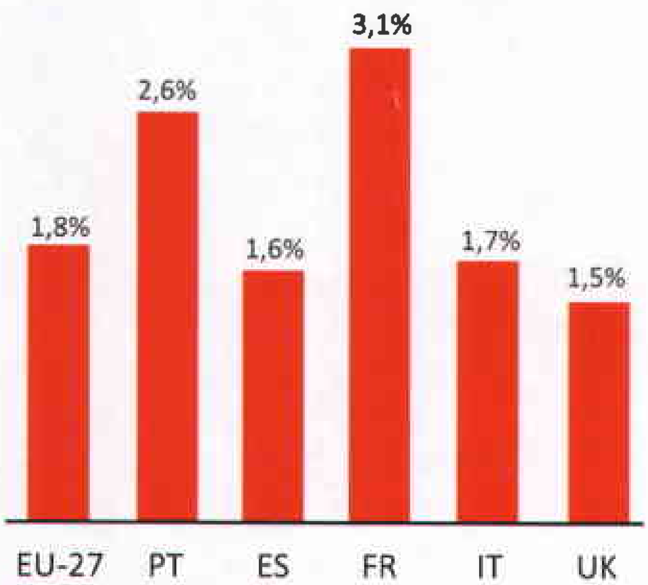
TRUTH

Impacts of renewable energy and CO_2 prices on households are relatively minor (2-4%), as the share of electricity among household expenditures is low and can be partially mitigated by allocating revenue from auctioned CO_2 allowances to the tariff.

Moreover, the short-term impact must also be weighed against the long-term benefits of energy bills shielded against rising fossil fuel prices.

Share of electricity costs in household expenditure

%, 2005



Source: Eurostat

MYTH 11

MYTH 11

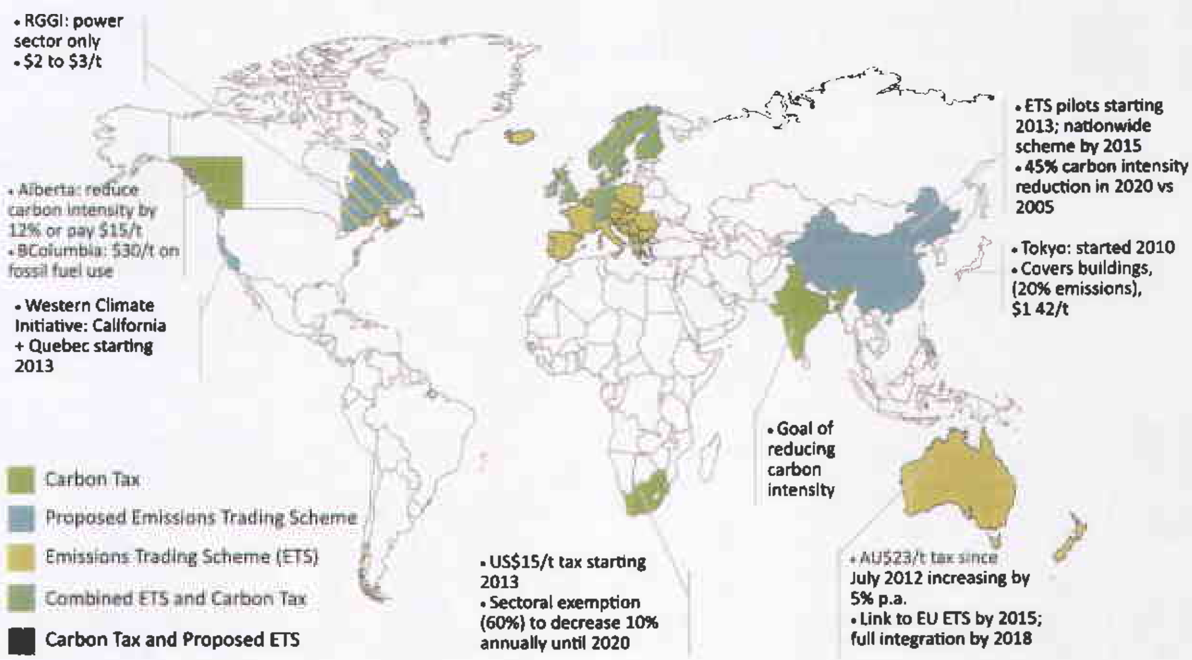
The European Union is currently the only economic region that is pursuing a low-carbon agenda and is thus jeopardising its global competitiveness.

TRUTH

Even if the European Emissions Trading System (ETS) is the most ambitious carbon market currently in place, other countries are also increasingly adopting carbon pricing policies.

China, for instance, has already put in place an emissions trading pilot programme in 2 regions and 5 cities, which is equivalent to ~85% of the emissions under the EU ETS. These pilots will pave the way for a national programme to start post 2015. In the 13th Five-Year Plan (2016-'20), China set a target to reduce carbon intensity by 40-45% from 2005's level.

Australia, New Zealand, Japan, South Korea and some regions of the United States and Canada are also pursuing low-carbon agendas.



Source: EESI - "Fact Sheet Carbon pricing around the world"

MYTH 12

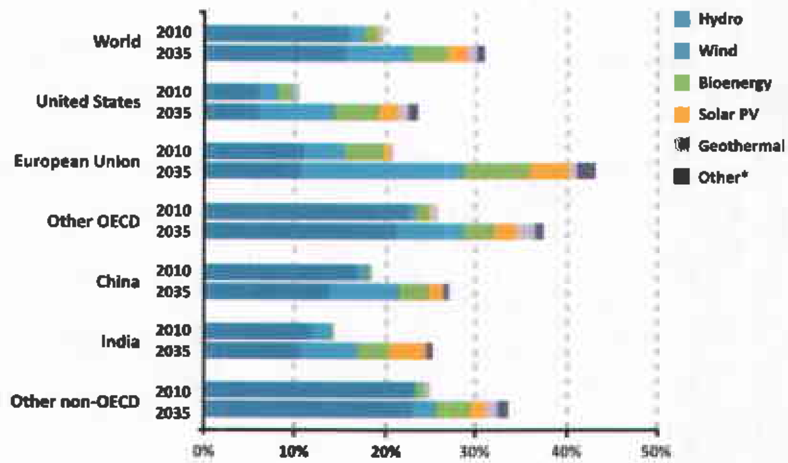
Europe is the only region investing in renewable energy.

TRUTH

The penetration of renewable energy sources in the electricity sector is set to grow in all regions, not only in Europe. In absolute terms, China's increase has been the largest (243Mtoe(*) vs 121 Mtoe in EU), while the USA continues investing as well (with 117 Mtoe).

(*) toe –tonne of oil equivalent is a unit of energy: the amount of energy released by burning one tonne of crude oil, approximately 42 GJ

RES development in the world
% of RES-E



*Other includes concentrating solar power and marine.

Source: IEA, WEO 2012 (New Policies Scenario)

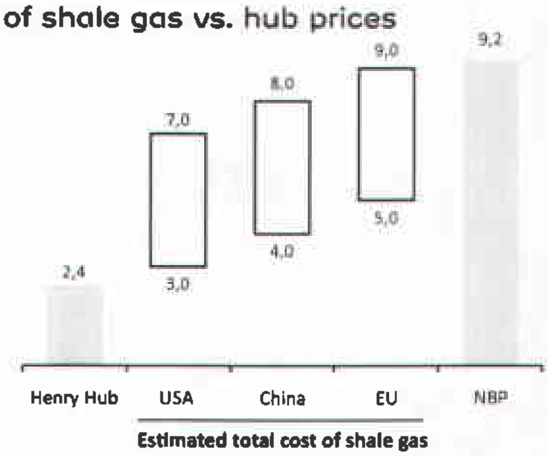
MYTH 13

Cheap shale gas production in the US will continue to depress gas prices in the U.S. and is likely to exert downward pressure in Europe as well, thus undermining the economic case for renewable energy.

TRUTH

Current low gas prices in the U.S. are not sustainable in the medium to long-run and will increase in the future.

Estimated total cost of shale gas vs. hub prices
$/Mbtu, 1H12



Indeed, current cost of shale gas in the U.S. is higher than its present market quotation due to the following reasons:

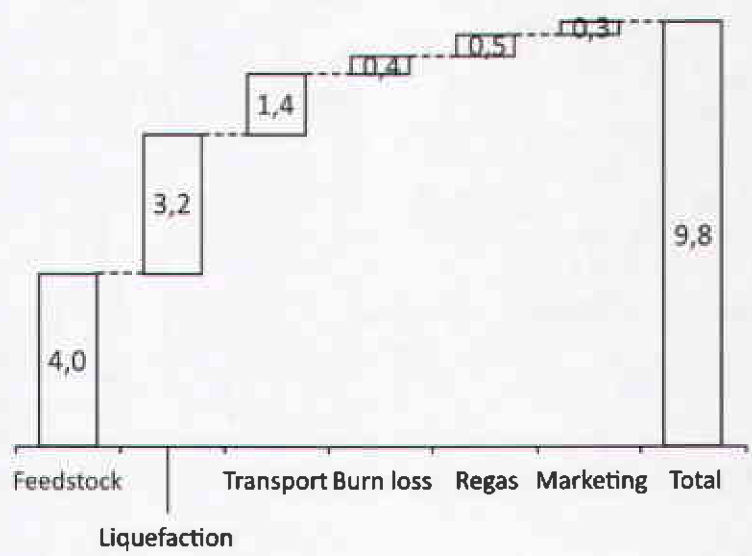
- *"Wet gas wells"*: players have been directing exploration to "liquids-rich" wells, in which natural gas is almost a sub-product that "floods" the market, creating overcapacity and depressing the price (profitability comes from natural gas liquids).

- *M&A*: company valuation is usually calculated through multiples based on production and proven reserves which creates an incentive for companies to continue exploring and producing shale gas wells.

- *Expiring land concessions*: land leases constitute one of the main total cost items, representing a sunk cost in the decision on whether to continue exploring a well.

U.S. shale gas delivered to Europe will be priced at higher levels (same as oil-linked contracts) after accounting for liquefaction in and shipping from the US, and the prospects of cheap shale gas production in Europe are very dim.

US Shale gas delivered into Europe
$/MBtu



Source: Merril Lynch, 2012

With regard to the impact of shale gas production on the renewables' economic case, it was already mentioned earlier that onshore wind is still competitive with shale gas-fired CCGT. Considering a sustainable shale gas price (5-7 $/mmbtu), wind farms with robust load factor (>2,500-3,000h) are competitive with full-cost CCGT.

Moreover, an increase in gas-fired power ultimately assists renewable energy in gaining greater penetration in electricity markets, as natural gas can be used as a back-up resource to balance renewables' variability.

MYTH 14

Current energy market design based on marginal cost pricing can provide a level playing field for all energy technologies and should be able to accommodate and promote the renewable energy due to their low operational costs.

TRUTH

Current energy-only markets are ill-suited for renewable energies as they penalise CAPEX-intensive low-carbon technologies, which have very low marginal costs. Long-term contracting that would lower risk premia and allow lower cost of capital would facilitate the deployment of these technologies.

European markets are currently discussing market design reform to adapt to this new paradigm, most notably the UK which has adopted a new Energy Bill with reforms in this sense.

MYTH 15

Only renewables receive government support through tax incentives and direct subsidies.

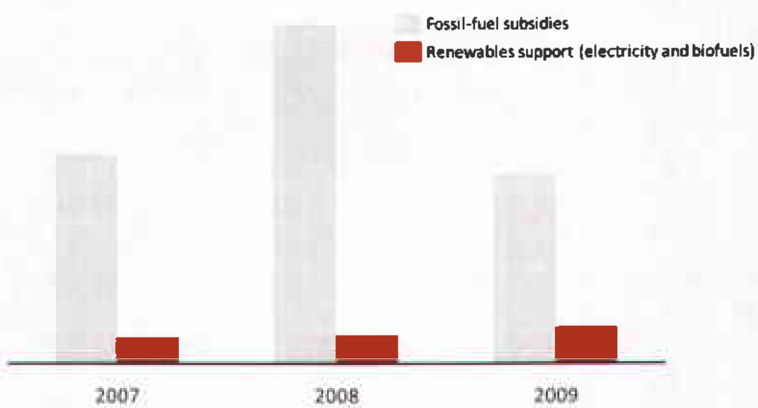
TRUTH

Fossil fuels worldwide have received significantly more government incentives at both the national and regional levels than renewable energy. Furthermore, most of these incentives are permanent and have been in place for more than half a century.

In fact, as recently as 2002-2007, fossil fuels in the US, to quote just one example, received nearly five times as much in tax incentives as renewable energy resources. At a worldwide level, the situation is similar, with government support for renewables accounting for only 18% of the value of fossil-fuel consumption subsidies in 2009. There are plenty of other examples of subsidies and tax breaks for conventional technologies in other regions of the world (eg coal subsidies in Spain).

Fossil fuel subsidies vs. Renewables support

B€



Source: IEA "Estimates of Fossil Fuel Consumption Subsidies" and "World Energy Outlook 2010"

First Solar is a leading provider of photovoltaic (PV) solar energy solutions whose mission is to create enduring value by enabling a world powered by clean, affordable solar electricity. Energy security, fuel price volatility, and the need for carbon dioxide emission (CO_2e) reductions are driving global demand for solar PV. First Solar's integrated PV power plant solutions provide an economically and environmentally compelling alternative to fossil fuels.

The seven gigawatts of First Solar modules installed worldwide displace seven metric tons of CO_2e per minute, the equivalent of removing two cars and saving more than 5,000 gallons of water every minute.

At First Solar we define sustainability as our "capacity to endure and scale." To achieve this, First Solar balances environmental, economic and social impacts throughout our business. Our sustainability mindset enables us to achieve long-term growth and lower energy costs while upholding social contracts with communities and partners and following environmentally responsible practices.

First Solar's PV power plants have the smallest carbon footprint and fastest energy pay-back time in the solar industry. We are dedicated to minimizing the environmental impact of our products and utility-scale solar projects across their life cycles. We are continuously reducing the energy and water intensity of our manufacturing processes, implementing responsible land use practices and biodiversity protection during construction, and providing recycling services for end-of-life solar modules. In 2012, First Solar set a goal to reduce our greenhouse gas (GHG) emissions intensity by 35 percent for 2016 from a 2008 base year. Since 2008, First Solar reduced our carbon intensity by more than 20 percent through improved module efficiency and energy conservation projects. This translates into significant cost reductions. Our Malaysia facility has already achieved savings of more than $1.8 million or 11,000 tons of CO_2e since 2010.

As part of our commitment to social responsibility, we engage in the communities where we manufacture, construct power plants or have other business interests. These communities benefit from local job creation, economic activity and training. First Solar is creating more than 40,000 global jobs throughout the value chain. We also engage with stakeholders such as governments and nongovernmental organizations, and we externally report on our sustainability performance.

With the combined environmental, social and economic benefits, there is a clear business case for following sustainability principles as a matter of practice. Sustainability is integral to First Solar as we deliver on our promise of providing the world with a clean, affordable energy solution.

James Hughes
CEO

First Solar

www.firstsolar.com/sustainability

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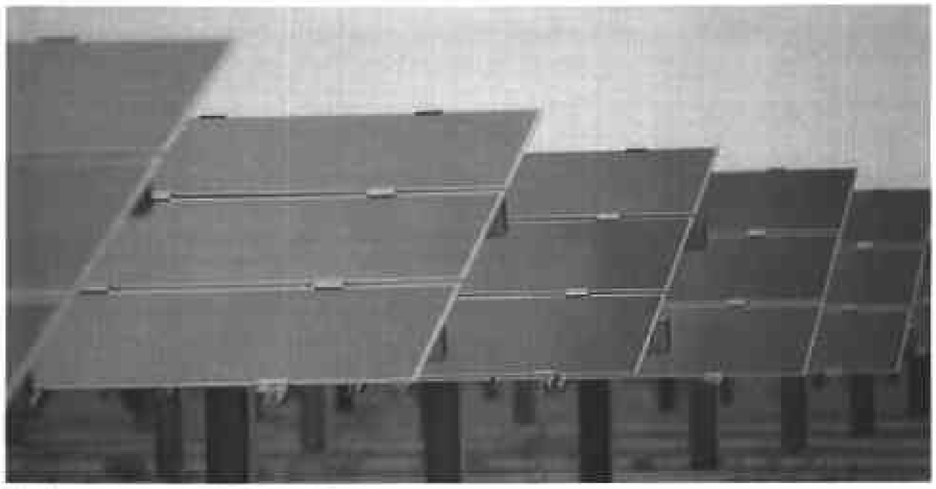
Avra Valley Solar Project

Project Quick Facts

- Avra Valley Solar Project
  Tucson, Arizona
- Project Size 25 MW
  (photovoltaic)
- Power Purchaser
  Tucson Electric Power
- Anticipated Groundbreaking
  1st Quarter 2012
- Anticipated Completion 2012



Solar photovoltaic panels at NRG's Blythe Solar Project

Project Overview

NRG Energy, through its wholly owned subsidiary NRG Solar, is developing the Avra Valley Solar Project, a 25 megawatt (MW) solar photovoltaic facility west of Tucson, Arizona. Once operational, the facility will produce clean, renewable electricity that will be sold to Tucson Electric Power under a 20-year power purchase agreement.

At full capacity, the Avra Valley Solar Project will generate enough power to supply approximately 20,000 homes. In addition to helping Arizona diversify its generation portfolio and meets the state's renewable energy goals, the project will create as many as 300 construction jobs.

The Avra Valley Solar Project is located on approximately 300 acres of fallow agricultural land, located about 20 miles west of Tucson, Arizona. NRG Solar anticipates breaking ground on the project in the first quarter of 2012, with an expected completion in 2012.

About NRG Solar

NRG Solar is developing two complementary technologies—photovoltaics and solar thermal—for large-scale solar plants and is a leading owner and operator of PV systems at residential and commercial locations.

Altogether, NRG Solar has more than 2,000 MW of solar projects under development or in construction across the southwestern United States.

NRG is at the forefront of changing how people think about and use energy. A Fortune 500 company, NRG is a pioneer in developing cleaner and smarter energy choices for our customers: whether as one of the largest solar power developers in the country, or by building the first privately funded electric vehicle charging infrastructure or by giving customers the latest smart energy solutions to better manage their energy use. Our diverse power generating facilities can support over 20 million homes and our retail electricity providers—Reliant, Green Mountain Energy Company and Energy Plus—serve more than two million customers.

nrg

Project Benefits

- Zero-carbon generation will avoid the annual emission of 33,000 tons of carbon into the atmosphere, the equivalent of taking 6,000 cars off the road
- Will create up to 300 construction jobs
- Commercially proven solar technology
- Minimal water consumption
- Efficient and environmentally friendly power generation
- Helps Arizona meet renewable energy goals

nrg

The power to change life.
The energy to make it happen.

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FIRST SOLAR LEADS AMERICAS CLEAN ENERGY M&A SPREE

US integrated solar group First Solar moved to strengthen its long-term credentials as a project developer and technology leader this month with the acquisition of a 1.5 GW solar project portfolio in North America and General Electric's cadmium telluride intellectual property (IP) portfolio.

The purchases were the most significant of a host of M&A deals within the wind and solar industries that indicated the extent to which large power producers, utilities and financial investors are increasing their project acquisition activities in the Americas.

First Solar bought the 1.5 GW development pipeline from independent power producer Element Power. The deal perfectly encapsulates what a large developer like First Solar is looking for when acquiring development assets.

The portfolio is diversified in location, covering sites in California, Arizona, Texas, Georgia, North Carolina, Colorado, Louisiana, Illinois and the Mexican state of Sonora.

All projects in the deal have secured site options, adopted queue positions for interconnections and have entered the environmental screening and permitting stages, which removes a degree of risk but more importantly cumbersome activity for First Solar, while leaving the company plenty of room to add value to the assets.

It can achieve this value by deploying its own thin-film modules or leveraging its expertise as the world's largest solar engineering, procurement and construction (EPC) contractor. US market researcher IHS forecast last week that First Solar will in 2013 become the first EPC provider to install more than 1.1 GW of solar capacity in a single year.

First Solar already used major acquisitions to enhance its development pipeline this year in January, purchasing the 50 MW Macho Springs project in New Mexico from Element Power and a 1.5 GW Chilean development pipeline through its takeover of Solar Chile.

The company's acquisition of GE's cadmium telluride solar IP portfolio, and the associated module purchase commitment it secured from GE alongside the deal, shores up its position in the thin-film technology market, which could become more lucrative if tariffs on Chinese solar imports to Europe and the US drive prices of crystalline silicon upwards.

As a major integrated company, First Solar is one of several types of players looking to acquire projects in a North and South American market where IPPs and small to medium developers like Element Power are eager to divest assets in order to secure capital for new projects.

Oregon-based utility Portland General Electric this month acquired development rights for the 267 MW Phase II of the Lower Snake Wind Farm in Washington, and will directly invest about $500 million of its own capital to build the project.

Although the wind farm will be built by renewable energy developer Renewable Energy Systems (RES), PGE will own the asset rather than simply purchase power from it, which is the usual manner in which US utilities procure their renewable power. In this case, PGE wants greater control over the process to ensure it meets an Oregon state requirement to source 15% of its power from renewables by 2015.

Japanese trading houses are another group recently highlighted as having a growing appetite for clean energy projects, and the latest major deal featuring their involvement was announced in early August when Marubeni Corp. bought a 25% stake in Ireland-based Mainstream Renewable Power for $100 million.

In relation to that deal, the Irish Times reported that Mainstream is planning a sale of its US projects because of the difficulty it is having in developing new viable clean energy projects in the country. The news highlights another driver of development-stage divestments in North America, as international developers with greater priorities elsewhere seek to exit the market due to continuing low energy prices and lack of long-term visibility on renewable energy policy.

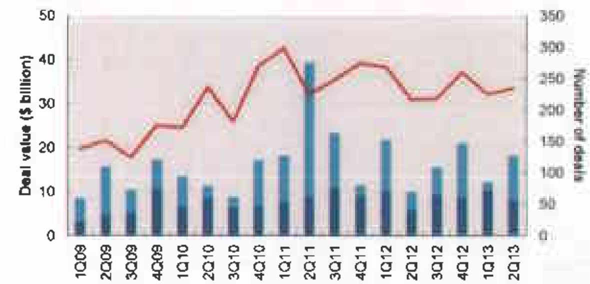
In Mainstream's case, it will seek to focus on other growth clean energy markets, most notably Chile, where it has amassed a large project pipeline.

Note: In August, we do not provide a full breakdown of transaction activity in the Weekly Review. A full list of transactions in August will be included in the September 3 issue.

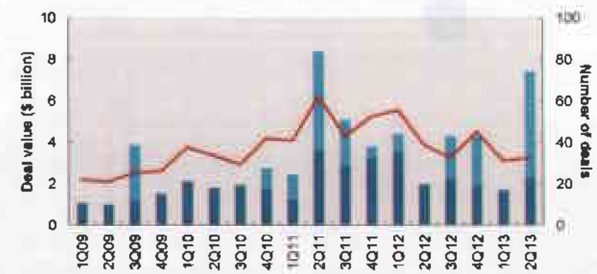
DEAL TRACKER 13 August – 19 August 2013	No. of deals	Deal value ($ million)
Venture Capital & Private Equity	17	$125.7
Mergers & Acquisitions	17	$121.0
Project / Asset Finance	21	$1,753.4
Public Markets	1	$34.4

Note: N/D deal values have been excluded from total "Deal Value". Deals with N/D values have been included in the "No. of deals"

GLOBAL MERGERS & ACQUISITIONS (1Q09 TO 2Q13)



PRIVATE EQUITY BUYOUTS (1Q09 TO 2Q13)



Sundt Solar Boost Project

A Clean Power Boost for Arizona

A UniSource Energy Company

Overview

Tucson Electric Power (TEP) is partnering with AREVA Solar to develop a solar addition to a dual-fueled coal/natural gas unit at TEP's H. Wilson Sundt Generating Station in Tucson, AZ.

At full output, TEP's "Sundt Solar Boost Project" will produce up to 5 megawatts (MW) of electricity without added emissions.

Solar steam augmentation projects, like the Sundt Solar Boost Project, are gaining momentum in the United States and around the world as a way to leverage existing power infrastructure to provide additional capacity with no added emissions.

Key Facts

What	A clean solar power "boost" for TEP's coal/gas-fired unit
Who	Tucson Electric Power Company and AREVA Solar
Where	TEP's Sundt Generating Station in Tucson
Capacity	Boosts dual-fueled 156 MW Unit 4 by up to 5 MW with Concentrated Solar Power (CSP)
Project Benefits	• Supplies low-cost solar energy to Sundt plant • Produces solar energy during peak demand periods without added emissions • Offsets the use of up to 46 million cubic feet of natural gas or approximately 3,600 tons of coal per year • Avoids 4,600 to 8,500 tons of CO_2 annually • Creates local jobs and other economic benefits • Powers more than 600 Tucson homes • Helps Arizona achieve its renewable energy goals
AREVA Solar's CLFR Technology	• Low-cost and most land-efficient CSP technology • Well-suited for new and existing power plants and industrial sites • Closed loop system to conserve water • Modular and scalable; simple and durable design • On-site and regional manufacturing; standard materials for high local content
Timeframe	Online by early 2013

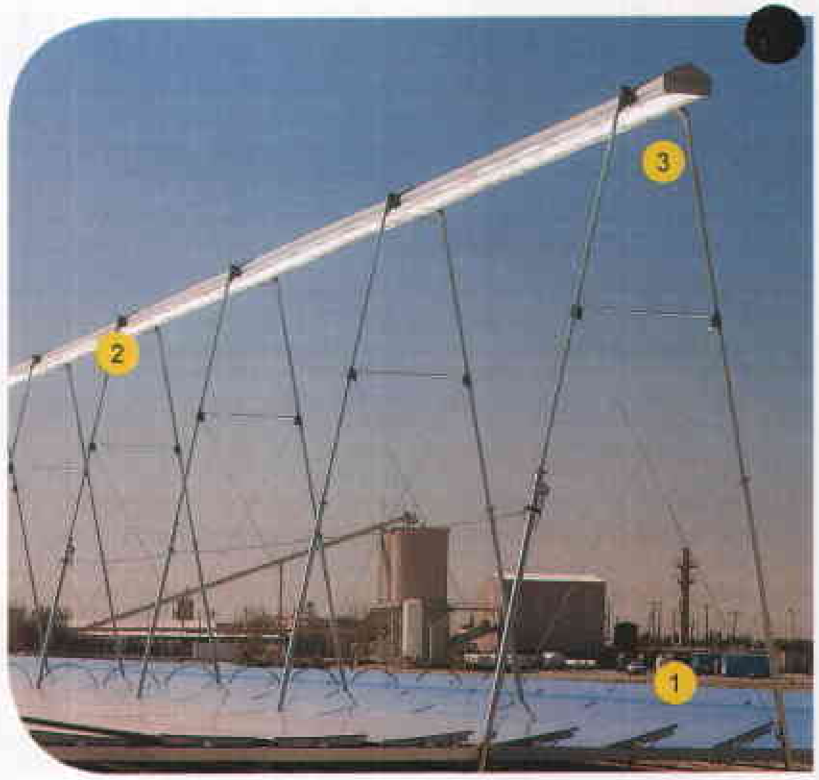
www.tep.com
www.solar.areva.com

How It Will Work

AREVA Solar will install a Compact Linear Fresnel Reflector (CLFR) solar steam generator at TEP's Sundt Generating Station.

- AREVA's CLFR technology uses rows of flat mirrors to reflect sunlight onto a linear receiver supported above the mirror field.
- Water flows through tubes in the receivers.
- The concentrated sunlight boils the water in the tubes, generating high-pressure, superheated steam for TEP's Sundt Generating Station.

AREVA has the most land-efficient CSP technology in operation today, lowering costs, simplifying permitting and reducing environmental impact.



Benefits

TEP and AREVA Solar are pioneers in developing sustainable, clean energy solutions. The innovative Sundt Solar Boost Project will enable TEP's Sundt Unit 4 to produce an additional 5 MW of solar-generated power while using the same amount of fuel.

The Sundt Solar Boost Project will also help Arizona achieve its Renewable Energy Standard, which requires electric utilities to increase their use of renewable power each year until it accounts for 15% of their power in 2025.

TEP is well on its way to achieving this goal. By 2014, TEP plans to have more than 200 MW of solar generating resources online. The Solar Electric Power Association ranked TEP sixth in the nation last year for per-capita additions to its solar energy portfolio.

Tucson Electric Power
A UniSource Energy Company

Tucson Electric Power provides safe, reliable service to more than 402,000 customers in the Tucson metropolitan area. To learn more, visit www.tep.com. For more information about parent company UniSource Energy, visit www.uns.com.

AREVA

AREVA Solar manufactures and installs solar steam generators for its global power generation and industrial customers in a dependable, competitive and environmentally responsible manner. AREVA's Compact Linear Fresnel Reflector CSP technology is water-conservative and the most land-efficient solar energy technology available. Please visit www.solar.areva.com for additional information on AREVA's global solar energy solutions.

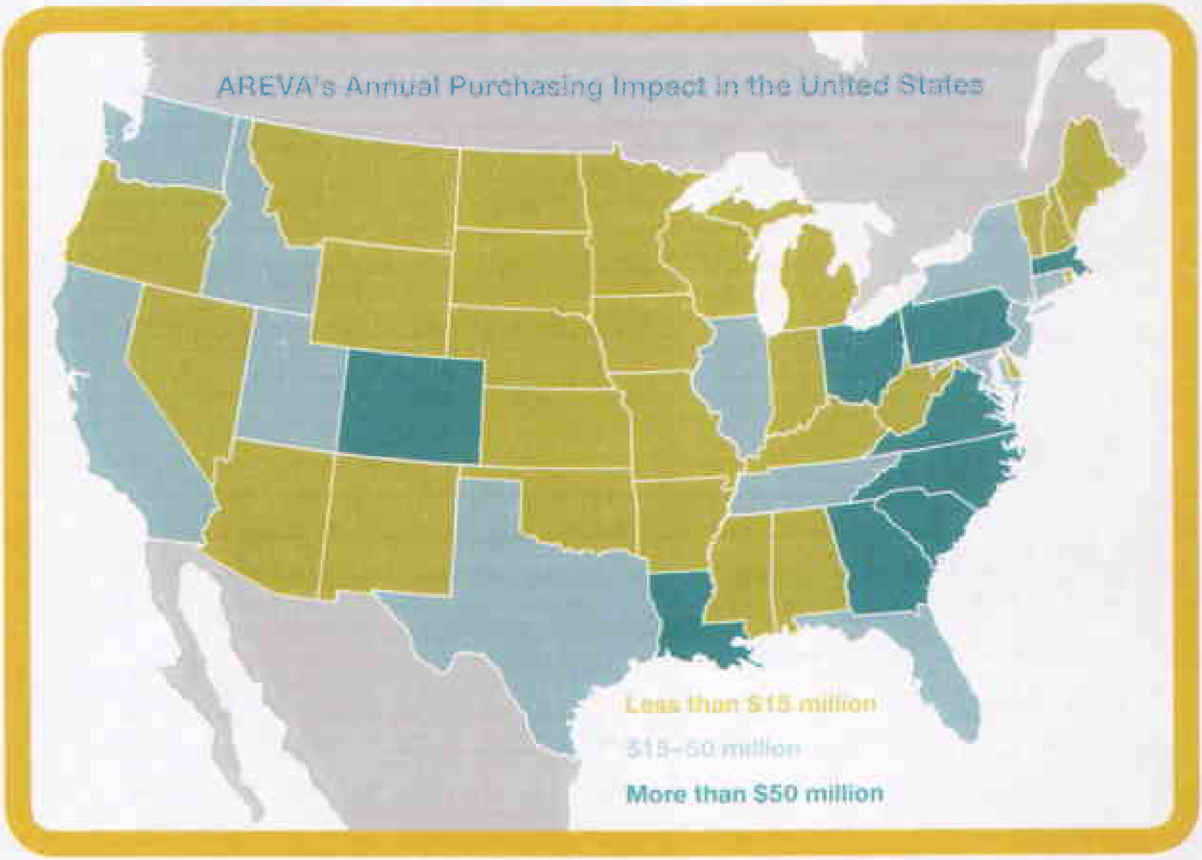
AREVA's Economic Impact in the United States

AREVA is America's **largest supplier** of innovative solutions for **carbon-free energy**.

We are the biggest employer in the nuclear energy sector with 6,000 highly skilled workers at 45 sites across the United States. AREVA has hired 700 new employees each year over the past few years and is creating 300 new American jobs each year for the next five years.

AREVA generates more than **$2 billion** in annual revenue, and directly contributes **$135 million** to the U.S. tax base.

Through business with our 5,000 American suppliers, AREVA injects $1.3 billion each year into the U.S. economy, supporting the creation of 9,000 jobs.



We are not just building **nuclear power plants**, we are **building an industry** that provides a **tremendous boost** to American **energy infrastructure** and the **U.S. economy** while creating **thousands of jobs**.

How AREVA is Building a U.S. Energy Base and Supporting the National Economy

U.S. EPR™ Reactor

First and only Generation III+ nuclear power plant currently under construction around the world

Evolutionary reactor design to meet America's growing clean energy demands

Eight reactors under consideration for America by U.S. utilities

- $200 million already invested in the certification process for the U.S. EPR™ reactor
- Recruitment of 500 additional engineers
- Each U.S. EPR™ reactor project will create approximately 3,000 construction jobs during peak construction. Over the seven-year construction period, the total economic output will be $8.9 billion and almost 40,000 jobs created or induced.
- During operation, the average nuclear plant generates more than $260 million in combined federal, state, and local tax payments and close to 4,500 jobs throughout the economy.

Shaw AREVA MOX Services LLC

Prime contractor for the Department of Energy Mixed Oxide (MOX) Fuel Fabrication Facility near Aiken, South Carolina

A major component in the United States weapons disposal program, the MOX facility will convert former weapons material into commercial reactor fuel

- Already employing 1,600 people on site
- $500 million invested in the United States through MOX suppliers

Modernizing and Investing in American Energy Technology

Providing services to 50 percent of Pressurized Water Reactors and 25 percent of Boiling Water Reactors in the United States

- $6.5 million invested in a Chemistry and Materials Center to perform testing and analysis for improved efficiency of plant components and fuel
- Invested approximately $40 million in U.S. fuel fabrication lines during the past five years, including $10 million during 2009

AREVA Newport News, LLC

Joint venture with Northrop Grumman Shipbuilding to produce heavy reactor components at a new facility in Newport News, Virginia

Domestic source of critical heavy reactor components for the U.S. EPR™ Reactor

- $360 million construction project launched in July 2009
- Creation of 500 skilled manufacturing and salaried jobs

Eagle Rock Enrichment Facility

AREVA's planned uranium enrichment facility to be built in Bonneville County, Idaho

Domestic supply of uranium enrichment needs for 25% of U.S. nuclear power plants

- A multi-billion-dollar direct investment in nuclear energy infrastructure
- Creation of an estimated 5,000 direct and indirect American jobs
- Economic impact estimated at more than $5 billion

ADAGE

Joint venture with Duke Energy to develop biopower facilities (biomass to power) throughout the United States

One facility will provide renewable energy for 40,000 homes

Two proposed projects for Florida and one project for Washington state

- $105 million in direct economic impact
- 700 direct and indirect jobs

» AREVA can create **even more** American jobs.

AREVA is the world leader and expert in the field of recycling spent fuel. Recycling provides an answer to current spent fuel storage concerns, reducing both volume and toxicity, and providing an additional source of nuclear fuel. But this solution also means the creation of thousands of jobs.

Construction of an 800mTHM recycling facility would create 12,000 jobs, including 1,000 design jobs. During operation, it would require 2,500 permanent personnel. An infrastructure project of this magnitude has the potential to spur a substantial economic impact and create 70,000 indirect jobs overall.

AREVA INC.
4800 Hampden Lane, Suite 1100 • Bethesda, Maryland 20814 • Tel: 301-841-1600 • Fax: 301-841-1614 • www.us.areva.com

Renewable Energies Business Group

AREVA recognizes the important role that renewable energies can play by complementing nuclear power in a CO_2-emissions-free energy mix for the United States. Renewable energies have become a valuable carbon-free solution as America strives to secure the nation's energy supply, increase U.S. economic vitality and battle climate change.

Because renewable resources are unevenly distributed among our nation's regions, AREVA has created a portfolio of solutions based on wind, solar and bio-energy sources. Our portfolio also includes energy carrier and storage solutions.

AREVA provides an array of complementary solutions that could help U.S. utilities meet Renewables Portfolio Standard obligations of 15 to 20 percent of their generation output.

AREVA has built more than 100 biomass plants around the world

Bio-Energies

Capitalizing on opportunities in the fast-growing bio-energies U.S. market, AREVA and Duke Energy launched ADAGE™, an industrial partnership offering biopower* electricity solutions for U.S. utilities. ADAGE™ uses wood debris from forest operations to generate electricity. ADAGE's™ mission is to design, build and operate a fleet of standardized wood biomass power plants, bringing to commercial scale this under-used renewable electricity source. ADAGE™ expects to have 10 to 12 plants under

ADAGE

An AREVA/Duke Energy advanced biopower company

construction in the United States by 2014. ADAGE™ provides fully integrated, turnkey solutions by negotiating Power Purchase Agreements and fuel contracts, securing suitable sites for each project, and managing all aspects of the projects from cradle to grave. Building and operating ADAGE™ biomass plants in the U.S. provides several advantages:

- ADAGE™ biomass plants create thousands of high-paying, sustainable, green-collar jobs.
- This plentiful green energy source is a carbon-neutral, non-intermittent energy source.
- Excess biomass removal creates healthy forests, less prone to wildfires and insect infestation.
- Domestic biomass sources contribute to the nation's energy security.

The environmental commitments outlined in the ADAGE™ strategic plan were featured at the Clinton Global Initiative 2008 Annual Meeting in New York.

*Biopower uses biomass (renewable organic material, such as from plants or animal waste) to generate electricity.

CONSIDER THESE FACTS...

- A single 50-megawatt wood biomass plant generates enough electricity for 40,000 households, avoiding net emissions of 400,000 tons of CO_2 per year in the process. Wood biomass currently produces approximately 7,000 megawatts of electricity in the U.S., an output expected to roughly double by 2020.
- With more than 100 plants in operation in the world, AREVA has more expertise in building biomass plants than any other company: to date, AREVA-built biopower facilities outside the United States have already saved a combined 3 million tons of CO_2 equivalent per year.

AREVA

Offshore wind turbines designed and built by AREVA Multibrid

Advantages of offshore wind include the following:

- Creation of thousands of high-paying, sustainable, green-collar jobs,
- Production of carbon-free electricity using turbines that are not very visible from the shore,
- Installation near large population centers on both coasts and around the Great Lakes,
- More plentiful renewable energy capacity for individual states,
- Greater capacity given stronger, steadier off-shore winds,
- Creation of artificial reefs for fish spawning without shipping/fishing interference.

Wind Power

Analysts expect wind power's share of the energy market to continue expanding on a global scale. AREVA broke into the fast-growing off-shore branch of the market with the acquisition of a 51 percent stake in Multibrid, a high-output offshore wind turbine designer and manufacturer.

Multibrid developed the M5000 technology, a 5 megawatt (MW) turbine that is among the largest commercially viable turbines to date. The M5000 is the only turbine in the marketplace specifically designed for offshore and marine conditions.

AREVA Multibrid has sold more than 180 M5000 turbines, which represents more than 900 MW in capacity. AREVA Multibrid recently won a $1 billion contract to provide 80 M5000 turbines for a 400 MW farm in Europe, one of the largest offshore wind farms in the world. This farm will provide electricity for one million users.

AREVA is extending its success to the United States, where the offshore wind market is emerging with support from developers, utilities and policy makers. With total potential resources of 430,000 MW in the United States, analysts project installed capacity at 6,000 MW by 2020.

Solar Power

AREVA is focusing on Solar Thermal Energy Generation (STEG), which offers competitive, utility-scale power solutions. In the Southwest, STEG produces energy during the warmest hours of the day, a tremendous advantage given that, at the same time, air-conditioning needs increase the load placed on electricity grids.

At AREVA, we plan to contribute to the renewed growth of the solar industry by providing to U.S. utilities both our reliable energy solutions and our large-scale industrial construction expertise.

Energy Carrier and Storage

Energy generated by the sun and wind can be intermittent sources of power. By developing energy storage solutions, AREVA will enable our utility customers to store energy from these valuable sources and distribute it according to grid-load needs.

Sundt Solar Boost Project

156 + 5 MW

Hybrid Coal-Fired + Linear Fresnel Concentrating Solar Power (CSP) Generation

The Sundt Solar Boost Project is the United State's first grid-linked, commercial-scale solar thermal power collector system installation for coal-fired power plant augmentation.

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Similar projects are in planning stages, such as Tri State G&T's 245 MW coal plant with 36 MW of proposed solar augmentation in Escalante, New Mexico.

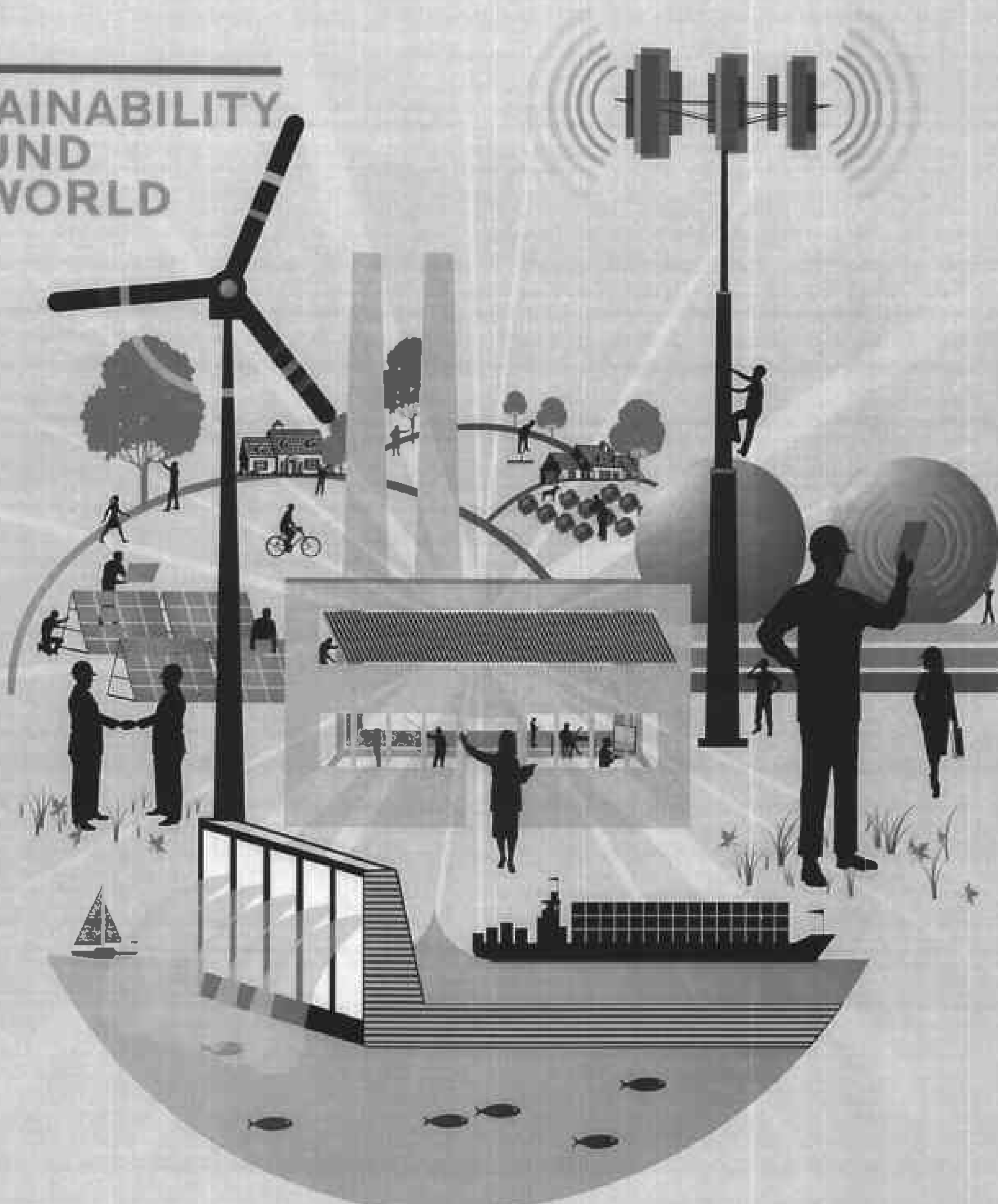
Location:	Tucson, Arizona
Date Commissioned:	Construction underway, to be completed early 2013
Rated Capacity:	Coal: 156 MW, Solar CSP: 5 MW
Annual Production:	TBD
Capacity Factor:	% Unknown (solar resource: 2,270 kWh/m2/yr)
Carbon Offset:	8,500 tons per year
Owner:	Tucson Electric Power (TEP): H. Wilson Sundt Generating Station
Generation Offtaker:	Tucson Electric Power (TEP)
Generation Technology:	AREVA compact linear fresnel reflector (CLFR) solar + Coal-fired generation (existing)
Cost:	Unknown

SOLUTIONS

ISSUE 3 | 2012

CREATIVE SOLUTIONS FOR CRITICAL HUMAN INFRASTRUCTURE

SUSTAINABILITY AROUND THE WORLD



BLACK & VEATCH
Building a world of difference.

Sustainability Requires Action

LEN RODMAN: CHAIRMAN, PRESIDENT & CEO

Sustainability comes quite naturally for a company like Black & Veatch. We deliver infrastructure to our clients that is durable and often lasts many decades, and our perspective in engineering, procurement, construction and consulting frequently focuses on the long term as dictated by our clients, not short-term or patch solutions.

But from our vantage point, sustainability doesn't happen by accident – it is a premeditated action. In other words, it is carefully planned. But even more importantly, it is then executed with determination *to meet the needs of the present generation while improving the ability of future generations to meet their own needs*. That, by the way, is the actual definition of sustainability that has been adopted by Black & Veatch. The company and our professionals live and breathe it every day.

No one will argue the fact that we need to be great stewards of the environment. But lack of funding, aging infrastructure and uncertain regulations are just a few of the obstacles that may stand in the way of this goal. The solution is to begin strategically thinking and implementing – even in small steps if necessary – in order to begin making an impact on truly sustainable practices.

We have some prime examples in this magazine of cities and regions that are making solid progress in planning and implementing sustainable practices. We see this occurring in multiple countries across the world. You could say that sustainability is becoming a global language.

Here are a few key points on how we put sustainability into action in all of our projects:

- We offer solutions that consider the *complete* life cycle of facilities, services and materials. We will help you look at the total picture, not individual snapshots, in order to present the widest view.
- Sustainability often involves water. We view all water as water – and not strictly as compartmentalized categories, such as drinking water, wastewater or stormwater. It is an attitude that says all water is a *resource*, and should be treated as such. The technology clearly exists to treat non-potable water to standards that are useful for irrigation, firefighting, industrial cooling or cleaning – and even up to drinking standards. In addition, there are solid business cases to be made for conversion of waste-to-energy and phosphorus recovery. We have adapted our thinking to consider the "water footprint" of various options.
- We actively conserve resources through the prudent and economic use of materials. Where feasible, we implement recycling and waste minimization. We continually promote energy and water conservation, renewables and resource reuse.
- We encourage our suppliers and subcontractors to adopt sustainable practices and, in fact, show preference to those who do.
- We strongly believe that an important part of sustainability is related to the communities we serve, and to that end, we encourage our 10,000 Black & Veatch professionals globally to take part in scores of local projects that improve their communities. We believe in giving back to our communities and find this to be a key aspect to engaging in sustainability through our *Building a World of Difference* Foundation. Furthermore, it fosters great teamwork across the company.

One word that is practically synonymous with sustainability is stewardship. We view stewardship, which is one of our company's seven Core Values, as leaving an entity in better shape than when you first encountered it. In many respects, the two words are interchangeable. If you believe in stewardship then you believe in sustainability, and vice versa.

In our view, sustainability comprises three key aspects – economic, community and environmental. You could think of it as a triangle. We actively participate in all three sides of the triangle, but ultimately, we help each of our clients to make their own decisions as to what is best for their communities and customer base. Our charge is to be armed with the best information and options, and to continually search for answers that further drive efficiency and sustainability.

This means that we continually work toward developing higher efficiency in power generation, lowering carbon emissions, making more reuse of water and energy resources, reducing the water footprint, producing cleaner waterways, and developing more renewables at lower costs. We offer these options to our clients so they can see the larger view and make choices for their multitude of stakeholders.

What are your plans for sustainability? How will you impact this generation and the next generation? If you need assistance developing these answers, we'd like to help!

Len

SOLUTIONS

EDITOR

CONTRIBUTING WRITERS

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GCC OFFERS HUGE MARKET IN INFRASTRUCTURE

Gulf Cooperation Council (GCC) member countries are witnessing an economic boom evidenced by the soaring demand for energy, water and telecommunications services. To supply the demand for such utilities, estimates place the value of projects needed by the end of 2016 at US$570 billion.

"The GCC market will continue to be a haven for mega energy and water projects," commented Mazen A. Alami, the newly appointed Regional Managing Director at Black & Veatch. He placed Saudi Arabia's needs at $48 billion for power by the end of the decade, and for the GCC as a whole, at $117 billion. He estimated the cost of additional desalination capacity [illegible] $5 billion in Saudi Arabia and more than $19 billion for the entire GCC region.

Black & Veatch has been serving communities in the Middle East since the 1920s. The latest surge in demand for utilities has prompted the company to attract and appoint greater resources in Saudi Arabia and the UAE.

LADWP DOUBLES SOLAR ROOFTOP CAPACITY VIA INCENTIVE PLAN

The Los Angeles Department of Water & Power (LADWP) has more than doubled electric generation capacity from its Solar Incentive Program since employing a streamlined program management solution one year ago.

Black & Veatch has been working with LADWP since 2011 to implement IT solutions and streamlined processes for its solar incentive program. A key feature of the streamlined solution was the integration of PowerClerk, an automated incentive processing Web service from Clean Power Research.

During the past fiscal year, LADWP provided incentives for approximately 1,900 solar projects totaling 21.8 megawatts (MW) of generation, up from 8.8 MW in the previous fiscal year. Since its inception in 1999, LADWP has supported construction of more than 5,500 solar power systems that total 52 MW.

The streamlined program management solution by Black & Veatch and Clean Power Research has enabled LADWP to reduce application review time by approximately 65 percent and double its rate of payments.

WELL RESTORATION PROJECT NAMED APWA PROJECT OF THE YEAR

The Charnock Well Field Restoration Project in Santa Monica, Calif., was recently named a 2012 Public Works Project of the Year by the American Public Works Association.

One of city's main well fields was closed in 1996 after discovering contamination from MTBE, a gasoline additive. The heart of the cleanup and filtration system lies in a granular activated carbon treatment, and then a three-stage [illegible] (RO) membrane system, which softens the water by removing minerals. RO uses pressure to force water through the membranes with small pores that don't allow the minerals to pass through.

The completed $60 million project went online in December 2010, and as a result, the city of Santa Monica can now provide approximately 70 percent of the water it needs on a typical day, compared to about 20 percent while the facilities were off-line.

Black & Veatch served as the primary contractor and the primary consultant on the project.

SUSTAINABILITY

RESOURCES FOR THE NEXT GENERATION, AND THE NEXT, AND THE NEXT . . .

[illegible]

Sustainability has many attributes. It requires creativity – a willingness to do business in a different manner than traditionally accomplished by a utility. It can also spawn many unique partnerships, and perhaps works best when multiple utilities and government entities are on board. Sustainability is often driven by regulations and goals, such as reductions in carbon footprints or energy usage by a given date. It is not cheap, yet it can be proven to pay long-term benefits.

It is a concept that requires forward thinking and a realization that many others will follow in our paths. In short, what each generation leaves behind is very important. In fact, while sustainability may be expressed in a variety of ways, the definition followed by Black & Veatch boils down to "meeting the needs of the present generation while improving the ability of future generations to meet their own needs."

Many cities are planning for the future. New York City and Philadelphia, for example, have PlaNYC and Greenworks Philadelphia, respectively – master plans for cities that have more than 300 years of development behind them and aging infrastructures that will need rebuilding. The plans lay out ambitious, visionary long-term efforts to address the needs of a growing population from an economic, environmental and community point of view, encompassing every city department.

At the other end of the urban planning spectrum, the United Arab Emirates has an ambitious greenfield effort under way developing an entire sustainable community. Masdar City in Abu Dhabi is planned to be home for 40,000 people when completed in 2025. Its plan takes into account almost every aspect of urban life – including configuring the street grid to reduce radiant heat, the use of treated wastewater for irrigation, reliance on renewable energy, and a public transit system of electric vehicles. Other "cities of tomorrow" are also being constructed, such as Energy City Qatar, Fujisawa Smart Town in Japan, Tianjin Ecocity in China, the Kronsberg District of Hanover, Germany, and Valle San Pedro in Mexico, to name a few.

DEVELOPING A SUSTAINABLE OUTLOOK

But sustainability doesn't have to be on such a comprehensive scale, nor completely greenfield.

The nexus of water and energy figures prominently in discussions of sustainability – energy is vital to urban water systems, just as water is vital for energy production. In fact, Black & Veatch's "2012 Strategic Directions in the U.S. Water Utility Industry" report showed that nearly 85 percent of the respondents cited energy efficiency, water scarcity or water conservation as a top sustainability concern.

Steve Tarallo, the North America Business Lead for Black & Veatch's sustainable water and energy solutions, said one way to look at sustainability is finding methods of boosting water availability, particularly in areas with water scarcity issues.

"In the western U.S., for example, utilities will increase their energy consumption if that is necessary to increase the water

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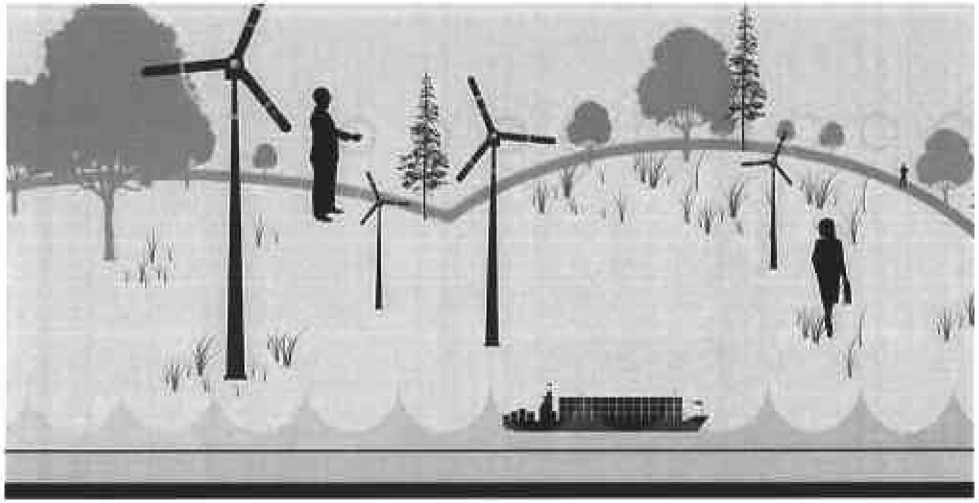

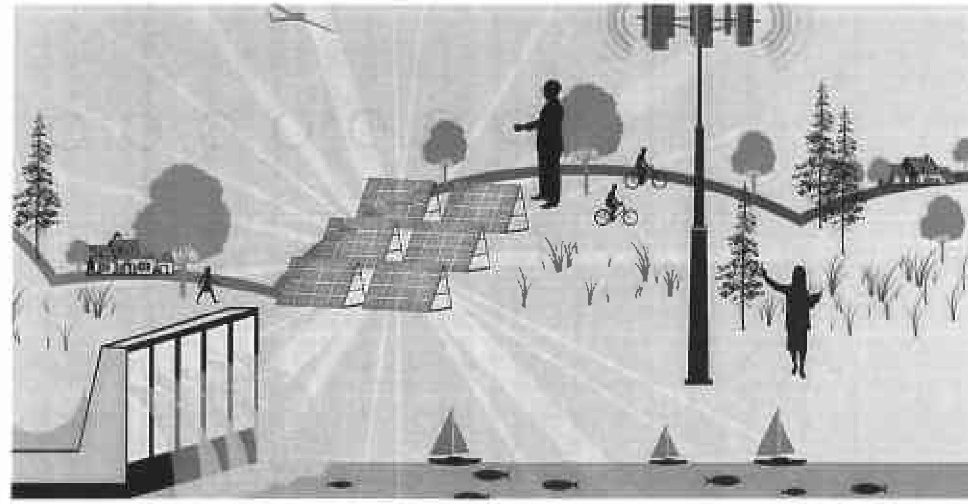

supply. But if it does increase energy use, a sustainable city will do so in such a way as to minimize that impact," he said. "The real sustainability issue for that region is water supply."

He noted that, at present, the use of renewable energy – solar and wind – does not play a large role for wastewater utilities or municipals. "Yet they seem to be very interested in trying to incorporate some renewables, even if only on a small scale – perhaps a few solar panels on a building. It's a small part, but many are serious about incorporating some level of renewables in their portfolio."

Other utilities, Tarallo said, will look for ways to minimize their use of nonrenewable energy by using resources they already have, such as biogas that is produced by the wastewater treatment plants.

The Philadelphia Water Department (PWD) is an all-in-one water utility providing potable water while processing wastewater and handling stormwater. The department has developed a Utility-Wide Strategic Energy Plan, setting energy conservation and green power generation objectives. It aligns with the wider Greenworks Philadelphia sustainability initiative, said Teresa DiGenova, Engineer with Black & Veatch's global water business.

"The Philadelphia Water Department is extremely forward thinking," she said. "Their planning and research group is investigating and implementing multiple projects that aid in the ambitious goals of the plan, while reducing energy use or generating alternate forms of green energy."

Historically, the PWD has controlled the timing of its power consumption to minimize energy use during peak hours. This reduces load on the electric grid during peak use and allows the water utility to take advantage of lower off-peak energy prices, DiGenova said.

Paul Kohl, Energy Program Manager at the PWD, said, "We use energy from a solar panel installation at one plant and feed aircraft de-icing fluid to our anaerobic digesters at another to increase digester production of methane, which can be used to power plant operations."

He added that the PWD is implementing projects that will harness sewage geothermal energy at various PWD and city locations, and it is constructing a biogas cogeneration facility at another plant. "The cogeneration unit will generate 85 percent of the plant's heat and power requirements."

RECYCLING WATER IN THE UK

In London, Black & Veatch designed and built a reclaimed water plant for the utility Thames Water to serve the various venues of a major sporting event. The processing plant is fed by the London sewer system, and the reclaimed water is used for irrigation of the landscaping and playing fields. It is also used for the lavatories.

"This is the first plant of its type in the UK," said Vikki Williams, Asset Management Consultant with Black & Veatch's global water business. "My assignment was to develop the risk assessment for using this water for the sporting event and into the future. There was no regulatory precedent for the use of reclaimed water in the UK for irrigation purposes," she said.

Thames Water will operate the treatment plant under contract with the owners of the sporting facilities for the next seven years. "The idea is that there will be quite a lot of research on reclaimed water and how customers use it, and how the separate distribution network operates with this type of water," Williams said.

Earlier, Black & Veatch designed a system that reduced potable water demand by 70 percent at the new Terminal 5 at Heathrow Airport in London. Separate potable and non-potable water delivery systems were installed.

Nick Merrick, Project Director with Black & Veatch's global water business, said the non-potable water came from two sources – boreholes and collected rainwater. It requires nominal treatment by filtration and the addition of chlorine. The uses for this water include lavatories, vehicle washing, irrigation and firefighting.

UTILITIES JOIN FORCES

Sometimes environmental issues, such as making brackish water drinkable, require multiple utilities working together to produce a sustainable solution.

For instance, Florida utility Tampa Bay Water desalinates seawater to provide up to 10 percent of the region's drinking water, in keeping with its long-term goal to significantly reduce pumping groundwater. Tampa Bay Water says that for every 44 million gallons of seawater that it pulls in, 25 million gallons of drinking water are produced, leaving 19 million gallons with twice the salinity to be returned to the bay.

The desalination plant, however, is situated next to Tampa Electric's Big Bend power station, which draws its cooling water from Tampa Bay and returns it through a discharge canal. The 19 million gallons of high-salinity water is blended with up to 1.4 billion gallons from the power plant's cooling stream, resulting in a slightly higher salinity than the bay. As the combined water flows through the canal, it is diluted even further. By the time the discharged water reaches the bay, according to Tampa Bay Water, the salinity is nearly the same as the bay.

USING EFFLUENT IN MINNESOTA

Resource cooperation is also evident in Minnesota. The Mankato, Minn., water reclamation plant, which opened in 2006, was one of the first of its kind in the United States to treat wastewater effluent for use as cooling water for a power generating plant.

"The project is a good example of partnering for local solutions to local issues," Tarallo said.

Planning began when the Minnesota Pollution Control Agency announced that it would reduce the quantity of phosphorus that could be discharged into the Minnesota River. The city had upgraded its 7 million-gallon-per-day wastewater treatment plant to improve effluent quality some years earlier, but the new regulations required additional improvement at a cost of millions of dollars.

At the same time, Calpine Corp., an independent power producer, began developing a 300-megawatt gas-fired power plant in the city. Calpine proposed re-using the treatment effluent after it was made aware of the complexities and costs associated with permitting and maintaining its own water supply and discharge facility.

The city agreed to provide the power plant with up to 6 million gallons a day of high-quality treated water. Calpine agreed to build a water reclamation facility that would address the

Sustainability is often driven by regulations and goals, such as reductions in carbon footprints or energy usage by a given date. It is not cheap, yet it can be proven to pay long-term benefits.

impending phosphorous restrictions and treat the effluent to standards suitable for reuse.

The water treatment plant was constructed through a public-private partnership of the city of Mankato, Calpine and the state pollution control agency. Calpine paid for the design and construction. The city owns and operates the reclamation facility, located at the treatment plant. The pollution control agency expedited the city's discharge permit, and Black & Veatch provided planning, design and construction-related services for the facility.

The solution solved the problems for the city and the power company at a far lower cost than if each went its own separate way.

In the same vein, Paul Kohl, from the Philadelphia Water Department, said, "We have been approached by various people to use our wastewater effluent for power plant generation. We are open to it – it's just those projects have not gone forward yet. Our effluent water would be an excellent source of cooling water."

BIOGAS FROM WASTEWATER TREATMENT

Some utilities look for ways to minimize the use of non-renewable energy by using resources they already have, such as biogas from the wastewater treatment plants. Black & Veatch's Tarallo said. Others supplement the output of their treatment plants by taking in other organic materials, such as food waste or fats, oil and grease to increase the amount of digester gas they produce.

The Alexandria, Va., Sanitation Authority recently changed its name to AlexRenew to reposition itself as more of a resource extraction organization than just a wastewater treatment utility, said Mike Hanna, Project Manager with Black & Veatch's global water business. The "new" stands for nutrient, energy and water – all by-products of water treatment, he said, although the utility has reaffirmed that its core mission has priority.

"Some utilities are now willing to look at projects that don't directly affect their ability to meet their discharge permits or their basic mission," Hanna noted, but then it becomes an issue that economic considerations often trump environmental and social considerations.

SINGAPORE EMBRACES SUSTAINABILITY

Perhaps no region has embraced sustainability quite as enthusiastically as Singapore. Using its limited water resources wisely is entrenched in its educational system, from the youngest of students onward. Singapore has no natural aquifers and relatively little land to collect rainwater. Historically, it has relied on a limited water catchment and importation of water from neighboring Malaysia.

A dramatic drought in the early 1960s, resulting in water rationing for 10 months, changed Singapore's outlook. It has steadily worked toward changing its situation, making self-sufficiency a long-term goal.

NEWater, Singapore's brand of ultra clean, high-grade reclaimed water was introduced in 2003, providing drinking water from wastewater. Desalination was added two years later. Today, 30 percent of Singapore's demand can be met by NEWater and 10 percent by desalination, with plans to increase these ratios to 40 percent and 25 percent by 2020. With holistic planning and investments in technology, water self-sufficiency by 2061 is beginning to look achievable.

"Singapore serves as a microcosm of lessons and implications for developing and developed nations alike," said Ralph Eberts, Executive Vice President of Black & Veatch's global water business. "There's a lot to learn from Singapore's journey. It is a model of forward-thinking – a template for truly integrated and sustainable planning."

STORY BY **SAMUEL GLASSER,** BLACK & VEATCH

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→ FURTHER READING ON INDUSTRY TRENDS:

› FURTHER READING ON SUSTAINABILITY

SCOTLAND AIMS TO BE A WORLD-LEADING HYDRO NATION

The Scottish government has set out its vision to develop Scotland into a world-leading hydro nation as a means of integrating sustainability into its infrastructure.

Scottish ministers' ambitious hydro nation strategy will see Scottish Water "generate 5 percent of the country's electricity through wind farms, water turbines and gas produced by sewage plants," according to *The Scotsman* newspaper.

Developing a hydro nation will engage many parts of Scotland's economy and society. But central to these plans will be publicly owned water utility Scottish Water.

Water is one of Scotland's primary assets. Scottish Water is the fourth-largest water and wastewater service provider in the UK. At £11 billion annually, the state-owned utility is one of Scotland's largest businesses by revenue. It also owns about 70,000 acres, including high ground with great potential value for onshore wind and hydro schemes – an asset that plays a large role in the overall vision.

PUTTING A PLAN INTO ACTION

Launching his consultation paper "Building a Hydro Nation," First Minister Alex Salmond spoke of the crucial role that could be played by Scottish Water in providing sustainable, green energy.

"Scottish Water is the largest consumer of electricity in Scotland. It consumes about 1.5 percent of Scotland's electricity. A very modest estimate of the generating capacity in the 70,000 acres that Scottish Water has as land holdings would be three or four times that. In other words, this company could generate 5 percent on its own land – not just from wind, but hydro and other energy projects, for about 5 percent of Scottish energy needs."

Minister Salmond explained how some of this could be accomplished.

"It means turning reservoirs into hydro dams, putting water turbines into high-pressure water pipes and putting wind turbines into Scottish Water land."

Scotland is a water-rich country and has the wettest climate in the United Kingdom. About 1.9 percent of land surface in Scotland is covered by freshwater, with around 70 percent of the area and 90 percent of the volume of all the UK's inland surface water found in Scotland.

The recently introduced Water Resources (Scotland) Bill advances the government's wish to develop the value of Scotland's abundant water resources in economic, social and environmental terms. The bill plays a strong role in the good governance of this critical global resource.

According to Alex Neil, whilst serving as Scottish government's Cabinet Secretary for Infrastructure and Capital Investment, "The new law will ensure Scotland's water has a sustainable future, helping to boost our low carbon economy and creating jobs."

Included within the bill are specific proposals to create a new duty on Scottish Water to promote the use of its assets for the generation of renewable energy, whilst safeguarding the fulfilment of its core water and sewerage functions.

Hydropower is a commercial technology, long established in Scotland, which contributes around 10 percent to Scotland's total current energy generation. Most output is produced by large-scale hydro schemes. Scottish Water is boosting its hydropower capacity through the development of hydro turbines to deliver an additional 25,000 megawatt-hours per year from existing assets by 2015.

For example, Scottish Water's new gravity-fed water treatment works, designed and built by Black & Veatch at Glencorse near Edinburgh, incorporates an on-site hydro turbine that provides two-thirds of the facility's energy needs.

Ian McMillan, who is leading the work for Scottish Water's Capital Investment and Delivery division, said, "This is a key part of our Climate Change Strategy and will substantially reduce our carbon footprint."

EVALUATING POTENTIAL PROJECT SITES

Through its role in Scottish Water's hydropower programme, Black & Veatch is supporting the delivery of the hydro nation plans. Initial studies have identified more than 30 sites with the potential for cost-effective hydropower generation. In its role as one of Scottish Water's design and build contractors, Black & Veatch was chosen to evaluate eight of these sites.

According to John Marshall, Contracts Manager for Black & Veatch's global water business, the first stage of the work is to develop the initial feasibility data to Capex 3 stage – fully scoped, priced and 70 percent design complete. "The turbine selection process and scheme design should identify the best commercial solution for each site, taking into account the annual generation requirement and the capital costs," he said.

> Hydropower is a commercial technology, long established in Scotland, which contributes around 10 percent to Scotland's total current energy generation.

Following completion of the scheme design to Capex 3, each site was reviewed by Scottish Water and ranked on its ability to meet programme dates, deliver the forecast annual generation figures, and the scheme's 25-year net present value. Of the eight schemes evaluated by Black & Veatch, three are already progressing to detailed design. At another two sites, further work with local planning authorities is required before detailed design commences.

Some of the principal challenges the hydro projects present are common to many water projects. These include installing new equipment in existing water infrastructure without interrupting service, ensuring each scheme is able to deliver efficient performance, and delivering reliability with minimal impact from servicing and repair. Other challenges, such as working with power utility networks to incorporate new or upgraded equipment to feed back into the grid, are specific to hydro and other renewable projects.

Scottish ministers' hydro nation agenda also sets priorities for action on developing domestic and international trade and technology innovation. It includes working with developing nations on practical water projects and promoting Scotland's academic excellence in water-related fields.

STORY BY **JULIE O'FEE,** BLACK & VEATCH

With an emphasis on sustainability, an onsite hydro turbine generates two-thirds of the energy needs for the Glencorse Water Treatment Works.

SUBJECT MATTER EXPERT
COLIN DOUGLAS: DouglasC@bv.com

Checking the gas intake is part of the transformer training for a group of Afghan power staff workers in Mumbai, India.

BUILDING SKILLS

LEAVES A SUSTAINABLE LEGACY

There is more to sustainability than the efficient and long-lasting use of water and energy resources. When Black & Veatch embarks on an infrastructure project, a major aspect of its economic sustainability plan oftentimes is to ensure that the nationals are thoroughly trained with technical skills to operate and maintain the facilities long after the company has handed over the keys.

It is sustainability at its best, and this knowledge transfer turns out to be a two-way street. Nationals receive in-depth engineering, procurement and technical skills, and Black & Veatch grows in its ability to develop stronger cultural ties and even better relationships with clients in all corners of the globe.

For instance, at the mammoth Kusile Power Station in South Africa, now under construction for the utility Eskom, approximately 30 percent of the Eskom staff is experienced, while the rest are younger professionals who are working on their first major construction project, according to Dave Leligdon, Black & Veatch Project Manager.

"One focus of our Black & Veatch team in South Africa is training and developing the Eskom professionals," Leligdon said. "One of our goals is that when we are done with Kusile, they won't need as many outside professionals helping them on their next project."

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Black & Veatch is providing project management, engineering and construction management services for the 4,800-megawatt mine-mouth plant located about two hours from Johannesburg. It is one of the largest coal-fired power plants ever built. Black & Veatch has about 150 professionals in South Africa, and approximately the same number dedicated to the project at its Overland Park, Kan., headquarters.

"There's a bit of a twist to what we're doing in regards to sustainability," Leligdon said. "What we're doing is, in essence, working ourselves out of a job" – an observation that managers on other projects made as well.

Kusile is one of Eskom's first new generating stations in about 20 years, and most of the professionals involved with the last project have since retired or moved into senior management. The final cost will be more than $20 billion, and there are currently about 10,000 workers on site with an expected peak at more than 14,000. "It's a stretch for any organization to plan and manage," Leligdon said.

Work teams are formed such that Black & Veatch professionals have Eskom supervisors and vice versa, and the appropriate professionals are assigned where needed. This ensures that a broad range of experience is gained.

Abram Masango, Eskom's General Manager responsible for Kusile, added, "The skills and knowledge transfer is very critical for the Kusile Project and South Africa. Given the economic growth in South Africa, we need the skilled professionals, and we need them now. Between now and the year 2030, there will be a massive infrastructure growth in this country. Therefore, acquired skills will assist in constructing and sustaining these infrastructures."

ON-SITE UNIVERSITY

For the younger professionals who come to the project with little work experience, Leligdon said Black & Veatch has a formal skill and knowledge transfer program for design engineering, field engineering, contract management, safety, construction management and project controls. There is also cross-training so a professional in one area can understand how others do their work.

"Essentially, it's an on-site university with five or six different colleges training Eskom professionals to execute complex projects," Leligdon said.

Approximately 150 Eskom professionals have gone through the program, and as new individuals come onto the project, they'll move into the program, too. The courses are tailored to run an average of 18 to 24 months. The program consists largely of hands-on, on-the-job training, supplemented by classroom work.

Leligdon noted that Black & Veatch professionals are growing personally from the opportunity to work in a new culture and environment.

"The learning and personal development required to succeed in a new culture benefits our professionals when they return home or take on their next assignment in a different country," Leligdon said. "Our professionals learn from Eskom as well. Eskom has a long history with coal-fired plants and has a lot of technical knowledge related to plant operation," he said. "As Black & Veatch tackles larger and more complex projects around the world, we will need to continually adapt our approach to project execution by having more cultural expertise and building even stronger relationships."

THREAT REDUCTION IN FORMER SOVIET STATES

In the Ukraine, Black & Veatch is working with the U.S. Defense Threat Reduction Agency (DTRA) to safeguard against the proliferation of biological weapons, technology and pathogens from the former Soviet Union (see *Solutions Issue No. 1, 2012*). The engagement is part of the worldwide Cooperative Biological Engagement Program (CBEP) that chalked up similar accomplishments in other former Soviet states and is now moving into Africa, Asia and the Middle East.

When the Soviet Union dissolved in 1991, most of its biological weapons production facilities were abandoned in place, said Matt Webber, Black & Veatch Vice President and Director of the Threat Reduction Service Area in the Federal Services Division. DTRA's CBEP mission includes preventing the proliferation of dangerous pathogens and knowledge that was left over from these biological weapons programs.

CBEP involves much more than providing brick and mortar solutions such as laboratories and research facilities. "There is a tremendous 'soft side' to the program," Webber said, including training and mentoring Ukrainian personnel to use the infectious disease surveillance system technology. In the process, the partnering nation is gaining an enhanced health system for both humans and animals that will allow it to rapidly detect and respond to naturally occurring infectious disease outbreaks and bioterrorism.

"We're introducing modern diagnostic and surveillance technologies that are completely new to them," said Webber, who is based in Kyiv, Ukraine.

Webber also said that Black & Veatch supports scientists to attend global conferences and trains them to write proposals for research grants. This helps provide financial sustainability for their biosurveillance systems.

TRAINING THE TRAINERS

A large part of the program is adapting expert material to the particulars of Ukraine. Some of the material has come from the Walter Reed Army Medical Research Center, the U.S. Army Medical Research Institute of Infectious Diseases, the U.S. Department of Agriculture, and the U.S. Centers for Disease Control.

Since 2008, Black & Veatch has trained more than 1,800 Ukrainian professionals, including epidemiologists, laboratorians, clinicians, veterinarians, and biosafety and security personnel.

"The secret to our success has been the creation and use of Ukrainian training cadres," explained Tony Borth, Black & Veatch's Training and Sustainment Manager. "We identify promising trainer candidates early on from a pool of academicians and practitioners. By pairing them together, we have been able to roll out an exhaustive train-the-trainer program. More than 70 percent of professionals have been trained by other Ukrainians."

The Black & Veatch team has worked to institutionalize the training curriculum into the existing post-graduate education system. "I am extremely proud that we have provided our Ukrainian partners with the capability to sustain the knowledge, skills and technology for many years to come," Webber said.

FOCUSING ON PROCUREMENT SKILLS

Bill Van Dyke, President of Black & Veatch's Federal Services Division, said training for skills in procurement is another way of assuring sustainability.

"We use in-country subcontractors and work to maximize the use of in-country suppliers for equipment, materials and services," Van Dyke said. "This way, when we turn over full responsibility to the partnering nation, its managers can easily tap sources for supplying operations and management needs."

Webber noted that the local approach is a key to the success of the program and DTRA's exit strategy. "We develop the capabilities of the entire business community, so if a partnering nation needs someone to lean on, it's not the United States government, and it's not Black & Veatch."

OPERATING POWER PLANTS IN AFGHANISTAN

Black & Veatch has worked for the U.S. Agency for International Development over the past six years developing vital electricity supplies to serve the people of Afghanistan. One of the projects included the 105-MW Tarakhil power plant, supplying the capital city of Kabul.

Mike Boehler, Black & Veatch Project Manager for Tarakhil, said, "During the two years that we operated the plant, we had a continuous training program that included a lot of technical instruction. Some of the Afghans turned out to be trainers themselves, and it was very effective having Afghans training Afghans."

Patrick Calhoun, a Training Manager with Black & Veatch who worked at Tarakhil for several months, put together course material. "We used many aids, such as photos and graphics, because of the cultural and language differences," he said.

The two major languages in Afghanistan are Dari and Pashto, and about 30 others are spoken. "But these languages didn't translate

Black & Veatch has helped train more than 1,800 Ukrainian professionals since 2008, which includes use of the infectious disease surveillance system technology.

A group of Afghan power plant workers receives instruction on mechanical assembly during their transformer training in Mumbai, India.

into a technical language, to speak of," Calhoun said. "The trainees couldn't relate to some of the technical terms. So a big challenge was to come up with photos and supporting graphics, and it worked."

Calhoun said that after classroom sessions in basic electrical theory, math, calculus and the operation of power plant components, the next phase was on-the-job training. "That's where we felt we'd get the most bang for the buck. We can show them what they need to be doing – that was the key," he said.

Paul Zink, a Black & Veatch Trainer, said the trainees were divided into two groups – plant operations and mechanical electrical. Zink said there was a wide range of education levels with the trainees.

He noted that some of the Afghans were very good at reading, understanding and communicating in English. Zink added that the trainees in one class requested that all of the handouts and test materials be given in English, because they wanted to improve their English skills.

Lynn Liikala-Seymore, a Black & Veatch Project Manager, works near Kandahar in the southern part of Afghanistan. She said that Black & Veatch sent a group of Afghans to Mumbai, India for transformer training. The next step is to go to Korea for switchgear training.

"These are opportunities that they would not have had otherwise," Liikala-Seymore said. "So as we help develop their technical skills, they are becoming the leaders of tomorrow. You can see them carry themselves a little taller."

MOTIVATED TRAINEES IN VIETNAM

In Vietnam, Black & Veatch was selected to help PetroVietnam Technical Services Corp. (PTSC) with the engineering and construction of the Long Phu 1 power project, a coal-fired plant that will supply much-needed additional power to the national electric grid. This will help supply power to more than 16 million people living in the Mekong River delta region.

Project Manager Andrew Lefin says that Black & Veatch has an engineering manager on site acting in a coordination and instructional role, and that more professionals will most likely join him in 2013.

He said the local staff is motivated. "Their day starts at 7:30 a.m., and I saw the majority of their staff working late into the evenings – it's all business."

He said Black & Veatch currently is engaging the Vietnamese engineers in a different way, through a three-hour video conference that meets once a week, which he said prompts very good discussions.

What is Black & Veatch learning from the relationship?

"We are learning their culture and the importance of slowing down – the American way of driving quickly to decisions is not how Vietnam is geared," Lefin said. "This project will take time, and we will persevere and learn much from it."

STORY BY **SAMUEL GLASSER**, BLACK & VEATCH

Developing Sustainable Solutions:

Partnerships Are the Model of the Future

BY **STEPHEN TARALLO**
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Louis D. Brandeis, U.S. Supreme Court Justice famously stated in 1932 that individual states in the U.S. were "laboratories of democracy" for policy experiments – and it would seem this metaphor could also be applied to the sustainability efforts of many municipalities and regions across the globe. Through innovation, experimentation and "stretch goals," communities are developing and implementing sustainability programs uniquely suited to their local conditions.

As we finalized the inaugural issue of the Black & Veatch "Strategic Directions in the U.S. Water Utility Industry" report, we noted that sustainability is increasingly viewed in the U.S. as a driver for investment and positive returns. Sustainability is evolving into a "value mindset" as opposed to a strictly environmental concept.

More generally, when faced with difficult challenges of asset deterioration, more stringent environmental regulations, declining revenues, increasing operating costs and dwindling capital reserves, many water utilities around the world have made the principles of sustainability foundational to their approach to solving complex problems.

This balancing of the short term with the long term can be difficult to do effectively – it is more a management art than a science. Seeking ways to optimize economic, environmental and community benefits and sustain them over the long term without unintended negative consequences requires innovation and careful planning. This is particularly true when the political, regulatory and economic environments are uncertain and fraught with risk.

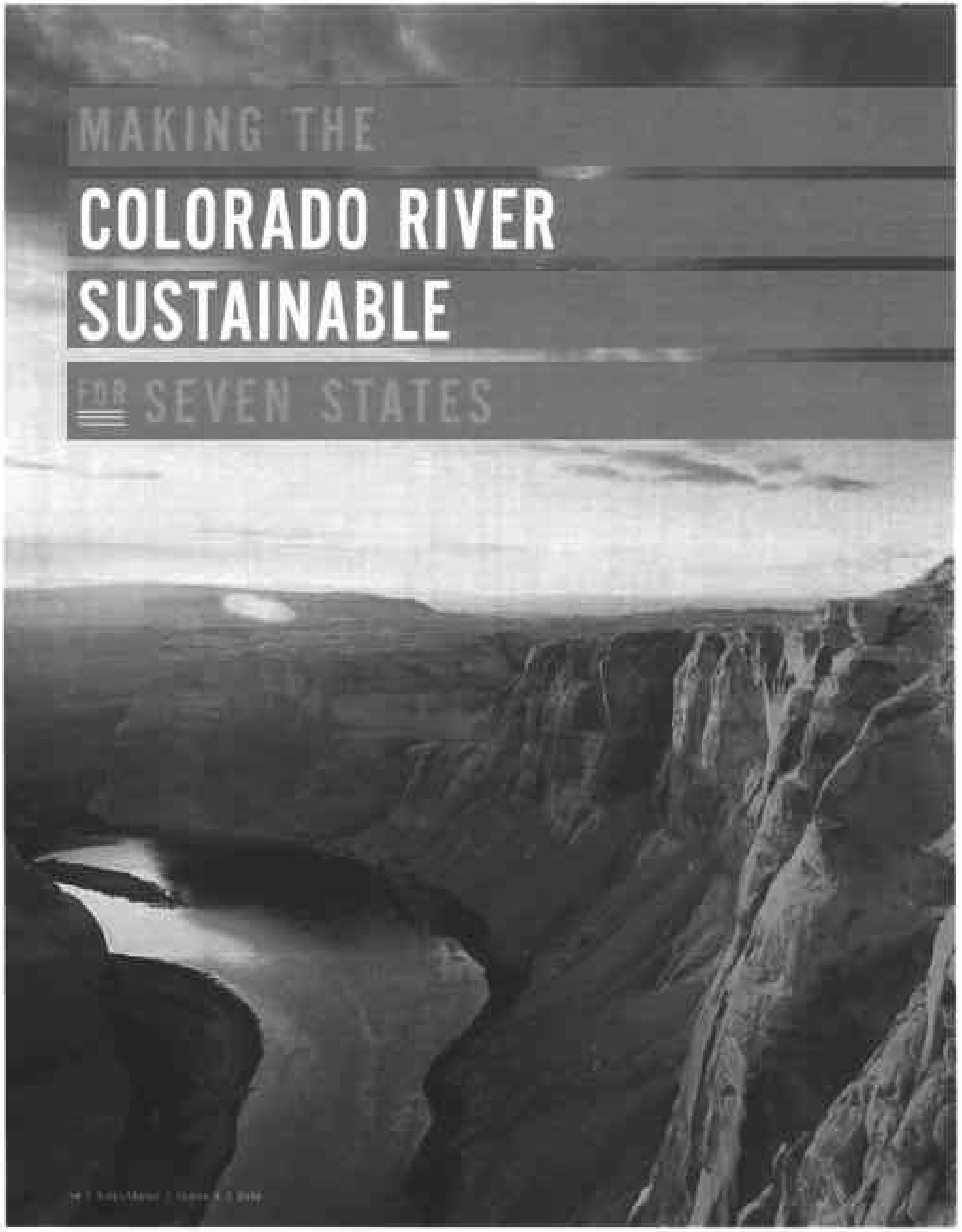
One thing is for certain – water is essential to life and there are no substitutes. It is also the lifeblood of society in that it is a critical resource for energy production, food production, mineral production, transportation and recreation. It is this centrality of importance that makes local water-related challenges a good starting point to achieve wider-reaching sustainability goals through partnerships with other industries and stakeholders.

For example, when the water level in Wivenhoe Dam was dropping rapidly in Brisbane, Australia, from 2004 through 2007 due to extreme drought conditions, finding an additional water supply was the single driver in implementing reuse. However, the primary end-users for the reclaimed water turned out to be power stations, which were in danger of losing their cooling water source. The implementation of the advanced water treatment plants provided both an increased water supply and a guaranteed, sustainable energy supply for the community.

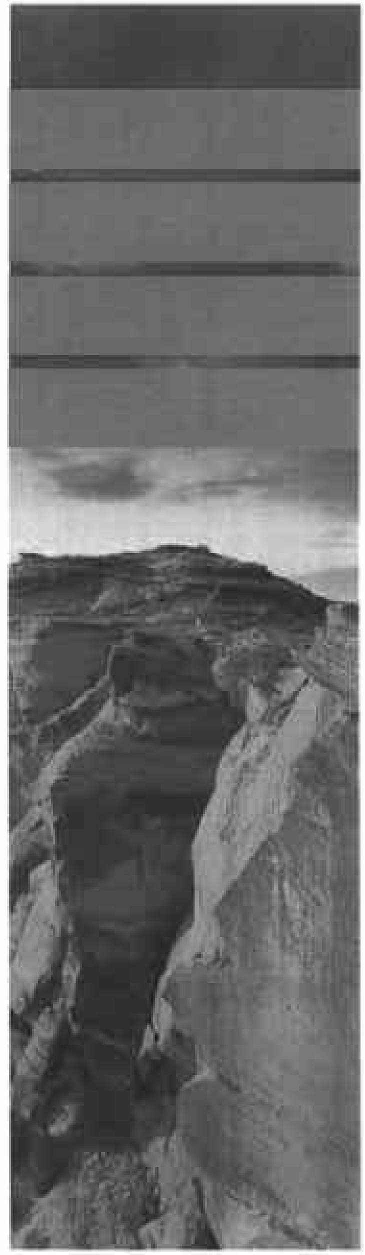
When Calpine, an independent power producer, required cooling water for a new 300 megawatt (MW) natural gas-fired power station in Mankato, Minn., the city offered the effluent from its wastewater treatment plant. By providing wastewater plant effluent to Calpine, the city was able to address the impending phosphorus restrictions in its discharge permit, and Calpine was able to get the cooling water it needed to generate energy. The water reclamation plant, which opened in 2006, has resulted in significant financial savings for the partners as well as approximately 680 million gallons of freshwater annually through reuse. These types of partnerships between utilities and municipalities should be the model for the future.

DC Water (District of Columbia) has recently undertaken a biosolids management program at its Blue Plains Advanced Wastewater Treatment Plant. The program will include thermal hydrolysis, anaerobic digestion and combined heat and power (CHP). The program will reduce the use of diesel trucks for biosolids hauling, offset the purchase of natural gas and electricity, and produce a biosolids product that can be used as fertilizer. The 15 MW CHP project is being delivered through a contract with Pepco Energy Services, which will operate the facilities for 15 years.

All of these examples are great models for sustainability. And there is a strong economic component to each one. Water resources and infrastructure across the water cycle are indispensible contributors to global sustainability, and their roles are set to expand greatly well into the future.



MAKING THE COLORADO RIVER SUSTAINABLE FOR SEVEN STATES



Officials are studying different options for solving water issues in the Southwestern U.S., including expanded use of a desalting plant in Arizona.

Spanning seven states and serving a combined population of over 35 million, the Colorado River Basin supports a variety of the region's water needs. The basin, however, has faced several challenges – including severe drought and increased demand – that have had an adverse effect on supply.

A series of interstate compacts, laws and treaties have governed the allocation of the Colorado River since the 1920s. Recent drought conditions, with the resultant low river flows and reduced reservoirs, have dramatically demonstrated the need for comprehensive planning, including an evaluation of ways to augment the supply from the river.

Therefore, the seven states bordering the Colorado River – Arizona, California, Colorado, Nevada, New Mexico, Utah and Wyoming – sponsored a study in 2006 to begin addressing various shortfalls and to craft a vehicle for evaluating augmentation efforts. The seven states selected the Colorado River Water Consultants, a joint venture comprised of Black & Veatch and CH2MHILL, to provide a technical evaluation of long-term augmentation options for the Colorado River system.

"This was a sophisticated project," said Les Lampe, Black & Veatch Global Practice Leader. "This entire process could be characterized as an evaluation of a sequence of augmentation options where the water supply capabilities of the basin would be enhanced."

Following completion of the augmentation study, the seven states and the Bureau of Reclamation embarked on completion of a comprehensive basin plan called the Colorado River Basin Water Supply and Demand Study. According to the Partners in Conservation citation awarded to the project by the U.S. Secretary of Interior in October 2012, the basin study "is a critical first step in the Colorado River Basin to establish a common technical foundation from which important discussions can begin regarding possible actions to resolve future water supply and demand imbalances, in order to help ensure the sustainability of the Colorado River system. It is a model for future water supply planning across the country."

Lampe said the project is working to advance the cause of sustainability along the Colorado River. "As the seven states consider and select a path going forward, their partnership will become the standard for regional cooperation," he said. "We want to ensure that the selected options will drive conservation and sustainability efforts for decades to come."

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The Colorado River and its tributaries impact seven large western U.S. states, which have joined together to develop a plan to share and sustain its resources.

DESALINATION FOR BRACKISH SOURCES

Twelve long-term options were identified in the augmentation study issued by the joint venture, and several of those are priority options included within the subsequent Colorado River Basin Study. One of the primary options within the basin is brackish water desalination particularly through rehabilitation and operation of the Yuma Desalting Plant (YDP), constructed in 1992, but used sparingly since. The YDP is the largest desalting facility in the United States.

The facility was operated during 2010 and 2011 on a limited basis as part of a pilot run, and it performed well in tests to assess its viability as a source of additional water supply. The treated water from the YDP would be used to augment the Colorado River flow into Mexico, and thereby preserve a like amount of water at Lake Mead in southern Nevada.

The YDP site has been well maintained throughout the years, and preliminary results from the pilot are encouraging, Lampe said. If the plant is returned to full-scale active operations, Arizona, California and Nevada stand to benefit from an extra 100,000 acre-feet of water per year (AFY). According to Lampe, 100,000 AFY would be sufficient to supply about 350,000 urban people with water for a year.

Further studies are under way by the joint venture to determine the optimum operating conditions for the YDP.

VALUE OF WATER

Lampe said the seven states will decide, in concert with the Bureau of Reclamation, which avenues to pursue. These efforts align with putting more emphasis on the value of water and the need to conserve, recycle and reuse, where feasible.

The inaugural Black & Veatch "Strategic Directions in the U.S. Water Utility Industry" report, published in 2012, found that "water conservation and water reuse present direct opportunities for achieving economic, environmental and social sustainability."

Cindy Wallis-Lage, President of Black & Veatch's global water business, wrote in the report that many utilities have made progress in recovering water.

"The planet's 7 billion-plus inhabitants need to adopt the mindset that continuous recycling of these resources will better serve future generations than delving deeper into dwindling supplies," she said. "Certainly, utilities in the Western U.S. and parts of the South are leading the way in adding water reclamation and reuse to their water resources portfolios."

STORY BY ROCHELLE NADHIRI, BLACK & VEATCH

Implementing Smart Initiatives

Don't Forget About the Workforce

BY KEVIN CORNISH
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Much of the conversation surrounding the smart grid has been centered on the evolving technologies that are available to utilities that support a more intelligent utility grid – whether those are electric, gas or water utilities. But the hallmarks of successful projects are those where the utility realizes that success will not be determined only by the choice of technology but instead by how the initiative is integrated with its business processes and how its organization embraces the changes.

That isn't to say that utilities don't need to pay close attention to the choice of technology. But in as much as smart grid projects are providing utilities with new tools and capabilities, an often overlooked subject is that they are also creating, in most instances, significant organizational turmoil and challenges. Workforce impacts must take center stage along with these new technologies.

To ensure that utilities achieve the business benefits for which they have received internal or regulatory approval, it is critical that the new tools, applications, devices or automation solutions deliver improvements in operational efficiency and customer service. And ultimately, people and organizations use the technologies.

All utilities have unique organizational structures, political environments and workforce challenges. Common elements that must be addressed include:

- What new skills sets are necessary to implement or support the new technologies?
- Are new job classifications or job redesigns required to receive promised efficiency improvements?
- Can resources be redeployed from roles being eliminated to new roles, or will significant resource disruption occur?
- Who will provide training, and how and when will it be provided?
- What organizational changes will be required to optimize the new solution's capabilities?
- What ongoing business impacts will the project itself be responsible for mitigating, and which ones will the business units address themselves?

Since smart grid solutions impact large segments of a utility, the organizational impact and potential realignment can be extensive. As utilities implement AMI solutions, the entire meter-to-cash process is impacted, and traditional meter reading, meter operations and billing data analysis are transformed.

Along with the significant work involved there are organizational turf battles, practitioners of old approaches that do not want to let go, and organizational inertia that must be overcome. Many utilities that Black & Veatch is supporting are introducing smart grid network operations centers that assume responsibilities traditionally done by T&D operations, IT and telecommunications. Utilities can struggle with deciding which part of the organization these new units will reside. While utilities have faced these challenges before, as they have implemented other technologies, the rapid pace of change and the breadth of impact make smart grid projects more challenging.

Many of the newer smart grid solutions are in the early stages of deployment and that lack of maturity makes it hard for utilities to look to their peers for ideas. The technology vendors themselves are usually unable to completely fill this void because their focus and core competencies are on expanding their technical solutions, not on workforce implementation.

Effective smart grid project management means applying lessons learned from complex technology projects on how to focus on the larger re-engineering effort as opposed to the technology being an end in itself. Even projects such as smart meter initiatives that involve millions of field devices are not really utility field technology projects as much as they are utility transformational projects, with broad impact on the organization.

Putting a strong focus on workforce training and reorganization will go a long way toward providing a successful conclusion to a major smart grid initiative.

TRI-GENERATION

A Sustainable Solution for Industry

BY **DR. SUQING WANG,** PROJECT DIRECTOR, BLACK & VEATCH'S GLOBAL ENERGY BUSINESS

The world's population is expected to reach [illegible] billion by [illegible], and energy consumption is predicted to increase by over 80 percent, according to the Organisation for Economic Co-operation and Development. With rising fuel costs and pressures to improve air quality and reduce carbon emissions, governments and business owners are seeking new methods for efficient and sustainable energy use.

Tri-generation could be an answer. Essentially a combined cooling, heat and power solution, gas-fired tri-generation is ideal as a self-contained (off the grid) energy source for an industrial park, for example. A property developer could offer tenants a compelling proposition. On top of other facilities management services, ready-made electricity, heating and cooling services could be provided at lower costs with reduced emissions.

HOW IT WORKS

In a typical turbine, heat is used during fuel combustion to generate electricity. Excess heat is then expelled into the environment as waste heat. Energy is lost.

With cogeneration, by-product heat, in the form of steam, is emitted and put to further use for heating water or the surrounding space, or as process steam. Tri-generation takes the process one step further. Waste heat is put toward generating cooling via an absorption chiller. So, tri-generation produces electricity as well as heating and cooling.

In conventional fossil fuel power plants, less than 50 percent of input heat is converted to electricity. The remaining heat emerges from the turbines as low-grade waste heat with no significant local uses. This is mainly due to the typical transmission distance from the plant to customers. The waste heat is therefore usually lost to the environment.

TRI-GENERATION HAS MANY POTENTIAL BENEFITS

1. **Higher efficiency** – When waste heat is used for heating and cooling, thermal efficiency can reach up to 90 percent. This high conversion rate suggests that tri-generation reaps its greatest benefits when scaled to fit facilities where electricity, heating and cooling are needed constantly. This is ideal for facilities such as 24-hour industrial parks, certain commercial building blocks, or even hospitals that operate all day.

2. **Energy surety** – Tri-generation is also useful in areas prone to brownouts. Operations can continue through erratic weather patterns that often would affect electricity transmission from a centralized power station.

3. **Economically sound** – Tri-generation can be an off-the-grid solution. This can help businesses scale back on the cost of electricity, as well as costs from heating and cooling requirements.

4. **Cut out the transmission costs** – Localizing energy transmission means electricity does not need to be transported over a long distance to reach consumers. It reduces the burden on a utility's transmission infrastructure.

5. **More sustainable air conditioning and lower heating bills** – Tri-generation also enables an opportunity for efficient repurposing of waste heat, producing heating and cooling for customers nearby.

6. **Reduced emissions** – Combining electricity, heating and cooling production from one source reduces carbon emissions significantly.

EXPLORING TRI-GENERATION OPPORTUNITIES

It is little wonder, then, why countries like China are exploring tri-generation options.

China is the world's largest user of coal – 4 billion tons will be used in 2012, according to the U.S. Department of Commerce. With electricity use soaring, the country recognizes the need for greener solutions. Hence, the government has reinforced the need for efficiency at all stages of the energy value chain.

Chinese Premier Wen Jiabao committed to a 7 percent economic growth target last year in a public address on the 12th Five-Year Plan. During his speech, he reiterated the importance of balancing growth with environmental sustainability. He said "(China) must not any longer sacrifice the environment for the sake of rapid growth ... as that would result in unsustainable growth featuring industrial overcapacity and intensive resource consumption."

[illegible]

To meet its targets, the Chinese government has begun developing smart electric power infrastructure. These are built to deliver power combining conventional grid components with new storage and information communication technology.

To support its latest efforts, the Chinese government was awarded a grant from the U.S. Trade and Development Agency (USTDA), and Black & Veatch was selected by the National Energy Administration (NEA) of China to conduct a clean energy feasibility study.

Black & Veatch will work with NEA to assess the implementation of "distributed energy-combined cooling, heat and power" (DE-CCHP) tri-generation. This technology will be looked at across two model facilities in China. The study supports the U.S. – China Energy Cooperation Program, a public-private partnership to advance the development of clean energy in China.

This is a major bilateral cooperative program between the United States and China. It leverages private sector resources for clean energy project development in China. The aim is to increase awareness of technology, product standards, regulatory processes and services that can assist China in developing its clean energy sector.

DE-CCHP will allow China to generate reliable power and thermal energy by reducing its dependence on coal-fired power plants. Tri-generation also provides China with significant opportunities to improve energy efficiency and reduce greenhouse gas emissions.

OVERCOMING BARRIERS

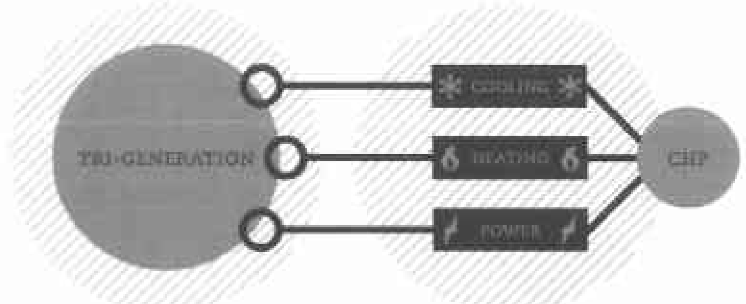
Tri-generation faces roadblocks. Climate suitability is crucial. The solution is more suitable for temperate climates where there is a need for power, heat and cooling throughout the year. Another challenge is the need to convince utilities that the benefits outweigh the losses in revenue. Taking large facilities off the grid means losing customers. And without the buy-in of regulators who give the ultimate green light, adoption of tri-generation is slow.

The industry needs a leader to pave the way for this new technology.

When China identified wind power as a key component of the country's growth, it stated ambitious claims to have 100 gigawatts (GW) of wind power generating capacity by the end of 2015 and to generate 190 billion kilowatt-hours (kWh) of wind power annually. According to the Global Wind Energy Council, wind power in China accounted for 6.2 GW of electrical generating capacity at the end of last year.

This is a good example of how government support can springboard the adoption of emerging energy solutions.

The DE-CCHP feasibility study represents the initial step the Chinese government is taking in approaching this relatively new development. At the rate Chinese cities are growing and the potential for top-down government and regulatory mandates, there is an opportunity for China to drive another sustainable energy solution.



AUSTRALIA

EMBRACES RESILIENCE AS A NEW PATH FOR SUSTAINABLE WATER PLANNING

BY RICHARD DAGWELL, DIRECTOR
BLACK & VEATCH'S GLOBAL WATER BUSINESS IN AUSTRALIA

"We are Queenslanders," cried Queensland Premier Anna Bligh. It was a famous, emotional rally call to the residents of Queensland, Australia, in the aftermath of devastating floods that ravaged the state in December 2010 and January 2011. It was the worst flooding to hit the country in half a century, and floods later that January also affected parts of Victoria. "This weather may break our hearts," continued Bligh, "but it will not break our will."

SUBJECT MATTER EXPERTS
RICHARD DAGWELL: [illegible]
JAMES CURRIE: [illegible]

Australians have learnt to be resilient.

Extreme weather conditions have plagued Australia this century. From the harshness of drought to the devastation of floods, many believe that Australia is the "canary in the coal mine" of climate change. In other words, they believe these extremes will become more commonplace in other regions of the world in the future. In response to the tough lessons the water industry has faced in the country, a new concept is emerging for sustainably planning water resources – resilience.

IMPACT OF DROUGHT

The previous decade saw cities throughout Australia face severe water restrictions. From the early 2000s, reservoir levels across Australia began declining. In Queensland, one of the main reservoirs for the city of Brisbane had reached an all-time low of 15 percent by August 2007, sufficient for only 18 months' supply. Not only was urgent action required, but a new approach to planning and securing future water resources had to be embraced.

Australia faced a major water crisis. Out of this crisis emerged many positive changes and also many lessons. In many ways, the Australian water sector managed the crisis admirably.

Responses focused on diversifying the available water resources, solving the short-term crisis and ensuring greater security of future supply. Demand management was also addressed. The Australian people embraced water restrictions and conservation efforts – noteworthy at the much loved community sports grounds throughout the country. Everyone was on board with the efforts.

Many institutional structures were changed in South East Queensland, for example, the fragmented utilities had complicated initiatives in the past. Regional plans for the Aus$2.4 billion Western Corridor Recycled Water Project had been stalled. As the reservoirs plummeted towards their historical lows of 2007, state government got involved and saw to it that the plans got a green light.

The country also embraced desalination. Large-scale desalination plants were delivered in Perth (2006), South East Queensland (2009) and New South Wales (2010). Other desalination facilities in South Australia, Victoria and Western Australia are nearing completion. Many of the desalination plants also incorporate renewable energy solutions, including wind power or renewable energy credits to provide sustainable power for these energy-intensive water sources.

THE RAINS RETURN

In most parts of Australia, the rains have returned and the water supply crisis has abated.

Despite this, Australian states remain vulnerable to the return of hotter, drier conditions. Rainfall midway through the last decade's drought provides an invaluable lesson. In 2004, good rainfall helped Melbourne's dams recover to about 60 percent capacity. However, the dry spell that followed saw them drop to below 30 percent less than three years later.

Public opinion has also wavered. The large investments made in water infrastructure, deemed necessary during the crisis, are now being scrutinized by politicians and the media. Government structures have also changed in New South Wales, Queensland and Victoria, and past decisions are more readily held up for scrutiny.

"One of the lessons Australia has been reminded of is that it is not a case of whether drought will occur again, but when," said James Currie, Client Director, Black & Veatch's global water business in Australia. "We need to adapt better to the Australian climate and protect our river flows and bays by making our water supplies go further. Demand management, finding and gaining acceptance of alternative ways of securing water and improving the way existing water assets are managed are high on the agenda of water utilities throughout the country."

CAN YOU "MIS-SELL" INNOVATION?

The Western Corridor Recycled Water Project was originally intended to provide additional water – indirect potable reuse – to the people of Brisbane. As the rains returned and before the integration of the new sources of treated, reused water to the Wivenhoe Dam, the initiative faced considerable media backlash. With growing public fears, the state reversed its decision in late 2008: recycled water would only be added to the Wivenhoe Dam if the dam level fell below 40 percent. The recycled water has been limited for use at two upstream power stations since and, once again, its operation has been subject to media scrutiny.

Many within the Australian water industry look back and point to the way these and other plans were communicated around the time of the water crisis. Speaking on the Australian Broadcasting Corp. "Breakfast" show, Cindy Wallis-Lage, President of Black & Veatch's global water business, said, "The decision was made under crisis. So, people were making decisions emotionally because there was a significant water supply shortage.

"You need to be able to [plan for the integration of reuse] under a non-crisis situation," she continued, "and have people making objective decisions."

Similar arguments have been used for some of the reasons behind the criticism of the investment in many of Australia's new desalination plants, according to water leaders at a number of Black & Veatch's water dialogue roundtables, a series of discussions that aim to share best practices within the water sector.

RESILIENCE AND SUSTAINABLE PLANNING

So, how can water utilities in Australia and throughout the world create and deliver sustainable water plans that truly diversify the supply portfolio, embracing solutions like water reuse and desalination, with the full support of the public and the media?

Many point to the concept of resilience, and this is a cornerstone of the 50-year plan from the Water Corporation, Western Australia's water utility. Entitled "Water Forever: Towards Climate Resilience," it calls for a need to reduce water consumption, recycle more water and develop new sources to supplement existing supplies to ensure Western Australia's water supply is indeed climate resilient.

Western Australia is a dry state in a dry continent; the 2011 ten-year version of its core 50-year plan is entitled "Water Forever: Whatever the Weather." The rains did not return to the South West of Western Australia and the state is still in the grips of drought conditions. The Water Corporation wants to ensure that Perth and surrounding areas can adapt to the drying climate and ensure enough water for future generations. Setting innovation and new infrastructure around resilience and long-term security, rather than only efficiency, is hoped to secure more sustainable opinion on the value and benefits of the water investments.

Good progress has been made to date. An advanced water recycling plant project, delivered by Black & Veatch and constructor Thiess, is central to a wastewater recycling trial that is currently under way. The Groundwater Replenishment Trial, which is recharging the confined Leederville aquifer, adheres to a transparent and engaging communications approach. More than 6,600 visitors have toured the site, and recent surveys show that community support for groundwater replenishment remains steady at 76 percent. This type of open communication informs the public about the need to diversify the water supply with a new source of water and gains public support for this method of indirect potable reuse.

The plan also received glowing public acclaim by Australia's National Water Commission Chair in March, stating, "The Water Corporation's public awareness program for the Groundwater Replenishment Trial in Perth offers a great model for how to engage the community in a practical way well before further decisions are taken."

RESILIENCE VS. EFFICIENCY

Resilience and efficiency are concepts that potentially can collide when it comes to planning a sustainable water supply. Efficiency is usually measured as a cost, and resilience measures the ability to deliver services when there is a stress, e.g., supplying water during climate change. Some may feel that the most efficient systems are not necessarily the most resilient. It's difficult to balance these, but this is what the Water Corporation is setting out to achieve.

When it comes to sustainable water resource planning, the world is facing new challenges with the potential effects of climatic shifts more apparent. The paradox of "planning for the unplanned" must be given thought. It calls on industry leaders, engineers, politicians and the public to adjust their current way of thinking. Developing plans that balance resilience with efficiency will be the key.

Richard Dagwell is Director, Black & Veatch's global water business based in Australia. Dagwell leads the company's large scale water infrastructure projects in Asia Pacific. With nearly 20 years of experience, he has played critical roles in many successful large scale water infrastructure projects in the UK and Australia.

Back to the Future

EPA to Continue Exercising its Authority in Air, Water and Waste

BY ANDY BYERS
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Despite being touted as a decisive moment in American history, the 2012 federal elections changed very little – leaving the country with the same president, Republican majority in the House and slight Democratic advantage in the Senate. Short of any schizophrenic shift towards bipartisanship compromise, it would appear the country is in for a rerun of recent history in Washington.

Picking up from the pause taken just before the presidential campaigns entered full swing, national energy and environmental policies are expected to resume their previous trajectories. With a divided Congress, the Department of Energy (DOE) and Environmental Protection Agency (EPA) will likely continue to face scrutiny, but no major obstacles, in pushing through their regulatory agendas.

TRANSITIONS IN ENVIRONMENTAL RULES

EPA emerges from four years of rulemakings focused primarily on air quality issues. Driven by consent decrees and court deadlines, in what some characterized as "sue and settlement" policymaking, numerous air pollution regulatory programs were devised and finalized. Most of these have now proceeded to litigation, where EPA's one-hour ambient air quality standards and authority to regulate greenhouse gas emissions were upheld by the federal appellate court, while its latest Cross-State cap-and-trade scheme was invalidated. Rulings on EPA's centerpiece Mercury and Air Toxics Standards (MATS) are expected in early 2013. Next up are ambient air quality standards rules for fine particulate matter due to be finalized in December 2012 and a new eight-hour ozone standard to be proposed in 2013.

The focus of much of EPA's upcoming rulemakings for power plants is set to shift from air to water and waste issues. Pursuant to consent decrees, new wastewater standards are due to be proposed very soon, and regulation of existing cooling water intakes is set to be finalized in June 2013. Resolution of EPA's 2010 proposed rulemaking on coal combustion wastes is also expected in the coming years.

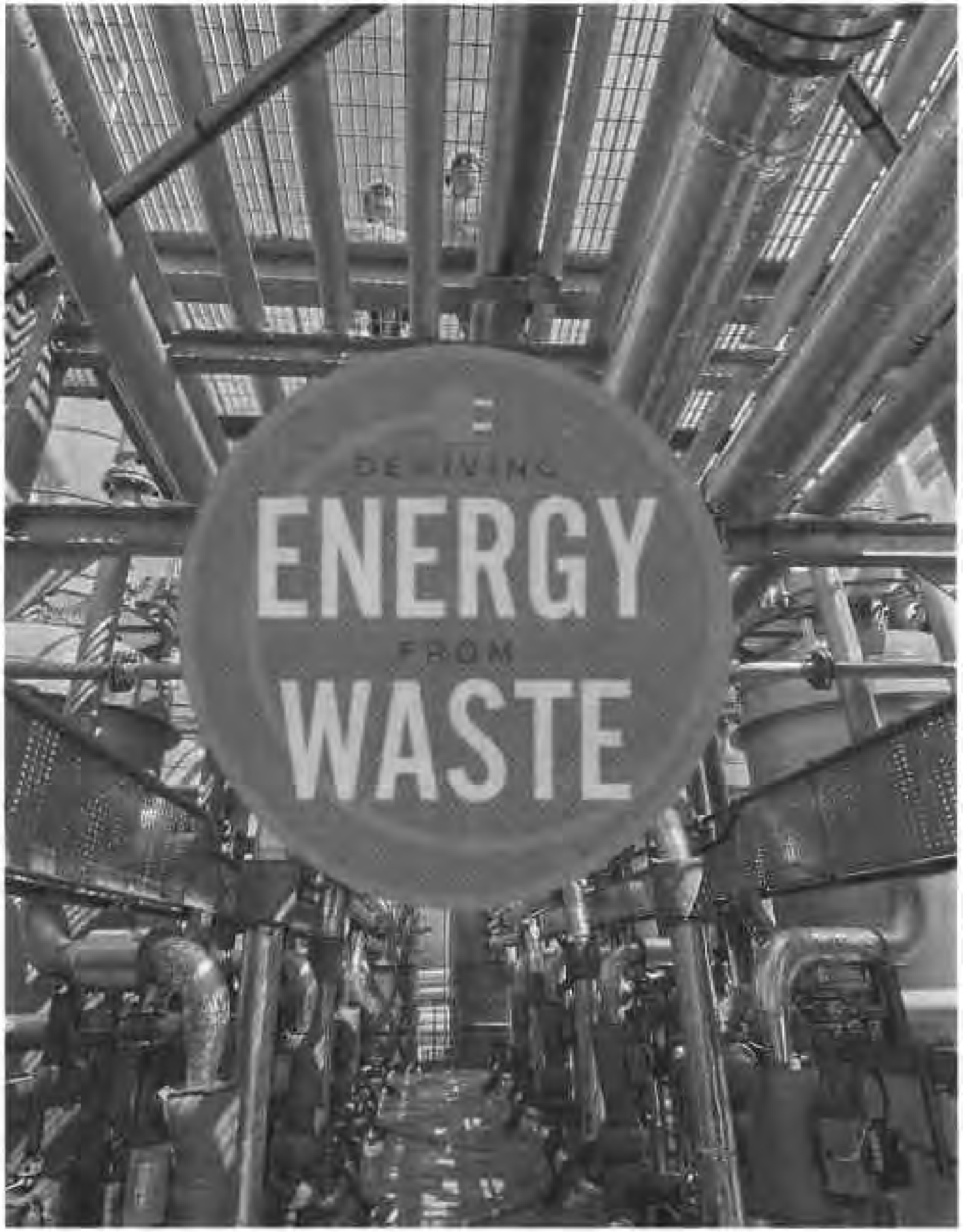
While the magnitude of projected impacts of these regulations to industry compliance costs, coal plant retirements and the price of electricity vary, the reality of these challenges is becoming clearer and nearer. The greatest unknown, and potential game-changer for environmental and energy policy, is what further steps EPA takes to regulate greenhouse gas emissions – and whether this may ultimately spur Congress to weigh in.

CLIMATE CHANGE BACK IN NATIONAL SPOTLIGHT

In the immediate aftermath of the presidential election and the "October surprise" of Superstorm Sandy, Washington was suddenly awash in discussions of a possible carbon tax. Fueled by reports from the Congressional Budget Office and Brookings Institute issued the week after the elections, as well as a high-profile meeting hosted by the conservative American Enterprise Institute, the specter of a carbon tax to raise revenues and reduce greenhouse gas emissions became a hot topic inside the beltway.

EPA is expected to continue to exercise its authority drawn solely from the Clean Air Act, which was not originally designed nor particularly well suited for greenhouse gas regulation. If EPA finalizes its fossil fuel new source performance standard as proposed, no new coal-fired power plants will be built without carbon capture and sequestration. EPA is also obligated under a previous settlement to address greenhouse gas emissions from existing plants, which would likely impose additional costs and burdens beyond coal to even include gas-fired generation.

Will the Obama administration continue to promote clean energy development, or will it make a more aggressive move to directly regulate reductions of greenhouse gas emissions? If so, will Congress find the willpower to step in to override this fate? And how much time is left until coal fades from the national picture? Alas, many may soon regret defunding research for that DeLorean time machine so long ago.



IT MAY LOOK LIKE GARBAGE TO THE AVERAGE PERSON, BUT THERE CAN BE A TREMENDOUS AMOUNT OF ENERGY LOCKED UP INSIDE THAT WASTE. CONVERTING THAT ENERGY IS NOT ONLY SUSTAINABLE, IT SAVES SIGNIFICANTLY ON OPERATING COSTS.

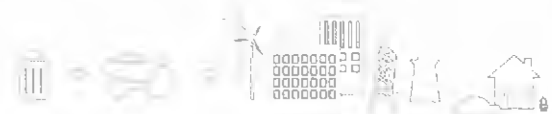
One of the greatest challenges facing the development and expansion of urban living is the issue of waste removal and management. Whether it is coping with over-capacitated landfills in developed countries, or handling the mass influx of people from rural areas into cities in developing countries, one of the common core issues is dealing with waste.

Clearly, it is difficult to have a discussion about long-term sustainability without a serious examination on how to reuse waste. All too often, waste – be it garbage, sewage, food or industrial – is disposed of in a landfill, where we can wait centuries (literally) for it to decay. There has to be a better solution – and there is.

Today private and municipal utility service providers around the world are developing new solutions for energy resource recovery and sustainability. With increasing efficiency, the world is learning how to turn yesterday's waste into today's usable energy.

"Waste-to-energy programs offer a comprehensive approach to achieving many sustainability goals," said Paul Street, Director for Sustainable Solutions, Black & Veatch. "This is important, especially in light of increasingly stringent regulatory requirements governing emissions and water quality in many regions of the world, and public demand for greater utilization of resources."

However, challenges to the technology, particularly in the area of capital investment costs, must be overcome to drive widespread adoption of the practice. Though the economics of waste-to-energy projects vary by region, all operators must address their most critical sustainability issue – economic sustainability.



PAUL STREET: StreetP@bv.com **KYRIACOS PIERIDES:** PieridesK@bv.com

THIS PAGE: The Davyhulme project in the UK required a keen understanding of the complex set of variables associated with steam, biogas and electrical energy production.

PREVIOUS PAGE: Utilizing biogas at the Davyhulme project increases the amount of renewable electricity generated at the site, enabling the entire works to be self-sufficient, and thereby significantly reducing plant operating costs.

BIOSOLIDS FOR ENERGY IN THE UK

In 2010, the United Kingdom passed legislation increasing the landfill tax £8 per ton each April through 2014 doubling the fee to £80 per year. Further, the EU Landfill Directive requires member states to cut the amount of biodegradable municipal waste they send to landfills to 50 percent of 1995 levels by 2013 and 35 percent by 2020

"Given significant economic and regulatory pressure to more effectively manage resources, and the billions of pound/sterling potentially lost through inefficiency each year, projects like United Utilities new sludge treatment scheme at Davyhulme Wastewater Treatment Works in Manchester, England, can play a beneficial role in achieving these targets," added Street

The Davyhulme project is one of the largest design-and-build biosolids-to-energy projects in the world and is being developed to increase the works capacity and improve the quality of treated sludge. It will produce both fertilizer for agriculture and gas that will be converted to electricity

The project will provide a central sludge processing facility, and upon its completion, the works will also receive imported raw sludge and imported raw liquid sludges from within and outside of the city.

Treated sludge will be recycled as a soil conditioner (fertilizer) to agricultural land or in part for flexibility by incineration at United Utilities' Mersey Valley Processing Centre The gas will pass through cleanup equipment to the 12 MW (electrical) combined heat and power engines, producing enough energy to use on-site or for export to the national electricity grid

Overall the facility is anticipated to generate more than 11 gigawatt-hours of extra electricity per year, save more than 16,000 tons of CO2 emissions and save over £3 million annually through reduced energy costs and better sludge management.

The Davyhulme project is one of the largest design and build biosolids to energy projects in the world and is being developed to increase the works capacity and improve the quality of treated sludge. It will produce both fertilizer for agriculture and gas that will be converted to electricity

WASTE-TO-GAS IN NY

Balancing resource and economic sustainability goals can be a particularly challenging task in the United States, where historically low natural gas prices impact stand-alone economic comparisons between landfill disposal waste-to-gas and other technologies However, regulatory standards and public policy goals are playing a role in determining the adoption of new technologies

For instance New York City has launched an initiative called PlaNYC, which calls for a 30 percent reduction of citywide greenhouse gas emissions and energy consumption by 2030 To help achieve this goal, the New York City Department of Environmental Protection (NYCDEP) is converting the main sewage pumps and process aeration blower systems at its North River Wastewater Treatment Plant to increase use of waste-to-gas resources

"Given the new landscape under which wastewater treatment plants must operate, there is a critical need to evaluate energy efficiency and production opportunities," said Anthony Fiore NYCDEP Chief of Staff to the Deputy Commissioner "As such DEP is looking at a variety of practices to harness the benefits of waste-to-gas technology."

Currently, diesel is the primary fuel stock powering the main diesel/biogas sewage pump and aeration blower engines at the North River Plant The system requires approximately 10 percent diesel even when utilizing digester gas. The existing 10 engines will be replaced with a cogeneration system using biogas obtained via enhanced gas recovery processes and cleaner-burning natural gas to increase the system's efficiency. This will reduce the plant's operating costs by eliminating the need to purchase diesel fuel and will help contribute to the PlaNYC goal

Kyriacos Piendes, Black & Veatch Client Services Manager, noted "Looking at the trends for greenhouse gas regulation and energy reduction requirements, we expect that both existing facilities and future waste treatment designs will seek to increase the use of waste-to-energy technologies to meet their operational and environmental goals."

RECYCLED METHANE GAS PRODUCES FERTILIZER

Another example of the move towards sustainable energy practices is the Morris Forman Water Quality Treatment Center, owned by the Louisville and Jefferson County (Kentucky) Metropolitan Sewer District Utilizing recycled methane gas from its wastewater treatment operations as the primary fuel for its dryers the center produced and distributed 28,210 tons of treated biosolids fertilizer to bulk agriculture, fertilizer blenders and local retail outlets

According to its 2010 Annual Report, as a result of its comprehensive approach to resource management, less than 0 5 percent of all solids processed at Morris Forman in 2010 were sent to the landfill For the 12-month period, this solution generated savings of approximately $663,500 in landfill costs, with an additional savings of more than $750,000 realized by using the recycled methane to power the facility

"Making advances in working with all forms of waste-to-energy technologies provides constant sources of renewable energy production," added Street "Whether it's food waste-to-energy projects, municipal waste recycling and conversion, or other biosolids conversion, by avoiding landfills and harnessing the inherent energy resources, plant operators are reducing the amount of fossil fuel required to dispose of waste and reducing capital and operational costs."

STORY BY **PATRICK MACELROY,** BLACK & VEATCH

Black & Veatch helped the Los Angeles Department of Water & Power develop an integrated resource plan, which outlines strategies for increasing renewable energy generation and reducing greenhouse gas emissions.

Photo courtesy of the Los Angeles Department of Water & Power

SUSTAINABILITY— CALIFORNIA STYLE

Communities in the Golden State continue to carefully consider the needs of future generations through integrated resource planning and sustainable infrastructure management.

Californians have historically been passionate protectors of natural resources. John Muir, who became an ardent advocate of nature upon moving to Yosemite in 1868, was instrumental in establishing several U.S. national parks as well as the Sierra Club. Developers of yesteryear may have taken issue with the ecology-minded Muir, but his passion to preserve nature's gifts for the benefit of future generations was a forerunner of today's sustainability practices.

Whereas Muir focused on the natural environment, the broad definition of sustainability adopted by Black & Veatch and other organizations today encompasses economic, community and environmental goals. Communities today must plan and develop infrastructure to meet current requirements and future sustainability goals with limited funds now available. Despite these obstacles, many California communities are successfully implementing holistic projects that are environmentally sustainable, financially feasible and commercially farsighted.

TIM CLARK

Orange County in California is expanding its successful Groundwater Replenishment System (GWRS), which will bring total production to 100 million gallons per day. GWRS is proving to be the most sustainable way to provide enough water for the region's population.

Traditional wastewater treatment plants are evolving into resource-recovery facilities, with increased focus on recovery of water, energy, phosphorus and other resources. Investing in the technology to produce energy from water and wastewater operations makes the most financial sense where energy costs are comparatively high.

The East Bay Municipal Utility District (EBMUD) in Oakland has reclaimed water for reuse since 1965, and its main wastewater treatment plant in 2012 became the first net electricity producer in North America. Black & Veatch recently assisted EBMUD with the award-winning Richmond Advanced Recycled Expansion water project. The collaboration among EBMUD, Chevron and the West County Wastewater District cost-effectively reduced demand for precious potable water supplies by treating more water for reuse to the level of purity required by refinery boilers.

Utilities can also make operations more sustainable by reducing energy use or employing renewable energy. For example, a wind turbine provides energy for 70 percent of the Palmdale Water District's operations, and Black & Veatch is currently working with the district to optimize that wind power.

Jim Clark, a Los Angeles-based Senior Vice President with Black & Veatch and Past President of the Water Environment Federation, believes that a mix of conditions have thrust California utilities into the sustainability spotlight.

"California's history of water resource challenges, appreciation of nature and stringent environmental regulations – combined with more recent funding issues – have set the stage for integrated resource planning and innovative programs that maximize all resources," Clark said.

It is a situation that many communities and governments find themselves in around the world.

RESOURCE RECOVERY IN ORANGE COUNTY

Two agencies in Orange County have broken ground in more ways than one. The county is expanding its successful Groundwater Replenishment System (GWRS), which is already the world's largest wastewater purification system for indirect potable reuse. This joint project with the Orange County Water District (OCWD) and Orange County Sanitation District (OCSD) produces water that exceeds all state and federal drinking water standards.

The GWRS uses a three-step advanced treatment process to purify wastewater that otherwise would have been discharged into the Pacific Ocean. It enhances existing water supplies by providing a reliable, high-quality source of water to recharge the Orange County Groundwater Basin and protect it from further degradation due to seawater intrusion.

Upon completion in the fall of 2014, the Black & Veatch-designed expansion will bring the total production of the GWRS to 100 million gallons per day. OCWD's advanced treatment process requires less energy than other water supply options, such as importation or seawater desalination, making GWRS expansion the most sustainable way to provide enough water for 850,000 people.

OCSD has central power generation facilities at its two wastewater and reclamation plants. The biogas produced in the solids digestion process provides fuel for the central generation engines. Exhaust heat boilers use excess heat from the engines to generate steam that is used to heat the digesters at both plants.

The central generation facilities produce about nine of the 13 megawatts of electrical power needed to run the treatment plants on average. According to Jim Herberg, OCSD Assistant General Manager and Director of Engineering, the green energy is cost-effective and increases the reliability of the district's electrical supply.

Black & Veatch is now helping OCSD design emission control facilities for central generating facilities at both plants to meet new air quality limits and maximize efficiency of energy recovery operations.

WATER AND ENERGY RECOVERY IN RIVERSIDE

Water scarcity, escalating energy costs, greenhouse gas emissions reduction and the need to preserve existing assets drove the design of recent improvements at the Riverside Regional Water Quality Control Plant, located in Riverside, Calif. Plant modifications and upgrades, which include the addition of a membrane bioreactor system for increased water recycling, were designed to yield increased capacity within a small footprint. The improvements also enable the city to meet more stringent reuse quality requirements while maximizing the value of current assets and minimizing future debt service costs.

To help offset increased energy requirements, the city is implementing sludge pretreatment to increase biogas production. A new fats, oils and greases (FOG) receiving station is included to enable the city to receive more FOG and generate more energy from and for operations.

WATERSHED MANAGEMENT IN SANTA MONICA

Black & Veatch experts worked closely with city of Santa Monica staff and key environmental stakeholders to develop a five-year capital improvement plan (CIP) to maximize the benefits of the city's Clean Beaches and Ocean Parcel Tax (Measure V) program. Approaches identified in the CIP to help the city increase beneficial groundwater recharge include permeable surfaces, retrofit of parks to utilize rainwater harvesting year-round and a pilot project to assess the potential for deep infiltration. Although the plan's primary focus is enhancement of stormwater quality, it also yields sustainable new supplies from water that had previously drained into the ocean.

"Effective watershed management enables us to address future water issues in a way that will provide multiple benefits to the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> "Effective watershed management enables us to address future water issues in a way that will provide multiple benefits to the community."

community," said Rick Valle, Santa Monica Watershed Program Manager. "Implementation of low impact development approaches helps recharge groundwater and will contribute to the city's future independence from imported water supplies."

Full implementation of a related sustainable water master plan will enable Santa Monica to operate in a dry climate – independent of imported water. Black & Veatch recently helped the city reach 72 percent of that goal with completion of the Charnock Well Field Restoration Project, which received awards from the American Public Works Association and the Design-Build Institute of America. That project restored local groundwater that had been contaminated by MTBE (a gasoline additive) leaking from area gas stations.

ACHIEVING BALANCE IN LOS ANGELES

Energy, water and financial resources are inextricably intertwined in other ways as well. As the largest municipally owned utility in the U.S., the Los Angeles Department of Water & Power (LADWP) discovered that an integrated resource plan can help utilities with broad roles keep the big picture in view moving forward.

The city is transitioning to a more balanced energy portfolio that further supports use of renewable energy. Black & Veatch and the LADWP collaboratively prepared an integrated resource plan for the Los Angeles power system that will enable the city to maintain a high level of electric service reliability, maintain competitive rates and exercise environmental stewardship.

Energy, water and management consulting specialists from both organizations together produced a 20 year framework that accounts for factors that range from energy demand forecasts to water considerations and rate impacts. Black & Veatch also assisted LADWP with the design of a renewable energy feed-in tariff (FiT) – an approach widely used in Europe, but little used in the United States. It allows the utility to pay for renewable energy at a predefined price on a long-term contract basis.

FiTs are offered by only a handful of U.S. utilities, but advocates hope a wider adoption will promote more sustainability by guaranteeing rates, thereby allowing producers to recover their investment costs. This is one more example of utilities making concerted steps to consider future generations and incorporate sustainability in all plans laid forth today.

STORY BY **LINDA SAIGER BOND,** BLACK & VEATCH

Not Much Change

Regulatory Agencies Will Step in as Congress Divides

BY BRENT FRANZEL
PRINCIPAL, CARDINAL POINT PARTNERS

QUESTIONS/COMMENTS?
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After two years of campaigning and record levels of spending, the 2012 elections delivered a government fairly similar to the one we have now. Although Democrats were able to pick up seats in both legislative bodies, their gains will have little impact on the operation of either body or the ability to enact legislation.

New faces are expected in the Cabinet-level spots at State, Defense, Treasury and Justice. Energy Secretary Steven Chu and Environmental Protection Agency Administrator Lisa Jackson are also considered likely to move on.

There will be a number of new faces in key committee slots, including Ron Wyden (D-OR), who will take over as Chairman of the Senate Energy Committee; David Vitter (R-LA), who is expected to replace James Inhofe (R-OK) as the senior Republican on the Senate Environment & Public Works Committee; and Bill Shuster (R-PA), who will take over as Chairman of the House Transportation and Infrastructure Committee.

When Congress returns in January, it will first have to turn to any remaining "fiscal cliff" issues not addressed in the November-December lame duck session. This is almost certain to include an effort to enact comprehensive tax reform to address not only basic corporate and personal rates, but also to determine how to deal with dozens of expiring tax credits – such as the wind production tax credit and a range of oil and gas provisions. There is much talk in policy circles of enacting a carbon tax. However, it seems very unlikely that such a measure would have a chance of surviving in Congress, where energy state members control a huge block of votes.

Other issues that need to be addressed by the new Congress include how to deal with the Highway Bill as gas tax revenues drop and dry up the funds available for new construction, and how to approve a new Water Resources Development Act within the confines of the current ban on Congressional earmarks.

What seems clear is that there is almost no chance of passage of a major climate bill along the lines of the bill pushed during the early part of the president's first term. More likely are efforts to push smaller, targeted provisions such as a renewable fuels standard. But even such smaller efforts will have difficulty getting through the closely divided Congress. With Harry Reid remaining as Senate Leader, Yucca Mountain will remain off limits as a storage site – likely slowing progress on nuclear energy adoption. However, it is possible the Department of Energy will continue moving forward with loan guarantees for new facilities.

Every decision Congress makes for the next two years will be colored by the ongoing pressure to reduce the federal deficit.

The real focus for energy and environmental policy in the next few years will take place not in Congress, but rather in the administrative agencies where the president will aggressively use his regulatory authority to move his policies forward. The EPA will likely issue new rules to cut greenhouse gas emissions from coal-fired power plants, plus set new standards for the ozone and particulate emissions. In 2013, expect new regulations on hydraulic fracturing and a decision by the State Department on whether to allow construction of the Keystone XL pipeline.

EPA is also likely to be active on the water regulatory front, including the possibility of new regulations to expand the Clean Water Act to cover intermittent streams, and to address the need of municipalities to deal with issues such as combined sewer overflows.

The bottom line is that we are looking at four more years of the same – little legislation moving through a divided Congress, with the administration moving aggressively through the regulatory process to achieve its energy and environmental goals.

NATURAL GAS INDUSTRY REPORT:

Optimism Pervades the Industry, but Regulatory Issues Still Linger

Black & Veatch's first "Strategic Directions in the U.S. Natural Gas Industry" report shows that optimism for future growth across the industry is as plentiful as domestic shale gas reserves. The report is based on a comprehensive survey of natural gas industry leaders and includes analysis from Black & Veatch experts.

When asked about their view of the industry's future growth, 92 percent of respondents stated they were either "optimistic" or "very optimistic."

However, for all its future promise, the natural gas industry must first overcome today's hurdles. Environmental concerns related to gas production, attracting capital for infrastructure investments and the maintenance of delivery system safety and security are all critical components for industry growth. All of these items have at least one common link – regulation.

While regulations govern the various markets of the natural gas industry in different ways, the impact of decisions all eventually funnel to the same end point – the price customers pay for natural gas and natural gas service. Each of the industry's market segments – upstream, midstream and downstream – is working with regulators to implement proactive solutions to industry challenges.

UPSTREAM MARKET

The upstream market largely consists of natural gas producers. For this market, environmental regulations and concerns are among the most critical.

"Clearly the concerns right now are with water and the hydraulic fracturing process," said Greg Hopper, Managing Director of Black & Veatch's Natural Gas and Power Generation Fuels Advisory Service. "While the technology is there and generally proven to be safe, people in communities nationwide need new demonstration of this. To achieve this, we expect more public private collaboration that promotes stakeholder trust in an economically feasible manner in order to assure the public that natural gas production can be and will be done in a safe and environmentally responsible manner."

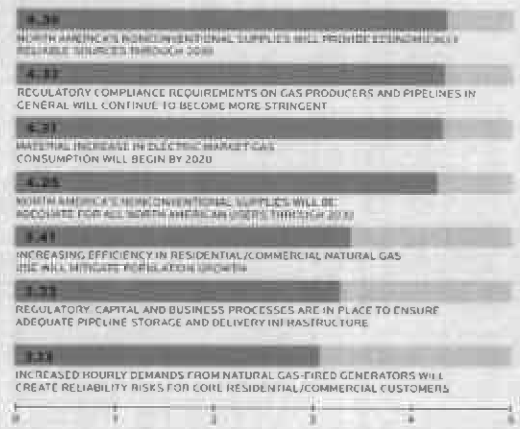
In the survey, 81 percent of respondents stated that environmental concerns regarding hydraulic fracturing will impede development of shale gas modestly, largely or significantly. Translating these public concerns into hard costs, 80 percent of respondents said that environmental concerns will result in modest ($0.10 – 0.50 per MMBtu) to significant (greater than $1 per MMBtu) price increases. A general observation is that most feel such costs could be compatible with future shale production growth.

SUBJECT MATTER EXPERTS
GREG HOPPER: HopperGA@bv.com; **RICK PORTER:** PorterRW@bv.com; **ROD WALKER:** WalkerRW@bv.com; **RUSSELL FEINGOLD:** FeingoldRA@bv.com

INDUSTRY OVERVIEW

The issue of safety and the need for economic growth to realize the industry's future promise were respectively ranked as the most important long-term industry issues. Gas supply reliability is quickly moving to the forefront among industry stakeholders. The report provides an in-depth view of these issues.

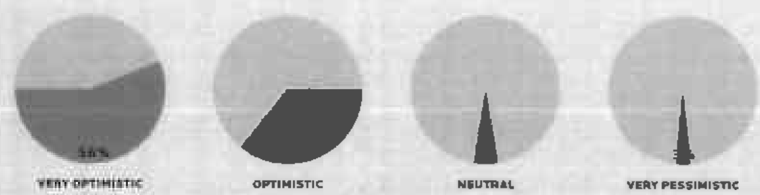
PERSPECTIVE ON INDUSTRY



The general consensus is that gas prices are at unsustainable levels for all producers and must eventually rise from the sub-$3 per MMBtu range to between $4.50 and $6.00 per MMBtu by 2020.

Source: Black & Veatch

OUTLOOK ON INDUSTRY GROWTH IN NORTH AMERICA BETWEEN NOW AND 2020



Source: Black & Veatch

MIDSTREAM MARKET

Pipelines are the largest component of the midstream market and provide the critical link between natural gas supply and market demand. The complex and vast infrastructure needs to be expanded and pipeline companies have numerous challenges associated with this.

Because supplies are diverse and plentiful, the majority of natural gas customers are purchasing their supplies via short-term (less than one-year) contracts. However, firm gas pipeline capacity is typically held under long-term contracts. Black & Veatch survey results show that the majority of buyers (61 percent) are holding firm transportation contracts that are greater than three years in length.

"Pipeline companies today are dealing with a truly unique challenge," said Rick Porter, Director of Black & Veatch's Rates and Regulatory Advisory Services. "We have tremendous investment needs for new pipelines in emerging basins across the country. At the same time, we have a growing issue of potentially stranded costs with pipelines that are no longer being used to their full capacity because the supply map has changed so dramatically."

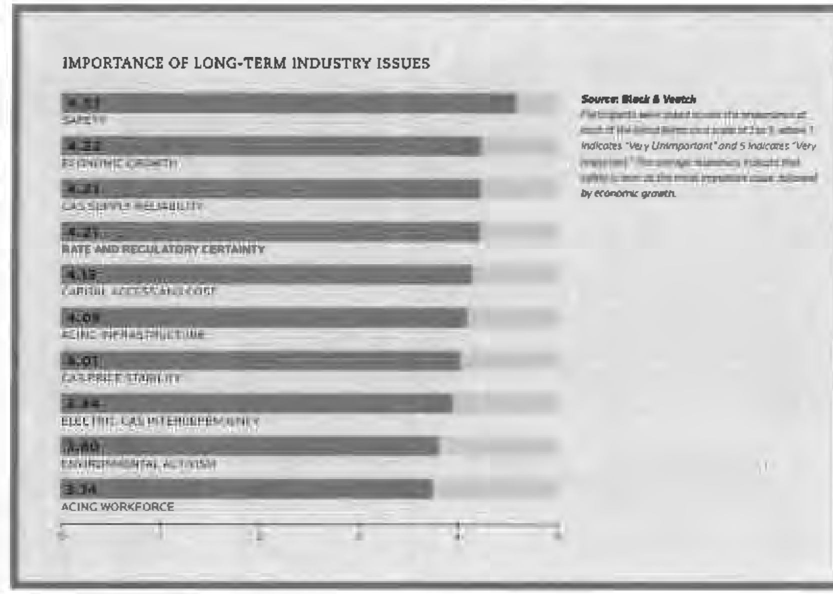
Porter said portions of the regulatory framework may need to be redefined to account for growth in some regions and contraction in others.

"Pipelines represent an area of significant growth, and investment is critical for this growth," Porter said. "To date there has been sufficient capital to support infrastructure growth in the unregulated sectors of the midstream. However, for various reasons, the regulated segments have not proven to be as attractive to investors. Consequently, regulators may need to intercede and enable pipeline businesses to not just recover operating costs, but to earn competitive returns so they will re-invest in the industry and grow their businesses."

DOWNSTREAM MARKET

Aging infrastructure was rated the top industry issue in Black & Veatch's Strategic Directions Reports for both the electric and water industries released earlier in 2012. Indeed, much of today's natural gas distribution systems were installed before 1970. In addition, 70 percent of industry respondents representing local distribution companies (LDCs) or gas utilities stated their organization has aging infrastructure that needs to be replaced. However, aging infrastructure overall ranked sixth out of 10 issues, and safety was rated as the overall top industry issue.

Rod Walker, a principal consultant in Black & Veatch's management consulting division, attributes this phenomenon to the industry largely considering aging infrastructure and the need for safe and reliable operations as overlapping issues.



"Because of the aging system and its proximity to large populations, industry participants are focused on maintaining safe and reliable operations," said Walker. "This includes managing the physical infrastructure through asset management programs, as well as the computer and communications networks through cyber security programs."

For utilities, regulation – and the resulting rates they can charge customers for services – has a fundamental impact on the pace at which they can address critical infrastructure needs, adopt new technologies and manage their long-term financial performance.

"The pressure on regulators to move cautiously on rates is of particular importance when considering the economic realities of the past four years," said Russell Feingold, Vice President who leads Black & Veatch's Rates & Regulatory Advisory Services Practice. "The public interest perspective has greatly influenced the action of utility regulators – and has created the perception of a fundamental imbalance in the regulatory compact in favor of consumers."

This is confirmed in the reports. The majority of industry participants said they believe that the current balance of the regulatory compact now favors consumers by nearly a 2-to-1 margin. This is particularly true among respondents serving customers in the Northeast U.S., who view the regulatory compact favoring consumers by more than a 13-to-1 margin.

Feingold noted that while rate and regulatory uncertainty is one of the top five long-term industry issues, there are regulatory practices that are viewed very favorably among respondents.

"A growing number of utility regulators have responded to this issue through adoption of step rate adjustments, rate cases with multi-year test periods, and infrastructure cost recovery rate mechanisms. These practices provide utilities with greater certainty, timeliness and flexibility in the recovery of large, one-time costs, or costs of a recurring nature," said Feingold. "Encouraging the replacement of aging infrastructure systems through these types of regulatory practices helps an LDC maintain safe and reliable operations."

STORY BY **LINDA LEA**, BLACK & VEATCH

SEE THE COMPLETE REPORT, "2012 Strategic Directions in the U.S. Natural Gas Industry," at bv.com/reports.

BALANCING
WATER DEMANDS IN VIETNAM

BY CHRISTINA HARTINGER, DIRECTOR OF PROJECTS, NORTH ASIA PACIFIC,
BLACK & VEATCH'S GLOBAL WATER BUSINESS

Vietnam is prospering. For almost 20 years, its growth rate has stood firm at around 7 percent annually. During the first decade of this century, its gross domestic product tripled, and its exports quadrupled.

With factors including greater political stability and reform, and 1 million young people arriving on the job market every year, investment persists. Many dramatic social and economic changes have resulted, and the question of *how* this emerging modern nation grows is just as important as by *how much*.

Agriculture remains a fundamental kernel of the economy. Sustainability is vital to Vietnam for many reasons. The country is one of the world's major rice, coffee and rubber exporters. Three out of four Vietnamese citizens also live in the countryside. Any sustainable development in Vietnam must consider the realities of these demographics and balance growth between city and countryside – or in other words, industry and agriculture.

Competing needs of industry and agriculture in times of rapid development have been brought to a head during periods of water shortages in recent years. In 2000, power cuts were ordered across Ho Chi Minh City as drought threatened hydroelectric production. In 2005, following another period of drought, a power shortfall of 854 million kilowatt-hours (kWh) occurred across 11 hydroelectric dams as water was diverted for agriculture. Similarly in 2008, water shortages in Hanoi led to the release of 2.2 billion cubic meters of water (equivalent to 430 million kWh of electricity) from three hydroelectric dams, again for agricultural use.

Holistic planning of the country's water resource, therefore, plays a significant role in the long-term development of Vietnam. Balancing the competing agriculture needs of rural areas with the emerging and consuming needs of burgeoning cities and industry is key if Vietnam is to strike the right long-term path for the country.

CHRISTINA HARTINGER: NGUYEN XUAN HUNG: ALAN MAN:

OPPOSITE PAGE: Finished canal work in Vietnam is part of the Phuoc Hoa Water Resources Project, which seeks more efficient use of water supplies for both agriculture and industrial development.

The Phuoc Hoa Water Resources Project sets out to plan for more efficient use and availability of water supplies for agricultural and industrial development in the southern portion of Vietnam, as well as increased municipal and domestic water demand. First conceived in the 1980s, the project takes a true regional view of the available water resource across the Dong Nai - Sai Gon Basin. It plans the long-term allocation of the supply across five provincial boundaries (Ho Chi Minh City, Binh Duong, Binh Phuoc, Tay Ninh and Long An), including some of the country's largest urban and industrial development areas. These areas in particular continue to expand, and their water demands will continue to increase.

"The master plan aims to approach water resource planning in a sustainable fashion for the people of Vietnam. It will make an important impact to the lives of the 9 million people, improving the water supply and salinity control in the region," said Alan Man, Vice President and Managing Director of Black & Veatch's North Asia Pacific water business.

Man pointed out that more importantly, the Phuoc Hoa Water Resources Project will directly increase agricultural income and employment opportunities for approximately 140,000 people currently not experiencing the fruits of Vietnam's modernization progress.

After a series of studies, the project got under way in 2004 with funding from the Asian Development Bank (ADB), Agence Francaise de Developpement (AFD), the Vietnamese government and project beneficiaries. It is a monumental effort.

Central to the project is the transfer of water from Phuoc Hoa Reservoir to Dau Tieng Reservoir and the subsequent reallocation of water for irrigation to two new irrigation areas at Tan Bien and Duc Hoa.

"These areas cover some 29,000 hectares of land, mostly paddy fields which are more remote from the effects of modernization," said Nguyen Xuan Hung, Black & Veatch Deputy Team Leader of the project. "They are poorer, less developed areas compared to downstream Ho Chi Minh City. This really is a balanced, sustainable water plan with diverse economic benefits at the heart of the solution."

As part of Phase One, the Phuoc Hoa Barrage has a capacity of 18.5 million cubic meters and connects to a 40-kilometer transfer canal. The barrage helps develop the water supply from the Be River and transfer it to the Dau Tieng Reservoir.

The transfer of water will intensify crop yields, thanks to increased and more effective irrigation. AFD said studies have shown that agricultural income could increase by 100 to 250 percent for some land. The drinking water supply in villages will also advance hygiene conditions, and improved drainage from irrigation will mitigate against flooding.

In addition, increased flows during the dry seasons in the Vam Co Dong and Saigon rivers will boost the supply of bulk water for Ho Chi Minh City and, importantly, control saline intrusion. Saline control is essential to the water supply for industry, as well as for municipal and domestic use. The increased flows also help mitigate effects of rising sea levels – a concern on every sustainable blueprint in Vietnam, which boasts 3,444 km (2,066 miles) of coastline.

Black & Veatch, involved in the original feasibility studies, has been working closely with the Investment and Construction Management Board 9 of the Ministry of Agriculture and Rural Development to review, design and construct the project since 2006. The first phase was completed in 2011 with the delivery of infrastructure, including the Phuoc Hoa Barrage (with a capacity of 18.5 million cubic meters) and a 40 kilometer transfer canal (with a flow of 55 cubic meters per second). Together the structures develop the water supply from the Be River and transfer it to the Dau Tieng Reservoir, conveying this surplus water resource toward the stressed Saigon (directly) and Vam Co Dong (indirectly) rivers.

The Tan Bien main canal was also constructed in Phase One, joining the existing Dau Tien West Canal, in preparation of the development of the new irrigation area at Tan Bien. Phase Two of the project is due for completion in 2014 and will see the development of the new irrigation areas as well as the Duc Hoa main canal – in preparation for the second new irrigation area at Duc Hoa.

Integral to the sustainability of this holistic water resource project have been other important development aspects. A resettlement program for affected living areas was delivered as well as environmental management programs to minimize the works' impacts. Black & Veatch continues to provide support to develop capacity within government institutions, irrigation management companies and water user groups.

Christina Herringer is the Director of Projects for Black & Veatch's global water business in North Asia Pacific. Across her 29-year career, she has worked in a number of global markets for Black & Veatch where she has steered and managed many successful water and wastewater projects. She is based in the company's Hong Kong office.

Utilities Band Together to Explore Zero-Energy in Wastewater

Twenty-three utilities, including many from the United States and several from Australia, have agreed to participate in a study that explores zero-energy solutions for wastewater treatment plants.

The 18-month study is being sponsored by the Water Environment Research Foundation (WERF) and the New York State Energy Research and Development Authority.

The research team will develop baseline energy flows for common wastewater treatment processes to identify ways utilities can reduce demand, increase energy efficiency, and recover and produce energy on-site. The team will also document successes and obstacles at energy-neutral or near-net-neutral facilities.

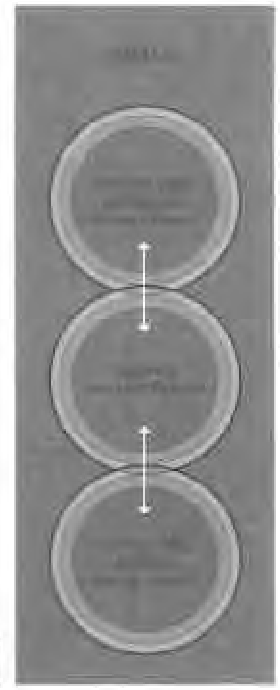
Lori Stone, Biosolids Global Practice and Technology Leader for Black & Veatch's global water business, and Paul Kohl, Energy Program Manager at the Philadelphia Water Department, will lead a team as co-principal investigators.

"Energy costs are a significant part of utility operating budgets," Stone said. "Today's utilities are increasingly striving to recover more energy from the treatment process than they use. Our research will provide guidance for achieving energy self-sufficiency while helping utilities share industry knowledge and experience."

The project is entitled Energy Balance and Reduction Opportunities, Case Studies of Energy-Neutral Wastewater Facilities and Triple Bottom Line (TBL) Research Planning Support. The team will use TBL assessments (economics, environment, community) to discover sustainable options for managing biosolids.

Experts from Black & Veatch's management consulting division will provide financial and business case evaluation for the study. By focusing the research on both business and technical issues affecting energy opportunities, Stone said the results will help pinpoint strategic opportunities for utilities.

LORI STONE:



Integrating renewables into remote or isolated power networks and micro grids Innovative solutions to ensure power quality and grid stability

Power and productivity
for a better world™

ABB

ABB is a leading provider of integrated power and automation solutions for conventional and renewable-based power generation plants and water applications, such as pumping stations and distribution plants. The company's extensive offering includes turnkey electrical, automation, instrumentation and control systems supported by a comprehensive service portfolio to optimize performance, reliability, and efficiency while minimizing environmental impact.

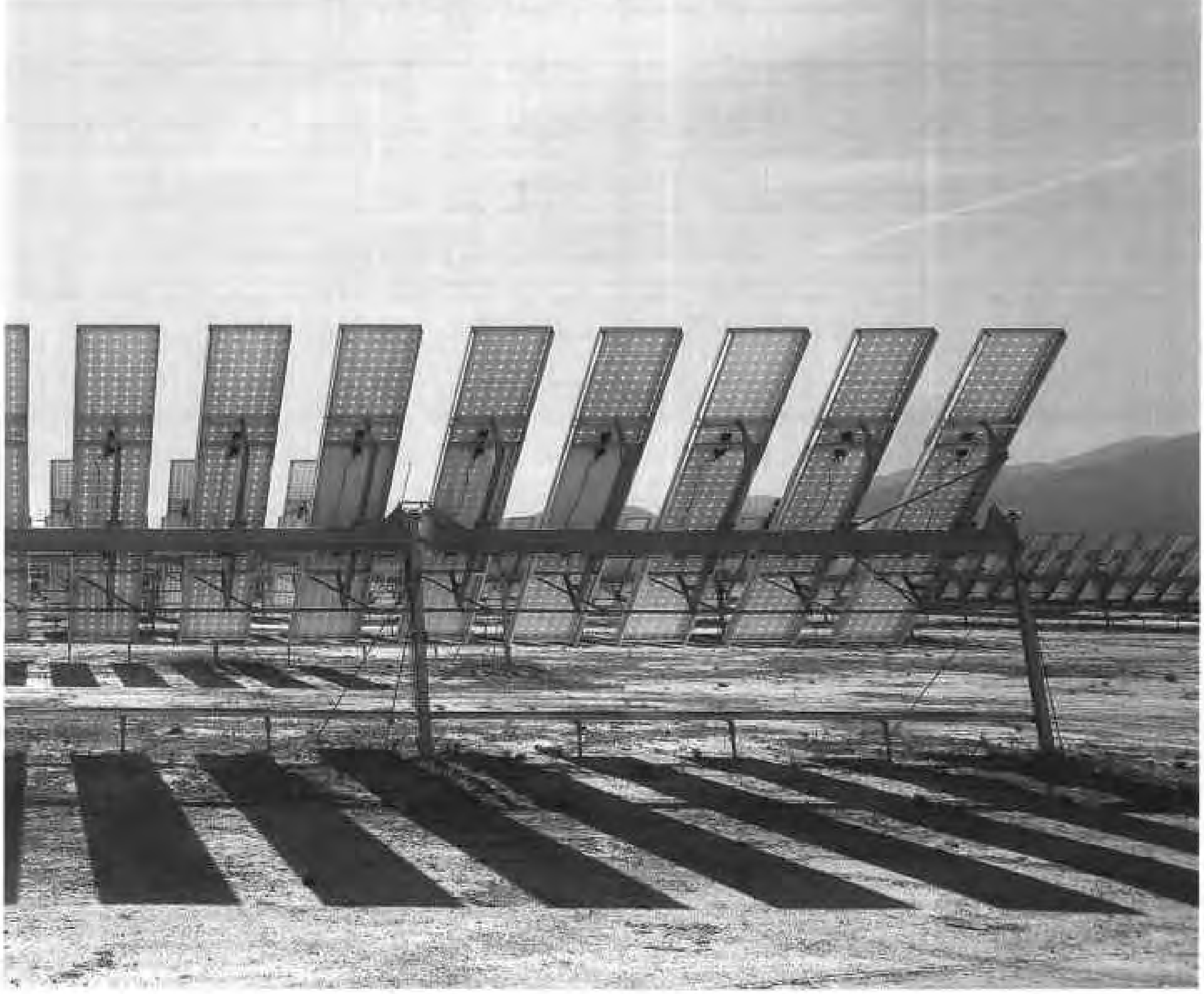


ABB technologies enable the flow and control be more flexible, reliable, efficient, intelligent

A renewable future

Most people never think about the vast, complex electrical networks behind every wall plug and how indispensable these networks are to our world.

Electricity plays a key role in economic and social development, yet more than 1 3 billion people in remote areas still don't have access to it.

Fortunately, technology exists that can ensure access to reliable sources of quality electricity, even in isolated areas far away from regular power networks

The power sector plays a major role in efforts to reduce greenhouse gas emissions by integrating renewables

# of electricity for power networks to and environmentally friendly

The power of innovation

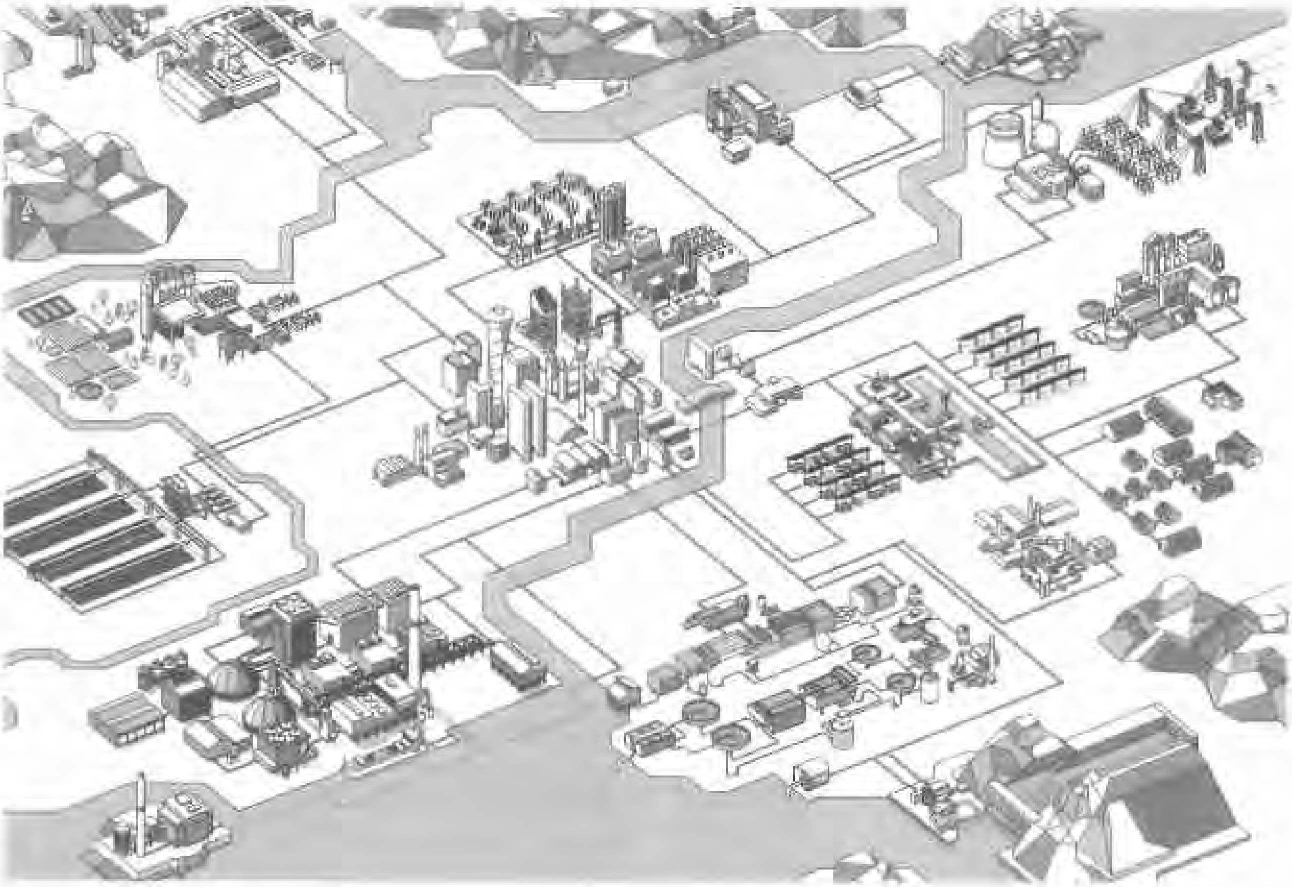
The easiest way to generate electricity in areas not serviced by electrical networks is with a generator that burns fossil fuels, like diesel, gas or heavy fuel oil. Yet remote places may also be rich in renewable energy sources, like sun, wind and water, which could be harvested.

Reducing the reliance of remote communities on fossil fuels is driving the development of technologies designed to integrate, manage and control renewable generation in isolated networks. This technology has successfully increased the production and integration of renewable energy into isolated power generation systems that once relied on fossil fuels alone. These hybrid generation solutions provide high-quality electricity in isolated places, making them much less vulnerable to escalating fossil fuel prices or erratic power supplies.

The intermittent nature of renewables makes this a challenge. Electricity generated by a wind turbine, for example, can create surges of electricity caused by gusting winds. An isolated grid must be equipped to overcome these surges, or it can collapse. The challenge has been to devise a method which can harvest clean energy when nature cooperates and compensate or smooth things out when it does not.

Now, ABB can offer a solution that successfully and safely integrates renewable power into small, isolated or remote grids.

Managing renewable energy



Electricity networks are complex systems that cannot be efficiently and securely operated without an appropriate energy management and control system.

ABB is a global leader in energy and generation management systems, with more than 5,000 installations worldwide. The Group recently acquired Powercorp, a company with a unique portfolio that connects remote communities and isolated enterprises with quality power which can be generated almost entirely from renewable sources, or easily combined with existing fuel generation systems to reduce costs and risks

Powercorp developed the technology to help automate diesel-generator power stations across Australia's remote Northern Territory. The challenge was to integrate renewables into remote power grids, initially focusing on wind-diesel hybrid systems before expanding into solar energy, enhanced by a control system capable of instantly balancing renewable and fossil fuel generation in one power network.

One of the biggest challenges of integrating renewable generation in any power grid is intermittent generation, which can be caused, for example, by gusting wind or clouds on a sunny day This simple occurrence can destabilize the grid and cause an unwelcome generator response known as hunting, even when wind flow is low, which leads to unnecessarily high consumption of backup fossil fuels, engine damage, and expensive blackouts.

Power fluctuation is common in isolated networks, but the problem also exists in large networks at the end of transmission lines, or at the interconnection point of wind farms and other critical nodes.

We have the solutions

Our innovative technology solution can stabilize an electricity network by rapidly absorbing power surges from the renewable energy source, or by supplying power to make up for short term lulls, in order to maintain high-quality voltage and frequency. Combined with automation and control systems that ensure the most efficient and reliable power flow possible throughout the network, it is a solution that makes it possible have utility-scale power virtually anywhere.

PowerStore

PowerStore™ is a flywheel-based, short-term energy storage system, which includes state-of-the-art inverters and virtual generator control software. It is designed to enable integration of intermittent and often erratic renewable generation. It can help achieve up to 100 percent penetration of this energy source into remote grids, and enables the utilization of renewable energy generators, protecting remote communities from exposure to volatile oil prices.

Poor integration design can inflict damage on a power generating station. PowerStore safeguards conventional micro grids, and ensures the safe integration of large amounts of wind and solar energy, reducing emissions and dependency on fossil fuels. High-speed software controls the power flow into and out of the flywheel, essentially making it a high inertia "electrical shock absorber" that can instantly smooth out power fluctuations generated by wind turbines or solar arrays.

PowerStore acts like a STATCOM (advanced grid technology that quickly stabilizes voltage and improves power quality) and in addition is capable of rapidly absorbing or providing real power. It can stabilize both voltage and frequency, hold 18 MWs (megawatt seconds) of energy and shift from full absorption to full injection in 1 millisecond to stabilize the grid. Without a grid stabilizing technology like PowerStore, the instantaneous penetration of renewable energy is limited to about 30 percent of the total system load before the renewable component starts to destabilize it. In small isolated networks, this is a frequently experienced problem.

Automation and control

PowerStore technology is augmented by a robust, specially designed distributed control system (DCS) that can manage the energy flow within a power network to ensure balance between supply and demand and optimize the use of the renewable energy.

The DCS controls and monitors all renewable generating units, all diesel and/or gas generator sets, consumer feeders and energy storage in a power system. It provides event reporting, trending, remote access and external alarm notification. Depending on system load conditions, the controllers start and stop generators to optimize station fuel efficiency. The system maintains optimum loading and spinning reserve on all in-service generator sets. It continuously monitors the feeder load and matches the most economical configuration of the generator sets with the renewable energy sources or demand.

Technology that can smooth out power surges and optimize flow control within isolated networks ensures maximum penetration of renewable energy into these networks, maximizing savings. PowerStore, combined with this enabling DCS technology, is the only technology of its kind to provide electricity in areas that cannot be supplied by a conventional electricity network.

Together, grid-stabilizing PowerStore technology and the DCS power management system enable up to 100 percent instantaneous penetration of renewable generation in a power network, while running thermal generation units at their optimal loading points, or as back-up. It is a proven renewable integration solution, installed in many projects worldwide, including Australia, Europe, North America and even Antarctica.

We have the solutions

ABB has been in the energy business for 125 years, and over the years has pioneered many additional product and system innovations to help improve efficient energy use and lower environmental impact in the industrial and utility sectors. These include:

Balance of system

ABB's comprehensive renewable energy portfolio ranges from electrical Balance of Plant (eBOP), automation, instrumentation and control system products and solutions supported by a service portfolio that optimizes performance, reliability, and efficiency, all the way to complete Balance of System (BOS) packages and turnkey project capability.

Our scope of supply can include an entire project, from site assessment to plant design, engineering, manufacture and procurement, installation, commissioning and grid connection.

Consulting

ABB has many years of experience integrating renewable energy sources in technically challenging micro grids, and this combined with strict adherence to industry-accepted tools and standards is the foundation of ABB's consulting offering. Making the right economic and technical decisions can be difficult, but using sophisticated simulation tools, ABB can tailor a solution to fit specific wind and solar conditions, commercial conditions and technical requirements.

> The power system of the future will be more flexible and interconnected, leading to the evolution of a stronger and smarter grid, balancing our growing need for power with environmental concerns

To start, ABB consultants evaluate design options for both off-grid and grid-connected distributed generation applications. Optimization and sensitivity analysis algorithms evaluate the economic feasibility of many technology options, and account for cost variations and energy resource availability.

In addition to thorough economic analysis, ABB provides a strong technical consulting capability, including flexible, dynamic simulation tools that produce extremely accurate grid models. ABB's experience with remote power generation is constantly helping to improve the tools and design process in these studies, while an experienced engineering team guarantees the end result is a high-quality, technically detailed project simulation.

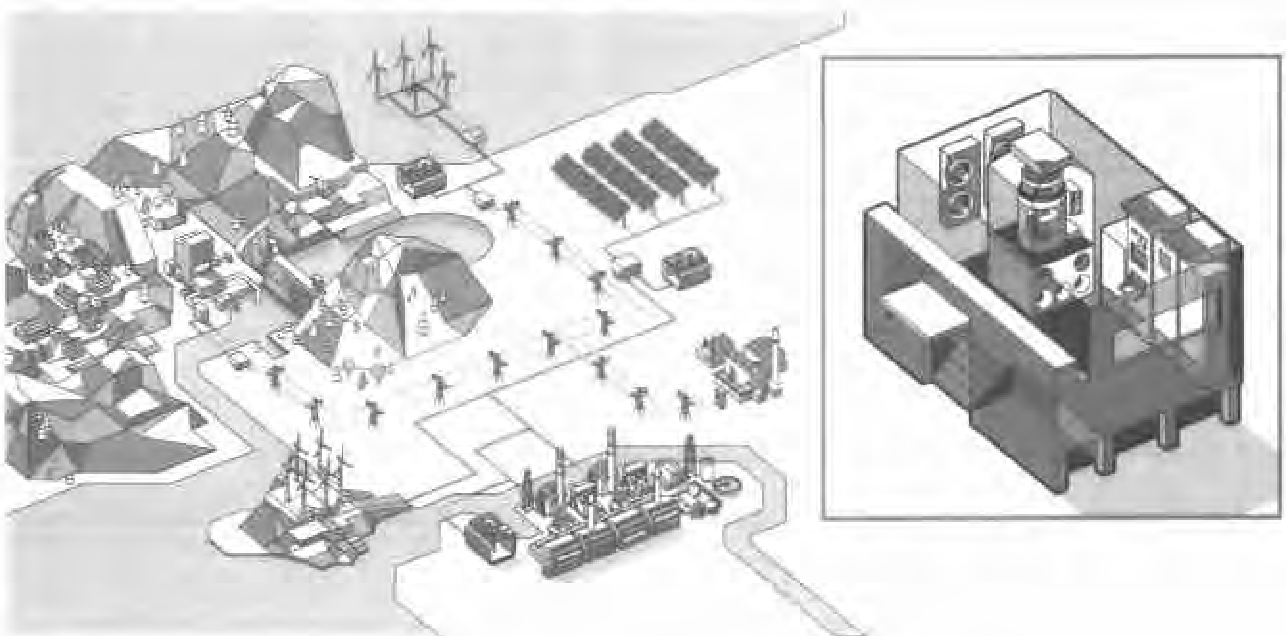
ABB verifies its models with data taken from similar completed, commissioned projects. This helps to identify problems in the simulation process, and increases the accuracy of future models. This way, ABB consultants can rely on real-world experience and working systems to ensure the most valid simulation models possible.

Service

Service is a key ABB competency. Over the past 10 years, ABB has built up a remote service capability for power generation facilities, and now provides several hundred plants with remote monitoring from dedicated control centers. The same concept is also available for renewable generation plants.

For micro grids, especially in remote areas, it is critical to maintain constant power supply and be connected to technical support at all times. ABB technology enables remote access, monitoring and control of such installations.

Servicing the components that hold remote systems together ensures essential power generation at remote sites is not interrupted. ABB can perform routine service checks, regular maintenance and unscheduled service remotely, with minimal impact on the micro grid.



Applications

PowerStore grid-stabilizing technology is extremely beneficial in remote and micro grids where it offers reactive power support in isolated communities and industrial settings, such as mines, fish canneries and construction sites, where fuel costs and production schedules are critically important. In addition it can provide virtually instantaneous support for and protection from electrical surges created by large scale electrical equipment on site.

This breakthrough solution combined with a solid DCS power management solution enables the injection of up to 100 percent renewable energy into remote networks. The benefits are clear for island communities cut off from mainland grids, isolated tourist centers, remote villages and industrial sites far removed from conventional power networks

ABB solutions facilitate the generation, transmission and distribution and utilization of electricity in remote or isolated areas - enabling efficiency, reliability and power quality

Helping our customers achieve their targets

Marble Bar

The world's first high penetration, solar photovoltaic diesel power stations were commissioned in 2010 in the towns of Nullagine and Marble Bar, in Western Australia. The projects include more than 2,000 solar modules and a solar tracking system that follows the path of the sun throughout the day. When the sun is shining, PowerStore grid-stabilizing technology and a DCS power management solution ensures maximum solar energy (100% peak penetration) goes into the network by lowering diesel generation, up to the minimum loading of the generation units. When the sun is obscured, the PowerStore covers the loss of solar power generation as the DCS ramps up the diesel generation, so the network has an uninterrupted energy supply. The solar energy systems generate over 1 GWh (gigawatt hour) of renewable energy per year, supplying 60 percent of the annual energy for both towns, saving 405,000 liters of fuel and 1,100 metric tons of greenhouse gas emissions each year.

Ross Island

New Zealand's Scott Base and America's McMurdo Station in Antarctica are important research bases and home to about 1,200 people in the Antarctic summer. They have always relied completely on fossil fuels for power, until a new system based on wind turbines, a new distributed control system and PowerStore grid-stabilizing technology was commissioned in 2009. The bases still need back-up diesel generators, but three 333 kW (kilowatt) wind turbines reduce the amount of diesel required for power generation by around 463,000 liters, and cut CO_2 emissions by 1,242 metric tons per year, while lowering the risks of transporting and storing liquid fuel in this precious environment. A frequency converter interconnects the Scott and McMurdo bases, which operate at different frequencies - 50 Hz (NZ) and 60 Hz (US), allowing power flow in both directions.

BHP Billiton Leinster nickel mine

BHP Billiton's Leinster nickel mine in Western Australia is the third-largest producer of nickel concentrate in the world. Ore is extracted from 1,000 meters underground with a large, electrically driven winder, which at 8 5 megawatts (MW) of demand shift over 120 seconds is a large cyclic load, given the unit's average power consumption is just 2 MW. To upgrade the winder's power supply, BHP installed a 1 MW PowerStore system, which reduced the total demand shift to 6.5 MW while adding 1 MW of spinning reserve to the system. Its flywheel-based energy storage system provides peak lopping and overcomes transient and cyclic loads on grid connected or isolated systems. The mine was able to increase winder production without affecting power system reliability. Fully automated, PowerStore gets power to the winder when it's needed most, and provides high resolution data of winder performance and local electrical grid disturbances.

Coral Bay

Coral Bay is the gateway to the Ningaloo Reef World Heritage Area in Northwestern Australia, where power demand increases significantly during the tourist season. A PowerStore grid-stabilizing system and DCS power management solution oversees the town's power supply, which consists of seven 320 kilowatt (kW) low-load diesel generation units combined with three 200 kW wind turbines. PowerStore's 500 kW flywheel technology enables the wind turbines to supply up to 95 percent of Coral Bay's energy supply at times, with a total annual wind penetration of 45 percent, while maintaining city grid standards of power stability and quality. Power station data indicates more than 80 percent of Coral Bay's power is wind generated for one-third of the year. The data also shows that for nearly 900 hours per year, wind provides more than 90 percent of Coral Bay's power supply. PowerStore maximizes an environmentally friendly solution.

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Section 1 – EXECUTIVE SUMMARY

1 EXECUTIVE SUMMARY

The San Diego Gas & Electric Company (SDG&E) Smart Grid Deployment Plan advances the utility's vision for a smart energy future while delivering new value to its customers, meeting its public policy requirements and delivering societal and economic benefits that exceed project costs.

SDG&E views the Smart Grid as an end-to-end transformation of its electric delivery system that applies advances in technology to deliver a range of new benefits to all stakeholders. The Smart Grid empowers customers, increases renewable generation, integrates plug-in electric vehicles (PEVs) and reduces greenhouse gas (GHG) emissions while maintaining and improving system reliability, operational efficiency, security and customer privacy. SDG&E anticipates that investments in Smart Grid infrastructure will yield additional benefits as the transformation progresses and its customers, policy makers and the industry are able to leverage lessons learned and achieve the Smart Grid's full potential.

Customer choice is a potent driver of SDG&E's deployment plan for the Smart Grid. SDG&E customers are adopting rooftop solar and PEVs at rates that are among the highest in the nation. They are seeking real-time information about their energy usage and rates in order to make more informed decisions. Some are looking for opportunities to participate in energy markets through demand response, time of use rates, distributed generation (DG) and storage. Lastly, SDG&E customers have consistently shown their support for more electricity from renewable resources and other important environmental initiatives resulting in government and regulatory policies that are the other major drivers of SDG&E's Smart Grid Deployment Plan.

The state and federal policies accelerating planned Smart Grid investments include Senate Bill (SB) 17, Assembly Bill (AB) 32, California's 33 percent renewable portfolio standard (RPS), the state's distributed generation goals, demand response mandate, improved building and appliance efficiency standards, implementation of the electric procurement loading order and national security standards such as the North American Electric Reliability Corporation's Critical Infrastructure Protection(NERC-CIP) program.

SDG&E's vision for its Smart Grid transformation is to work in collaboration with key stakeholders to create the foundation for an innovative, connected and sustainable energy future. Consistent with this vision, SDG&E has engaged the input of representative stakeholders from across its service territory in the development of this Smart Grid Deployment Plan. These include environmental, academic, business, municipal/regional government, ratepayer advocacy, consumer, large customer and workforce development organizations. In addition to engaging these external groups, internal stakeholders at SDG&E have aligned behind the utility's Smart Grid vision and strategy which now further integrates Smart Grid across all utility planning efforts and operations.

SDG&E's deployment baseline is bolstered by the utility's nearly-complete, customer-empowering smart meter rollout, which is already supporting new customer behaviors, such as the use of third-party applications to see energy interval usage data. Its prior Smart Grid investments either already deployed or in the process of deployment, stretch back 20 years and have laid the foundation for the utility of the future through improved efficiency and reliability and maximized customer value. These include early investments in automation and control technologies; the development of the Sustainable Communities program; its "OpEx 20/20" program to reengineer operational processes and associated software for Smart Grid support; installation of a microgrid in Borrego Springs; and full-scale Supervisory Control and Data Acquisition (SCADA) deployments which now control 95 percent of the SDG&E transmission system.

SDG&E's Smart Grid investments to date have been carefully chosen and deployed to allow the flexibility to leverage future innovations, address evolving or new policy requirements and to capture more benefits as new opportunities and challenges arise. Some of these challenges include addressing issues associated with the two-way energy flow that results from distributed generation, the intermittent power of solar and wind generation and the unknown and potentially unpredictable load imposed by electric vehicle charging. SDG&E's Smart Grid investments are intended to manage such changes and transform the grid of the past into the smarter grid of the future that is increasingly needed today. Where technology innovations or energy markets are not mature enough to support a full deployment of a new or potentially promising Smart Grid investment, SDG&E's strategy is to leverage pilot and demonstration projects to improve the utility's understanding of likely costs and benefits before a full deployment decision is proposed.

SDG&E's Smart Grid strategy is guided by this vision, consistent with the goals of SB 17 and follows a decision-making framework that includes a five-pronged approach to ensure compatibility with SB 17's goals: a) identify applicable regulations; b) identify investment options that help meet policy requirements; c) determine if investment options aid SDG&E in meeting policy requirements; d) determine if investment options enhance customer value; and e) choose investments based on standard economic criteria, necessity for meeting policy requirements, and equity.

SDG&E's Smart Grid deployment strategy also prioritizes projects according to customer value, policy drivers or the need to pilot. Investments driven by customer value are those where the projected benefits outweigh costs or where the investment is necessary to effectively communicate with customers. For investments driven by state or federal policies, SDG&E still calculates the potential customer and societal benefits to pursue a least-cost and best-fit approach. By following this strategy, SDG&E's Smart Grid deployment efforts will significantly reduce the environmental footprint of electricity generation and delivery in the region; reduce energy dependence on foreign sources; enhance the grid's resilience to natural or manmade threats; provide customers with greater choice, convenience and value; mitigate risk; and ensure the provision of safe, reliable and secure electricity for its stakeholders.

In addition, SDG&E's strategy includes continued industry leadership in supporting General Order 156 with respect to including Diverse Business Enterprises (DBEs) in its supplier selection process. SDG&E has incorporated supplier diversity throughout all of its policies and procurement processes and has exceeded state targets for DBE spending and procurement, a trend it expects to continue with its Smart Grid Deployment Plan procurement practices.

Security is a priority impacting every component in SDG&E's Smart Grid Deployment Plan. Preventing or reducing physical and cyber security threats becomes more vital and complex in a Smart Grid; however, it also presents opportunities. With the new communications and control technologies for physical and cyber security, SDG&E anticipates the ability to integrate and correlate physical and cyber security monitoring and data to better protect grid assets and systems. SDG&E's Smart Grid security approach will begin at the earliest stages of system decision-making and design. It will also seek to prevent or isolate the impacts of any physical or cyber threats to one or multiple portions of the Smart Grid to maintain system reliability in the event of a threat.

Just as security is designed into Smart Grid systems and solutions, so too is privacy. SDG&E will ensure a robust approach to enterprise architecture and information modeling, leveraging the National Institute of Standards and Technology's (NIST) four dimensions of privacy as well as the seven "privacy by design" foundational principles as guidance for its privacy program.

SDG&E's deployment plan will also leverage open standards where possible to ensure interoperability and avoid stranded costs.

To build the capabilities required to realize Smart Grid benefits for customers and to meet the state's ambitious energy policy goals, SDG&E's portfolio of Smart Grid projects is structured around nine specific program areas:

1. **Customer Empowerment** – SDG&E is investing to ensure customers have the knowledge and necessary information to make informed energy management decisions to maximize their energy value and to support their access to third-party value-added services and offerings while protecting their privacy.

2. **Renewable Growth** – SDG&E is making Smart Grid investments that will mitigate the impact of distributed and other intermittent energy sources by increasing measurement, control, and management capabilities.

3. **Electric Vehicle Growth** – SDG&E is deploying new Smart Grid technologies in conjunction with traditional infrastructure upgrades to ensure the safe, reliable, and efficient integration of PEVs.

4. **Reliability and Safety** – SDG&E is maintaining and/or improving reliability by mitigating the challenges that intermittent resources and electric vehicles present to an aging electric infrastructure through implementation of advanced sensors and associated systems, and other capabilities that will improve employee and public safety.

5. **Security** – SDG&E is investing to address the increased physical and cyber security risks and threats associated with Smart Grid system design, development, implementation, and operations.

6. **Operational Efficiency** – SDG&E is leveraging existing and developing new capabilities to improve the efficiency of planning processes and system operations through remote monitoring and real-time responsiveness enabled by the deployment of advanced sensors and management systems.

7. **Smart Grid Research, Development and Demonstration (RD&D)** – SDG&E is improving its capabilities by researching new technologies, integrating emerging technology solutions, testing for interoperability and providing proof-of-concept demonstrations.

8. **Integrated and Cross-cutting Systems** – SDG&E is deploying systems in areas such as application platform development, data management and analytics and communications that support Smart Grid functionalities across multiple business units.

9. **Workforce Development** – SDG&E is investing to develop its current workforce and to transition to a future workforce that will meet the unique requirements of Smart Grid through implementation of effective organizational change management and workforce planning.

By applying an adaptive management strategy to the projects listed under each of these program areas, SDG&E expects to continually evolve its roadmap to leverage or respond to future technology breakthroughs, changing state and federal policies, shifting stakeholder priorities and other unanticipated events that the utility considers as a given over the coming 10-year period.

SDG&E has defined and included consensus metrics for its Smart Grid Deployment Plan, which permit the utility to benchmark and assess the progress achieved through its Smart Grid deployments. SDG&E plans to continue working with the California Public Utilities Commission, the Environmental Defense Fund, the other California Investor Owned Utilities (IOUs), interested parties and key stakeholders in the development and adoption of additional Smart Grid-related metrics.

SDG&E has identified, quantified, and monetized associated cost and benefit estimates for all of the projects in its nine Smart Grid program areas, including in-flight and planned roadmap projects. SDG&E will not request authorization for funding of projects that are not necessary to comply with policy unless the estimated benefits exceed the associated costs or where they are required to effectively communicate with the utility's customers.

SDG&E's analysis of the costs and benefits is intended to be as accurate as possible, given currently available information. However, due to the nascent state of much Smart Grid technology and the fact that actual deployment will be based on future events, lessons learned and pilots, these estimates are subject to change and are presented as conceptual for 2011-2015 and preliminary for 2016-2020. In addition, a range is provided to allow for more conservative cost and benefit scenarios. SDG&E will file supporting applications only when sufficiently precise estimates are available.

SDG&E's estimated cost of Smart Grid deployments for the years 2006 – 2020 described in this plan are approximately $3.5 to $3.6 billion and include previously authorized investments such as SDG&E's Smart Meter and OpEx 20/20 programs, Smart Grid projects included in its Test Year 2012 (TY2012) General Rate Case (GRC), other active applications such as SDG&E's proposed Demand Response and Dynamic Pricing projects, and estimated incremental investments, which are approximately 25 percent of the overall estimated costs.

The total benefits associated with the Smart Grid deployments discussed in this plan are estimated to be between $3.8 and $7.1 billion. This calculation includes estimated societal and environmental benefits of $760 million - $1.9 billion based on avoided emissions through the integration of renewable energy and PEVs as well as the estimated avoided fuel costs PEV owners realize by the successful integration of PEVs. They also include economic and reliability benefits of $3.0 - $5.1 billion resulting from previously authorized investments such as Smart Meter, TY2012 GRC and other active applications as well as incremental investments.

Because the majority of benefits derive from maintaining and/or improving reliability in the face of a more complex grid, avoided costs, reduction of commodity cost, environmental and other societal and "soft" benefits, they minimally reduce operating costs and so are not projected to significantly impact rates, although customers who leverage Smart Grid technologies and data will have the capabilities they need to manage and reduce their bills.

As with its cost estimations, SDG&E's economic and reliability benefits calculations extend back to 2006 to include the historical benefits realized from previously authorized Smart Grid projects. Because benefits will also accrue after 2020, SDG&E has included forecasted benefits based on the associated terminal value of its Smart Grid projects.

The SDG&E Smart Grid Deployment Plan is not a static document. Consistent with its Smart Grid vision, SDG&E intends to continue engaging with stakeholders in order to align its Smart Grid strategy to their priorities. The utility also plans to update its roadmap as its customers, stakeholders, available technologies, and services evolve; adopt new security strategies as new threats or best practices emerge; and adjust its cost and benefit estimates as its pilot and deployment experiences and new information bring greater certainty to anticipated inputs, timelines and outcomes.

ECO Substation

SDGE connected
A Sempra Energy utility

ECO Project Benefits:

- **Deliver renewable energy**
- **Reduce emissions and fossil fuel dependence**
- **Improve energy reliability**
- **Facilitate the creation of jobs**

Overview

Utilizing the vast potential for renewable energy development present in our region is vital. According to the National Renewable Energy Laboratory (NREL), portions of eastern San Diego County, Imperial County and Northern Baja California provide some of the best locations in the entire country to generate electricity from renewable resources, including the sun, wind and steam heat from the earth (geothermal power).

To best access this renewable energy and deliver it to local customers, we're developing the East County (ECO) Substation Project. Local renewable energy projects will have a connection point to the electric grid. The new substation project has four main components:

1. **Developing the ECO Substation –** This new, state-of-the-art substation will connect future wind farms and other renewable energy projects to the transmission system, allowing clean, emissions-free electricity to flow to local customers. The 58-acre substation will be located at 47317 Old Highway 80, Jacumba, between Interstate 8 and the U.S./Mexico Border.

2. **Linking ECO Substation with the existing Southwest Powerlink –** This tie-in will help get renewable energy to the San Diego region. Connecting to a major transmission line like the Southwest Powerlink will also provide a steady flow of reliable power to the local area.

3. **Rebuilding the Boulevard Substation –** We plan to rebuild and modernize the 50-year-old Boulevard Substation near Highway 80. Rebuilding this existing substation provides a connection point for several proposed wind projects, will improve energy reliability and minimize outages to local communities such as Jacumba, Boulevard and Campo.

4. **Connecting the two substations with a new 14 mile, 138 kilovolt power line –** This new power line will improve reliability of the local electric grid and transmit power from renewable energy projects to the Southwest Powerlink.

The ECO Substation Project will connect renewable energy facilities to the electric grid, like the wind turbines shown here.

Benefits

- **Delivering renewable energy –** The project will deliver clean power into the electric grid by connecting proposed renewable energy projects to the existing Southwest Powerlink transmission line. This project, together with the Sunrise Powerlink, will help us meet state requirements to produce 33% of our power from renewable sources by 2020.

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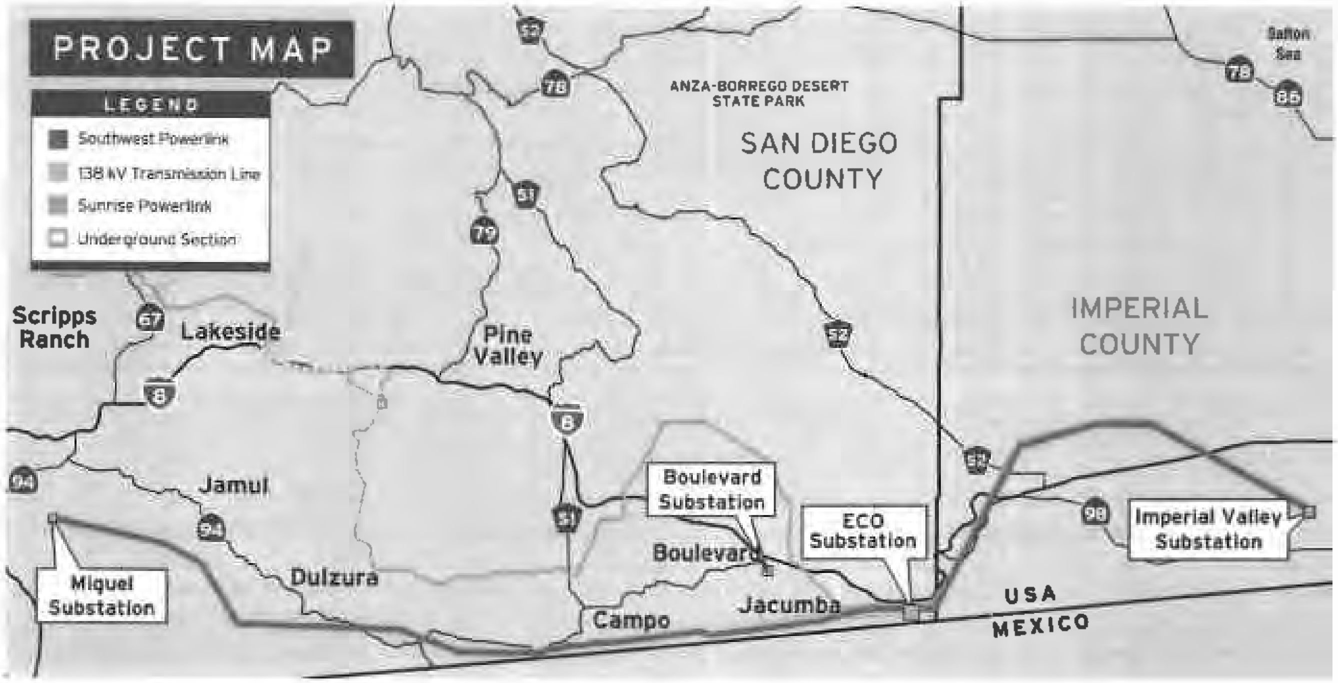

- **Reducing emissions and fossil fuel dependence –** By accessing locally sourced renewable energy, the new substation will help reduce the region's dependence on imported electricity generated from fossil fuels and cut greenhouse gas emissions. The ECO Substation will tap into the vast renewable energy potential of the San Diego/Imperial Valley/Baja California region and help the area become a national leader in clean energy development.
- **Improving energy reliability in rural eastern San Diego county –** Rebuilding the Boulevard Substation will improve electric grid reliability and reduce the potential for outages in local communities. The project will replace aging infrastructure and provide more direct access to reliable power in the area.
- **Creating jobs and boosting the local economy –** The ECO Substation project will create between 100 to 200 jobs over two years. In addition, the substation will facilitate the creation of hundreds, if not thousands, of "green" jobs at related renewable energy projects which need the ECO Substation Project to connect to the grid. It's also estimated that the project will inject approximately $36 million directly into the local economy through contracts for goods and services, and create tax revenue for local public agencies. These increases in employment and revenue will greatly benefit the region.

Permitting Update

The ECO Substation Project received two major regulatory approvals when the California Public Utilities Commission approved the project on June 21, 2012 and the U.S. Bureau of Land Management issued a Record of Decision for this vital electric infrastructure project on August 21, 2012.

Construction Schedule

Pre-construction of the ECO Substation Project commenced in the second quarter of 2013. The project is scheduled to come "online" in late Fall 2014.

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A Sempra Energy utility

SDG&E and SoCalGas
Grounded in Sustainability

- » **Sustainability – It's Key to our Culture**
- » **SDG&E and SoCalGas: Keys to Success**
  - Sustainable Collaborations
  - Innovation
  - Customers and Community
  - Grassroots Commitment
- » **SDG&E: Environmental Leadership**
- » **SoCalGas: Demonstration of Success**
- » **SDG&E and SoCalGas: Path Forward**

Sustainability – It's Key to our Culture

- » **Protecting the environment now and for the future while meeting today's business needs**

Financial

- Financially sound
- Strong operating results
- Listen > Plan > Act
- Prudent capital investment
- Strong governance

Social

- Safety focus
- Employee diversity
- Diverse Business Enterprise (DBE)
- Employee engagement
- Community stakeholder outreach
- Service reliability

Environmental

- Avoid or minimize impacts
- Leverage technology
- Cultivate innovation
- Focus on compliance
- Renewable energy

Sustainable Collaborations

» **Mutual success with our partners**

- SDG&E collaborated with agencies and other stakeholders to identify and acquire ~11,000 acres of desirable habitat that meets the environmental mitigation needs of the Sunrise Powerlink and benefits endangered and threatened species
- SoCalGas provided technical assistance to the Los Angeles County Metropolitan Transportation Authority (MTA) to support their transition from diesel fuel to CNG. Today, MTA fuels over 2,200 CNG buses at 11 CNG refueling stations, reducing GHG emissions and air pollution throughout the LA Basin

Innovation

» **Innovation is a key to all areas of Environmental Sustainability including:**

- Enterprise-wide Geographic Information Systems (GIS) for more efficient review of the environmental impacts of a project
- Operations-related technology
- Innovative outreach to community stakeholders
- Employee engagement

GIS Data Layers

Customers and Community

» **Grant programs and charitable giving**
  - Nearly $2 million donated to environmental organizations in 2011

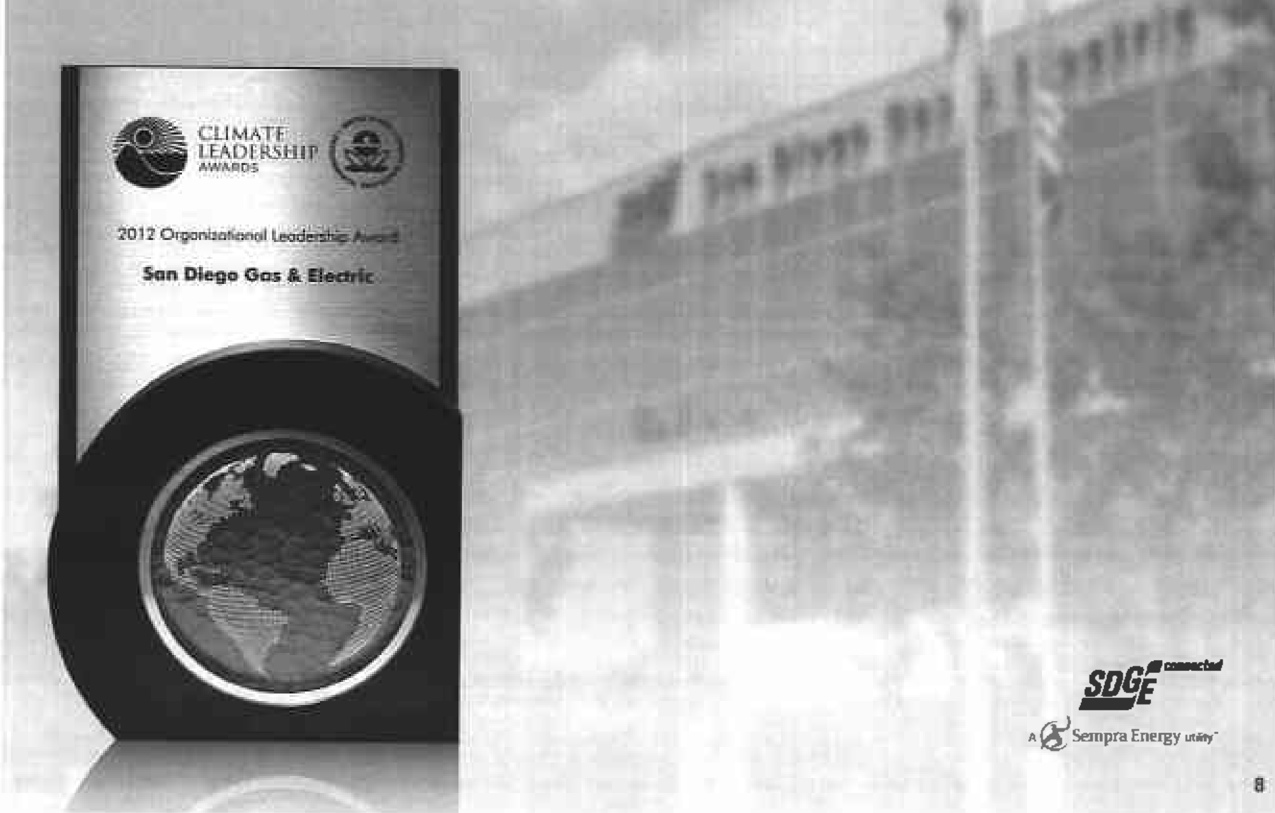
» **Connecting with our customers, including underserved communities**
  - 79% of our giving benefitted the underserved in 2011

» **Connecting with our customers through our energy centers**

Grassroots Commitment

» **Empowering employees ignites passion, inspires change, creates momentum**
  - Green Teams at both utilities initiate change at all levels
    - "Ban the Bottle", "Stamp out Styrofoam", "Stop the Stub"
    - Earth fairs, Photo contests, "Gathering of Green Teams"
  - Community Environmental Events: 22 in 2011
  - Employee-led initiatives
    - Filtered water saves over 200K bottles/year
    - Bill Click's initiative at SDG&E reduced substation landscape watering needs by >110 million gallons since 2006
    - Andy Linde's initiative at SoCalGas' Redlands facility created a walking track that reduces landscaping water and promotes health and well-being

Environmental Leadership

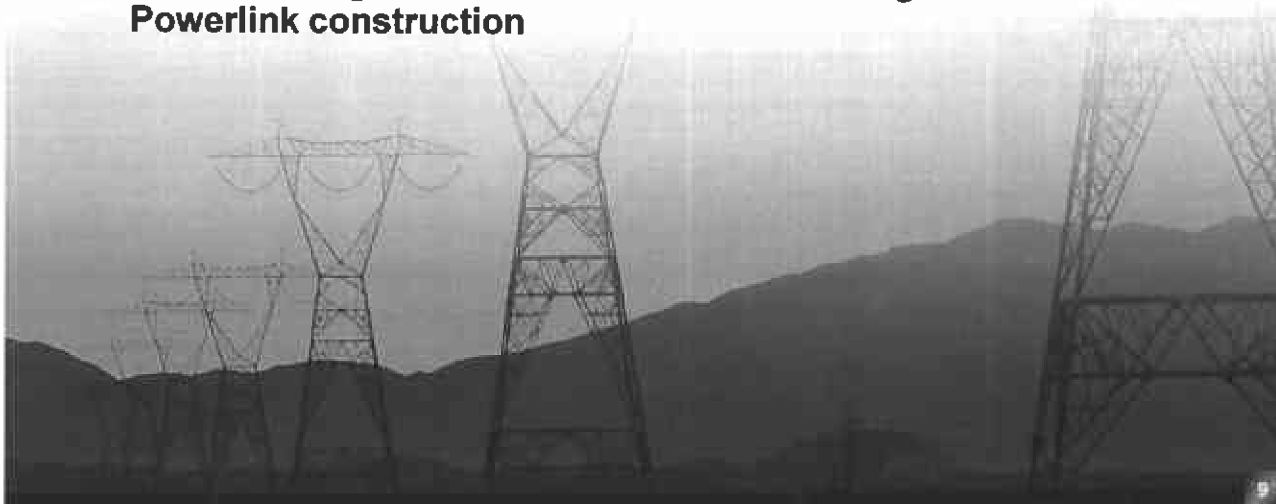


SDGE connected
A Sempra Energy utility

SDGE connected
A Sempra Energy utility

Building for the Future

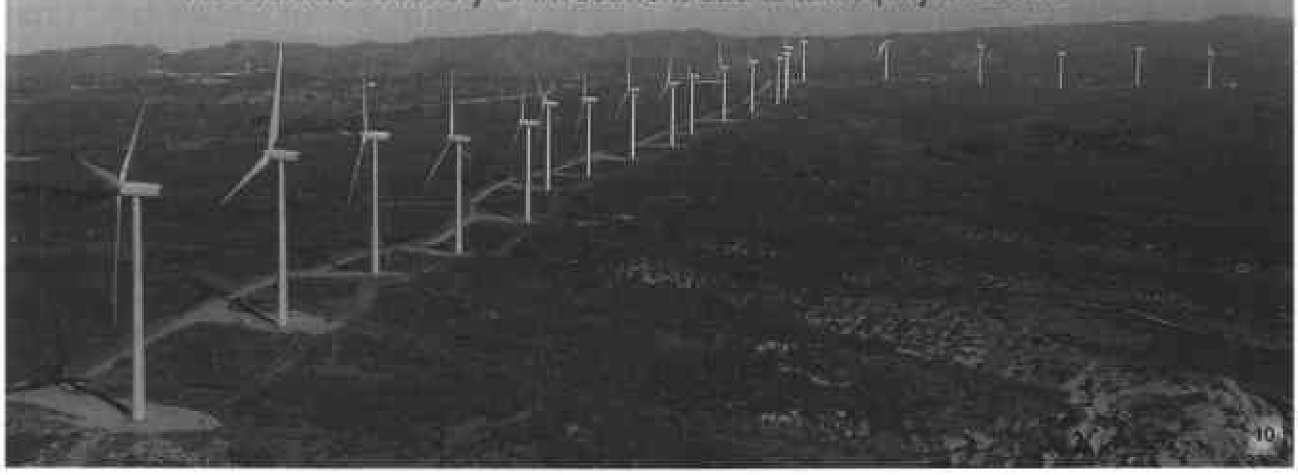
- **Reducing construction impacts: Sunrise Powerlink tower foundations**
  - Steel pile caps were installed in lieu of concrete footings on 234 towers: an industry first
  - Saved 17,900 tons of concrete and reduced helicopter flights by 11,900
- **Used 87,000 gallons of reclaimed water during Sunrise Powerlink construction**



Supporting Renewable Procurement

» **Smart Grid: Smart MicroGrid demonstration in Borrego**
- Utilizes advanced technologies to integrate and manage distributed resources within the Smart Grid

» **Regulated utility investment in wind power project in support of Federal energy policies**
- Reduces cost of wind power by passing through the benefits of renewable tax credits to customers
- Accelerates recovery of investment due to tax equity structure



Smart Technology for Savvy Customers

» **Best Energy App contest Co-Sponsor**
- XNERGY won for app that helps SDG&E customers to analyze their energy usage from SDG&E's Green Button tool

» **San Diego Energy Challenge**
- Launched an online game from SimpleEnergy so energy management is "Social, Fun and Simple"

- Kicked off summer contest so that customers can save energy and win money for their local school

Grounded in sustainability

SDGE connected
A Sempra Energy utility

Long-term Commitment to Preservation Lands

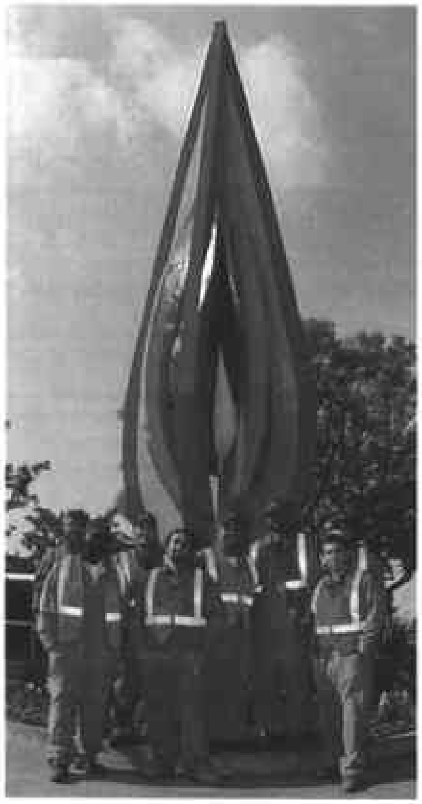
- **San Dieguito Lagoon and Wetlands: continuing engagement with SONGS Mitigation Project**
  - Funding buses for children in underserved communities to visit wetlands
  - Employee clean-up and planting event in 2011 at wetlands
- **Sunrise Powerlink Environmental Mitigation Properties: Planning for the Future**
  - Funded ~11,000 acres in total *(Or ten times the size of Golden Gate Park)*
  - Initiating an Advisory Council to provide ongoing stakeholder input on the properties

SDGE connected
A Sempra Energy utility

The Future is NOW...still more to do

- **Most Intelligent Utility in the U.S. Award: 3rd year in a row**
- **Best in the West Reliability: 6th year in a row**
- **Renewable Energy: 20% of sales in 2011, up from 1% in 2002**
- **Involved Employees: 2,300 participants in clean-up and planting events in 2011, planning for more in 2012**
- **Clean Transportation: 86% of sedans in Fleet are CNG, hybrid-electric or battery-electric... moving toward a cleaner future...**

Southern California Gas Company
A Sempra Energy utility



Demonstration of Success

- » **Ultra-Low Emissions Technology**
- » **Converting Natural Gas to Energy Using Fuel Cells**
- » **Leader in Renewable Technologies – Biogas**

Southern California Gas Company
A Sempra Energy utility

Ultra-Low Emissions Technology

- » **Fontana Wholesale Lumber (Fontana)**
  - Partnered with Continental Controls Corporation to create and install ultra-low emission control technology for gas engines
- » **Clean Energy Systems (Bakersfield)**
  - Developed the first natural gas-fueled zero emissions power plant demonstration facility in Bakersfield

Converting Natural Gas to Energy Using Fuel Cells

» **Fuel cell research and demonstrations**
- SoCalGas is co-founder of the National Fuel Cell Research Center at the University of California, Irvine

» **Constellation Place, Century City (Los Angeles)**
- First high-rise building in LA to be served by electricity-generating fuel cells, reducing carbon footprint by 30%

» **Roger's Gardens (Corona Del Mar)**
- ClearEdge fuel cell systems (5kW) supply electricity and heat for the seven-acre facility and reduce carbon footprint by 41%

Leader in Renewable Technologies - Biogas

» **Enertech Environmental's SlurryCarb (Rialto)**
- Biosludge from wastewater plants is moved through a centrifuge to create biopellets for rotary kilns at a cement company

» **Gills Onions' waste-to-energy Project (Oxnard)**
- Converts onion waste to biogas that powers fuel cells

» **Hale Avenue Resource Recovery Facility (Escondido)**
- Converts raw biogas, a byproduct of sewage treatment, and purifies the methane to pipeline quality for potential injection into the natural gas system

» **Point Loma Wastewater Treatment Facility (San Diego)**
- Conditions raw biogas for pipeline injection

CALIFORNIA ENERGY COMMISSION 2012 ACCOMPLISHMENTS

Leading statewide energy policy

■ The California Energy Commission's *2012 Integrated Energy Policy Report (IEPR) Update* provides practical recommendations to address the many complicated energy policy issues facing California. The 2012 IEPR Update includes a renewable energy action plan, a 10-year electricity and natural gas demand forecast, and an analysis of natural gas market outlook and trends.

■ The State's third major assessment on climate change featured more than 20 scientific papers funded by Energy Commission Public Interest Energy Research (PIER) grants. The studies, which describe local and statewide risks and suggest concrete options for action, provided the basis for the California Natural Resources *Agency's California Climate Adaptation Strategy, 2012 Update*.

Improving energy efficiency for California's homes and businesses

■ The Energy Commission's 2013 Building Energy Efficiency Standards will save Californians $1.6 billion in energy costs over the next 30 years. The standards, adopted in May, are 25 percent more energy efficient than previous standards for residential construction and 30 percent better for nonresidential construction. For a single-family home with a 30-year mortgage, the standards will return more than $6,200 in energy savings on a homeowner's $2,300 investment. The standards ensure that better windows, insulation, lighting, ventilation systems, and other features that reduce energy consumption are installed in homes and businesses. Since 1975, the Energy Commission's building energy efficiency standards (Title 24) have saved California consumers over $30 billion.

Adopting first-in-the-nation efficiency standards for battery chargers

■ New energy efficiency standards approved in January will reduce wasted energy by battery chargers commonly used to power cell phones, laptop computers, power tools, and other devices, saving nearly 2,200 gigawatt-hours each year – enough energy to power nearly 350,000 homes or a city roughly the size of Bakersfield. After energy efficient battery charger systems replace older inefficient chargers, the standards will save California ratepayers more than $300 million annually and eliminate one million metric tons of carbon emissions. Since 1975, the Energy Commission's appliance energy efficiency standards (Title 20) have saved California consumers nearly $37 billion.

Enforcing appliance standards to save Californians energy and money

■ The Energy Commission validated and published more than 19,000 new certified appliance listings as a part of its program to ensure that all regulated appliances sold in California meet State and federal energy and water efficiency standards. Keeping inefficient and wasteful appliances out of the California market saves California consumers money through reduced energy bills and reduces statewide electricity demand by an estimated 18,000 gigawatt-hours annually.

Addressing California's environmental and energy future through American Recovery and Reinvestment Act (ARRA) funds

Through 2012:

- The Commission's State Energy Program (SEP) Energy Conservation Assistance Act program made $20 million in low-interest loans for 33 projects to improve the energy efficiency of public buildings. These projects will save ratepayers $2.3 million in energy costs each year, reduce annual energy demand by 16,681 megawatt hours and eliminate nearly 5,600 tons of carbon dioxide emissions annually.

- The Commission's State Energy Program Clean Energy Business Financing Program made $18 million in loans to four solar panel manufacturing companies, attracting new in-state manufacturing facilities and expanding existing ones while keeping or creating more than 175 California jobs.

- The Commission Energy Efficiency and Conservation Block Grant Program provided more than $29 million to 260 small California cities and counties to support energy efficiency retrofits, building upgrades, lighting retrofits, and clean energy systems. These projects will save Californians more than $4 million in energy costs each year, reduce annual energy demand by nearly 31,000 megawatt hours and eliminate more than 11,500 tons carbon dioxide emissions every year.

- The Commission's Energy Assurance Planning Initiative provided technical assistance to 23 local jurisdictions to create new emergency preparedness plans and improve existing ones, and to ensure regional electricity grid resiliency.

Transforming vehicle technology

■ The Energy Commission's Alternative and Renewable Fuel and Vehicle Technology Program (ARFVTP) invested in next generation alternative and renewable fuels, advanced technology low and zero emission cars and trucks, electric vehicle manufacturing, and alternative fueling infrastructure for electric vehicles and hydrogen fuel cell vehicles, to support a strong California manufacturing base, develop a skilled workforce, reduce California's reliance on petroleum-based fuels, improve air quality, and reduce greenhouse gas emissions.

■ The ARFVTP awarded $147.8 million to 91 projects in 2012. This investment leveraged nearly $265 million in private and public sector matching funds. Investments included:

- $90 million to support the development and commercialization of alternative and renewable fuels, alternative fuel infrastructure, and advanced vehicle technologies.
- Nearly $27 million in new grants for commercial scale biogas, bio/renewable diesel, and first round awards for ethanol produced from woody materials, or cellulosic ethanol. All of these biofuels projects use non-food materials such as agricultural, municipal and food-processing waste, algae and non-food-crop beets, rather than food crops such as corn or soybeans.
- More than $20 million to assist in the development of approximately 5,200 electric charging stations statewide, supporting the emerging plug-in electric vehicle (PEV) market. The Energy Commission also awarded about $2 million to help local governments across California plan for more plug-in electric vehicles. These projects help fulfill Governor Brown's Zero Emission Vehicle Executive Order, which set a target of 1 million PEVs by 2020, and 1.5 million PEVs by 2025.
- $22 million in zero emission, advanced technology truck projects, including electric drive, heavy-duty goods movement trucks, and electric drive shuttles and transit.
- $10 million to support a California vehicle manufacturing facility expected to create more than 500 new manufacturing jobs in California.
- A demonstration project of battery-powered heavy-duty trucks that can haul loads up to 80,000 pounds and will cut pollution at busy Los Angeles County ports.

- A project to develop an advanced electric motorcycle power train and establish its pilot scale production line.

- Buy-down incentive reservations for approximately 850 alternative and renewable fuel vehicles on California roadways, from school buses fueled by propane to trucks fueled by natural gas.

- An anaerobic digester project in south Sacramento that is the nation's largest facility converting food waste into renewable natural gas and electricity.

Improving reliability by adding new clean generation to the grid

- The Energy Commission oversaw the construction of seven natural gas-fired plants totaling 4,034 megawatts and three solar thermal projects totaling 870 megawatts.

- The Commission licensed three new natural gas-fired power plant projects totaling 943 megawatts.

- The Commission also initiated the licensing process for two solar thermal power plants totaling 1,000 megawatts and four natural gas-fired plants totaling 1,835 megawatts.

- The Commission worked closely with the California Public Utilities Commission, the California Independent System Operator, and others to make sure the San Diego region had a reliable supply of electricity in 2012 despite the loss of over 2,000 megawatts of generation caused by the outage of the San Onofre Nuclear Generating Station.

Generating green jobs and a skilled workforce

■ ARFVTP grant recipients reported that the funding they received created more than 5,000 short- and long-term jobs.

■ More than 500 contractors and certified raters participated in the Energy Upgrade California program.

■ Through 2012, ARRA investments provided job skills training for more than 8,200 unemployed and underemployed Californians, who learned how to perform energy audits, install solar photovoltaic systems, build large-scale renewable power plants, and make Leadership in Energy and Environmental Design certification determinations.

Protecting the desert while developing renewable energy

■ The Energy Commission led an unprecedented collaboration of public and private groups working to create the Desert Renewable Energy Conservation Plan (DRECP). Working with the California Department of Fish and Wildlife, the U.S. Bureau of Land Management, and the U.S. Fish and Wildlife Service, the Energy Commission is developing guidelines to identify areas suitable for renewable energy projects and transmission corridors, while developing long-term natural resource conservation areas that protect fragile desert ecosystems.

■ In December, State and federal agencies released an interim document called the *Description and Comparative Evaluation of Draft DRECP Alternatives* to allow stakeholders another opportunity to review the plan and provide input before the publication of the Draft Environmental Impact Report/Environmental Impact Statement.

■ The Commission signed Memorandums of Understanding with Imperial and San Bernardino counties to form cooperative relationships to effectively plan for and promote renewable energy development in California.

Funding cutting-edge energy research

■ The Energy Commission's Research and Development program awarded $63.7 million to 59 projects designed to improve California's energy system; these awards were matched by more than $303 million in federal and private funds.

■ Automated demand response technologies funded by the Research and Development program saved California ratepayers an estimated $12 million in electricity costs. Demand response cuts customers' energy bills while protecting grid reliability.

■ The Research and Development program funded projects to demonstrate that wireless cooling controls reduce data center cooling costs. The controls saved ratepayers an estimated $1.7 million in 2012. As data center cooling technologies are optimized and wireless automation spreads, these savings are expected to increase.

Advancing clean energy innovation

■ The Energy Commission developed and submitted the Electric Program Investment Charge (EPIC). The $368.7 million 2012–14 plan promotes the development of next generation clean energy technologies. These investments funds will be directed over the next three years to critical funding gaps in the energy innovation pipeline and will provide California's electricity ratepayers safer, cleaner, more reliable, and less costly electricity.

Establishing a quality specification for light-emitting diode (LED) lamps

■ The Energy Commission developed a voluntary performance specification for LED lamps, to ensure that the lamps will meet consumer expectations. The specification will lead to the production of high-quality lamps that will encourage consumers to switch from the inefficient incandescent lighting of the past century to more cost- and energy-efficient LED lighting technology.

Implementing the aggressive Renewables Portfolio Standard

■ The Renewables Portfolio Standard (RPS) requires California utilities to procure 33 percent of their electricity from renewable energy sources within the next eight years. To support RPS targets, the Energy Commission is required to certify a renewable facility as RPS-eligible before its electricity can be included in meeting a utility's RPS obligations. In 2012, the Energy Commission pre-certified and certified 353 renewable energy facilities for a total of 3,762 megawatts in generating capacity.

The Clean Energy Race: How Do California's Public Utilities Measure Up?

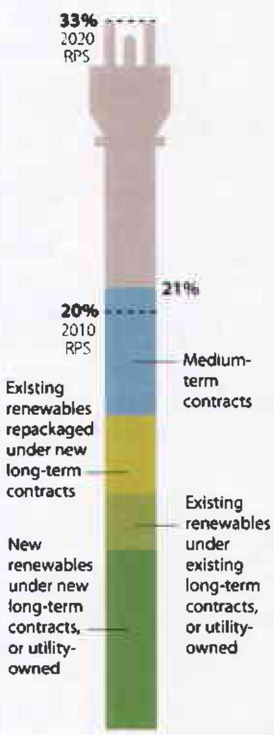
California's local publicly owned utilities, which supply about a quarter of the electricity used in the state, have made significant strides in investing in clean, renewable energy since the state passed its first renewable energy purchase law in 2002. The Renewables Portfolio Standard (RPS) was enacted to help California transition away from polluting fossil fuels and invest in electricity generation from renewable sources such as the wind and sun, in order to improve air quality, reduce global warming pollution, and expand the state's green economy. The original RPS set a goal for each California utility to obtain 20 percent of its electricity sales from renewable sources by 2010. In 2011, the law was strengthened to require all utilities to obtain 33 percent from renewables by 2020.

Not All Investments in Renewable Electricity Are Created Equal

While a utility can take many approaches to procuring renewable energy, direct ownership and long-term contracts best support the development of new resources by providing financial security to developers. These long-term investments also lock in stable electricity prices for customers and help put a utility on track to meet the 33 percent RPS.

We evaluated the renewable energy investments made by California's 10 largest publicly owned utilities. We then classified each utility into one of three categories: "sprinting ahead," "on the right track, but must keep moving," or "false start," based on how much it has promoted the development of new sources of renewable energy, and whether it is on track to meet the 33 percent RPS.

SMUD's 2010 RPS Investments



SMUD'S RPS PROGRAM

On the Right Track, but Must Keep Moving

SMUD was an early investor in wind and solar energy, and exceeded the state's RPS goal in 2010. However, many of the utility's investments were relatively short in length, and so provided little support for new renewables and must be renewed or replaced for future RPS compliance.

By 2010, SMUD sourced 21 percent of its retail electricity sales from RPS renewables. The utility also made long-term investments in new renewable energy projects equivalent to another 2 percent of sales through its voluntary green pricing program. However, SMUD obtained 30 percent through contracts of eight years. Most of these contracts, if not renewed, will expire before 2020.

Sacramento Municipal Utility District (SMUD)

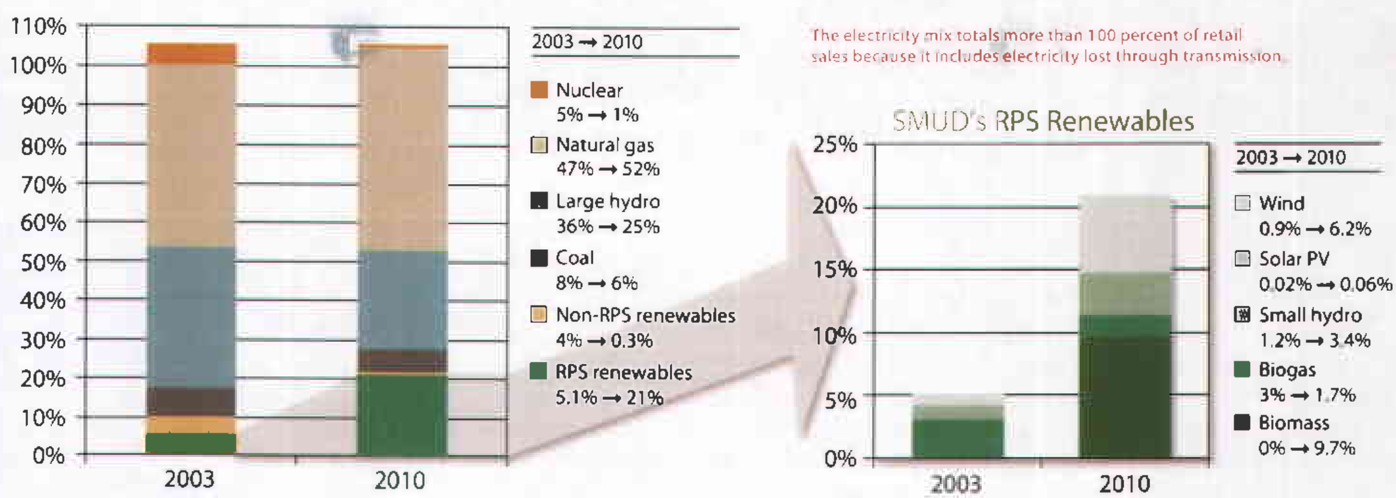
SMUD is the second-largest publicly owned utility in California, and the sixth-largest in the country. SMUD was established in 1923, and began delivering electricity in 1946. Today it provides electricity to most of Sacramento County, and small portions of Placer and Yolo Counties.

FAST FACTS

- Customers served: 600,000
- RPS renewables in 2003: 5.1%
- RPS renewables in 2010: 21.0%

Photos: © Thinkstock/Jan Wachala (wind); © Thinkstock/Daniel Grill (solar); © Flickr/Patrick Dirden (turbines in field)

SMUD's Electricity Mix, 2003 and 2010



What's Powering SMUD?

In 2003, SMUD relied on "unspecified" market purchases—purchases from other utilities, power traders, and the electricity spot market containing a mix of resources—for just under half of its electricity. The utility generated a quarter of its electricity from its own natural gas plants. SMUD's Upper American River Project and federally owned large hydropower facilities contributed another 25 percent of electricity sales. The utility relied on a mix of renewables for the remaining 5.1 percent.

By 2010, SMUD had built the Cosumnes natural gas plant, which delivered 29 percent of the utility's electricity needs. In total, SMUD relied on natural gas to supply 52 percent of total sales. From 2003 to 2010, SMUD quadrupled its renewables to 21 percent of retail electricity sales. These investments replaced "unspecified" power purchases, which declined to 17 percent in 2010.

SMUD's Renewables

SMUD built the nation's first utility-scale photovoltaic (PV) solar array in 1984, at Rancho Seco, the site of its closed nuclear facility. A decade later, SMUD built wind turbines on land it purchased in Solano County that now hosts 230 megawatts of capacity. By 2003, SMUD sourced 5.1 percent of its electricity from renewables. In addition to its early investments in solar and wind energy, SMUD procured electricity from an existing wood-waste biomass plant in Washington, its own small hydropower facilities, biogas from two local landfills, and two other wind projects that came online in 2003.

SMUD built the nation's first utility-scale PV solar array in 1984, at the site of its closed nuclear facility. A decade later, SMUD built wind turbines on land it purchased in Solano County that now hosts 230 MW of generation capacity.

© Clean Energy Ltd./Alex Marshall

By 2010, SMUD was procuring 21 percent of its retail electricity sales from RPS renewables. From 2003 to 2010, SMUD signed additional contracts with existing small hydropower, biomass facilities in Washington and Idaho, existing small hydropower facilities in California, and biogas from two in-state landfills and a local dairy manure digester. The utility also invested in solar PV through its SolarShares program and the first installations under its feed-in tariff program.[1]

SMUD obtained 30 percent of its 2010 RPS mix through eight-year contracts. Most

1 SMUD's SolarShares program allows customers who cannot install solar on their roofs to invest in solar PV elsewhere and receive credit on their electricity bills for the energy those arrays produce. Of the 10 POUs we reviewed, SMUD is the only one to offer such a program.

of these brought electricity into the state temporarily from existing small hydropower and wood-waste biomass plants in Washington and Idaho. SMUD also purchased a 15-year contract for injected landfill gas from Shell Energy, collected at the McCommas Bluff landfill in Texas. The RPS-eligible electricity associated with this contract is generated at SMUD's Consumnes natural gas power plant. This contract comprised approximately 9 percent of SMUD's 2010 RPS mix. The CEC is currently reassessing how to treat the eligibility of injected landfill gas contracts for the RPS.

SMUD obtained another 37 percent of its 2010 RPS mix through 10- and 12-year contracts with out-of-state wood-waste biomass, local landfill biogas, and in-state small hydropower facilities. This group of contracts also included the 2003 contract with the High Winds wind facility in Solano County.

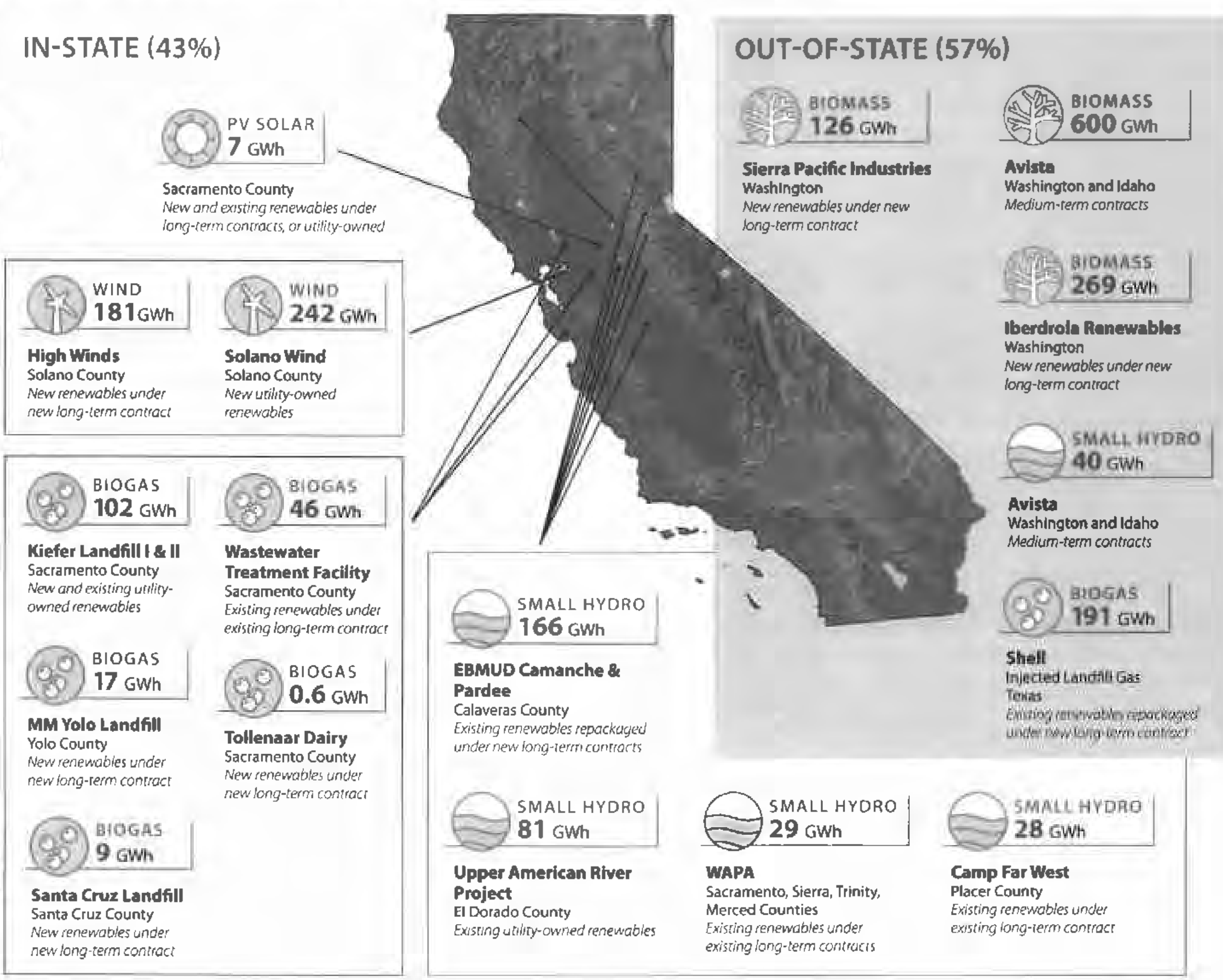
SMUD obtained just over a third of its 2010 RPS mix through longer-term investments. These include the Solano wind project; a variety of small, in-state hydropower facilities, some owned by SMUD; in-state landfill biogas units; and solar PV through SMUD's various programs and investments.

Most utilities offer voluntary green pricing programs that allow customers to purchase renewable energy at a premium. In most cases, these programs make REC-only purchases on behalf of their customers. SMUD is the only utility we reviewed that made long-term investments for new renewable energy projects as a part of its voluntary green pricing program, called Greenergy. These long-term investments, which otherwise could have been used for SMUD's RPS program, contributed approximately another 2 percent of electricity sales.[2]

SMUD obtained 30 percent of its 2010 RPS mix through eight-year contracts. Most of these brought electricity into the state temporarily from existing small hydropower and biomass plants in Washington and Idaho.

2 By the end of 2010, SMUD's Greenergy program contributed 3.8 percent of its retail electricity sales. Approximately half of this came from REC-only purchases and half from long-term contracts for new renewable energy facilities.

Sources of SMUD's RPS Renewables, 2010



© Flickr/ATIS547

Looking Ahead to 33 Percent

The 33 percent RPS law requires each utility to procure 20 percent of its retail electricity sales from renewables by 2013, 25 percent by 2016, and 33 percent by 2020. Each utility must also make "reasonable progress" on renewable energy investments between those deadlines. If the state is to transition to a clean, safe, and sustainable electricity system, utilities must meet these standards in a way that prepares them to move well beyond the 33 percent RPS.

In 2010, SMUD's renewable energy portfolio was diverse, but its contracts were relatively short in length. Nearly 70 percent of SMUD's investments were for 12 years or less and 30 percent were for eight years or less. The utility will need to renew these contracts or sign new ones just to maintain its level of RPS renewables, let alone reach 33 percent. In addition, less than half of SMUD's investments for its 2010 RPS program were comprised of long-term commitments for new renewable energy facilities.

Since 2010, SMUD has more than doubled the generation capacity at its Solano Wind facility. The utility is also expanding the generating capacity of a local wastewater treatment plant, and expects to receive electricity from new solar PV projects through its feed-in tariff program. This additional electricity generation is expected to increase SMUD's RPS mix by another 6 percent of retail sales.

If the state is to transition to a clean, safe, and sustainable electricity system, utilities must meet these standards in a way that prepares them to move well beyond the 33 percent RPS.

Tracking Future Progress

SMUD's RPS Procurement Plan will provide details on the utility's strategy for reaching the 33 percent RPS by 2020. The utility's board of directors must approve this plan and make it available to the public. Any changes to this plan trigger a 10-day public notice that must be posted on the website of the California Energy Commission (CEC): *http://www.energy.ca.gov/portfolio/rps_pou_reports.html.* The CEC also maintains a database of contracts executed to meet the RPS, available on the same website. More information on SMUD's renewable energy programs is also available at *https://www.smud.org.*

Upper American River Project: © Trout Unlimited

Union of Concerned Scientists
Citizens and Scientists for Environmental Solutions

The Union of Concerned Scientists is the leading science-based nonprofit working for a healthy environment and a safer world.

The full report can be downloaded (in PDF format) from *www.ucsusa.org/cleanenergyrace.*

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California ISO

Shaping a Renewed Future

COMPANY INFORMATION AND FACTS

California Independent System Operator Corporation

GUARDIAN
of the grid

The California Independent System Operator Corporation

The ISO manages the flow of electricity across the high-voltage, long-distance power lines that make up 80 percent of California's power grid. The nonprofit public benefit corporation safeguards the economy and well-being of 30 million Californians by "keeping the lights" on 24/7.

As the main grid operator for California, the ISO grants equal access to 25,865 circuit miles of power lines and reduces barriers to diverse resources competing to bring power to customers. It also facilatates a competetive wholesale power market designed to diversify resources and lower prices.

Every five minutes, the ISO forecasts electrical demand, accounts for operating reserves and dispatches the lowest cost power plant unit to meet demand while ensuring enough transmission capacity is available to deliver the power.

The ISO opened its Northern and Southern California control centers in 1998 when the state restructured its wholesale electricity industry. While utilities still own transmission assets, the ISO acts as a traffic controller by routing electrons, maximizing the use of the transmission system and its generation resources, and supervising maintenance of the lines. As the nerve center for the California power grid, the ISO matches buyers and sellers of electricity, facilitating nearly 27,000 market transactions every day to ensure enough power is on hand to meet demand.

POWER FACT

The ISO keeps a pulse on about **59,000 megawatts** of capacity from nearly **1,400 power plant** units connected to **25,627 circuit miles** of transmission lines serving the electricity needs of **30 million** Californians

The ROLE of the California ISO

California's electricity industry includes traditional utilities, private power plant owners and state and federal agencies, each playing a unique role. The ISO is charged with ensuring the safe and reliable transportation of electricity on the "electron superhighway" we know as the power grid. As the impartial grid operator, it has no financial interest in any market segment and makes sure diverse resources have equal access to the transmission network and markets used to fine-tune the flow of electricity.

ISO Market Offers:

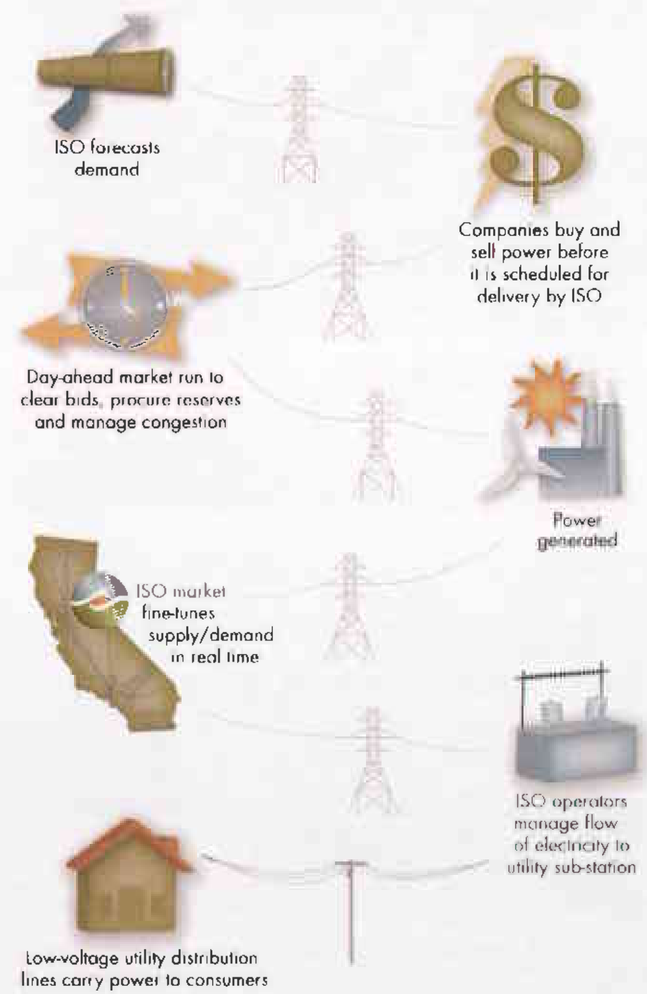
A full network model that analyzes generation and transmission schedules submitted a day in advance to better manage or avoid real-time bottlenecks.

An **integrated forward market** that provides a one-stop shop for trading and analyzing the electricity bids, transmission capacity and reserves needed to keep the grid in balance.

Locational marginal pricing that creates a highly transparent system that prices electricity based on the cost of generating and delivering it.

How power FLOWS in California

The California ISO network is a long-distance, high-voltage transmission system that delivers wholesale electricity to local utilities for distribution to 30 million Californians. The ISO grid is one of the largest in the world, encompassing three quarters of the state and delivering almost 300 million megawatt-hours of electricity each year.



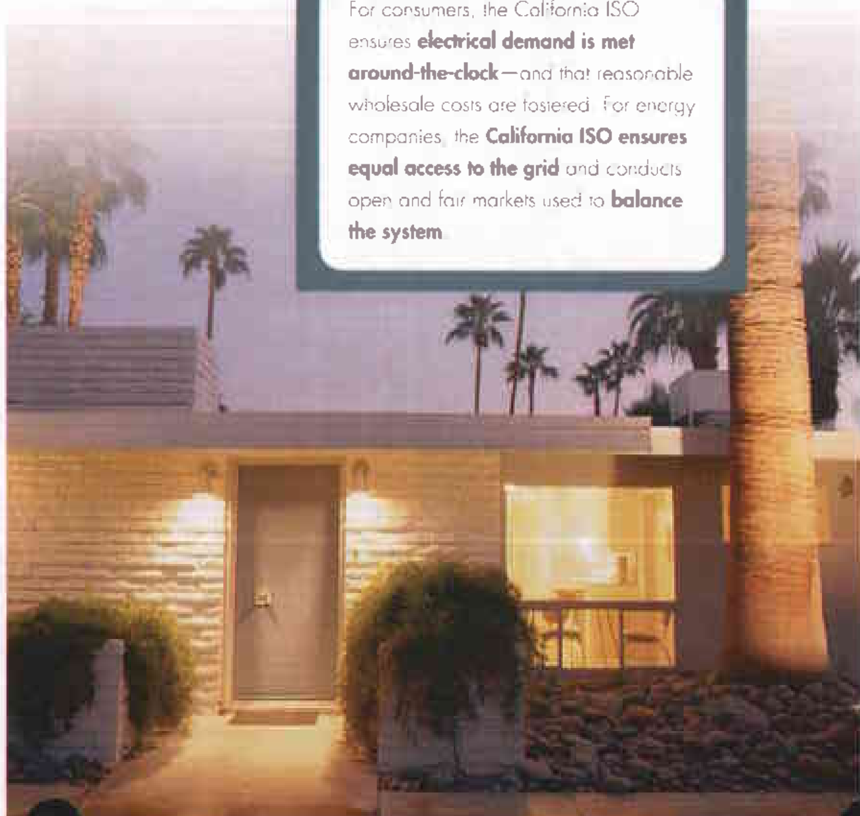
Competition brings
TRANSPARENCY

More than one hundred electric transmission companies and generators participate in the ISO market, which is used to allocate transmission space, maintain operating reserves and match supply with demand.

Another central function of the ISO is to provide transparent information about the state of the system and prices. This information helps market participants assess the economics and manage the risks of wholesale power transactions and supply options. Timely and accurate information about wholesale markets is the centerpiece of an effective and competitive marketplace. At the same time, economists within the ISO Department of Market Monitoring keep a close eye on market activity, reviewing wholesale prices and policing potential instances of market power abuse.

POWER FACT

For consumers, the California ISO ensures **electrical demand is met around-the-clock**—and that reasonable wholesale costs are fostered. For energy companies, the **California ISO ensures equal access to the grid** and conducts open and fair markets used to **balance the system**.



The ISO
GRID

The California ISO manages the flow of electricity for about 80 percent of California, which encompasses all of the investor-owned utility territories and some municipal utility service areas. There are some pockets of California where local public power companies manage their own transmission systems.

The ISO is the largest of about 40 balancing authorities in the western interconnection, handling an estimated 35 percent of the electric load in the West. A balancing authority is an entity responsible for operating a transmission control area. It matches generation with load and maintains electric frequency of the grid no matter what extreme weather or natural disasters California may face.

ISO
HISTORY

Before the establishment of independent transmission operators, electricity was a matter of local concern and was regulated strictly at the state level. The technology simply wasn't there to move electricity over great distances, which required power plants to be located close to customers. For this reason, the industry operated for years as a monopoly with one local utility providing generation, transmission and distribution services for its area. When technology evolved to provide the ability to move electrons over many miles, plants could be located away from consumers and the introduction of competitive markets became viable.

> **POWER FACT**
>
> Today, **competitive wholesale power grids are managed** by entities called **independent system operators (ISOs)** or **regional transmission organizations (RTOs)**

Independent system operators and regional transmission organizations, virtually unknown to most, were created following the 1992 passage of the Federal Energy Policy Act, which introduced competition to the wholesale side of the electricity business.

Upon implementing the act, federal policymakers recognized the need for an independent entity without a stake in the outcome to manage the power grid and make sure competitive generation flows to customers.

ISOs and RTOs are often compared to air traffic controllers. It would be grossly unfair for air traffic controllers to represent one air carrier and profit from allowing its planes to take off before others. In the same way, ISOs and RTOs operate independently—managing the electron traffic on a power grid they do not own—making sure companies can get their electricity safely delivered to utilities and consumers on time and reliably.

Opening
ACCESS

The California ISO is one of nine independent system operators in North America. Collectively, they deliver 2.2 million gigawatt-hours of electricity each year and oversee more than 270,000 miles of high-voltage power lines. Two-thirds of the United States is served by these independent grid operators.

Studies confirm that organized wholesale competitive energy markets improve grid reliability, optimize use of the transmission system, lower wholesale prices, improve power plant availability, and reduce market barriers for clean energy resources and demand response providers.

CONTROL
center

Grid reliability is a 24-hours-a-day job requiring California ISO operators to assess the status of the transmission system at all times. The ISO operates two control centers, with the main headquarters in Folsom and a second control room in Alhambra. The Folsom headquarters houses one of the most modern control centers in the world. The second center in Southern California is a fully-functioning facility that is ready to assume control of the grid within minutes.

Advanced grid technology is now at the fingertips of ISO operators as they manage the transmission system and the competitive power market. Robust systems provide increased reliability and efficiency, readying the ISO to respond to the most challenging conditions that includes sudden changes in electrical demand, power plant disruptions or fast-moving fires and other natural disasters. The ISO main control center hosts the first renewables dispatch desk in the country, showing the commitment the ISO is making to use green power reliably and efficiently.

HIGH-TECH
control centers

High-tech visual displays dominate the control centers in Folsom and Alhambra. These video display systems allow operators to assimilate large volumes of information at a glance.

- **Advanced features** include enhanced visualization capabilities, high-tech work consoles, a modern computerized energy management system and synchrophasor technology that reads the power grid every 33 milliseconds rather than using the former industry standard of every four seconds.
- **High-Tech tools** focus on fast start up of power plants, voltage stability, renewable forecasting, congestion management and reliability. Computer systems provide this information with pictures rather than thousands of individual data points.
- **The Energy Management System** is the most advanced in the industry, providing the latest application software on the newest server hardware. This increases performance, capacity, and automation functions.
- **Ten visualization screens** display information from Google Earth and other applications spanning an 80' wide x 6.5' high video wall at the Folsom headquarters with a slightly smaller wall of the same screens in Alhambra. These screens serve a crucial need as the ISO integrates thousands of megawatts of green power onto the grid. The enhanced visibility improves wind and solar performance forecasting as well as advance weather prediction to anticipate consumer demand on the grid.

1 Enhanced Reliability

Because they span large geographic areas, regional markets optimize the power grid by promoting efficiency through resource sharing. These organized markets are designed so that an area with surplus electricity can benefit by sharing megawatts with another region via the open market. This allows them to see the big picture when it comes to dispatching electricity as efficiently as possible. By maximizing megawatts as the demand for electricity increases, ISOs/RTOs help "keep the lights on" during peak periods.

2 Efficient Grid Dispatch

Through the use of advanced technologies and market-driven incentives, the performance of power plants within regional markets tends to be better than in areas under monopoly control. Evidence indicates there are lower power plant outage rates within competitive market regions because generation owners are motivated to keep plants on line, especially during peak periods, to maximize their revenues.

3 Better Price Transparency

ISOs/RTOs are better equipped to identify transmission bottlenecks, analyze reliability and evaluate the economic benefits of investing in additional transmission in an unbiased manner. In monopoly-controlled markets, consumers and investors are faced with a "black box" regarding information about prices and locational value of transmission, which inhibits investment in the power grid. In contrast, competitive markets have seen billions spent to strengthen the power grid.

4 Ease of Entry and Private Investment

ISOs/RTOs develop standardized non-discriminatory rules for grid interconnection and provide important price signals for new investment. As grid planners, they provide the mechanisms for identifying the most economic solutions to transmission issues across a large footprint. ISOs and RTOs provide greater access to the infrastructure investment necessary to keep up with the growing demand for electricity in the United States.

5 Green Power Added to Grid

ISOs and RTOs level the playing field for diverse types of power plants to compete to bring the lowest cost electricity to consumers. Whether it is ensuring non-discriminatory access to high-voltage power lines or creating markets that open doors to renewable power, ISOs and RTOs are seeing robust investment in environmentally-friendly power generation in their regions.

Why ISOs/RTOs are GOOD for America

6 Market Monitoring Benefits

ISO and RTO market monitors play an important role in enhancing the performance of competitive wholesale electric markets. Competitive markets benefit customers by assuring that prices properly reflect supply and demand conditions. Market monitors identify ineffective market rules and tariff provisions, identify potential anticompetitive behavior by market participants and provide the comprehensive market analysis critical for informed policy decision-making.

7 Market Flexibility

Organized markets offer diverse power products and services that can be used to hedge against price risks. Because average real-time energy prices correlate to short-term forward bilateral prices, ISO and RTO markets foster forward contracting that can stabilize prices. More and better price transparency means better contract pricing.

8 Liquidity in the Marketplace

ISO and RTO markets have more buyers and sellers than non-competitive markets. For instance, hundreds of companies are now vying for customers. Prior to restructuring, only a handful of companies were competing to bring the lowest cost power to consumers.

9 Market Diversity

Regions with organized wholesale markets have numerous buyers and sellers, but generator ownership is more concentrated in non-competitive regions. Formalized markets are able to monitor for the exercise of market power abuse and address market power through mitigation rules, recommending new operating procedures or proposing market structure changes.

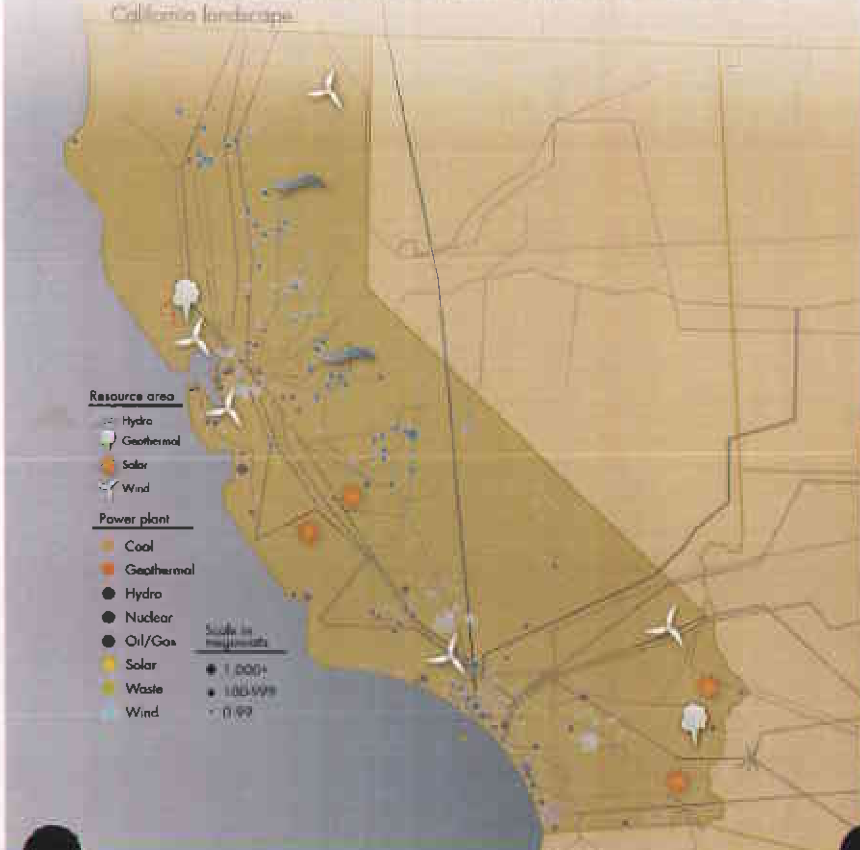
10 Demand Response Development

ISOs and RTOs provide more information. And because grid and market data is available publicly, anyone can see it. As a result, more companies are encouraged to participate in energy markets—even companies that are paid to reduce demand on the grid. Demand response bids are very important during peak periods of electricity use because reducing demand is just as effective as increasing supply—and it is cleaner and more economical.

The ISO conducts an annual transmission planning process that uses engineering analysis to identify any grid expansions necessary to maintain reliability, lower costs or meet future infrastructure needs based on public policies.

ISO engineers design, run and analyze complex formulas and models that simulate grid use under wideranging scenarios, such as high demand days coupled with wildfires. This process includes evaluating power plant proposals submitted for study into our interconnection queue to determine viability and impact to the grid.

The long-term comprehensive transmission plan is the culmination of 15 months of hard work. It takes into account future growth in electricity demand and the need to meet state energy and environmental goals that require the ISO grid to connect to renewable-rich, but remote areas of the California landscape.



Open-market grid welcomes diverse resources

The ISO market makes it easier for resources to compete to bring power to consumers. The key to reliably integrating renewable generation is to maintain a broad power mix with traditional generators and advanced technologies that can quickly respond to fluctuations in wind and solar production. California's natural resources provide a vast array of "fuel" for an energy landscape as diverse as its people and its climates.

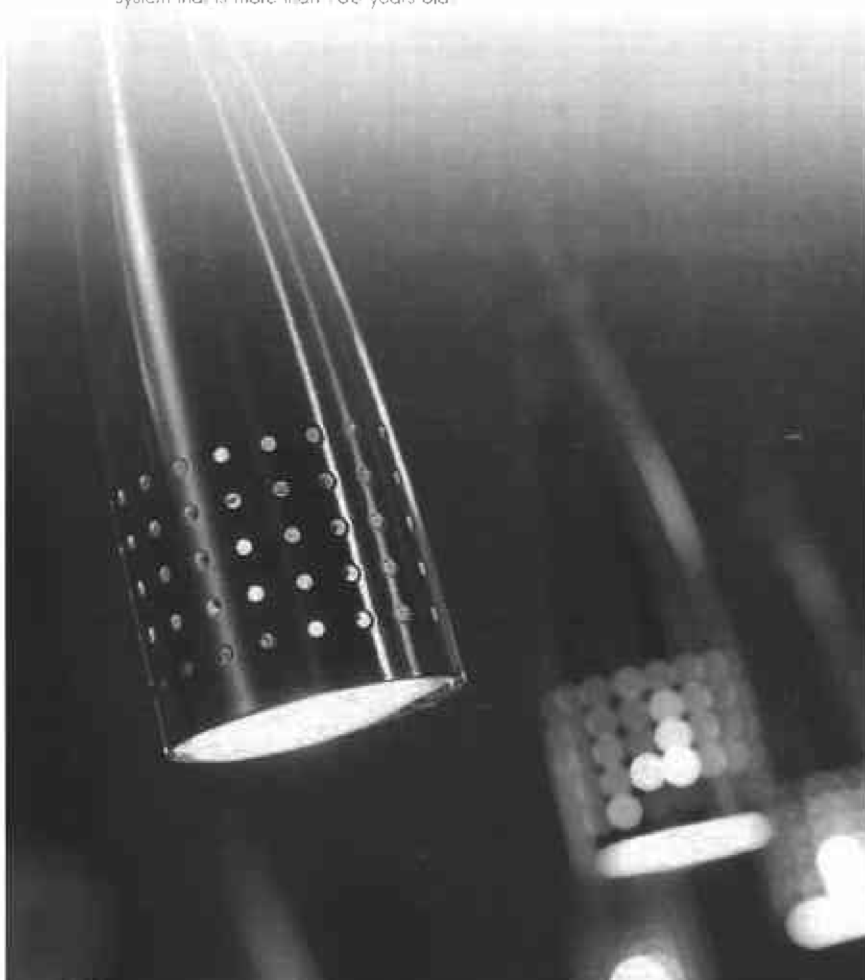
POWER FACT

By reducing barriers to renewable energy sources, such as **wind and solar power**, the California ISO is helping **the state reach its renewable goal** of increasing the **environmentally friendly** portion of California's energy mix to **33 percent** by 2020.

People
POWER

With advancements in automation and smart technology, consumers are becoming sellers, not just buyers of electricity. Customers who enroll in demand response programs provide electricity curtailments to help balance system needs.

The ISO is creating market mechanisms that enable demand response either through utility programs or aggregated by third-party entities, to bid into the wholesale market and be dispatched similar to a generator. The powerful combination of a competitive wholesale marketplace and operational flexibility is the foundation for modernizing a power delivery system that is more than 100 years old.



What we
STAND for

OUR MISSION

For the benefit of our customers, we

- Operate the grid reliably and efficiently
- Provide fair and open transmission access
- Promote environmental stewardship
- Facilitate effective markets and promote infrastructure development

All through the provision of timely and accurate information

OUR VISION

California ISO strives to be a world-class electric transmission organization built around a globally-recognized and inspired team providing cost-effective and reliable service, well-balanced and transparent energy market mechanisms, and high-quality information for the benefit of our customers.

THE CORNERSTONES

CORE VALUES

Integrity
We are honest, ethical and trustworthy with each other and stakeholders in all business dealings, reflecting the highest professional standards.

Teamwork
We strive for one common vision and are inspired by working together, with clear points of accountability, to be a world-class organization in meeting corporate objectives and serving our customers.

Excellence
Internal and external excellence—we earn customer trust based on our quality, competence and discipline in our business dealings.

People-Focused
We value diversity, promote employee development, support work/life balance and foster an invigorating and fulfilling work environment.

Open Communication
We seek out diverse ideas and opinions, value transparency, promote "thought leadership" and openly share information both internally and externally.

A GUIDE TO INDUSTRY TERMINOLOGY

What's a Watt?

A watt is a measure of electricity. If you have ten 100-watt bulbs on at the same time, the "demand" or instantaneous measure of the power required for the job is 1,000 watts, also called one kilowatt or kW. If you keep them lit for one full hour, you have used 1,000 watt-hours of electricity, also called a kilowatt-hour or kWh. The typical American home uses about 840 kWh per month.

Megawatt

One megawatt equals one million watts or 1,000 kilowatts, which is roughly enough electricity for the instantaneous demand of 750 homes at once. That number fluctuates because electrical demand changes based on the season, the time of day and other factors.

Voltage

Just as it takes pressure to move water through a pipe, it takes voltage to move electricity across a wire. The high-voltage transmission lines operated by the ISO carry power at 500, 230, 115 and 70 kV. It is "stepped down" into lower voltage by transformers at utility-operated substations and then to 12 or 21 kV for delivery to homes and businesses. Final delivery by the utilities is at 220 volts; most household plugs deliver power at 110 volts.

Capacity

The amount of electricity an electrical facility can carry or generate, usually applied to generators, transmission lines, substation equipment and distribution lines.

Energy vs. Capacity

If you're filling up a bucket with water from a garden hose, the amount of water moving through the hose is the "energy" or wattage, and the water pressure inside the hose is the voltage. The size of the hose is the capacity.

The Electrical Grid

Continuing the water analogy, envision the electrical grid as a big pressurized water system with hundreds of devices (generators) pumping water into the system through long pipes (transmission lines), and literally millions of customers sucking water out through smaller straws (utility distribution systems). There are hundreds of places (substations) where valves and adapters (switches and transformers) are used to break the large volumes of water down into smaller units under less pressure for delivery through straws. The ISO job is to make sure that the high-pressure system, the water pressure (voltage) and the pump output (frequency) remain constant even though inflow and outflow (measured in wattage) are changing minute by minute.

Frequency

Much like radio signals, electric generators can be "tuned" to produce power that vibrates at different frequencies. In the United States, virtually all electricity is generated and transmitted at 60-hertz or 60 cycles per second (cps). If the frequency fluctuates, it can damage all manner of electrical equipment. Frequency can be affected by a variety of factors and must be monitored closely by the ISO to make sure it remains very close to the 60 cps target.

Load

Load is the energy used. The ISO refers to utilities as load serving entities (LSEs) because that's what they do, serve load. Load is frequently confused with demand, which is actually how much power the load requires.

Demand

The number of kilowatts or megawatts delivered to the load at a given instant.

Market Participant

Any entity that buys, sells, trades, transmits or distributes electricity in the California ISO control area. This includes utilities, generating companies, transmission owners, energy-trading companies and Scheduling Coordinators (SCs).

Scheduling Coordinators

Entities that buy or sell power through the California ISO have to do so through a SC that is specifically authorized by the ISO to handle these transactions. SCs may be a subsidiary of the company they represent or hired as agents for a company.

Investor-Owned Utility (IOU)

The term investor-owned utility or IOU refers to the fact that these are private companies, owned by stockholders, as opposed to municipal utilities that are owned by the customers they serve. The three IOUs in California are: Pacific Gas and Electric (PG&E), Southern California Edison (SCE) and San Diego Gas and Electric (SDG&E).

National Renewable Energy Laboratory
Analysis Capabilities

Overview

The National Renewable Energy Laboratory (NREL) is the nation's primary laboratory for renewable energy and energy efficiency research and development (R&D). NREL's mission and strategy are focused on advancing the U.S. Department of Energy's and our nation's energy goals. The laboratory's scientists and researchers support critical market objectives to accelerate research from scientific innovations to market viable alternative energy solutions.

NREL's world-leading energy decision science and analysis capability draws on extensive knowledge of energy resources, technologies, markets, policies, and systems to conduct leading-edge analysis and to develop data, tools, and models that are broadly disseminated for energy stakeholder and public use. The insights gained from these analyses and tools inform RD&D directions, policy formulation, and technology and investment decisions. NREL's capability is increasingly underpinned by strong domain knowledge in energy informatics, which derives knowledge and insights from measured and modeled data sets. Primary supporting disciplines include engineering, environmental science, applied math, finance, economics, and social and political science.

NREL has a deep understanding of existing electricity, buildings, and fuels and transportation infrastructure and practical knowledge of the barriers to deploying existing or new clean energy technologies within these systems. NREL researchers apply computational methods to develop resource and technology screening and decision tools. Particular strengths are in techno-economic analyses of renewable and efficiency technologies, geospatial resource data and analysis, sustainability and impact analysis, and evaluation of optimal technology options for off-grid and grid-connected power systems.

NREL stewards its crosscutting analysis and decision support capability in its Strategic Energy Analysis Center (SEAC) and technology-specific modeling and analysis capabilities in the science and technology research centers. During FY12, SEAC conducted approximately $30 million of analytic research for the Department of Energy (DOE) and others. NREL extends it analytical capabilities by collaboration with stakeholders throughout the energy analysis community, from university researchers to other laboratories and to analysts working for federal, state and local governments. It hosts the Joint Institute for Strategic Energy Analysis (JISEA), whose founding partners include NREL, Massachusetts Institute of Technology, Stanford University, University of Colorado, Colorado State University and the Colorado School of Mines. Focused on the nexus of energy, finance and society, JISEA conducts studies and supports research by diverse teams involving NREL experts, industry and academic participants from the founding and affiliate research institutions from around the world. Recent analyses have explored the potential synergies between renewables and other energy pathways, with a particular focus on nuclear and natural gas.

NREL's energy analysis is conducted in support of NREL programs and initiatives, DOE's Office of Energy Efficiency and Renewable Energy (EERE), technology transfer, and the greater energy community, providing technical knowledge and tools to help inform decisions that include energy program development, investment prioritization, policy formulation, and energy project development. For example, the Department of Defense looks to NREL as a strategic technical resource as it addresses energy security issues at fixed installations and forward operating bases. Other major governmental partners include the Department of State, Environmental Protection Agency, Department of Interior, and Department of Homeland Security (DHS). Analysis clients include companies from the oil and gas and electric utility industries. NREL analysts partner with others at other national laboratories or leading research institutions as well; for example, NREL is collaborating with Oak Ridge National Laboratory (ORNL), Lawrence Berkeley National Laboratory (LBNL) and Northwestern University on tool and data development for EERE's Advanced Manufacturing Office. NREL is a primary technical resource for United States Agency for International Development (USAID) and the Department of State on clean energy and climate programs. In addition, NREL provides analytical support at the state and local government level such as the Wyoming Infrastructure Authority, NYSERDA, and the California Energy Commission, and to international entities. Through the Laboratory Consortium that NREL leads, NREL is working with Argonne National Laboratory, Brookhaven National Laboratory, LBNL, ORNL, and Pacific Northwest National Laboratory to support the USAID funded *Enhancing Capacity for Low Emission Development Strategies* (EC-LEDS) program in more than 8 developing countries.

Analysis Capabilities

Analysis at NREL aims to increase the understanding of the current and future interactions and roles of energy policies, markets, resources, technologies, environmental impacts, and infrastructure. These analyses are used to inform energy system decisions as energy-efficient and renewable energy technologies advance from concept to commercial application. Distinctive analysis capabilities include the following:

- Techno-economic modeling and analysis
- Sustainability analysis
- Clean energy manufacturing and supply chain cost and economic competitive analysis
- Integrated electric sector/grid modeling
- Project finance analysis
- Market and policy analysis
- Geospatial and resource energy analysis
- Energy informatics
- Web-based energy decision tools

Techno-economic modeling and analysis: NREL's technology systems analysis examines the performance and cost of technologies, systems, and processes or identifies and evaluates the tradeoffs among currently available electricity generation and fuels technologies given location-specific resources and demand profiles. NREL has technology-specific models that support analysis in the buildings efficiency, transportation (vehicles and renewable fuels), and electricity end-use sectors, as well and models that encompass multiple technologies to enable comparisons within and across sectors on a consistent basis.

Sustainability Analysis: NREL's sustainability analysis investigates the environmental, life-cycle, climate, and other impacts of renewable energy technologies. Our energy choices have global implications that affect greenhouse gas emissions, water resource distribution, and mineral consumption. The school of thought is that renewable energy technologies are more sustainable than many current sources of energy. However, we need to verify that this is true before we miss some important opportunities.

NREL's capabilities in this analysis area include:

- resource-use optimization
- life cycle assessment
- environmental externalities analysis, including carbon and other air emissions
- co-benefits analysis
- Water and land use requirements and distribution analysis.

Clean Energy Manufacturing and Supply Chain Cost and Economic Competitiveness Analysis: NREL looks at economic competitiveness through the lens of the national energy dialogue, which is increasingly focused on American prosperity and U.S. competitiveness in the global economy. NREL conducts industry-validated analysis to quantify specific factors that drive U.S. competitiveness in clean energy sectors and examines the broader impacts of manufacturing on the economy, including assessing manufacturing costs, supply-chain constraints, innovation opportunities, and comparative advantages associated with deployment of renewable energy technologies. NREL maintains data and information on current clean energy technology performance and costs, including photovoltaic (PV) manufacturing costs used, to understand the opportunities for further cost reduction and to benchmark the state-of-the-art technology in the United States relative to other countries. Analysis also investigates the potential impact of growing renewable technology deployment on state and national economies, including jobs and workforce development needs.

Integrated Electric Sector/Grid Modeling: Integrating higher levels of renewable resources into the U.S. electricity system could pose challenges to the operability of the nation's grid. NREL's electric sector integration analysis work investigates, with electric utilities, energy policymakers, and other industry partners, the potential impacts of expanding renewable technology deployment on electricity, grid operations and infrastructure expansion. Analysis investigates the feasibility of higher levels of renewable electricity generation on the grid, options for increasing electric system flexibility to accommodate higher levels of variable renewable electricity, and the impacts of renewable electricity generation on the efficiency and emissions of conventional generators.

Project Finance Analysis: At the project level, NREL's financial analysis helps potential renewable energy developers and investors gain insights into the complex world of project finance. Renewable energy project finance requires knowledge of federal tax credits, state-level incentives, renewable attribute markets, renewable technology installation and operation costs, and many other site-specific considerations. Analysis also examines the effects that policy can have on the development and financing of renewable energy projects, including how policies such as feed-in tariffs, clean renewable energy bonds, and power purchase agreements can shape the pace and structure of financing.

Market and Policy Analysis: NREL's market and policy analysis assesses the current state of renewable energy and energy efficiency technologies in the marketplace and explores future technology, policy, and market development scenarios and their implications, providing strategic information to stakeholders interested in rapidly changing electricity and fuels markets. Market analysis focus areas include technology and program market data, and renewable energy certificate and green power markets. Policy analysis assesses the market implications of policies that can advance — or provide alternatives to — renewable energy technology deployment, at the national, state, and local level. NREL analyzes existing policies and proposed policy legislation related to clean energy.

Geospatial and Resource Energy Analysis: NREL conducts geospatial analysis of renewable resource availability, location, accessibility, quality, and other characteristics. These geospatial analysis capabilities are used broadly to screen opportunities across regions and sites, identify the technical and economic potential for clean energy development, and create supply curves that help inform energy plans.

Energy Informatics: NREL is invested in acquiring and adapting systems to access, manage, mine, and visualize data sets of various types and sources, including complex and massive streams of measured and modeled data from energy system experiments and deployed systems, to build knowledge and derive insights to inform decisions. Access to these data will represent a significant user resource to enable virtual experimentation, developing and testing advanced data mining and visualization techniques, and validating models.

Tools and Models

NREL analysts develop or support a variety of tools and models to assess, analyze, and optimize renewable energy and energy efficiency technologies. Many of these tools can be applied on a global, regional, local, or project basis. Increasingly, the tools are being delivered as complete Internet-based applications that access data repositories maintained by NREL and others, and as web services, so that other application developers can directly utilize NREL-developed algorithms and data.

Geospatial Tools: NREL has developed a variety of geographic information system (GIS) based applications that are freely available to the public. A listing and links to some examples is provided below:

- **OpenPV** – The Open PV Project is a community-driven database of PV installations. Users can visualize trends in PV costs, installations, and add their individual information to the database. http://openpv.nrel.gov/

- **PVWATTS** – NREL's PVWatts™ calculator estimates the energy production and cost savings of grid-connected PV energy systems throughout the world. It allows homeowners, installers, manufacturers, and researchers to easily develop estimates of the performance of hypothetical PV installations. http://www.nrel.gov/rredc/pvwatts/

- **IMBY** – The In My Backyard (IMBY) tool estimates the electricity you can produce with a solar PV array at your home or business. Homeowners, businesses, and researchers use IMBY to develop quick estimates of renewable energy production. http://www.nrel.gov/eis/imby/

- **BioPower Tool** – The BioPower Tool is an interactive geospatial application allowing users to view biomass resources, infrastructure, and other relevant information, as well as query the data and conduct initial screening analyses. http://maps.nrel.gov/biopower/launch

- **Solar Power Prospector** – This interactive mapping tool allows users to examine, distribute, and analyze solar resource data for the United States and northern Mexico. It assists in making decisions about optimal locations for CSP plants. http://maps.nrel.gov/prospector

- **Geospatial Toolkits** – NREL's Geospatial Toolkit (GsT) is a map-based software application that integrates resource data and base GIS data to allow data visualization, simple renewable energy related GIS analysis, and mapping for users in selected countries who otherwise may not have access to such information. http://www.nrel.gov/international/geospatial_toolkits.html

- **HyDRA** – HyDRA (Hydrogen Demand and Resource Analysis) is a web-based application that allows users to explore, query, download, and analyze dynamic spatial data related to the hydrogen infrastructure. HyDRA contains data from a wide range of sources including modeling results that estimate hydrogen demand, resource, infrastructure, cost, production, and distribution. http://maps.nrel.gov/hydra

- **Mapsearch** – For most people, maps are synonymous with GIS, and they are the final delivered product for the majority of NREL's GIS projects. The GIS team has an online map repository for publicly available products. Users may browse, search and download hundreds of maps produced by NREL. http://www.nrel.gov/gis/mapsearch.html

Crosscutting Analysis Models: NREL's models and tools help analysts' provide insight into renewable energy technologies and their uses. Integrated assessments using these models and tools enable NREL analysts to analyze energy scenarios and/or the benefits and impacts of and uncertainties and risks associated with energy plans, programs, portfolios, or policy options. Some key NREL models include:

- **Biomass Scenario Model** – The Biomass Scenario Model (BSM) is a system dynamics model of the full cellulosic ethanol supply chain for the United States. The BSM represents the primary system effects and dependencies in the biomass to biofuels supply chain and provides a framework for developing scenarios and conducting biofuels-related analysis. https://bsm.nrel.gov/

- **Cost of Renewable Energy Spreadsheet Tool (CREST)** – CREST is an economic cast flow model designed to enable public utilities commissions and the renewable energy community assess projects, design cost-based incentives (e.g., feed-in tariffs), and evaluate the impact of tax incentives or other support structures, currently for solar (PV and solar thermal), wind and geothermal technologies. https://financere.nrel.gov/finance/content/crest-model

- **Jobs and Economic Development Impacts (JEDI)** – These economic input/output-based models are used to calculate gross jobs (direct, indirect and induced), earnings and economic outputs within a region or state resulting from construction and operation of RE installations. http://www.nrel.gov/analysis/jedi/

- **REFlex** – REFlex is a reduced form dispatch model that evaluates the limits of variable renewable generation as a function of system flexibility. It can also evaluate the role of enabling technologies such as demand response and energy storage. Contact: Paul.Denholm@nrel.gov

- **Regional Energy Deployment System (ReEDS)** – Regional Energy Deployment System (ReEDS) is a multiregional, multi-time period, GIS, and linear programming model of capacity expansion in the electric sector of the United States. http://www.nrel.gov/analysis/reeds/

- **Regional Planning Model (RPM)** – An integrated resource planning and dispatch tool for regional electric systems, with high spatial and temporal resolution; an hourly chronological model with a highly discretized regional structure that co-optimizes transmission, generation, and storage options. Contact: Trieu.Mai@nrel.gov

- **REopt** – An early screening tool that identifies and prioritizes renewable energy projects using site, resource, cost, incentive and financial data. http://www.nrel.gov/tech_deployment/tools_reopt.html

- **SERA (Scenario Evaluation, Regionalization and Analysis)** – The SERA model is a geospatially and temporally oriented infrastructure analysis model that determines the optimal production and delivery scenarios for hydrogen, given resource availability and technology cost. http://en.openei.org/wiki/Scenario_Evaluation,_Regionalization_%26_Analysis_%28SERA%29

- **Stochastic Energy Deployment Systems (SEDS)** – The SEDS model is a stochastic, capacity-expansion, simulation model of the U.S. energy market. Contact: emily.newes@nrel.gov

- **System Advisor Model (SAM)** – The SAM model is a performance and financial model designed to predict performance and cost of grid-connected power projects based on installation and operating costs and system design parameters. The model addresses projects on the customer side of the utility meter, buying and selling electricity at retail rates; and on the utility side of the meter, selling electricity at a price negotiated through a power purchase agreement. https://sam.nrel.gov/

<u>Data Sets</u>

Access to data is essential to models and tools. NREL collects and makes available a range of data sets for the broader research community. NREL maintains knowledge resources on policies at the state and national level, utility-rate data, as well as renewable energy cost, performance, and installation information (e.g., PV, renewable fueling stations). Laboratory analysts provide access to high-quality measured and modeled national and global renewable resource data at various time scales; these are also made available as data sets, maps and tools. Some examples are described below:

Energy Data for Decision Makers: NREL's digital assets platform links energy communities and decision makers such as policy makers, researchers, technology investors, venture capitalists, and market professionals – with valuable energy data, information, analyses, tools, images, maps, and other resources. The Open Energy Information (http://www.openei.org) open data platform, developed by NREL with DOE support, catalyzes the world's energy information and links data together in new ways using "linked open data". Another example, the SmartGrid data hub (http://www.smartgrid.gov/), collects data from DOE American Recovery and Reinvestment Act (ARRA)-funded SmartGrid projects throughout the United States. These digital assets provide worldwide access to NREL's valuable analytical capabilities to help inform the energy decisions that will transform our energy system.

Geographic Data: NREL's Data and Visualization team has access to a wide variety of geospatial data; some is available to the public; others are proprietary, but may be used in analyses and can then be made publicly available. The data downloads are available in ESRI's shapefile format, which will require an ESRI GIS or compatible product to view and manipulate. This data is intended for users familiar with and who have access to GIS software, and includes renewable energy resource data for the United

States as well as a limited number of international locations. For more information visit http://www.nrel.gov/gis/data.html. A sampling of key datasets is listed below:

- **Biomass resources** – County-level summaries of available biomass in the United States, representing 2005 and 2008. The data contains residue quantities for crop, manure, forest, primary mill, secondary mill, urban mill waste, landfill, wastewater and switch grass. The 2008 county dataset has been further processed to produce a second dataset showing residue distribution at a finer resolution for crop, forest, landfill, primary mill, urban and secondary mill, and wastewater. A 2010 update dataset was completed for crops, plus specifics for sugarcane and sugar beets. Additional biomass-related resource datasets include biodiesel facilities, ethanol plants and pulp mills. For biomethane specifically, datasets include anaerobic digester gas facilities, dairy farms and sewage treatment plants.

- **Geothermal resources** – Datasets include hydrothermal well sites from the USGS, and enhanced geothermal systems potential (EGS) which was derived by NREL using modeled temperature at depth data from 3.5 to 9.5 km in 1 km intervals from the Southern Methodist University geothermal lab.

- **Hydrogen** – Datasets include hydrogen generation potential from biomass, coal, gas, solar, wind and all renewable sources, estimated by NREL. There is also a hydrogen refueling facilities dataset.

- **Solar resources** – Datasets include photovoltaic solar resource and concentrating solar resource (CSP) for all 50 states. The data for Hawaii and the lower 48 states are a 10-km satellite modeled dataset (SUNY/NREL, 2007) representing data from 1998 – 2005. The data for Alaska are a 40-km dataset produced by the Climatological Solar Radiation Model (NREL, 2003.) Data for other collector types include East-West 1-axis tracker and global horizontal for the lower 48 and Hawaii, and solar vent preheat for the lower 48 and Alaska. Additional solar resource datasets include the National Solar Radiation Database (NSRDB) and Typical Meteorological Year (TMY2/3) sites. Since 1981, NREL has continuously gathered basic solar radiation information and its Colorado site, and now gathers high-resolution data (in 1-minute intervals) from the World Meteorological Organization's first-class instruments. Daily instrument maintenance and annual calibrations are performed to ensure data quality. The Solar Radiation Research Laboratory is heavily instrumented with pyranometers, pyrheliometers, pyrgeometers, photometers, and spectroradiometers to provide the solar resource information necessary for renewable energy research and development.

- **Wind resources** – 50-meter onshore wind power density and speed for most states, including land-based areas where applicable. A few states in the Southeastern United States, as well as portions of Alaska, have only low resolution (40 km) wind power resource data produced by the 1987 Wind Energy Atlas of the United States. NREL maintains 90-meter offshore wind speed for most states, extending to 50 nautical miles offshore. Additional wind resource datasets include state/regional datasets at different heights, and wind data modeled for specific years. For more information see http://www.windpoweringamerica.gov/wind_maps.asp

- **Energy Infrastructure** – Fueling stations (biodiesel, compressed natural gas, electricity, ethanol/E85, gasoline, hydrogen, liquid natural gas or liquid petroleum gas), biodiesel plants, electric control centers (facilities responsible for balancing electricity load), electric power generating plants, electric service territories, electric substations, electric transmission lines, energy control areas (aggregation of electric retail service areas based on control area membership), Federal Energy Regulatory Commission (FERC) regions, natural gas storage, North American Electric Reliability Council (NERC) regions and subregions, nuclear research facilities, oil/gas facilities, oil/gas pipelines, oil terminals, offshore oil platforms, pipeline interconnects (includes oil/gas/petrochemical, etc.), propane retailers, Radiological Assistance Program (RAP) regions (provides Department of Energy {DOE} assistance to organizations responding to nuclear emergency), refineries, strategic petroleum reserves, oil/gas wells.

Recent Studies, Reports, Other Examples

Manufacturing, Supply Chain and Economic Competitiveness

Goodrich, A.; Hacke, P.; Wang, Q.; Sopori, B.; Margolis, R.; James, T. L.; Woodhouse, M. (2013). Wafer-Based Monocrystalline Silicon Photovoltaics Road Map: Utilizing Known Technology Improvement Opportunities for Further Reductions in Manufacturing Costs. Solar Energy Materials and Solar Cells. Vol. 114, July 2013; pp. 110-135; NREL Report No. JA-6A20-57504. http://dx.doi.org/10.1016/j.solmat.2013.01.030

Goodrich, A.; Woodhouse, M.; Hacke, P. (2012). Value Proposition for High Lifetime (p-type) and Thin Silicon Materials in Solar PV Applications. [Proceedings] 38th IEEE Photovoltaic Specialists Conference (PVSC '12), 3-8 June 2012, Austin, Texas. Piscataway, NJ: Institute of Electrical and Electronics Engineers (IEEE) pp. 003238-003241; NREL Report No. CP-6A20-56932. http://dx.doi.org/10.1109/PVSC.2012.6318267

Goodrich, A.; James, T.; Woodhouse, M. (2012). Residential, Commercial, and Utility-Scale Photovoltaic (PV) System Prices in the United States: Current Drivers and Cost-Reduction Opportunities. 64 pp.; NREL Report No. TP-6A20-53347. http://www.nrel.gov/docs/fy12osti/53347.pdf

Feldman, D.; Barbose, G.; Margolis, R.; Wiser, R.; Darghouth, N.; Goodrich, A. (2012). Photovoltaic (PV) Pricing Trends: Historical, Recent, and Near-Term Projections. 30 pp.; NREL Report No. TP-6A20-56776; DOE/GO-102012-3839. http://www.nrel.gov/docs/fy13osti/56776.pdf

Friedman, B. (2012). PV Installation Labor Market Analysis and PV JEDI Tool Developments (Presentation). NREL (National Renewable Energy Laboratory). 28 pp.; NREL Report No. PR-6A20-55130. http://www.nrel.gov/docs/fy12osti/55130.pdf

Woodhouse, M.; Goodrich, A.; James, T. L.; Margolis, R.; Lokanc, M.; Eggert, R. (2012). Supply Chain Dynamics of Tellurium (Te), Indium (In), and Gallium (Ga) Within the Context of PV Module Manufacturing Costs (Presentation). NREL (National Renewable Energy Laboratory). 25 pp.; NREL Report No. PR-6A20-57138. http://www.nrel.gov/docs/fy13osti/57138.pdf

Goodrich, A.; James, T.; Woodhouse, M. (2011). Solar PV Manufacturing Cost Analysis: U.S. Competitiveness in a Global Industry (Presentation). NREL (National Renewable Energy Laboratory). 45 pp.; NREL Report No. PR-6A20-53938. http://www.nrel.gov/docs/fy12osti/53938.pdf

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Renewable Electricity Futures Study

Executive Summary

Volume 1	Volume 2	Volume 3	Volume 4
PDF	PDF	PDF	PDF

NREL is a national laboratory of the U.S. Department of Energy,
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Renewable Electricity Futures Study

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Renewable Electricity Futures Study: Executive Summary

Mai, T.; Sandor, D.; Wiser, R.; Schneider, T (2012). Renewable Electricity Futures Study: Executive Summary. NREL/TP-6A20-52409-ES. Golden, CO: National Renewable Energy Laboratory.

Perspective

The Renewable Electricity Futures Study (RE Futures) provides an analysis of the grid integration opportunities, challenges, and implications of high levels of renewable electricity generation for the U.S. electric system. The study is not a market or policy assessment. Rather, RE Futures examines renewable energy resources and many technical issues related to the operability of the U.S. electricity grid, and provides initial answers to important questions about the integration of high penetrations of renewable electricity technologies from a national perspective. RE Futures results indicate that a future U.S. electricity system that is largely powered by renewable sources is possible and that further work is warranted to investigate this clean generation pathway. The central conclusion of the analysis is that renewable electricity generation from technologies that are commercially available today, in combination with a more flexible electric system, is more than adequate to supply 80% of total U.S. electricity generation in 2050 while meeting electricity demand on an hourly basis in every region of the United States.

The renewable technologies explored in this study are components of a diverse set of clean energy solutions that also includes nuclear, efficient natural gas, clean coal, and energy efficiency. Understanding all of these technology pathways and their potential contributions to the future U.S. electric power system can inform the development of integrated portfolio scenarios. RE Futures focuses on the extent to which U.S. electricity needs can be supplied by renewable energy sources, including biomass, geothermal, hydropower, solar, and wind.

The study explores grid integration issues using models with unprecedented geographic and time resolution for the contiguous United States. The analysis (1) assesses a variety of scenarios with prescribed levels of renewable electricity generation in 2050, from 30% to 90%, with a focus on 80% (with nearly 50% from variable wind and solar photovoltaic generation); (2) identifies the characteristics of a U.S. electricity system that would be needed to accommodate such levels; and (3) describes some of the associated challenges and implications of realizing such a future. In addition to the central conclusion noted above, RE Futures finds that increased electric system flexibility, needed to enable electricity supply-demand balance with high levels of renewable generation, can come from a portfolio of supply- and demand-side options, including flexible conventional generation, grid storage, new transmission, more responsive loads, and changes in power system operations. The analysis also finds that the abundance and diversity of U.S. renewable energy resources can support multiple combinations of renewable technologies that result in deep reductions in electric sector greenhouse gas emissions and water use. The study finds that the direct incremental cost associated with high renewable generation is comparable to published cost estimates of other clean energy scenarios. Of the sensitivities examined, improvement in the cost and performance of renewable technologies is the most impactful lever for reducing this incremental cost. Assumptions reflecting the extent of this improvement are based on incremental or evolutionary improvements to currently commercial technologies and do not reflect U.S. Department of Energy activities to further lower renewable technology costs so that they achieve parity with conventional technologies.

RE Futures is an initial analysis of scenarios for high levels of renewable electricity in the United States; additional research is needed to comprehensively investigate other facets of high renewable or other clean energy futures in the U.S. power system. First, this study focuses on renewable-specific technology pathways and does not explore the full portfolio of clean technologies that could contribute to future electricity supply. Second, the analysis does not attempt a full reliability analysis of the power system that includes addressing sub-hourly, transient, and distribution system requirements. Third, although RE Futures describes the system characteristics needed to accommodate high levels of renewable generation, it does not address the institutional, market, and regulatory changes that may be needed to facilitate such a transformation. Fourth, a full cost-benefit analysis was not conducted to comprehensively evaluate the relative impacts of renewable and non-renewable electricity generation options.

Lastly, as a long-term analysis, uncertainties associated with assumptions and data, along with limitations of the modeling capabilities, contribute to significant uncertainty in the implications reported. Most of the scenario assessment was conducted in 2010 with assumptions concerning technology cost and performance and fossil energy prices generally based on data available in 2009 and early 2010. Significant changes in electricity and related markets have already occurred since the analysis was conducted, and the implications of these changes may not have been fully reflected in the study assumptions and results. For example, both the rapid development of domestic unconventional natural gas resources that has contributed to historically low natural gas prices, and the significant price declines for some renewable technologies (e.g., photovoltaics) since 2010, were not reflected in the study assumptions.

Nonetheless, as the most comprehensive analysis of U.S. high-penetration renewable electricity conducted to date, this study can inform broader discussion of the evolution of the electric system and electricity markets toward clean systems.

The RE Futures team was made up of experts in the fields of renewable technologies, grid integration, and end-use demand. The team included leadership from a core team with members from the National Renewable Energy Laboratory (NREL) and the Massachusetts Institute of Technology (MIT), and subject matter experts from U.S. Department of Energy (DOE) national laboratories, including NREL, Idaho National Laboratory (INL), Lawrence Berkeley National Laboratory (LBNL), Oak Ridge National Laboratory (ORNL), Pacific Northwest National Laboratory (PNNL), and Sandia National Laboratories (SNL), as well as Black & Veatch and other utility, industry, university, public sector, and non-profit participants. Over the course of the project, an executive steering committee provided input from multiple perspectives to support study balance and objectivity.

RE Futures is documented in four volumes of a single report: Volume 1—describes the analysis approach and models, along with the key results and insights; Volume 2 describes the renewable generation and storage technologies included in the study; Volume 3 presents end-use demand and energy efficiency assumptions; and Volume 4 discusses operational and institutional challenges of integrating high levels of renewable energy into the electric grid. The Executive Summary for RE Futures is both included in Volume 1 and presented separately here.

The Renewable Electricity Futures Study (RE Futures) is an initial investigation of the extent to which renewable energy supply can meet the electricity demands of the contiguous United States[1] over the next several decades. This study includes geographic and electric system operation resolution that is unprecedented for long-term studies of the U.S. electric sector. The analysis examines the implications and challenges of renewable electricity generation levels—from 30% up to 90%, with a focus on 80%, of all U.S. electricity generation from renewable technologies—in 2050. At such high levels of renewable electricity penetration, the unique characteristics of some renewable resources, specifically geographical distribution and variability and uncertainty in output, pose challenges to the operability of the U.S. electric system. The study focuses on some key technical implications of this environment, exploring whether the U.S. power system can supply electricity to meet customer demand with high levels of renewable electricity, including variable wind and solar generation. The study also begins to address the potential economic, environmental, and social implications of deploying and integrating high levels of renewable electricity in the United States.

RE Futures was framed with a few important questions:

- The United States has diverse and abundant renewable energy resources that are available to contribute higher levels of electricity generation over the next decades. Future renewable electricity generation will be driven in part by federal incentives and renewable portfolio standards mandated in many states.[2] Practically, how much can renewable energy technologies, in aggregate, contribute to future U.S. electricity supply?

- In recent years, variable renewable electricity generation capacity in the United States has increased considerably. Wind capacity, for example, has increased from 2.6 GW in 2000 to 40 GW in 2010, while solar capacity has also begun to grow rapidly. Can the U.S. electric power system accommodate higher levels of variable generation from wind or solar photovoltaics (PV)?

- Overall, renewable energy contributed about 10% of total power-sector U.S. electricity supply in 2010 (6.4% from hydropower, 2.4% from wind energy, 0.7% from biopower, 0.4% from geothermal energy, and 0.05% from solar energy).[3] Are there synergies that can be realized through combining these diverse sources, and to what extent can aggregating their output over larger areas help enable their integration into the power system?

[1] Alaska, Hawaii, and the U.S. Territories were not included in this study because they rely on electric grid systems that are not connected to the contiguous United States. However, both states and the territories have abundant renewable resources, and they have efforts are underway to substantially increase renewable electricity generation (see Volume 1, Text Box Introduction-1).

[2] Some states have targets of a 20%–30% share of total electricity generation (see http://www.dsireusa.org/ for information on specific state standards) and are making progress toward meeting these goals.

[3] These data reflect estimates for the electric power sector only, and they exclude the end use sectors (i.e., on-site electric power supply that directly meets customer demands). If the end-use and electric power sectors are considered together, the percentage contribution from biomass would increase from 0.7% to 1.4%, and the contribution from solar would increase from 0.05% to 0.12%.

Multiple international studies[4] have explored the possibility of achieving high levels of renewable electricity penetration, primarily as a greenhouse gas (GHG) mitigation measure. RE Futures presents systematic analysis of a broad range of potential renewable electricity futures for the contiguous United States based on unprecedented consideration of geographic, temporal, and electric system operation aspects.[5]

RE Futures explores a number of scenarios using a range of assumptions for generation technology improvement, electric system operational constraints, and electricity demand to project the mix of renewable technologies—including wind, PV, concentrating solar power (CSP), hydropower, geothermal, and biomass—that meet various prescribed levels of renewable generation, from 30% to 90%. Additional sensitivity cases are focused on an 80%-by-2050 scenario. At this 80% renewable generation level, variable generation from wind and solar technologies accounts for almost 50% of the total generation.

Within the limits of the tools used and scenarios assessed, hourly simulation analysis indicates that estimated U.S. electricity demand in 2050 could be met with 80% of generation from renewable electricity technologies with varying degrees of dispatchability, together with a mix of flexible conventional generation and grid storage, additions of transmission, more responsive loads, and changes in power system operations.[6] Further, these results were consistent for a wide range of assumed conditions that constrained transmission expansion, grid flexibility, and renewable resource availability. The analysis also finds that the abundance and diversity of U.S. renewable energy resources can support multiple combinations of renewable technologies that result in deep reductions in electric sector greenhouse gas emissions and water use. Further, the study finds that the incremental cost associated with high renewable generation is comparable to published cost estimates of other clean energy scenarios. Of the sensitivities examined, improvement in the cost and performance of renewable technologies is the most impactful level for reducing this incremental cost.

While this analysis suggests such a high renewable generation future is possible, a transformation of the electricity system would need to occur to make this future a reality. This transformation, involving every element of the grid, from system planning through operation, would need to ensure adequate planning and operating reserves, increased flexibility of the electric system, and expanded multi-state transmission infrastructure, and would likely rely on the development and adoption of technology advances, new operating procedures, evolved business models, and new market rules.

[4] As examples, recent detailed studies include those prepared for Europe (ECF 2010) and Germany (SRU 2010), as well as a review of 164 global energy scenarios by the Intergovernmental Panel on Climate Change (IPCC 2011). Cochran et al. (2012) also describes several case studies of countries successfully managing high levels of variable renewable energy on their electric grids.

[5] Previous, more conceptual or more-limited analyses of high penetrations of renewable energy in the United States and globally include (but are not limited to) Pacala and Socolow (2004); ACORE (2007); Kutscher (2007); Greenblan (2009); GWEC/GPI (2008); Fthenakis et al. (2009); Jacobson and Delucchi (2009); Sawin and Moomaw (2009); EREC/GPI (2008); and Lovins (2011).

[6] The study did not conduct a full reliability analysis, which would include sub-hourly, stability, and AC power flow analysis.

Key results of this study include the following:

- Deployment of Renewable Energy Technologies
  - Renewable energy resources, accessed with commercially available generation technologies, could adequately supply 80% of total U.S. electricity generation in 2050 while balancing supply and demand at the hourly level.
  - All regions of the United States could contribute substantial renewable electricity supply in 2050, consistent with their local renewable resource base.
  - Multiple technology pathways exist to achieve a high renewable electricity future. Assumed constraints that limit power transmission infrastructure, grid flexibility, or the use of particular types of resources can be compensated for through the use of other resources, technologies, and approaches.
  - Annual renewable capacity additions that enable high renewable generation are consistent with current global production capacities but are significantly higher than recent U.S. annual capacity additions for the technologies considered. No insurmountable long-term constraints to renewable electricity technology manufacturing capacity, materials supply, or labor availability were identified.
- Grid Operability and Hourly Resource Adequacy
  - Electricity supply and demand can be balanced in every hour of the year in each region with nearly 80% electricity from renewable resources, including nearly 50% from variable renewable generation, according to simulations of 2050 power system operations.
  - Additional challenges to power system planning and operation would arise in a high renewable electricity future, including management of low-demand periods and curtailment of excess electricity generation.
  - Electric sector modeling shows that a more flexible system is needed to accommodate increasing levels of renewable generation. System flexibility can be increased using a broad portfolio of supply- and demand-side options, and will likely require technology advances, new operating procedures, evolved business models, and new market rules.
- Transmission Expansion
  - As renewable electricity generation increases, additional transmission infrastructure is required to deliver generation from cost-effective remote renewable resources to load centers, enable reserve sharing over greater distances, and smooth output profiles of variable resources by enabling greater geospatial diversity.
- Cost and Environmental Implications of High Renewable Electricity Futures
  - High renewable electricity futures can result in deep reductions in electric sector greenhouse gas emissions and water use.
  - The direct incremental cost associated with high renewable generation is comparable to published cost estimates of other clean energy scenarios. Improvement in the cost

and performance of renewable technologies is the most impactful lever for reducing this incremental cost.

- Effects of Demand Growth
  - With higher demand growth, high levels of renewable generation present increased resource and grid integration challenges.

This report presents the analysis of some of the technical challenges and opportunities associated with high levels of renewable generation in the U.S. electric system. However, the analysis presented in this report represents only an initial set of inquiries on a national scale. Additional studies are required to more fully assess the technical, operational, reliability, economic, environmental, social, and institutional implications of high levels of renewable electricity generation, and further explore the nature of the electricity system transformation required to enable such a future.

Study Organization and Report Structure

RE Futures was led by a team from the National Renewable Energy Laboratory (NREL) and the Massachusetts Institute of Technology (MIT). The leadership team coordinated teams of subject matter experts from U.S. Department of Energy (DOE) national laboratories, including Idaho National Laboratory (INL), Lawrence Berkeley National Laboratory (LBNL), NREL, Oak Ridge National Laboratory (ORNL), Pacific Northwest National Laboratory (PNNL), and Sandia National Laboratories (SNL), as well as Black & Veatch and other utility, industry, university, public sector, and non-profit participants. These expert teams explored the prospects for large-scale deployment of specific renewable generation and storage technologies, along with some of the issues and challenges associated with their integration into the electric system.

In total, this report is the culmination of contributions from more than 110 individuals at more than 35 organizations (Appendix D lists the contributors to the study). Over the course of the project, an executive steering committee provided input from multiple perspectives to support study balance and objectivity. Technical reviewers from the renewable technology and electric sector industries, universities, public sector, non-profits, and other entities commented on a preliminary version of this report.

Most of the analysis informing the study, particularly the scenario assessment, was conducted in 2010. As a result, study assumptions concerning technology cost and performance and fossil energy prices were generally based on data available in late 2009 and early 2010. Where possible, more recent published work has been referenced; however, the implications of these publications may not have been fully reflected in the RE Futures study assumptions. For example, both the rapid development of domestic unconventional natural gas resources that has contributed to historically low natural gas prices, and the significant price declines for some renewable technologies (e.g., photovoltaics) since 2010, were not reflected in the study assumptions. Finally, the technology projections presented in RE Futures do not necessarily reflect the current DOE estimates.

RE Futures is documented in four volumes of a single report: Volume 1—describes the analysis approach and models, along with the key results and insights. Volume 2 describes the renewable generation and storage technologies included in the study; Volume 3 presents 2050 end-use demand and energy efficiency assumptions; and Volume 4 discusses some operational and institutional challenges of integrating high levels of renewable energy into the electric grid.

This Executive Summary, which is also included in Volume 1, highlights the analysis approach and key results from RE Futures. First, it summarizes the analysis approach, including scenario framework, renewable resources characterization, and modeling tools used to analyze the expansion of the U.S. electricity system and its operational characteristics. The key results from the analysis are then presented, including results associated with renewable technology deployment, grid operations, and economic, environmental and social implications. Finally, additional research opportunities are identified in the conclusions.

Analysis Approach

Scenario Framework

Given the inherent uncertainties involved with analyzing alternative long-term energy futures, and given the variety of pathways that might lead to higher levels of renewable electricity supply, multiple future scenarios were modeled and analyzed. The scenarios examined included the following considerations:

- **Energy Efficiency:** Most of the scenarios assumed adoption of energy efficiency (including electricity) measures in the residential, commercial, and industrial sectors that resulted in flat demand growth over the 40-year study period.[7]
- **Transportation:** Most of the scenarios assumed a shift of some transportation energy away from petroleum and toward electricity in the form of electric and plug-in hybrid electric vehicles, partially offsetting the electricity efficiency advances that were considered.[8]
- **Grid Flexibility:** Most scenarios assumed improvements in electric system operations to enhance flexibility in both electricity generation and end-use demand, helping to enable more efficient integration of variable-output renewable electricity generation.
- **Transmission:** Most scenarios expand the transmission infrastructure and access to existing transmission capacity to support renewable energy deployment. Distribution-level upgrades were not considered.
- **Siting and Permitting:** Most scenarios assumed project siting and permitting regimes that allow renewable electricity development and transmission expansion subject to standard land-use exclusions.

[7] The efficiency gains assumed are described in Volume 3. They do not represent an upper bound of energy efficiency, i.e., they were not as large as estimated by NAS/NAE (2010).
[8] The flat demand (low-demand) projection included this increase in demand from the transportation sector, whereas the business-as-usual demand (high-demand) projection did not. The contribution of biofuels to the transportation sector is not quantified in RE Futures.

In all the scenarios analyzed, only currently commercially available technologies (as of 2010) were considered, together with their incremental or evolutionary improvements despite the long-term (2050) timeframe, because the focus of this study was on grid integration and not on the potential advances of any individual technologies.[9] Technologies such as enhanced geothermal systems; ocean energy technologies (e.g., wave, tidal, current or ocean thermal); floating offshore wind technology; and others that are currently under development and pilot testing—and which show significant promise but are not yet generally commercially available—were not included.

More than two dozen scenarios were modeled and analyzed in this study as outlined in Figure ES-1 and detailed below. The number and diversity of scenarios allowed an assessment of multiple pathways that depended on highly uncertain future technological, institutional, and market choices. The framework included scenarios with specific renewable electricity generation levels to enable exploration of some of the technical issues associated with the operation of the U.S. electricity grid at these levels.[10] This scenario framework does not prescribe a set of policy recommendations for renewable electricity generation in the United States, nor does it present a vision of what the total mix of energy sources should look like in the future. Further, the framework does not intend to imply that one future is more likely than another.

[9] RE Futures did not allow new nuclear plants, fossil technologies with CCS, as well as gasified coal without CCS (integrated gasification combined cycle) to be built in any of the scenarios presented in this report. Existing nuclear (and integrated gasification combined cycle) units, however, were included in the analysis, as were assumptions for the retirement of those units.
[10] The scenarios were not constructed to find the optimal GHG mitigation or clean energy pathway (e.g., to minimize carbons emissions or the cost of mitigating these emissions). In addition, because the scenarios included specific renewable generation levels, they were not designed to explore how renewable technologies might economically deploy under certain technology advancement projections without the generation constraints.

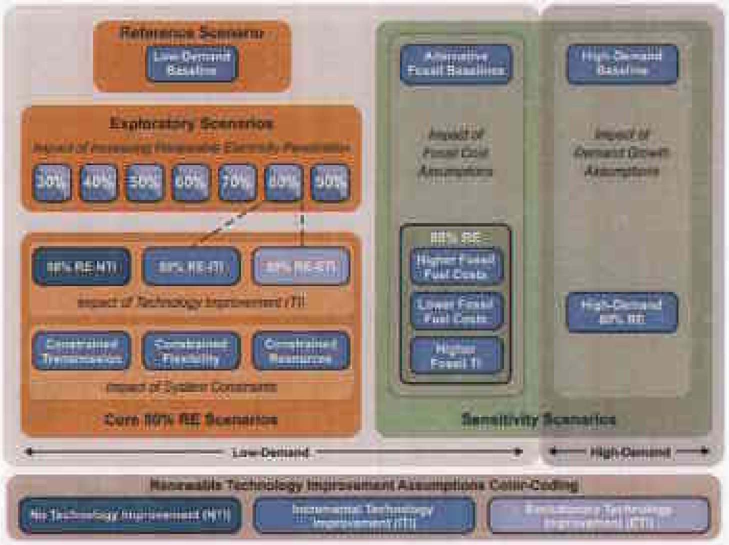


Figure ES-1. Modeling scenario framework for RE Futures

Dotted lines indicate that the 80% RE exploratory scenarios are the same as the 80% RE-ITI and 80% RE-ETI scenarios

Low-Demand Baseline Scenario

A Low-Demand Baseline scenario was designed to reflect a largely conventional generation system as a point of comparison, or reference, for the high-penetration renewable electricity scenarios. The Low-Demand Baseline scenario assumes that a combination of emerging trends—including policies and legislation dealing with codes and standards, innovation in energy efficiency, and the green building and supply chain movements—drive the adoption of energy efficiency measures in the residential, commercial, and industrial sectors (see Volume 3 for details).[11] Substantial adoption of electric and plug-in hybrid electric vehicles was also assumed. In aggregate, these low-demand assumptions resulted in overall electricity consumption that exhibits little growth from 2010 to 2050. Existing state policies (e.g., renewable portfolio standards) and existing federal policies (e.g., investment tax credits, production tax credits, tax depreciation rules) were assumed to continue only as allowed under existing law, with no

[11] In addition to these trends, the primary historical drivers of electricity demand, population growth, and economic growth, were also considered in the construction of the scenario. While investment costs of these efficiency measures were not considered in the scenario development, findings from other studies generally indicate that such measures can be considered cost-effective or cost-competitive.

extensions. Expiration dates for existing federal policies vary, but generally are 2017 or earlier.[12] In combination with incremental technology improvements, these assumptions result in low levels of renewable electricity generation in the Low-Demand Baseline scenario.

Exploratory Scenarios

A series of "exploratory scenarios," in which the proportion of renewable electricity in 2050 increased in 10% increments from 30% to 90%, was evaluated. The primary purpose of these exploratory scenarios was to assess how increased levels of renewable electricity might impact the generation mix of renewable and non-renewable resources, the extent of transmission expansion in these cases, and the use of various forms of supply- and demand-side flexibility to enable a match between electricity supply and demand. These exploratory scenarios were evaluated under two distinct sets of renewable electricity technology advancement assumptions: Incremental Technology Improvement (ITI) and Evolutionary Technology Improvement (ETI).

Core 80% RE Scenarios

Further analysis was performed on six core 80% RE scenarios, each of which met the same 80%-by-2050 renewable electricity penetration level and each of which was designed to elucidate the possible implications of certain technological, institutional, and market drivers.[13] Three scenarios explored the impacts of future renewable energy technology advancements of currently commercial technologies and the resulting deployment of different combinations of renewable energy technologies.[14]

- The RE – No Technology Improvement (80% RE-NTI) scenario simply assumed that the performance of each renewable technology was maintained at 2010 levels for all years in the study period (2010–2050).
- The RE – Incremental Technology Improvement (80% RE-ITI) scenario reflected only partial achievement of the future technical advancements that may be possible (Black & Veatch 2012).
- The RE – Evolutionary Technology Improvement (80% RE-ETI) scenario reflected a more-complete achievement of possible future technical advancements (Volume 2). The RE-ETI scenario is not designed to be a lower bound and does not span the full range of possible futures; further technical advancements beyond the RE-ETI are possible.[15]

Three additional scenarios explored the impacts of different electricity system constraints based on assumptions that limited the building of new transmission, reduced system flexibility to

[12] Similarly, indirect incentives for conventional energy technologies—sometimes delivered through the tax code without sunset provisions—were assumed to be maintained as allowed under existing law. These same renewable and conventional technology policy assumptions were consistently applied to all the other scenarios as well.

[13] The specific assumptions used for these scenarios are discussed in Chapter 1.

[14] Although the methods used in RE Futures to project the future cost of each renewable electricity technology differ to some degree by technology, the resulting forecasts are largely based on anticipated scientific and engineering advancements rather than on learning-curve-based estimates that are endogenously driven by an assumed learning rate applied to cumulative production or installation. In reality, costs may decline in part due to traditional learning and in part due to other factors, such as research and development investment, economies of scale in manufacturing, component, or plant size, and reductions in material costs.

[15] Indeed, current DOE initiatives are focused on achieving substantially better cost and performance in many cases, with a target of achieving parity with conventional technologies.

manage the variability of wind and solar resources, and decreased renewable resource availability:

- The Constrained Transmission scenario evaluated how limits to building new transmission might impact the location and mix of renewable resources used to meet an 80%-by-2050 future
- The Constrained Flexibility scenario sought to understand how institutional constraints to and concerns about managing the variability of wind and solar resources, in particular, might impact the resource mix of achieving an 80%-by-2050 future
- The Constrained Resources scenario posited that environmental or other concerns may reduce the developable potential for many of the renewable technologies in question, and evaluated how such constraints could impact the resource mix of renewable energy supply

High-Demand Scenarios

The scenarios described above—the Low-Demand Baseline scenario, the exploratory scenarios, and the six core 80% RE scenarios—were based on the low-demand assumptions, with overall electricity consumption that exhibits little growth from 2010 to 2050. To test the impacts of a higher-demand future, a scenario with the 80%-by-2050 renewable electricity generation but a higher end-use electricity demand was evaluated, with demand in 2050 30% higher than in the low-demand scenarios.[16] A corresponding reference scenario, the High-Demand Baseline scenario, with the same higher demand was also evaluated.[17]

Alternative Fossil Scenarios

Finally, given uncertainties in the *future cost of fossil energy sources*, the analysis included 80%-by-2050 RE scenarios in which: (1) the price of fossil energy (coal and natural gas) was both higher and lower than otherwise assumed in the other scenarios and (2) fossil energy technologies[18] experienced greater technology improvements over time than assumed in the other scenarios. Corresponding reference scenarios with these alternate fossil energy projections were also evaluated.

Renewable Resources Characterization

The United States has diverse and abundant renewable resources, including biomass, geothermal, hydropower, ocean, solar, and wind resources. Solar and wind are the most abundant of these resources. These renewable resources are geographically constrained but widespread—most are distributed across all or most of the contiguous states (Figure ES-2). Within these broad resource types, a variety of commercially available renewable electricity generation technologies have been deployed in the United States and other countries, including stand-alone biopower, co-fired

[16] The low-demand scenarios assume an annual growth rate of 0.17%; the high-demand scenarios assume an annual growth rate of 0.84%. Details on end-use energy demand assumptions are provided in Volume 3 of this report.
[17] For comparison, all high renewable electricity scenarios require a baseline or reference scenario that uses the same high-level assumptions regarding electricity demand.
[18] Consistent with the study's focus on commercially available renewable generation technologies, emerging fossil and nuclear technologies, such as carbon-capture and sequestration and modular nuclear plants, were not included.

biopower (in coal plants), hydrothermal geothermal, hydropower, distributed PV, utility-scale PV, CSP,[19] onshore wind, and fixed-bottom offshore wind.

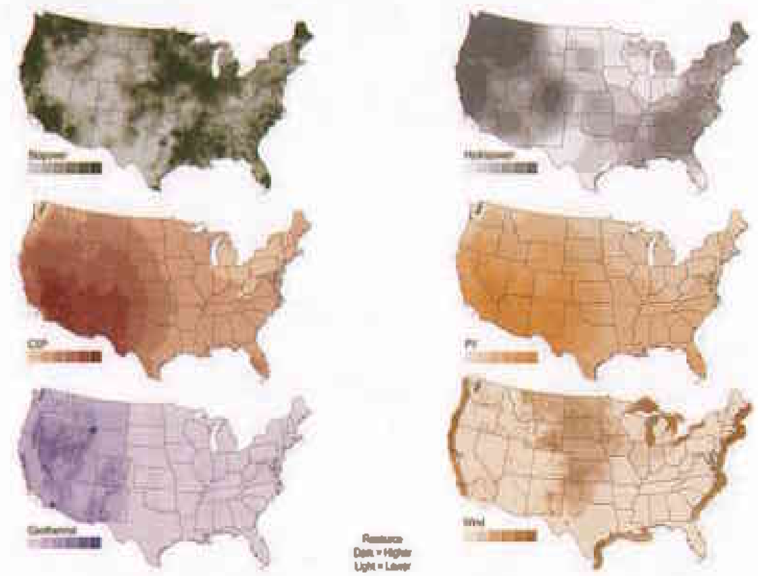


Figure ES-2. Geographic distribution of renewable resources in the contiguous United States

The United States has potential ocean energy and enhanced geothermal resources, however, these technologies were not modeled and therefore the resource potential is not included in this figure

While only commercially available biomass, geothermal, hydropower, solar PV, CSP, and wind-powered systems were considered in the modeling analysis—only incremental and evolutionary advances in renewable technologies were assumed—the study describes a broad range of commercial and emerging renewable energy technologies in Volume 2, including the following[20]

[19] In this report, CSP refers to concentrating solar thermal power. Concentrating photovoltaic technologies were not considered in the modeling analysis.
[20] The renewable resource characterizations described below and used in the models are based on historical climatic average resource patterns and have standard land area exclusions applied. After accounting for these standard exclusions, the aggregate renewable generation resource is many times greater than current electricity demand

- **Biomass power** (Chapter 6, Volume 2) is generated by collecting and combusting plant matter and using the heat to drive a steam turbine. Biomass resources from agricultural and forest residues, although concentrated primarily in the Midwest and Southeast, are available throughout the United States. While biomass supply is currently limited, increased supply is possible in the future from increased production from energy crops and advanced harvesting technologies. DOE (2011) provides an estimate of 696–1,184 million annual dry tonnes of biomass inventory potential (of which 52%–61% represents dedicated biomass crops) in 2030.[21] The estimated biomass feedstocks correspond to roughly 100 GW of dedicated biopower capacity. Biopower can be generated from stand-alone plants, or biomass can be co-fired in traditional pulverized coal plants.
- **Geothermal power** (Chapter 7, Volume 2) is generated by water that is heated by hot underground rocks to drive a steam turbine. Geothermal resources are generally concentrated in the western United States, and they are relatively limited for hydrothermal technologies (36 GW of new technical resource potential), which rely on natural hot water or steam reservoirs with appropriate flow characteristics. Only commercially available hydrothermal technologies were included in the modeling analysis. Although not modeled, emerging technologies, including enhanced geothermal systems, engineered hydrothermal reservoirs, geopressured resources, low temperature resources, or co-production from oil and gas wells, could expand the geothermal resource potential in the United States by more than 500 GW.
- **Hydropower** (Chapter 8, Volume 2) is generated by using water—from a reservoir or run-of-river—to drive a hydropower turbine. Run-of-river technology could produce electricity without creating large inundated areas, and many existing dams could be equipped to generate electricity. The future technical potential of run-of-river hydropower from within the contiguous United States is estimated at 152–228 GW. Only new run-of-river hydropower capacity was considered in RE Futures modeling, and existing hydropower plants were assumed to continue operation. Other hydropower technologies, such as new generation at non-powered dams and constructed waterways, have the potential to contribute to future electricity supply, but they were not modeled in this study.
- **Ocean technologies** (Chapter 9, Volume 2) are not broadly commercially available at this time, and therefore were not modeled in this study, but both U.S. and international research and development programs are working to reduce the cost of the technologies. Ocean current resources are best on the U.S. Gulf and South Atlantic Coasts, wave energy resources are strongest on the West Coast. All resources are uncertain; preliminary estimates indicate that the U.S. wave energy technical potential is on the order of 2,500 TWh/yr. Other ocean technologies, including ocean thermal energy conversion technologies and tidal technologies, may also contribute to future electricity supply.

[21] To be conservative, for each modeled year, the analysis used feedstock estimates from Walsh et al. (2000) and Milbrandt et al. (2005), which are consistent with the low end of the DOE (2011) estimate for 2030, and did not assume any increase in resource over time; on the other hand, the analysis also did not include potential future growth in demand for biomass from the fuel sector. Maximum biopower capacity deployment was assumed to be roughly 100 GW in this study, with 27% from dedicated biomass crops.

- **Solar resources** (Chapter 10, Volume 2) are the most abundant renewable resources. They extend across the entire United States, with the highest quality resources concentrated in the Southwest. The technical potential of utility-scale PV and CSP technologies is estimated to be approximately 80,000 GW and 37,000 GW, respectively, in the United States. Distributed rooftop PV technologies are more limited, with approximately 700 GW available. PV technologies convert sunlight directly to electricity while CSP technologies collect high temperature heat to drive a steam turbine.
- **Wind resources** (Chapter 11, Volume 2) on land are abundant, extending throughout the United States, and offshore resources provide additional options for coastal and Great Lakes regions. Onshore and fixed-bottom offshore technologies are currently commercially available.[22] Floating platform offshore wind technologies that could access high-quality wind resources in deeper waters are less mature and were not considered in the modeling. Wind technical resource estimates exceed 10,000 GW in the contiguous United States.

Renewable resource supply varies by location and, in most cases, by the time of day and season. The electricity output characteristics of some renewable energy technologies also vary substantially, potentially introducing electric system operation challenges. A key performance characteristic of generators in general is their degree of dispatchability, specifically the ability of operators to control power plant output over a range of specified output generation levels. Conventional fossil plants are considered dispatchable, to varying degrees. Several renewable generator types, including biopower, geothermal, and hydropower plants with reservoir storage, are also considered dispatchable technologies in that system operators have some ability to specify generator output, if needed. Concentrating solar power with thermal storage can similarly be considered a dispatchable technology but is limited by the amount of storage. The output from run-of-river hydropower is generally constant over short time periods (minutes to hours) but varies over longer periods (days to seasons). Several emerging ocean technologies, such as ocean-current, may also provide fairly constant output and, in some cases, may be able to offer some level of dispatchability.

Wind and solar PV have little dispatchability—the output from these sources can be reduced, but not increased on demand. An additional challenge is the variability and uncertainty in the output profile of these resources, with wind and solar having limited predictability over various time scales. High levels of deployment of these generation types can therefore introduce new challenges to the task of ensuring reliable grid operation. However, it deserves note that the requirement for balanced supply and demand must be met on an *aggregate* basis—the variability and uncertainty of any individual plant or load entity does not ultimately define the integration challenge associated with high levels of variable renewable generation.

The analysis presented here focuses on electricity generation technology deployment, system operational challenges, and implications associated with specified levels of renewable generation, which represent the total annual renewable electricity generation from commercially available biomass, geothermal, hydropower, solar, and wind electricity generating technologies.

[22] Although there are no offshore wind power plants operating in the United States, a number of projects have been proposed. In addition, offshore wind is widely deployed in Europe.

U.S. Electricity Grid Expansion and Operational Characterization

RE Futures employs two key models to characterize U.S. electricity grid operations with high levels of renewable generation. The NREL Regional Energy Deployment System (ReEDS) model explores the adequacy of the geographically diverse U.S. renewable resources to meet electricity demand over future decades. The ABB model, GridView, explores the hourly operation of the U.S. grid with high levels of variable PV and wind generation.[23] The linked-but-separate use of the two models, ReEDS and GridView, allows for a rich assessment of the technical, geographic, and operational aspects of renewable energy deployment.[24]

ReEDS is the analytical backbone of the study, providing estimates of the type and location of conventional and renewable resource development; the transmission infrastructure expansion requirements of those installations; and the composition and location of generation, storage, and demand-side technologies needed to maintain balance between supply and demand. ReEDS is unique among national, long-term capacity expansion models for its highly discretized regional structure and statistical treatment of the impact of variable wind and solar resources on capacity planning and dispatch. GridView was used to supplement the ReEDS analysis by modeling the hourly operation of the power system in 2050 for a subset of the high renewable scenarios. As one of the commercially available production cost models used by utilities, systems operators, and industry experts, GridView enables a more detailed exploration of the operational implications of a system with high levels of renewable electricity penetration through the use of an hourly time step, a more accurate representation of thermal generation ramp-rate limits, and a more realistic representation of transmission power flows compared with ReEDS.

These models were used to investigate a broad portfolio of supply- and demand-side options available to increase the flexibility of the electric system, including: having dispatchable renewable or conventional generators available to supply needed electricity when there is insufficient electricity generation from variable renewable plants, having the ability to provide reserves or change electricity demand through demand response (interruptible load) or transportation electric loads, deploying storage technologies for added system flexibility; and expanding the electric system transmission infrastructure to move more distant electricity supply to meet the load. Geospatial diversity was also taken into account, since it can assist in the integration of variable renewable generation because wind and solar plants that are located far apart generally have a combined output profile that is less variable than the individual plant profiles. Further, wind and solar resources may be uncorrelated or even anti-correlated depending on location; if so, combining their outputs would then further reduce aggregate variability.

[23] The NREL Solar Deployment Systems (SolarDS) model was also used in RE Futures to represent rooftop PV deployment.

[24] In assessing high penetrations of variable renewable electricity, RE Futures addressed some aspects of electric system adequacy through statistical treatments of reserve requirements and hourly dispatch analysis; however, the analysis did not include a complete assessment of power system reliability (addressing such issues as stability, contingencies, and AC power flows). Similarly, RE Futures is not a fully detailed renewable energy integration study. Such studies typically seek to understand the impacts of variable and uncertain wind and solar generation on the operations of regional electric power systems and networks, relying on high time-resolution data and using methods that range from statistical analysis and production cost modeling to power flow simulations and steady state and transient grid analysis. RE Futures assessed electric system integration issues on a broader, national level, and the modeling tools used considered the variability and uncertainty of some renewable technologies, but not to the level of detail typical in integration studies.

Key Results

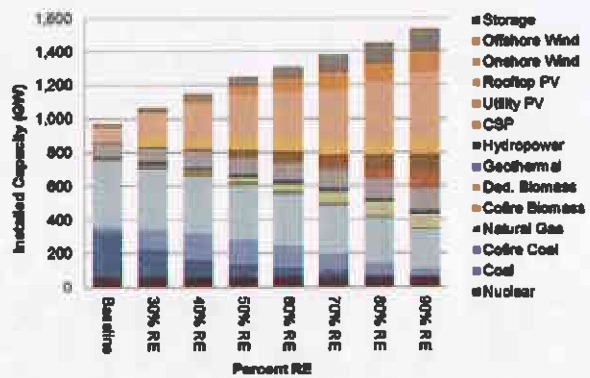
Deployment of Renewable Energy Technologies in High Renewable Electricity Futures

Renewable energy resources, accessed with commercially available renewable generation technologies, could adequately supply 80% of total U.S. electricity generation in 2050 while balancing supply and demand at the hourly level. Figure ES-3 presents estimated 2050 capacity and generation, by technology, for the exploratory scenarios.[25] Generation from wind and PV technologies is variable, with lower capacity factors and relatively limited dispatchability. The growing deployment of this variable generation in these scenarios, increasing with renewable electricity penetration (from 20% in the baseline scenario to as high as 90% at the other end), drives the need for a growing amount of aggregate electric generation capacity in order to meet demand. Specifically, adequate capacity from dispatchable resources is required to ensure delivery of necessary generation year-round.

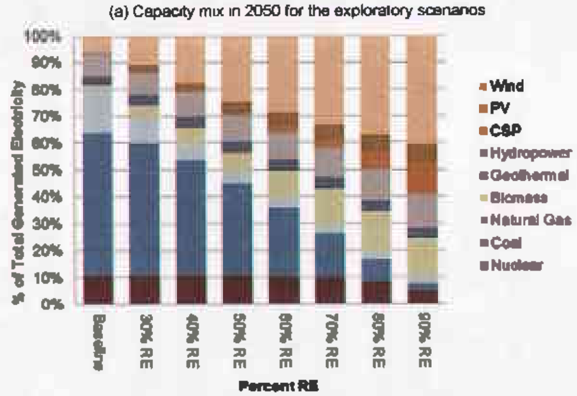
Commercially available renewable technologies were deployed in the modeling to varying degrees in the exploratory scenarios, in part to exploit geographic and temporal diversity in achieving high renewable electricity penetration levels. Onshore wind was found to contribute most significantly in these exploratory scenarios, with offshore wind becoming an increasingly important player as higher renewable electricity levels were achieved. Among the solar technologies, PV (utility-scale and rooftop, combined) was generally found to play a more-sizable role than CSP under the relatively lower renewable penetration scenarios. Electricity supply from CSP was projected to grow more rapidly under the higher renewable penetration scenarios, in part because CSP with thermal storage provides added dispatchability. Both dedicated and co-fired biomass were also found to contribute significantly to the renewable energy mix, with a shift from co-firing to dedicated biomass plants as renewable electricity penetration levels increased. Geothermal and hydropower were found to contribute proportionately less than the other renewable energy sources, especially under the highest renewable electricity scenarios considered, due to assumed resource and cost constraints.[26] However, even for this limited set of geothermal and hydropower resources, capacity expansion was substantial relative to recent trends, and much of the estimated available resource potential was accessed. Enhanced geothermal systems, ocean energy, and floating platform offshore wind energy were not considered, but these technologies may offer large resource potential, additional diversity, and regional advantages if technological advancements enable commercialization.

[25] Deployment results shown in Figure ES-3 used the renewable electricity incremental technology improvement (RE-ITI) assumptions. Results for the RE-ETI scenarios are included in Chapter 2.

[26] The assumptions used in the analysis were particularly constraining on geothermal technologies, for which advanced technologies, such as enhanced geothermal systems that can tap large quantities of energy inside the earth, were not considered in the grid modeling. The modeling analysis focused on currently commercial technologies only.



(a) Capacity mix in 2050 for the exploratory scenarios



(b) Generation mix in 2050 for the exploratory scenarios

Figure ES-3. Installed capacity and generation in 2050 as renewable electricity levels increase (low-demand, RE-ITI technology improvement)

All regions of the United States could contribute substantial renewable electricity supply in 2050, consistent with their local renewable resource base Figure ES-4 presents the modeled location of renewable electricity generation and capacity by 2050 for one 80%-by-2050 RE scenario (80% RE-ITI) It also compares total regional electricity generated in 2050 to regional electricity demand (based on low-demand assumptions) In the scenario shown, wind energy supply was significant in most regions but was most prominent in the Great Plains, Great Lakes, Central, Northeast, and Mid Atlantic regions (with a large fraction of wind generation coming from offshore resources in the Northeast and Mid Atlantic regions) Solar energy was found to deploy most substantially in the Southwest (dominated by CSP), followed by California and Texas (CSP and PV), and then by the Florida and the Southeast regions (dominated by PV) Biomass supply was most significant in the Great Plains, Great Lakes, Central, and Southeast regions Hydropower supply was most significant in the Northwest, but hydropower was also a sizable contributor in California, the Northeast, and the Southeast Geothermal was found to deploy primarily in California and the Southwest

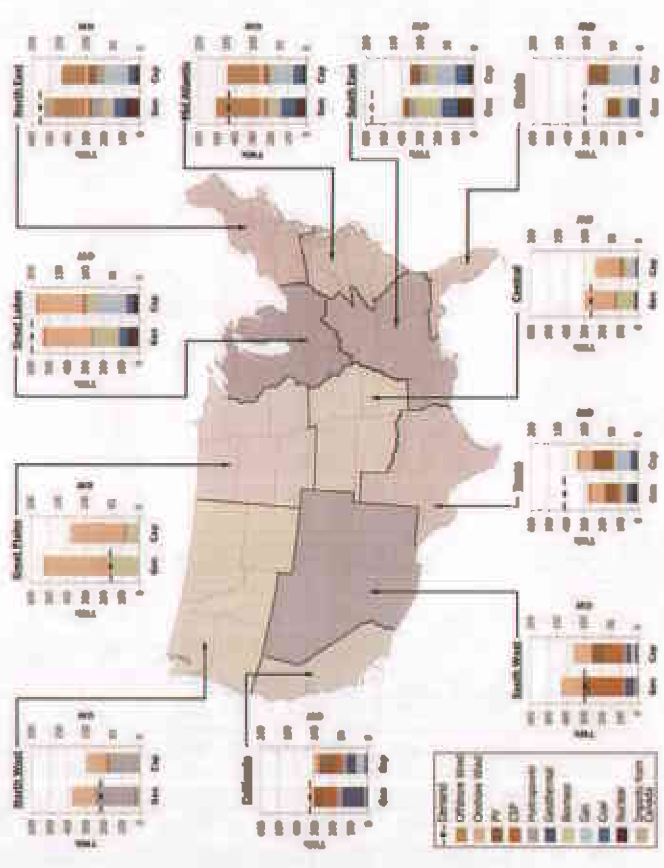


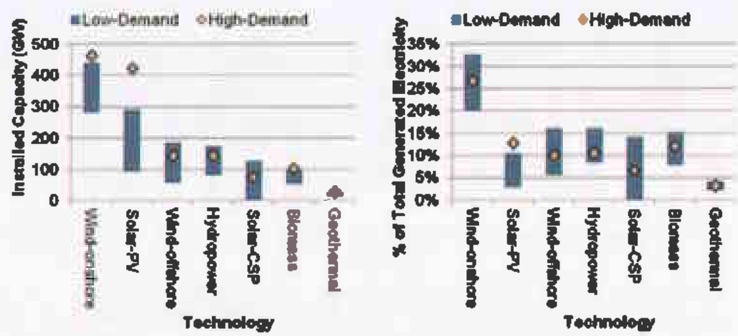
Figure ES-4. Renewable generation and capacity in 2050 by region under 80% RE-ITI scenario (low-demand, RE-ITI technology improvement)

Multiple technology pathways exist to achieve a high renewable electricity future Assumed constraints, which limit power transmission infrastructure, grid flexibility, or the use of particular types of resources can be compensated for through the use of other resources, technologies, and approaches. The renewable energy resource base of the United States is both abundant and diverse As a result, a central finding of the analysis is that there are many possible ways to achieve high renewable penetration levels

For example, the technology improvement scenarios included in the six core 80% RE scenarios (Impact of Technology Improvement scenarios) showed that technologies that are currently at earlier stages of commercialization (e g , solar) could achieve greater deployment if significant technology improvements were realized in the future In contrast, if these improvements were not realized, currently more commercially mature technologies (e g , onshore wind) could deploy to a greater extent Also, a set of scenarios included in the core 80% RE scenarios explored the impacts of limits on building new transmission, constraints on the flexibility of the electric system to manage the variability of wind and solar resources, and constraints on the developable potential for many renewable technologies (Impact of System Constraints scenarios) The mix of renewable resources deployed and the deployment of flexible supply- and demand-side technologies were significantly impacted in these scenarios In particular, when new transmission builds were constrained, greater deployment was observed for resources located closer to load centers, including PV, offshore wind, and biomass A future where the flexibility of the electric system was limited resulted in a shift of renewable electricity supply away from variable wind and PV technologies and toward more dispatchable options, particularly CSP with thermal storage, and to storage technologies When the assumed availability of renewable energy supply was reduced—due to siting or permitting challenges, for example—the contributions from the most resource-constrained technologies (biopower, geothermal, and hydropower) declined, while more abundant wind and solar resources were used to a greater degree Figure ES-5 shows the range in 2050 capacity and generation by technology among the six low-demand 80%-by-2050 RE scenarios examined Although the type and quantity of renewable technologies deployed in these scenarios varied significantly, estimated direct electric sector aggregate cost was relatively insensitive to most of these variations.[27]

Finally, the analysis found that the renewable resource base in the United States was sufficient to support 80% renewable electricity generation by 2050 in a higher demand growth scenario Figure ES-5 also shows 2050 deployment results for the High-Demand 80%-by-2050 RE scenario, which features a much greater amount of solar capacity compared with the low-demand scenarios

[27] See individual technology chapters in Volume 2 for a discussion of the specific scenarios that lead to high and low estimates for each technology individually; Volume 1 provides more discussion of the operational and cost implications these scenarios.



(a) 2050 installed capacity by technology

(b) 2050 contribution to total generated electricity

Figure ES-5. Range of 2050 installed capacity and annual generated electricity by technology for the low-demand core 80% RE scenarios and the High-Demand 80% RE scenario

Annual renewable capacity additions that enable high renewable electricity are consistent with current global production capacities but are significantly higher than recent U.S. annual capacity additions for the technologies considered No insurmountable long-term constraints to renewable electricity technology manufacturing capacity, materials supply, or labor availability were identified. The analysis showed that achieving high renewable electricity futures would require a sustained increase in renewable capacity additions In the core 80% RE scenarios, average annual renewable capacity additions of 19–22 GW/yr from 2011–2020 were estimated, increasing to a maximum rate of 32–46 GW/yr from 2041–2050 Given recent historical experience with U.S. renewable electricity capacity additions (11 GW in 2009 and 7 GW in 2010),[28] achieving these rates of deployment may pose challenges as production ramps up, including those related to materials availability, equipment manufacturing capacity, labor needs, and project development and siting processes However, no insurmountable long-term technical constraints to renewable technology manufacturing capacity, materials supply, or labor availability were identified; better informed siting practices and regulations can mitigate potential constraints related to project development and siting processes (see Chapter 3 and Volume 2)

Growth in renewable capacity additions in the United States and globally over the last decade has been considerable, and it demonstrates the ability to scale manufacturing and deployment at a rapid pace The wind power additions required in the scenarios, for example, were substantial,

[28] The challenges associated with the rates of deployment presented here depend on technology. For example, renewable installations in the United States in recent years were dominated by new wind technologies; therefore, achieving the deployment rates envisioned in the scenarios for wind energy would likely be less challenging from an industry growth perspective compared with other technologies

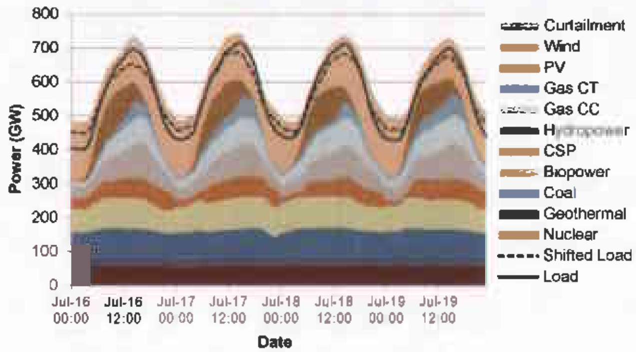
but historical growth in manufacturing and installation suggests that manufacturing need not be a major constraint to the continued growth that would be necessary to meet an 80%-by-2050 generation level The biopower and geothermal additions resulting from the scenario modeling, although greater than recent historical trends, are similarly unlikely to place undue strain on supply chains The estimated rate of PV deployment is particularly high, but PV manufacturing and deployment are highly scalable, and worldwide PV production capacity has been growing rapidly and is already comparable to the deployment rates projected in high renewable scenarios presented here for the United States Moreover, many of the renewable technologies are based on common materials that are not supply-constrained Even for PV, which does use some materials that may be supply-constrained, worldwide production capacity is already sizable and that capacity continues to expand rapidly In addition, alternate approaches exist to reduce dependence on supply-constrained materials if necessary While a comprehensive analysis of industry scale-up, including labor demands and access to critical materials, is beyond the study scope, the initial analysis did not identify any insurmountable technical challenges associated with industry scale-up at the technology deployment levels considered

Grid Operability and Hourly Resource Adequacy in High Renewable Electricity Futures

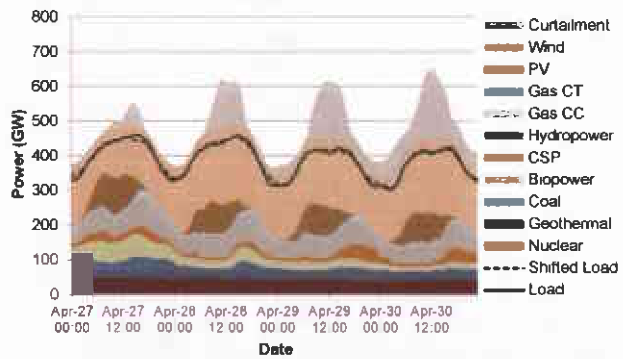
Electricity supply and demand can be balanced in every hour of the year in each region with nearly 80% of electricity from renewable resources, including nearly 50% from variable renewable generation, according to simulations of 2050 power system operations.[29] Although a full reliability assessment is beyond the scope of this analysis, hourly production simulation did consider unit commitment with imperfect forecasts, DC optimal power flow, and thermal generator flexibility limits (e g , ramp rates and minimum generation levels) Figure ES-6 shows nationwide dispatch by generator type during the annual peak coincident load (Figure ES-6[a]) and during the lowest coincident load of the year (Figure ES-6[b]) in 2050 for a high renewable electricity scenario The operational simulations did not project any hours of unserved load during the peak load hour, lowest coincident load hour, or any other hour of the year [30]

[29] Although the capacity expansion modeling (ReEDS) planned for renewable resources to contribute 80% of annual generation in 2050, the hourly operational model (GridView) simulated roughly 75%, in part due to a lack of a renewable generation requirement GridView model dispatch decisions were based on the variable cost of generation and did not consider the renewable or non-renewable nature of the generation source.

[30] The electric system is a complex system of systems that operates on many time scales ranging from milliseconds to years, ultimately, analyses must be conducted to address all of the potential operating aspects of future electricity generation systems as they evolve Electric system operations are described in detail in Volume 4



(a) Summer peak load in 2050



(b) Lowest coincident load in 2050

Figure ES-6. Hourly dispatch stacks for the 80% RE-ITI scenario[a]

[a] The solid black line representing "load" includes charging of electric vehicles The broken line representing "shifted load" represents "load" minus storage The Gas CT category includes a small number of oil-fired units The unit types are ordered (subjectively) from least variable or flexible (at the bottom) to most variable (at the top)

Additional challenges to power system planning and operation would arise in a high renewable electricity future, including management of low-demand periods and curtailment of excess electricity generation The hourly analysis also found that, in contrast to today's fossil-fuel-dominated electricity system for which the time of peak load (e g., summer afternoons) is of most concern, operational challenges for high renewable generation scenarios were most acute during low-demand periods (e g , spring evenings) when the abundance of renewable supply relative to demand would force thermal generators to cycle or ramp down to their minimum generation levels [31] During low-demand periods in today's system and in the baseline scenario, most of the peaking needs are met with hydropower and combined cycle units; combustion turbines are needed but to a much lesser extent than in the summer Although the load characteristics in 2050 are similar in the baseline scenario and the high renewable scenarios, during low-demand periods in the latter (e g , Figure ES-6[b]), there was enough aggregate renewable electricity to fully serve load, causing the net load (load minus variable wind and PV generation) to be much more variable compared to the rest of the year This increased variability in net load creates challenges associated with greater power plant cycling and ramping

A primary challenge of variable renewable energy integration at higher levels of penetration is the need at times to curtail excess electricity, particularly during periods with low electricity demands [32] The hourly dispatch analysis estimated that overall in 2050, 8%–10% of wind, solar, and hydropower generation would need to be curtailed under an 80%-by-2050 RE scenario Curtailments reduce capacity factors and introduce uncertainty in electricity sales, thereby negatively impacting plant economics A variety of technical and institutional approaches could be applied to reduce these levels of curtailment First, additional transmission capacity in congested corridors would help alleviate congestion and reduce curtailment Second, increasing the size of reserve-sharing groups could help reduce the number of inflexible generators online to provide spinning reserves; curtailment of renewable generation could be reduced if fewer plants operate at minimum levels Third, the flexibility of the thermal fleet could be improved, or market structures could be implemented to encourage the operation of more flexible generators Fourth, additional energy storage and controllable loads could be used to improve system flexibility Finally, new or existing industries could take advantage of the low-cost electricity available during seasons or times when curtailment would have occurred, and the resulting increased demand could then consume electricity that otherwise would have been curtailed

Electric sector modeling shows that a more flexible system is needed to accommodate increasing levels of renewable generation System flexibility can be increased using a broad portfolio of supply- and demand-side options and will likely require technology advances, new operating procedures, evolved business models, and new market rules As renewable electricity generation increased from 20% in the baseline scenario to 90% in the exploratory scenarios, the annual contribution from *variable* generation (wind and solar PV) grew from 7% to 48% in 2050 At

[31] Peak load still requires management and will be challenging for the same reasons it is today, but in addition, management of low-demand periods and curtailment will be required with high variable renewable electricity.

[32] This situation parallels the use of combustion turbines in conventional systems, which are typically used just a few hundred hours per year to meet summer peak loads and are largely idle much of the rest of the year As such, both the conventional and the high renewable electricity systems operate with excess capacity most of the time While the high renewable system generates power with the excess capacity as long as resources are available, the conventional system simply leaves the excess capacity idle

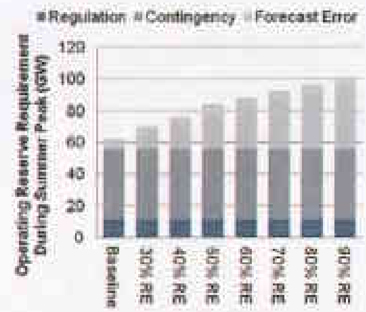
this high level of variable generation, ensuring a real-time balance between electricity supply and demand is more challenging The variability and uncertainty associated with these high levels of wind and PV penetration were found to be manageable through the application of adequate flexible generation capacity, the use of grid storage and demand-side technologies, the expansion of transmission infrastructure, and greater conventional plant dispatch flexibility, including significant daily ramping of fossil generators (Dispatchable renewable technologies, like conventional technologies, do not impose significant additional challenges to system operability, and they are also used to help manage wind and solar PV integration)

The RE Futures analysis considers reserves necessary for reliable electric system operations, spanning a wide range of timescales (from long-term planning reserves to short-term operating reserves) The same capacity reserve margin requirements were satisfied across all scenarios despite the relatively low capacity values of variable resources and their increasing deployment as renewable penetration increased Partly to satisfy planning reserve requirements, greater aggregate capacity was needed in high penetration renewable scenarios (see Figure ES-3)

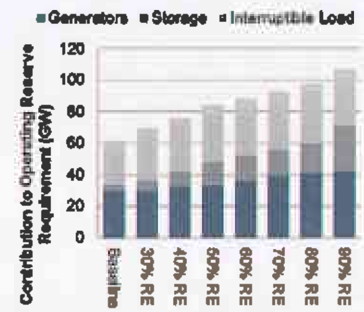
Additional operating reserves were also found to be required in high variable renewable generation systems and were accommodated through the availability of conventional power plants, storage technologies, and demand-side practices The analysis included multiple components of operating reserves, namely contingency reserves, frequency regulation reserves, and reserves associated with imperfect forecasts of wind and PV generation Figure ES-7 shows how operating reserve requirements increased as renewable deployment increased and the different options used to meet these requirements in the exploratory scenarios.[33] Although operating reserve *requirements* increase with wind and PV deployment (due to greater forecast errors), because the dispatch of existing conventional power plants declines to accommodate additional wind and PV generation, these existing conventional units were found to be more available to satisfy the necessary operating reserve requirements In other words, a high renewable electricity future would reduce the energy-providing role of the conventional fleet and increase its reserve-providing role

The analysis found use of storage to be an attractive option to increase electric system flexibility due to the ability of storage to shift load to better correlate with output from variable generators, reduce curtailments by storing excess generation in times of low demand, and provide firm capacity for a variety of reserve services In the core 80% RE scenarios, for example, storage deployment was found to increase from approximately 20 GW in 2010 to 100-152 GW in 2050 Demand-side options were also found to play a significant role in meeting the integration challenges of a high renewable electricity future For example, in the core 80% RE scenarios, 28–48 GW of demand-side interruptible load were deployed in 2050, compared with just 15 6 GW deployed in 2009

[33] In Figure ES-7, the total contribution to operating reserves exceeds the requirement due to the fact that only one time (summer peak) is shown, while certain reserve-types (e g , interruptible load) are annual in nature and deployed to serve other times not shown



(a) 2050 operating reserve requirement during the summer peak by reserve type



(b) 2050 contributions toward total operating reserve requirement by technology type

Figure ES-7. Operating reserve requirements as renewable electricity levels increase

The RE Futures analysis suggests that variable generation levels of up to nearly 50% of annual electricity can be accommodated when a broad portfolio of supply- and demand-side flexibility resources is available at a level substantially higher than in today's electricity system A broad portfolio of flexible supply- and demand-side resources and options were made available in the scenario modeling, and were relied upon particularly in the high renewable generation scenarios, including

- Maintaining sufficient capacity on the system for planning reserves
- Relying on demand-side interruptible load, conventional generators (particularly natural gas generators), and storage to manage increased operating reserve requirements
- Mitigating curtailment with storage and controlled charging of electric vehicles
- Operating the system with greater conventional power plant ramping
- Relying on the dispatchability of certain renewable technologies (e g , biopower, geothermal, CSP with storage and hydropower)
- Leveraging the geospatial diversity of the variable resources to smooth output ramping
- Transmitting greater amounts of power over longer distances to smooth electricity demand profiles and meet load with remote generation

Achieving the system flexibility required to integrate high levels of renewable generation will require some combination of technology advances, new operating procedures, evolved business models, and new market rules. Although the analysis does not examine how these mechanisms could be implemented, it does describe the power system flexibility characteristics needed for the integration of high levels of renewable generation

Transmission Expansion in High Renewable Electricity Futures

As renewable electricity generation increases, additional transmission infrastructure is required to deliver generation from cost-effective remote renewable resources to load centers, enable reserve sharing over greater distances, and smooth output profiles of variable resources by enabling greater geospatial diversity Many of the system flexibility resources and options described above can benefit from transmission infrastructure enhancements to enable the transfer of power and sharing of reserves over large areas to accommodate the variability of wind and solar electricity generation in combination with variability in electricity demand With high penetrations of variable generation, net load (load minus variable generation) in a specific region can show dramatic ramps Transmission between regions helps reduce ramps in net load because it allows system operators to access a larger pool and more diverse mix of variable generation, with some smoothing of output profiles and demand profiles over larger geographic areas Figure ES-8 shows projected new transmission capacity deployed over the 40-year study period for the exploratory scenarios Demands for new transmission capacity are much greater in the higher renewable generation scenarios than in lower renewable generation scenarios, outstripping the effects of the low-demand assumption, reductions in transmission use by conventional fossil generation (freeing up the lines for renewable generation), and deployment of renewable resources that are proximate to load centers (e g , PV and offshore wind) [34] The increase in transmission needs as renewable electricity supply grows, for all 80%-by-2050 renewable electricity scenarios, result in an average annual projected transmission and interconnection investment that is within the recent historical range for total investor-owned utility transmission expenditures in the United States (i e , $2 billion/yr to $9 billion/yr from 1995 through 2008) (Pfeifenberger et al 2009)

[34] The analysis assumed that the existing transmission infrastructure is operational throughout the study period and did not consider maintenance needs for the existing transmission lines or other infrastructure In addition, the analysis did not consider distribution-level maintenance or upgrades

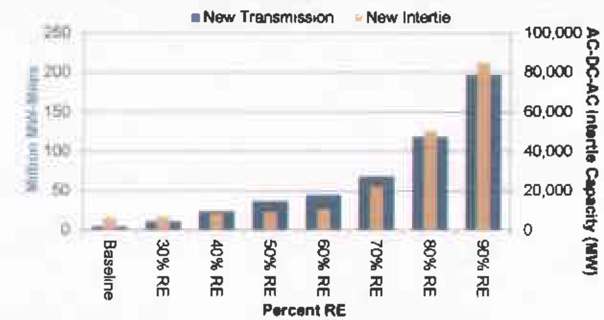


Figure ES-8. New transmission capacity requirements in the baseline and exploratory scenarios

Existing total transmission capacity in the contiguous United States is estimated at 150–200 million MW-miles[35]

New transmission in the high renewable electricity scenarios was found to be concentrated in the middle and southwestern regions of the United States, mainly to access the high-quality wind and solar resources in those regions and to deliver generation from those resources to load centers For example, Figure ES-9 presents a conceptual map of new transmission infrastructure needed in an 80%-by-2050 scenario As shown in Figure ES-9 and quantified in Figure ES-8, the current isolation of the three asynchronous interconnections—Western Electricity Coordinating Council (WECC), Electric Reliability Council of Texas (ERCOT), and Eastern Interconnection—was greatly reduced in many of the high renewable electricity scenarios through the expansion of AC-DC-AC interties This expansion enabled the East to have greater access to the high-quality renewable resources located in the western United States, although the hourly simulations and DC transmission power flow analysis suggests that these east-west transmission linkages were used bi-directionally to manage temporal variations in electricity supply and demand Expanding interties between the three asynchronous interconnections was found to be desirable in many of the high renewable scenarios, however, results from the Constrained Transmission scenario showed that an 80%-by-2050 RE scenario was achievable even when such expansion was not allowed

Significant institutional obstacles, including constraints in siting new transmission lines, cost allocation concerns with transmission projects, and coordination between multiple governing entities, currently inhibit transmission expansion The mechanisms to overcome these obstacles were not explored in the study, but the analysis demonstrates that additional long-distance transmission capacity can be an important characteristic of high renewable electricity futures

[35] The ReEDS model assumed 150 million MW-miles of existing inter-BA transmission capacity; the 200 million MW-mile estimate is from Homeland Security Infrastructure Database (2008) and other sources

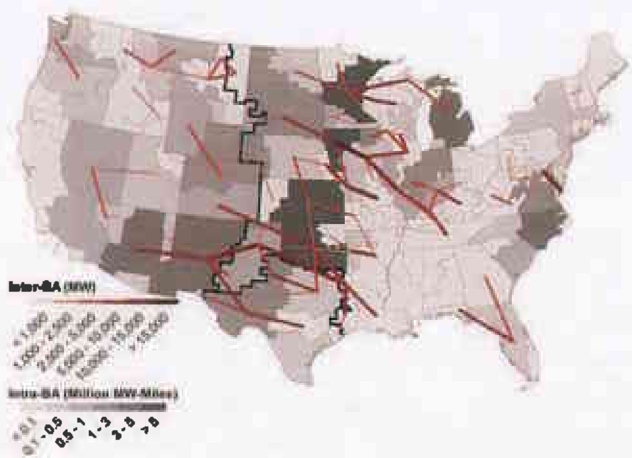


Figure ES-9. New transmission capacity additions and conceptual location in the 80% RE-ITI scenario

Cost and Environmental Implications of High Renewable Electricity Futures

High renewable electricity futures can result in deep reductions in electric sector greenhouse gas emissions and water use Direct environmental and social implications are associated with the high renewable futures examined, including reduced electric sector air emissions and water use resulting from reduced fossil energy consumption, and increased land use competition and associated issues At 80% renewable electricity in 2050, annual generation from both coal-fired and natural gas-fired sources was reduced by about 80%, resulting in reductions in annual greenhouse gas emissions of about 80% (on a direct combustion basis and on a full life cycle basis) and in annual power sector water use of roughly 50% At 80% renewable electricity, gross land-use impacts associated with renewable generation facilities, storage facilities, and transmission expansion totaled less than 3% of the land area of the contiguous United States [36]

The direct incremental cost associated with high renewable generation is comparable to published cost estimates of other clean energy scenarios. Improvement in the cost and performance of renewable technologies is the most impactful lever for reducing this incremental cost. The retail electricity price implications estimated for the 80%-by-2050 RE scenarios are comparable to those seen in other studies with similarly transformative electricity futures, as shown on Figure ES-10. Low carbon and clean energy scenarios, evaluated by the U S Energy Information Administration (EIA) and the U S Environmental Protection Agency (EPA), with avoided carbon emissions trajectories similar to the core 80% RE scenarios showed increases in average retail electricity prices (relative to their own reference scenarios) in 2030 of $9–$26/MWh, rising to $41–$53/MWh by 2050 These studies generally considered a portfolio of clean generation technology options, including renewable, nuclear, and low emissions fossil The estimated incremental price impacts of the core 80% RE scenarios are comparable to these estimates

[36] Net land-use impacts, considering the implications of reduced conventional generation, and land-use impacts based on disrupted lands, are both expected to be smaller As an example of the latter case, disrupted land would generally be less than 5% of gross land area for wind generation facilities

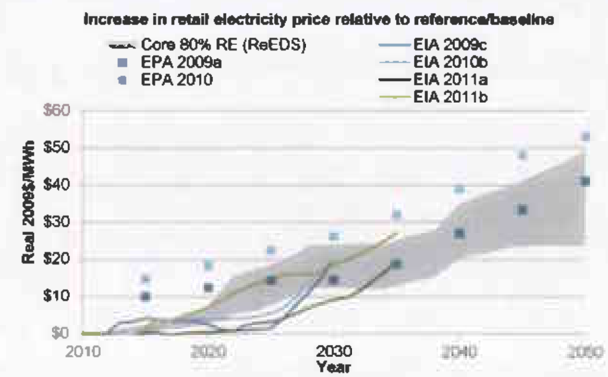


Figure ES-10. Average increase in retail electricity rates relative to study-specific reference/baseline scenarios

EIA 2011a and 2011b document analysis of clean energy scenarios EIA 2009, EPA 2009, EIA 2010, and EPA 2010 report on analysis of several low carbon emissions scenarios

As with these other clean generation scenarios that would represent a nearly wholesale transformation of the U S electricity system, the high renewable generation scenarios examined show a direct incremental cost relative to the continued evolution of today's conventional generation-dominated system Higher electricity prices associated with the high renewable scenarios are driven by replacement of existing generation plants with new generators (mostly renewable); additional balancing requirements reflected in expenditures for combustion turbines, storage, and transmission, and the assumed higher relative capital cost of renewable generation, compared to conventional technologies, assumed in the analysis The increased capital investments associated with these drivers, compared to the baseline scenario, were not fully offset by cost savings associated with lower fossil energy consumption The incremental cost does not include investments in energy efficiency implied by low electricity demand assumptions, or the savings in avoided generation resulting from these investments Further, the incremental cost estimate does not consider indirect societal costs associated with the scenarios (e g , associated with the greenhouse gas emissions described above), or economy-wide impacts

Advancements in renewable technologies, reflected by technology cost and performance improvement assumptions, had the greatest impact on the incremental cost of the high renewable generation scenarios. For example, the low end of the range of incremental electricity price shown in Figure ES-10 reflects the scenario with the highest assumed renewable technology improvement (RE-ETI), while the high end reflects the lowest technology improvement scenario (RE-NTI).[37] Assumed system constraints had more modest impact on direct incremental costs; scenarios reflecting constraints to transmission expansion, renewable resources, and grid flexibility all had similar costs, which fell well within the bounds identified in Figure ES-10. Finally, incremental costs were largely insensitive to differences in projections for fossil fuel prices and fossil technology improvements.

The lower renewable generation levels examined in the exploratory scenarios showed lower incremental 2050 retail electricity prices. For example, the 30% RE scenario under highest technology improvement assumptions (RE-ETI) showed no price increase in 2050 relative to the baseline scenario (which used RE-ITI assumptions). This result suggests that significant expansion of renewable generation beyond the 2010 level (10% of total generation) could be achieved with little or no incremental cost, assuming evolutionary improvements in renewable technologies.

There are significant inherent uncertainties with respect to future electricity demand, technology improvements, fossil energy prices, social and institutional choices, and regulatory and legislative actions related to the scenarios examined that, in turn, contribute to significant uncertainty in the implications reported above. Further, there are a variety of indirect (or downstream) implications that may result from the direct electric sector cost, environmental, and social implications identified. For example, incremental investment in generation capacity and associated infrastructure will have implications related to economic activity and employment in the energy industry. Reductions in fossil energy consumption will have environmental implications beyond air emissions, including implications related to water quality, terrestrial and marine contamination, and waste disposal, not only associated with electricity generation facilities but also for activities related to fuel extraction and transportation. Further, air emissions reductions will have implications for human health and climate change. Identification, and in some cases quantification, of these indirect implications is an active area of wide-ranging research. This analysis does not attempt to evaluate these indirect impacts of high renewable electricity futures. Further research is critically needed to systematically assess the relative impacts of different forms of energy supply in the context of a robust comprehensive framework that assesses both direct and indirect impacts. Such research could inform national energy policy decisions as well as local siting and permitting processes related to proposed generation facilities and supporting infrastructure.

Effects of Demand Growth on High Renewable Electricity Futures

With higher electricity demand growth, high levels of renewable generation present increased resource and grid integration challenges. RE Futures did not explicitly evaluate the cost effectiveness of energy efficiency adoption compared with supply-side options. However, the

[37] The RE-ETI assumptions are based on evolutionary improvements to currently commercial technologies and do not reflect DOE activities to further lower renewable technology costs so that they achieve parity with conventional technologies.

analysis suggests that under a high-demand scenario, greater and more rapid deployment of renewable and other supply- and demand-side technologies would be required. For example, while 32–46 GW/yr of renewable capacity additions were estimated from 2041 to 2050 in the low-demand core 80% RE scenarios, approximately 66 GW/yr would be needed during the same time period under a more-traditional, higher-demand trajectory. The analysis also found that in the 80%-by-2050 renewable electricity high-demand scenario, variable resources (wind and PV) were deployed to a greater extent in absolute and percentage terms than they were in the low-demand scenarios due to the greater resource available for wind and solar generation compared with other forms of renewable generation. As a consequence, additional flexible supply- and demand-side technologies, such as storage facilities, natural gas combustion turbine power plants, and interruptible load, were deployed and greater transmission expansion was needed to connect remotely located renewable resources of all types.

Higher end-use electricity demand increased the environmental impacts from the electric sector, such as greater greenhouse gas emissions, water use for thermoelectric cooling, and land use. In addition, higher demand growth also resulted in a greater increase in electricity prices. For example, in the High-Demand 80% RE scenario, the average annual retail electricity price increased by 1.3% per year (2011–2050, in real dollar terms) compared with 1.1% per year in the (low-demand) 80% RE-ITI scenario.[38] The increase in retail electricity prices driven by higher demand growth is not restricted to the high renewable penetration scenarios; it is evident under the baseline scenario as well. In particular, the average annual retail electricity price increased by 0.6% per year (2011–2050, in real dollar terms) in the High-Demand Baseline scenario compared with 0.3% per year in the Low-Demand Baseline scenario. While these results indicate that higher demand growth would lead to greater electricity price increases, they also demonstrate that the direct *incremental* costs associated with high renewable generation levels actually decreased under higher demand growth.

Conclusions

The RE Futures study assesses the extent to which future U.S. electricity demand could be supplied by commercially available renewable generation technologies—including wind, utility-scale and rooftop PV, CSP, hydropower, geothermal, and biomass—under a range of assumptions for generation technology improvement, electric system operational constraints, and electricity demand. Within the limits of the tools used and scenarios assessed, hourly simulation analysis indicates that estimated U.S. electricity demand in 2050 could be met with 80% of generation from renewable energy technologies with varying degrees of dispatchability together with a mix of flexible conventional generation and grid storage, additions of transmission, more responsive loads, and foreseeable changes in power system operations. While the analysis was based on detailed geospatially rich modeling down to the hourly timescale, the study is subject to many limitations both with respect to modeling capabilities and the many assumptions required about inherently uncertain variables, including future technological advances, institutional choices, and market conditions. Nonetheless, the analysis shows that realizing this significant transformation of the electricity sector would require:

[38] To isolate the effect of demand growth, the High-Demand 80% RE Scenario is compared with the 80% RE-ITI scenario since they both relied on the same technology improvement projection and used the same assumptions related to transmission, system flexibility, and renewable resources.

- Sustained build-up of many renewable resources in all regions of the United States
- Deployment of an appropriate mix of renewable technologies from the abundant and diverse U.S. renewable resource supply in a way that accommodates institutional or operational constraints to the electricity system, including constraints to transmission expansion, system flexibility, and resource accessibility
- Establishment of mechanisms to ensure adequate contribution to planning and operating reserves from conventional generators, dispatchable renewable generators, storage, and demand-side technologies
- Increasing the flexibility of the electric system through the adoption of some combination of storage technologies, demand-side options, ramping of conventional generation, more flexible dispatch of conventional generators, energy curtailment, and transmission
- Expansion of transmission infrastructure to enable access to diverse and remote resources and greater reserve sharing and balancing over larger geographic areas

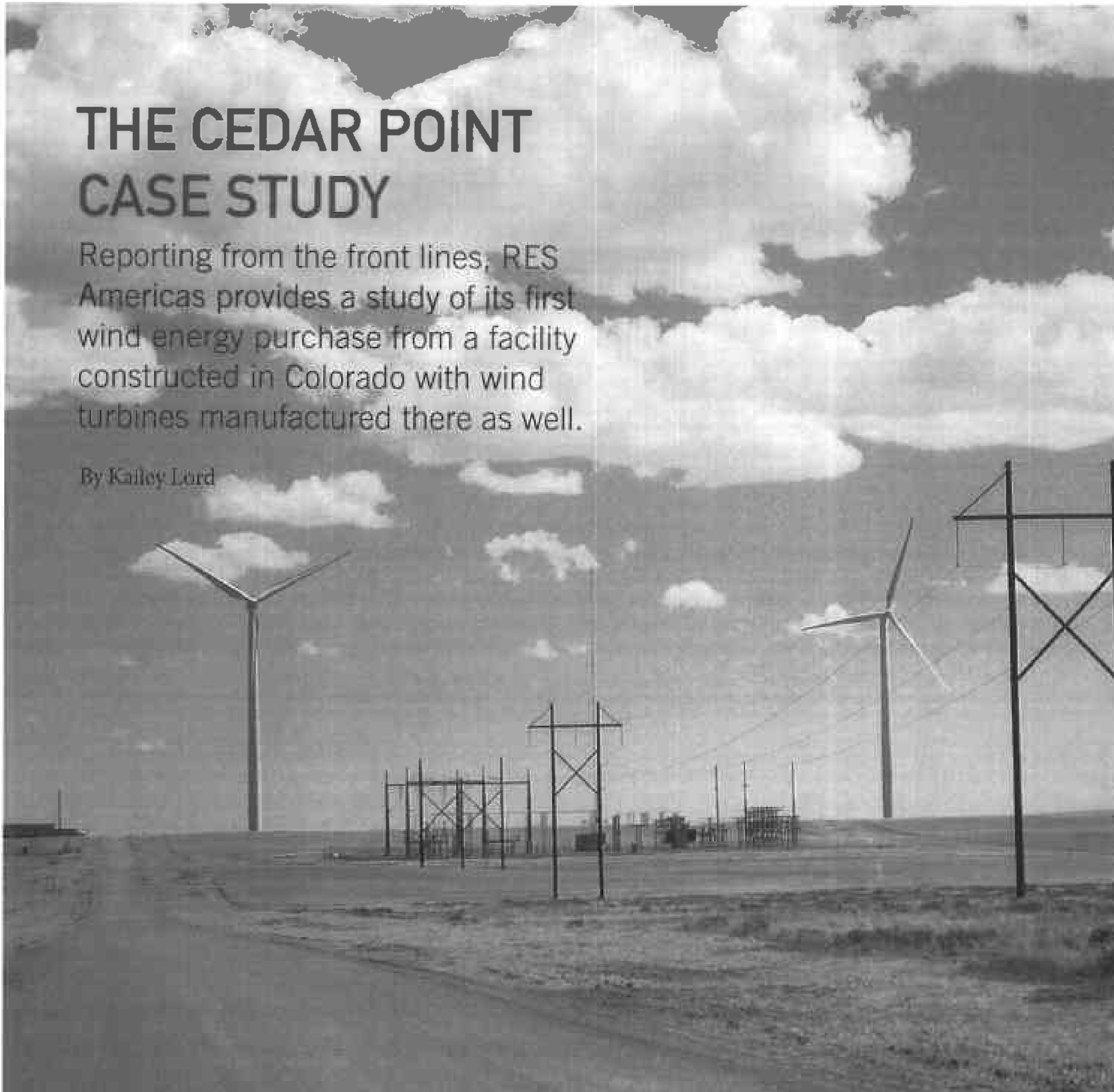
These general requirements indicate that many aspects of the electric system may need to evolve substantially for high levels of renewable electricity to be deployed. Significant further work is needed to improve the understanding of this potential evolution, such as the following:

- A comprehensive cost-benefit analysis to better understand the economic and environmental implications of high renewable electricity futures relative to today's electricity system largely based on conventional technologies and alternative futures in which other sources of clean energy are deployed at scale
- Further investigation of the more complete set of issues around all aspects of power system reliability because RE Futures only partially explores the implications of high penetrations of renewable energy for system reliability
- Improved understanding of the institutional challenges associated with the integration of high levels of renewable electricity, including development of market mechanisms that enable the emergence of flexible technology solutions and mitigate market risks for a range of stakeholders, including project developers
- Analysis of the role and implications of energy research and development activities in accelerating technology advancements and in broadening the portfolio of economically viable future renewable energy supply options and supply- and demand-side flexibility tools

THE CEDAR POINT CASE STUDY

Reporting from the front lines, RES Americas provides a study of its first wind energy purchase from a facility constructed in Colorado with wind turbines manufactured there as well.

By Kailey Lord



Kailey Lord represents RES Americas. Learn more at www.res-americas.com.

WIND INDUSTRY PROJECT DEVELOPMENT is a dynamic business. One of the key challenges is identifying and securing project sites. What makes a site attractive can vary from state to state. Good wind is essential, of course, but access to transmission, ease of permitting, and community support can also be important factors. This case study examines the development of one project that is currently under construction: Cedar Point Wind.

LOCATION, LOCATION

In 2004 Renewable Energy Systems Americas, Inc. (RES Americas), worked diligently to analyze wind resources and identify wind project sites in Colorado. The company's in-house experts, a team of experienced wind analysts, focused on a ridgeline running through Lincoln and Elbert counties in northeastern Colorado.

Eastern Colorado is a sparsely populated area. The plains experience extreme weather throughout the year, ranging from whiteout blizzards to hailstorms and tornadoes. The land is fertile and has yielded generations of cash crops for family-owned farming operations. It is also a region of blustery winds. This, combined with

Fig. 1: Cedar Point is located in Eastern Colorado, a sparsely populated area that experiences extreme weather throughout the year.

its proximity to the Denver load center, made it an attractive prospect.

RES Americas, a company that takes risk assessment very seriously, had to ensure the Cedar Point Wind Project had all these attributes: a strong, consistent wind resource, available transmission capacity, and a welcoming community with available land. The Cedar Point site passed with flying colors. Four years of wind data and research confirmed the reliability of the power generating resource, but the biggest challenge ahead would be leasing 20,000 acres of private property from multiple owners, some whose families had lived in the area for generations.

A TOPOGRAPHIC JACKPOT

The tipping point for RES America's quick move to develop Cedar Point was the geographic characteristics of the land; it was unique, even in renewable-friendly Colorado. RES Americas estimated that the site could accommodate 139 turbines, or roughly 252 megawatts (MW).

Kara Cubbage, lead developer for the project, says that "Cedar Point was a distinctive opportunity. It was a topographic jackpot. Our wind data was great and created an enormous amount of internal excitement and support for the project. Approaching the landowners and residents of the tri-county area would be the next major obstacle in getting this project off the ground and headed in the right direction. Early stage development was competitive in the region. We had to make our case to this community that Cedar Point was a candidate for successful and timely development."

Fortunately for Cubbage and RES Americas, residents in the area embraced the project from the onset. Initial leasing began in 2003, and within a year most of the land for the project was under contract. By 2007, all leasing was complete. The flat land, primarily utilized for agricultural operations, was determined to be more than suitable to host turbines and transmission facilities.

COMMUNITY RELATIONS

RES Americas made a commitment at the onset of project development to community relations. The company understood that winning over local residents and the business community in the area was as important as having landowner partners.

Through a series of open houses and other public

Fig. 2: Towers begin dotting the landscape at the Cedar Point Wind Farm

meetings, largely led by Cubbage herself, the project saw little to no resistance in the community or through the complex permitting process. Area residents recognized the community benefits immediately. They learned that construction alone would bring 100-200 temporary jobs to local contractors, and up to 12 full-time jobs after the site was operational. The area tax base would enjoy expanded revenue to benefit local schools and promote economic development in surrounding communities. Pat Vice, executive director of Lincoln County Economic Development, says that "The generation of electricity from wind produces revenue for farmers and ranchers and benefits rural communities by the creation of new jobs during construction, for ongoing maintenance, and as tax revenue supporting local schools and hospitals."

TRANSMISSION AND OFFTAKE

Like most states, Colorado is diligently working on the expansion of transmission capacity to carry much-needed power from generators—whether renewable or fossil fuel—to load centers where it will be used. Windy sites are not always right next to substations or other points of interconnection to the electrical grid. This was the case with Cedar Point, and it posed a significant hurdle.

The RES Americas team faced a great challenge in identifying a spot on the grid where power could be delivered upon project completion without additional grid construction, which could be a very costly endeavor. After further analysis it was determined that the project would be able to connect to an existing Public Service Company (PSCo) 230k transmission line at the Missile Site Substation, just north of Deer Trail. In order to gain access, RES Americas would need to construct 42 miles of private transmission to link the project to the grid. A majority of the path for this proposed line follows the right of way path for a previously proposed line, the Eastern Plains Transmission Project, making the daunting task a much easier assignment. Nonetheless, it took several months to secure the rights of way for 42 miles of easements.

By 2010 it appeared that Cedar Point was well on its way to becoming a reality. The wind resource had been confirmed through years of measurements. The leasing agreements were finalized. Rights of way had been obtained, and permitting was nearly complete to begin construction of the project and transmission line. However, the project wouldn't be built until there was a buyer for the power to be generated.

Through a national movement spurred by the American drive to free our country from foreign energy sources and to make use of our renewable energy assets, states have adopted renewable standards for utilities servicing their state. Colorado has been a leader in adopting such standards.

Cedar Point was a project of significant size that would have value to a utility working to reach the required renewable standards of 30 percent by 2020. Cedar Point, along with two other projects, won the 2009 renewable power procurement process run by PSCo.

In March of 2010, RES Americas executed a 20-year PPA with PSCo under which the utility agreed to buy

Fig. 3: Tower sections are delivered to the construction site

Fig. 4: Foundations being poured at Cedar Point

Fig. 5: Trenching begins, connecting turbines to the grid

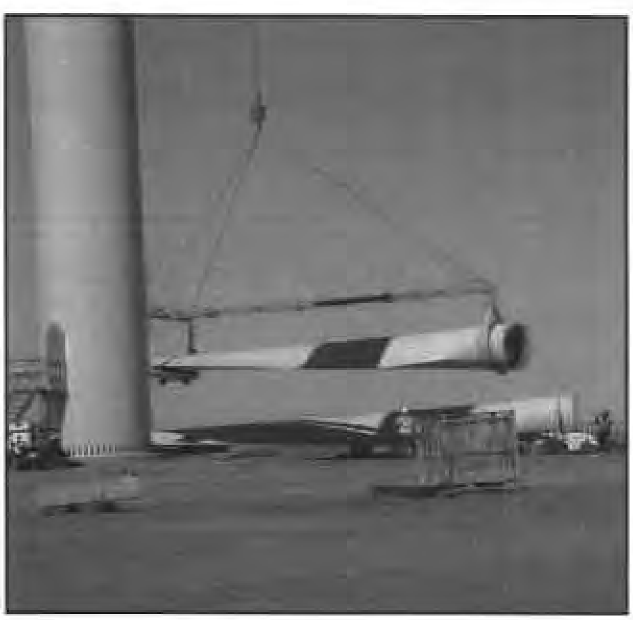


Fig. 6: Blades are lifted into place at the Cedar Point Wind Farm

252.2 MW of clean power from Cedar Point. "The Cedar Point Wind power purchase agreement is the first to be completed from the 2007 Colorado Resource Plan by Public Service Company of Colorado, an Xcel Energy company. The project will expand the utilization of Colorado's desirable wind resource into another region of the state to deliver this clean wind energy to our customers," said Tom Imbler, Xcel Energy vice president for commercial operations, at the time the PPA was announced. "Not only will this project help us to meet our renewable energy standard for Colorado, it will be our first wind energy purchase from a facility constructed in Colorado with wind turbines manufactured in Colorado."

SELLING POINT

RES Americas made the strategic decision to sell the project to a new owner while retaining engineering, procurement, and construction rights. This would allow the company to realize value from the project while freeing resources to focus on other projects in its development portfolio.

Once the PPA was finalized, the bidding process to own the project intensified. RES Americas reviewed a number of bids from several prospective owners. Ultimately, the $500 million project was sold to Enbridge, Inc., a Canada-based energy company with American affiliates.

"Renewable energy aligns very well with our objective to profitably grow our energy infrastructure business," according to Al Monaco, executive vice president, major projects and green energy at Enbridge. "The investment in Cedar Point bolsters our already strong portfolio of green energy projects and establishes a beach head for future investment into the growing U.S. green energy market. We expect to continue to grow our renewable portfolio, particularly in states such as Colorado that support green energy development."

BREAKING GROUND

The Cedar Point Wind Project officially broke ground on August 25, 2010, more than seven years after the early stages of development had begun. RES Americas is serving as the engineering, procurement, and construction contractor for the site, and on completion it will operate the project for at least two years.

Just over nine months into construction, RES Americas is poised to deliver ahead of schedule. In this part of Colorado, harsh winters and weather can play a significant role in construction. RES Americas understood this variable in the construction timeline and planned accordingly. "Luckily the weather has been very cooperative, so much so that the transmission line was completed ahead of schedule and the turbine deliveries began almost a month ahead of time. We are continuing to stay focused on the tasks at hand and stay ahead of schedule," says Jason Zingerman, vice president of construction at RES Americas.

During the early part of the construction phase all efforts were focused on infrastructure, excavation, and foundations. Each foundation was comprised of nearly a half-million tons of concrete and rebar, requiring an immense amount of earthmoving and backfilling with aggregate material.

Tower installation and erection started in March of 2011 as the winter season began to fade and electrical infrastructure neared completion. All the wind tower components for Cedar Point are being manufactured in Colorado by Vestas Wind Systems.

Local subcontractors were heavily engaged during excavation and road construction; nearly 100 local jobs were created to complete these tasks. "We're excited about being part of this community," says Zingerman. "Really, this is the community's project and everyone has been very supportive during the construction phase."

THE FUTURE

RES Americas and Enbridge expect that the project will begin commercial operation in November of 2011. Once completed, Cedar Point will consist of 139 1.8 MW Vestas V90 turbines, two onsite project substations, an operations and maintenance building, and over 42 miles of an electrical transmission line. It will be the second largest wind project in Colorado and is contributing to the state's economic development.

Vestas has recently announced plans to hire more than 1,000 people in Colorado by the end of 2011, largely due to projects like Cedar Point. Colorado is one step closer to reaching the renewable standards goals designated by former Governor Ritter and the landmark legislation requiring 30 percent renewable by 2020. Cedar Point will yield approximately 875,000 MWh, roughly the annual energy consumption of around 80,000 Colorado households. The project will displace fossil generation, keeping approximately 710,000 tons of CO_2 per year out of the atmosphere.

The Cedar Point Wind Project is a great accomplishment for both Enbridge and RES Americas. The project will bring the RES Americas constructed/under construction portfolio to over 5,200 MW and is the company's first large project in Colorado. Cedar Point is Enbridge's seventh wind power facility and brings the total generating capacity of their green energy projects to 810 MW. More importantly, it is a significant accomplishment for Colorado. It is a project that was born in state, developed in state, constructed in state, and will operate in state to benefit Coloradoans.

RES in North America

64 projects | >6,500 MW | 534 miles OHL

(constructed or under construction)

Texas – 2,159 MW
- Woodward Mountain, Pecos County–160
- King Mountain, Upton County–278
- Sweetwater II, Nolan County–92
- Sweetwater IV, Nolan County–106
- Sweetwater V, Nolan County–81
- Whirlwind, Floyd County–60
- Lone Star, Shackelford & Callahan Counties–400
- Hackberry, Shackelford County–166
- South Trent Mesa, Nolan & Taylor Counties–101
- Buffalo Gap III, Nolan & Taylor Counties–170
- Bull Creek, Nolan County–180
- Gulf Wind, Kenedy County–283
- Harbor Wind, Nueces County–9
- Gaines Cavern, Gaines County–2
- Webberville Solar, Travis County–30
- OCI Alamo I Solar, Bexar County–41

Canada – 661.5 MW
- SNEEC–4.1
- Talbot–99
- Greenwich–99
- Brooke-Alvinston–10
- Halkirk I–149.4
- South Kent–270
- Rutley Solar–10
- Norfolk Solar–10
- Demorestville Solar–10

Washington – 1,650 MW
- Nine Canyon I, Benton County–48
- Nine Canyon II, Benton County–16
- Nine Canyon III, Benton County–32
- Hopkins Ridge I, Columbia County–149
- Hopkins Ridge II, Columbia County–7
- Marengo I, Columbia County–140
- Marengo II, Columbia County–71
- Wild Horse, Kittitas County–229
- White Creek, Klickitat County–205
- Harvest Wind, Klickitat County–99
- Wild Horse II, Kittitas County–44
- Lower Snake River, Garfield County–343
- Lower Snake River II, Garfield County-267

Wyoming – 380 MW
- Mountain Wind I, Uinta County–61
- Mountain Wind II, Uinta County–80
- High Plains, Carbon & Albany Co–99
- McFadden Ridge I–Carbon & Albany Counties–29
- Dunlap Wind Energy Project–Carbon County–111

Oklahoma – 326.5 MW
- Crossroads, Dewey County–227.5
- Blue Canyon VI, Caddo County–99

California – 208.2 MW
- Cameron Ridge, Kern County–60
- Pacific Crest, Kern County–47
- Hatchet Ridge, Shasta Co–101.2

Colorado – 256 MW
- NREL, Superior–3.8
- Cedar Point, Lincoln, Elbert & Arapahoe Counties–250.2
- NREL II, Superior–2

Pennsylvania – 381.2 MW
- Armenia Mountain, Tioga & Bradford Counties–101
- Mehoopany, Wyoming County–140.8
- Twin Ridges, Somerset County–139.4

Kansas – 349 MW
- Buffalo Dunes, Grant County–250
- Central Plains, Wichita County–99

Nebraska – 119 MW
- Ainsworth, Brown County–59
- Flat Water, Richardson County, NE & Nemaha County, KS–60

Wisconsin – 54 MW
- Butler Ridge, Dodge County–54

New Mexico – 28.3 MW
- Llano Estacado, Curry County–1
- Wildcat, Lea County–27.3

Jamaica – 21MW
- Wigton–21

Harmonic Interaction Between a Large Number of Distributed Power Inverters and the Distribution Network

Johan H. R. Enslin, *Senior Member, IEEE,* and Peter J. M. Heskes, *Senior Member, IEEE,*

***Abstract*—Power quality problems associated with distributed power (DP) inverters, implemented in large numbers onto the same distribution network, are investigated. Currently, these power quality problems are mainly found in projects with large penetration of photovoltaics (PVs) on rooftops of houses and commercial buildings. The main object of this paper is to analyze the observed phenomena of harmonic interference of large populations of these inverters and to compare the network interaction of different inverter topologies and control options. These power quality phenomenons are investigated by using extensive laboratory experiments, as well as computer modeling of different inverter topologies. A complete network simulation study on an existing residential network with large penetration of PVs, is included.**

***Index Terms*—Distributed power (DP), photovoltaic (PV).**

I. Introduction

Several governments and utilities worldwide promote the use of distributed power (DP) generation using renewables with subsidies and customer programs. Some examples include offshore wind farms [16] and several "Green" suburbs where roofmounted photovoltaic (PV) arrays are installed on most of the roofs of individual homes, apartments, and communal buildings [9]. An example of such an endeavor is the Dutch Nieuwland Project, near Amersfoort, The Netherlands, where in total, 12 000 m^2 PV arrays were installed, on 500 homes. (See a photograph of this suburb in Fig. 1.) In total, renewable energy of 1-GWh p.a. is generated by this project.

Only a few DP inverter-network interaction problems are reported [8], [15]. Newly developed standards [21], [22] indicate that it is expected that interaction problems may arise in the future. With the increased utilization of DP, the interface of fuel cells, microturbines, and other conversion technologies into the homes, these power quality problems are expected to increase. The voltage regulation problem with the power feedback at high isolation levels and possible islanding problems are mainly discussed in [8] and [15]. The problems associated with generated harmonics and possible network resonances are seldom investigated [14], [18], [19].

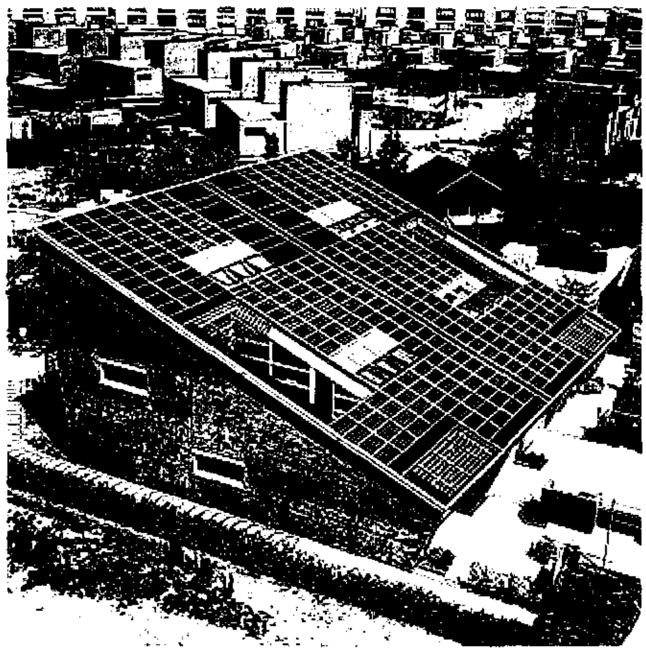


Fig. 1. Roofmounted Dutch PV Suburb, Nieuwland, Amersfoort.

The general objective of this paper is to investigate the power quality problems and the interaction of these inverters with the distribution network. For this paper, the generated current harmonics, the effect of background voltage distortion in the network, and the possible resonances between the inverters and the network are investigated.

II. Power Quality Problems

Measurements in Dutch networks with a high penetration of PV generation [9] showed that the PV inverters, under certain circumstances, switched off undesirably, or exceeded the harmonic regulations. As a result, the Dutch national point of common coupling (PCC) power quality standards [19] might be exceeded. This might be the case even when all the PV inverters individually satisfy the IEC 61 000-3-2 specification [20]. By using the measured and experienced power quality problems of these large scale PV projects, the following analysis on inverters, practical laboratory measurements, distribution network layout, and simulation studies were conducted.

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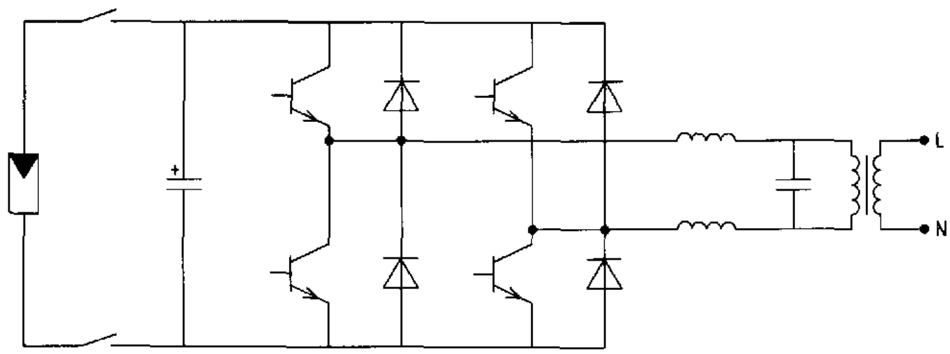

Fig. 2. Single-stage H-Bridge PWM converter, line frequency transformer, and filter elements.

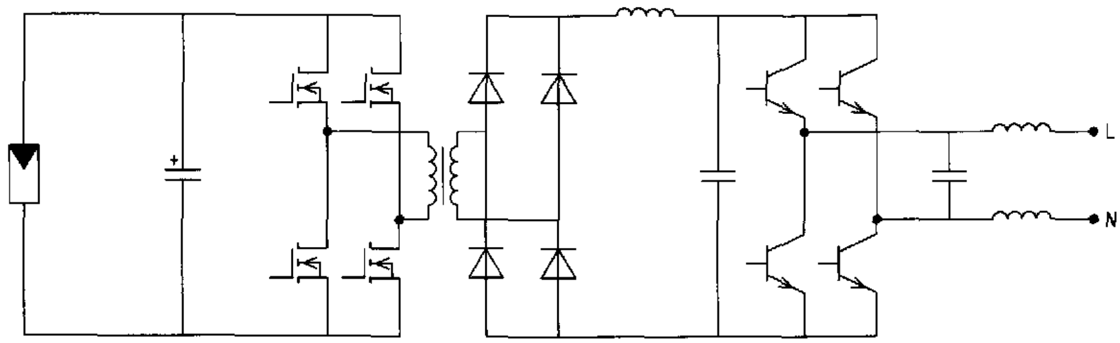

Fig. 3. Multistage converter with high-frequency transformer and low-frequency unfolding bridge.

III. Inverter Considerations

A. *Inverter Topologies*

Distributed power, and in particular PV inverters, are currently based on single-phase self-commutated voltage-source converters in the 1–5 kW power range for individual households [10]. These inverters consist, furthermore, of different power stages, with high-frequency and line-frequency transformers or even transformerless designs [1]–[4], [6], [7], and [10]–[12]. For efficiency reasons, transformerless topologies [1], [6] were proposed, but for safety reasons and in some cases based on standard requirements, an isolation transformer is required. To comply with the IEC 61000-3-2 [20] standard, as well as the newly developed standards [21], [22], these inverters use pulsewidth modulation (PWM) controllers to generate sinusoidal output currents. In practice, switching frequencies of 20–500 kHz are used in different power stages with mainly metal oxide semiconductor field effect transistors (MOSFETs) and insulated gate bipolar transistors (IGBTs) as switching elements for these PV inverters [10]. These inverter topologies can mainly be summarized into the two figures and the discussions as follows.

1) Single-stage pulse-width-modulated (PWM) dc–ac converter topology (H-bridge or push–pull), directly coupled to the grid via a low-frequency (LF) isolation transformer and filter (Fig. 2).
2) Multistage topology of PWM dc–ac converter front-end including a high-frequency (HF) isolation transformer, a high-frequency rectifier, and a line-frequency unfolding bridge coupled to the network through small filter components (Fig. 3).

Some inverters make use of a single or cascaded input boost dc–dc converter for the purpose of dynamic range improvement. The energy storage capacitor is placed at the input of the inverter or between the two converter stages [11]. In some cases, the HF ac-link (Fig. 3), [7], or output transformer (Fig. 2), may also be shared by several primary inverters on individual PV arrays [10].

B. *Inverter Controllers*

Distributed power inverters have multiple control loops to perform a variety of tasks, including one or more of the following: maximum power point tracking (MPPT); dc–ac power conversion; reactive power compensation; harmonic cancellation; protection against islanding; UPS operation; etc. In some cases, these controllers are implemented in multitasking converters [4], [12].

For most of these inverter types the ac output current will mainly be characterized by the inner current feedback loop. The control references of these inverters are internally self-generating a sinusoidal output current based on internal tables, that is synchronized with the supply voltage. The zero-crossings in the voltage are normally detected by using a phase locked loop (PLL) or voltage zero-crossing technique.

Some inverters, however, combine the reference source and the synchronization with the supply voltage by using the waveform shape of the supply voltage as a reference source. However, if this voltage is polluted with background distortion, the reference source will also be polluted and the current regulator of the inverter will pollute its own output current accordingly. Filtering of the pollution using such a controller is difficult. This kind of inverter has the character of a negative resistor.

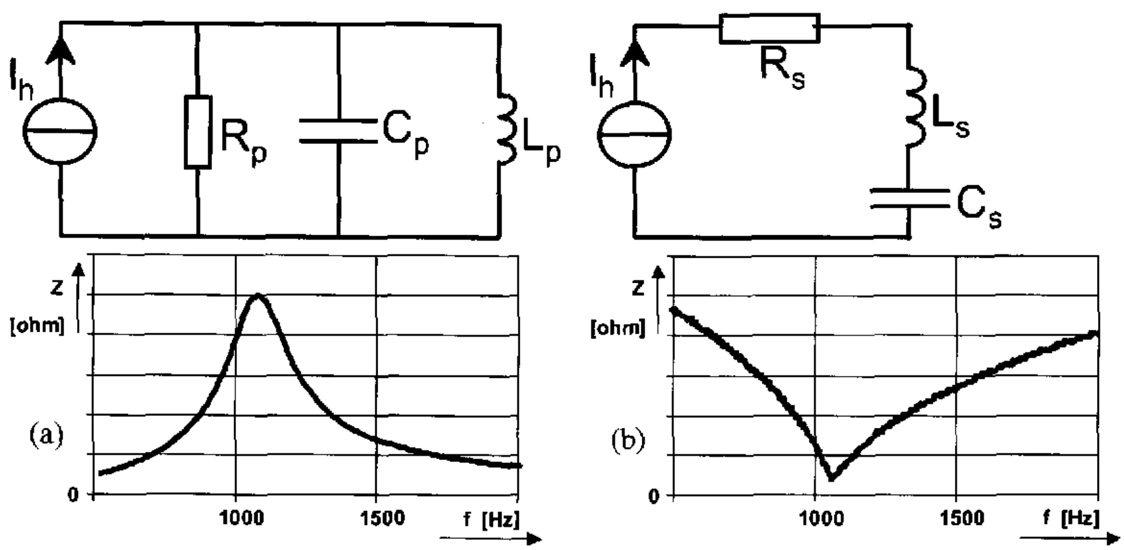

Fig. 4. Mechanisms of (a) parallel and (b) series resonance.

If it is desired to design an inverter with an unpolluted sinusoidal output current shape, even if the network voltage is polluted with harmonics, the inverters output impedance, as function of the frequency, has to be high. In practice, the output impedance of the inverter has to be high for up to the 40th harmonic, to avoid harmonic current injection into the network. This can be achieved by means of passive filtering and/or active filtering techniques build into the inverter controller.

To generate a good output current source, the controller with a sufficiently high-gain-bandwidth product of the current feedback-loop is required. For a good result, the position of the current sensor in the inverter power circuit is also important. The best place to sense the output current is directly on the output of the inverter, however in general electromagnetic interference (EMI) filters and output filter capacitors are the last components in the output wires. Very often, these current sensors will be combined with current sensors already needed in the dc–ac converter circuit. All of these aspects ensure that the current source behavior of the PV inverter is not as good as it should be.

C. Inverter Output Filters

Due to the high-frequency switching of the inverter, some low-pass filtering and damping networks are normally found in the inverter. In order to make the inverter cost-effective, manufacturers try to minimize external reactors and increase the size of the output capacitor. The output capacitor(s) of the inverter strongly reduces the current source behavior of the inverter and can also be responsible for setting up a resonance circuit together with the network reactance (transformer and cable reactance). Normally these effects are not detected or reduced by the current loop controller of the inverter. At this stage, the output impedance of the inverters is not driven by obliged standards.

D. Summary of Inverter PQ Issues

The key PQ problems, associated with DP inverters, are obtained when the inverter topology and control behavior has the following behavior.

1) The current-shape reference source is a copy of the grid voltage.
2) The inverter has a low-output impedance as a function of frequency.
3) The inverter has a nonideal current source behavior associated with a high-output capacitance, small-output reactor, and incorrect positioning of the current measurement.

In order to improve the inverter PQ characteristics in a network, the following should be done in the inverter design.

1) The inverter current reference source should be generated internally from a sinusoidal table inside the controller.
2) The output impedance of the inverter should be high up to the 40th line frequency harmonic.
3) A low-output capacitance should be used as filter.
4) The current should be measured directly in the output wires.

IV. Analysis of Harmonic Pollution

This section analyzes the possible resonance phenomenon in electrical networks where a large number of DP inverters are concentrated. The resonance phenomenon in transmission and distribution networks is common where reactive power compensation filter banks or vast cable networks are implemented [5]. There is always a possibility of a series- and a parallel-resonance in any network, depending on the configuration of the network and the location of harmonic generating sources.

Distributed power resources are normally connected to low-voltage networks. In the case of PV inverters, they are connected directly to the 230/400-V ac network.

To establish the range of the natural frequencies in such a low-voltage network, values for the network inductance and capacitance (cable and transformer) of a low-voltage network should be available. For the home connection, the equivalent capacitance of connected appliances also has a large influence. This equivalent capacitance can vary over a wide range from

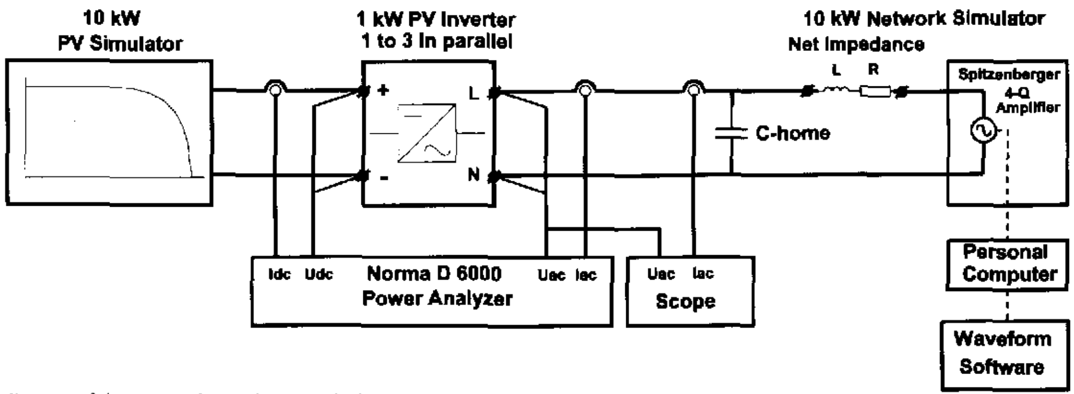

Fig. 5. Block-diagram of the power electronic network simulator.

around 0.6 to 6 μF. The typical values for the inverter input capacitance change also over a wide range as discussed in the previous paragraph. Commercial inverters in the 1–3 kW power range typical use values of 0.5 to 10 μF for the output capacitance.

The resonance phenomenon for these networks with large numbers of DP inverters connected on the low-voltage network can be divided into the following.

1) Parallel resonance, Fig. 4(a), of the parallel network capacitance C_p (inverter, household, and cable) and the supply inductance L_p (transformer leakage and cable), resulting from distortion currents generated internally I_h, i.e., within the point of common coupling (PCC). In this case, the inverter can be assumed to be the generating harmonic source I_h. In this case, the impedance at the resonance is high, resulting in higher voltage distortion at the PCC, or where the inverter and the household load are connected.
2) Series resonance, Fig. 4(b), of the network capacitance C_s, and the supply reactance L_s, resulting from externally generated or injected distortion. In this case, the background supply voltage distortion is the generating mechanism. Here, the impedance at the resonance is low, resulting in higher current distortion through the load and inverter capacitor. This effect will be enhanced if the inverter output impedance is low at the different background harmonics.

In practice, these two phenomenon are linked in one circuit and both the increased voltage and the current distortions are practically measured.

The series and parallel resonance can simply be calculated at the frequency f_r, using the following simple equation:

$$f_r = \frac{1}{2\pi\sqrt{LC}} \tag{1}$$

where f_r is the resonance frequency and L and C are the equivalent reactance and capacitance in the series or parallel network.

If one of the harmonics generated by the inverter (parallel resonance mechanism) corresponds with the parallel resonance frequency, very high-resonance voltages, damped only by the associated network and load resistances, will occur on the network voltage at the PCC. This may have operational effects on the PV inverter and other equipment connected to the PCC. Furthermore, this resonance can even be more severe if the power network is weak, i.e., L is large, which results in a lower frequency parallel resonance.

When one of the harmonics present in the network background distortion (series resonance mechanism) corresponds with the series resonance frequency, very high-resonance currents will flow in the network, damped only by the associated network resistance. The load is parallel to the network resistance for a parallel resonance and can be ignored since it is much higher than the network resistance (see Fig. 5).

Assuming that there are about 10 to 30 households on one phase of a single 400-V cable feed, the natural resonance frequency can be as low as the fifth harmonic (250 Hz).

V. Experimental Inverter Measurements

Different PV-inverter topologies were experimentally evaluated [17], to quantify the above-mentioned power quality phenomenon. It should be noted, that all the PV inverters studied in the experimental, and later, simulation study for this paper, satisfied individually the IEC 61 000-3-2 specification [20]. The line diagram of the experimental setup is shown in [13].

The experimental setup mainly consists of a 10-kW PV simulator and four-quadrant single-phase power supply. The inverters are connected in-between the PV simulator and power supply in series with some equivalent network components (L and R). The household capacitor C-home is also included in the simulator. In the network simulator, different harmonics can be added to the output to represent a network with some background distortion [17].

In order to evaluate the performance of the different PV inverters under different levels of background supply distortion, voltage harmonics were added at three different levels. First, a clean sinusoidal supply voltage, second, the Dutch national average, based on annual harmonic measurements, and last, the maximum allowable voltage distortion at a PCC based on the EN50160 [19], were added.

A result of a PV inverter with a clean sinusoidal supply, the Dutch average background distortion, and with the EN 50160 background distortion, as well as added network impedance, is presented in Fig. 6. In the results, from this inverter, with included network impedance, the inverter still operated under conditions with the Dutch average background distortion of 3% THD. This inverter however tripped when the background distortion conditions were set to the maximum allowable EN 50160

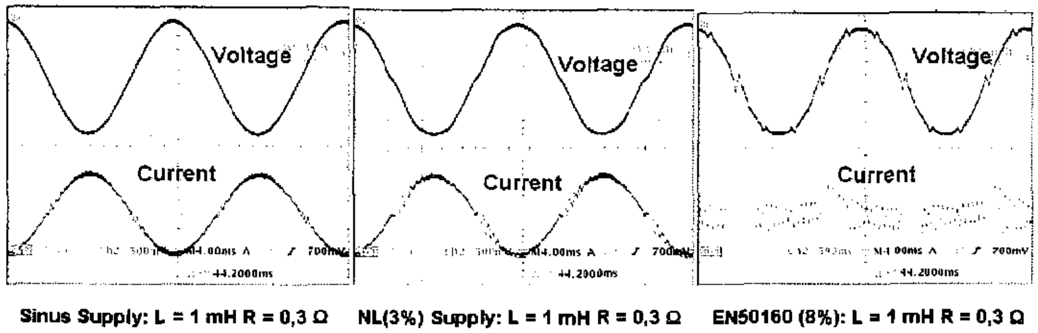

Fig. 6. Practical results of a PV inverter under conditions of sinusoidal supply, Dutch average ($\mathrm{THD} = 3\%$) and maximum allowable background distortion ($\mathrm{THD} = 8\%$) {200 V/div; 5 A/div; 4 ms/div}.

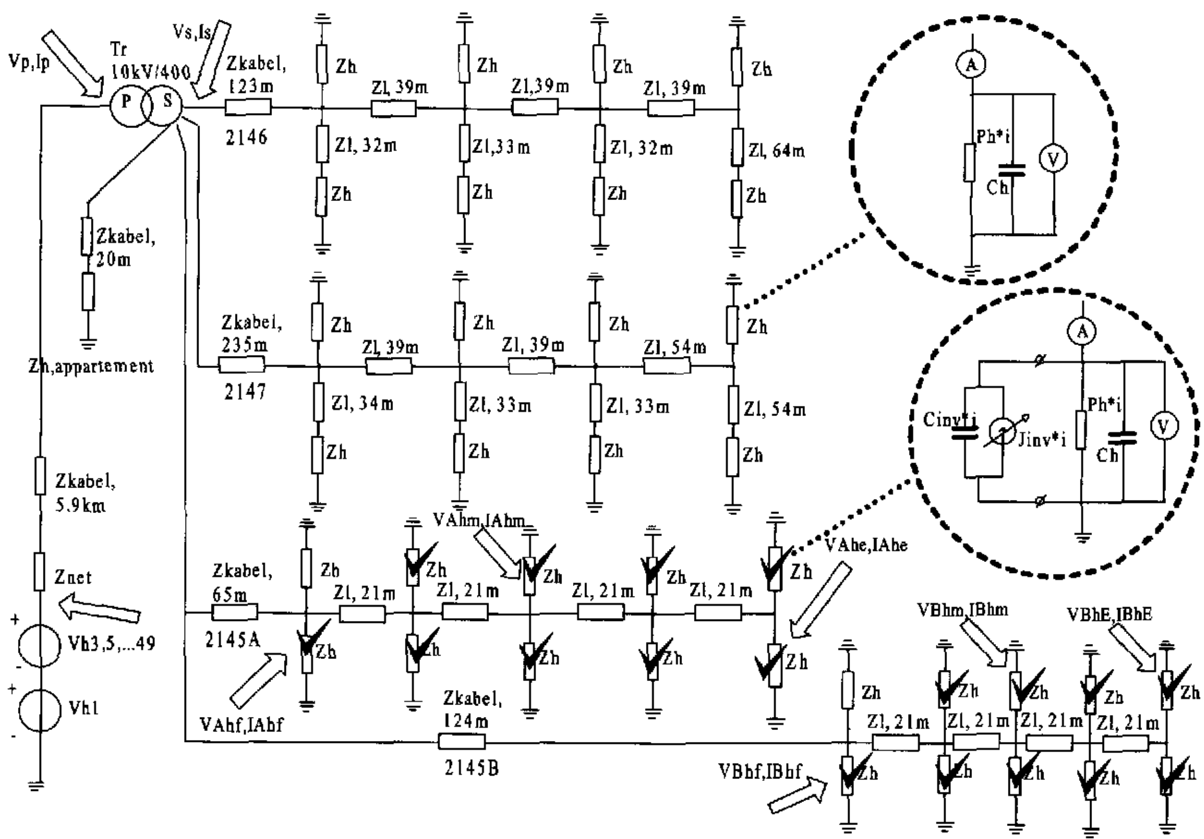

Fig. 7. Model of VP4 network with PV inverters.

[19] levels. Some of the other commercially available inverters still operated under this condition [17].

Using this setup, the resonance phenomenon and computer models for the simulation of a whole suburb with different types of inverters, were experimentally evaluated [17], [18].

VI. Network Simulation

A. Network Description

A Dutch residential network, currently under development, includes large-scale PV arrays connected on the roofs of most of the houses. As a first phase, a total of 197 homes with PV arrays and inverters are currently being installed. This network provides an excellent network to study possible PV inverter interaction issues and is used as basis for these simulations [14], [18].

This 10-kV network is fed from two sets of 50/10-kV transformers in two different substations. The maximum total loading of this network is around 60 MVA. The maximum power feedback from the PV generators is planned to be 36 MW.

The individual homes with roof mounted PV arrays are connected on three 400-V network sections, each supplied from a separate 10-kV/400-V transformer. Different types of PV inverters are currently installed on this network. As a followup, future field measurements may be conducted on this network to compare the results with the simulation results.

B. Network Modeling

Fig. 7 shows the model of a part of this network (VP4). This network section includes a 10-kV–400-V transformer, associated low-voltage network, and houses with different types

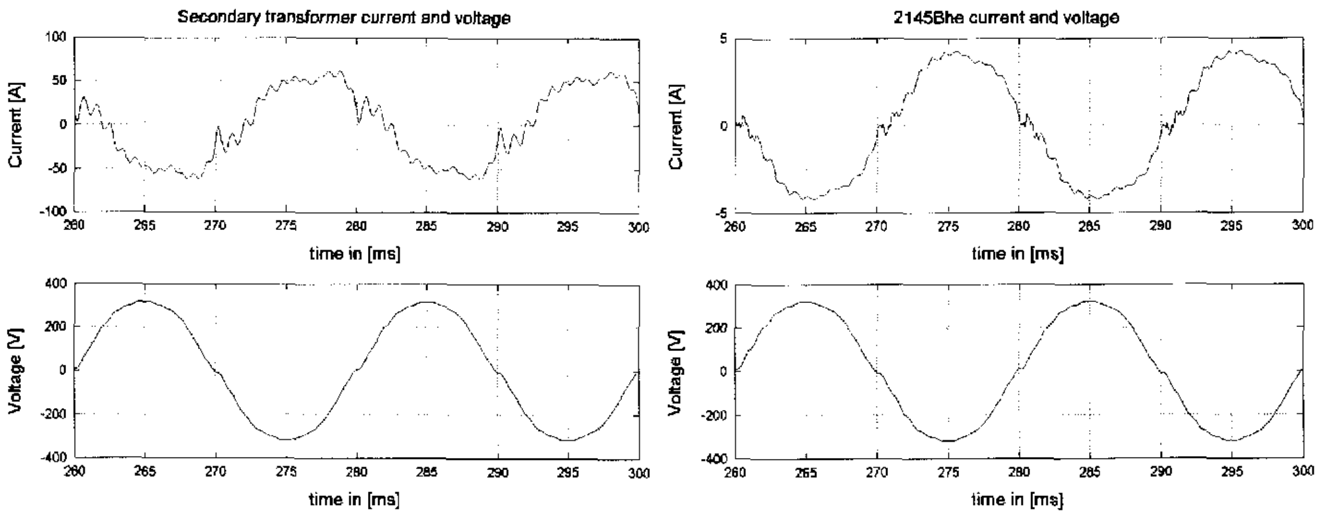

Fig. 8. Simulated waveforms at two locations for the VP4 network section with average background distortion ($V_{main} - 2\%$).

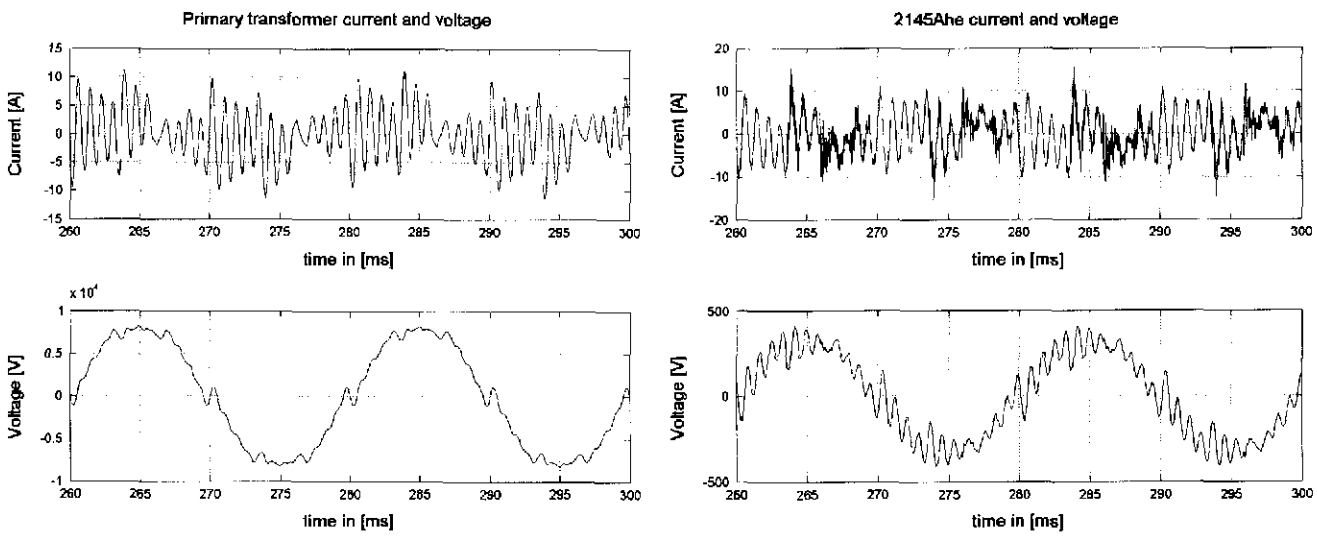

Fig. 9. Simulated waveforms at two locations for the VP4 network section with maximum allowable distortion.

of PV inverters. The individual models of these inverter types were validated with the experimental setup discussed in the previous paragraph. In the houses without an inverter, the home capacitances were correctly modeled. A number of houses, near to each other, with similar characteristics, are lumped as a single model, as shown in Fig. 7. The different inverters are, however, included using a self-developed individual MATLAB inverter models at each of the connection points. Lumped models are also used for the different cables and home capacitors. The rest of the household loads are modeled as linear resistive components. A high-frequency transformer model was used for the 10-kV/400-V transformer and cable sections. The label references used in the simulation results are indicated per cable feeder, as shown in Fig. 7.

C. Simulation Results

The simulation results with the Dutch national average background distortion (THD $= 3\%$) are presented in Fig. 8. For this case, the nominal effective voltage at V_{main}, was reduced by 2% in order to keep the voltage within the regulation limits at all the different household connections. Under conditions of maximum distortion, several inverters tripped. This was mainly because the maximum voltage levels were exceeded. These increased voltages were due to the increased voltage distortion and double zero crossings in the voltage waveforms. Some examples of these waveforms are shown in Fig. 9. The effect of the tripped inverters are clearly seen at the different connection points.

From these results, it is clear that the inverters in the network, with the average background distortion should operate well, but at increased levels of distortion currents. This is mainly due to the series resonance initiated by the background supply harmonics and the network components. In the results with the maximum levels of voltage distortion (Fig. 9), some inverters tripped and furthermore large levels of voltage distortion are visible.

D. Harmonic Analysis of Results

Taking this network section (VP4) into account, some harmonic analysis was performed. From the network data files

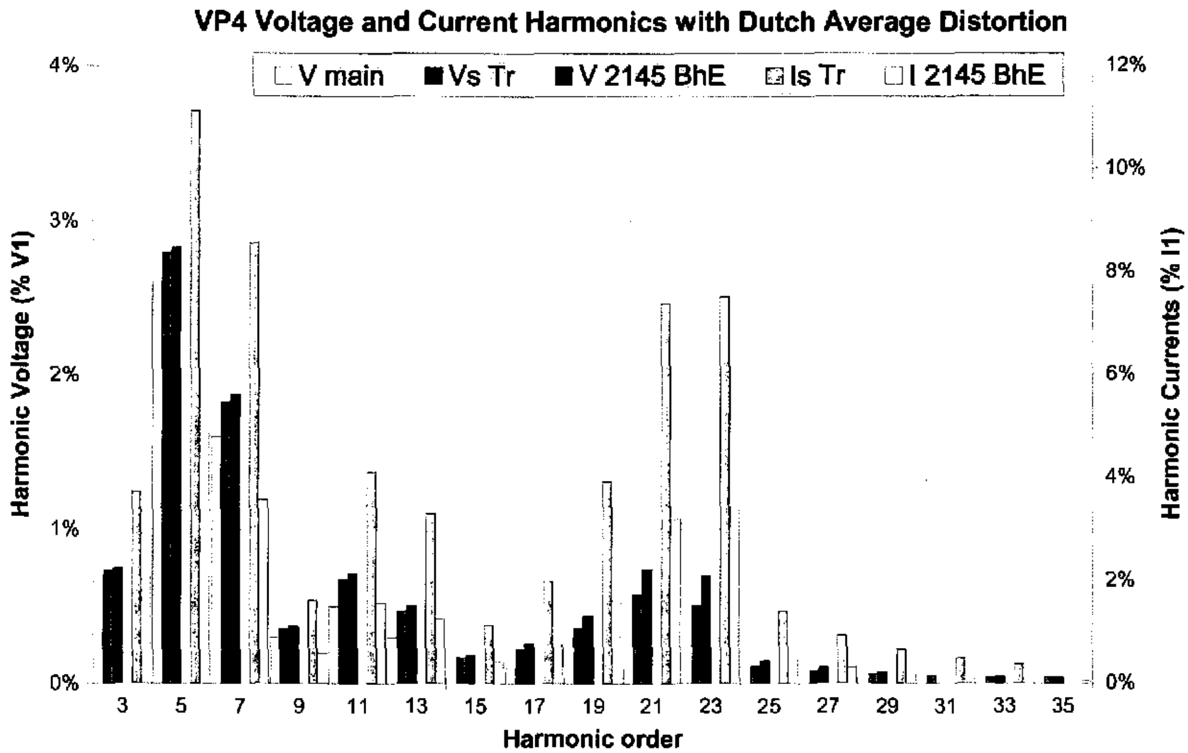

Fig. 10. Harmonic Spectra of VP4 network section with Dutch average distortion levels.

the dominant resonance frequency can be calculated using the simple resonance (1). From the network data.

Combination of VP4 transformer and cable reactances

$$L = 80\ \mu\text{H}.$$

House capacitance of all 36 homes

$$C_{\text{home}} = 108\ \mu\text{F}.$$

PV inverter capacitance (18 A and B types $-6\ \mu$F)

$$C_{\text{PV-Inv.}} = 108\ \mu\text{ F}.$$

Most dominant resonance frequency f_r

$$f_r = \frac{1}{2\pi\sqrt{LC}} = 1,2\ \text{kHz} \approx 24\ \text{harmonic}.$$

The harmonic analysis of the network with average background distortion ($\text{THD} = 3\%$) is presented in Fig. 10.

In most of the analyzed voltage harmonics, an increase from the original injected values is obtained. If we look closely at the results in Fig. 10, we see a large increase in the harmonic voltage from V_{main} to V 2145, around the 21st–23rd harmonic. From this analysis of the simulation results, the most dominant parallel resonance frequency is indeed around the 23rd harmonic. The large increased current harmonics, around the 23rd harmonic, due to the series resonance circuit, is also clearly dominant.

VII. Conclusion

The interaction between the distribution network, household capacitance, and DP inverters has been presented with analysis, experimental measurements, and computer simulations. Parallel and series resonance phenomenon between the network and these inverters are responsible for higher than expected current and voltage distortion levels in DP networks. Mainly, the parallel resonance phenomenon (initiated by small inverter current harmonics) can trip inverters on a distorted supply voltage. The equivalent household capacitance of 0.6 to 6 μF, together with the inverter input capacitance of 0.5 to 10 μF, is the dominant capacitance in resonance circuit calculations.

It was also found that the topology of an inverter has a large influence on the anticipated distortion in the network using laboratory experiments. Better-defined specifications (i.e., IEC 61 000-3-2) for DP-inverters in relation with the background voltage distortion and harmonic levels in networks are required.

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Dynamic Reactive Power and Energy Storage for Integrating Intermittent Renewable Energy

Johan H.R. Enslin, PhD, PrEng

***Abstract*— The role and application of energy storage and dynamic reactive power support is discussed in this paper. A well-engineered energy storage plant can help alleviate some of the problems encountered with the integration of intermittent renewable resources and at the same time make renewable power plants more cost effective in existing traditional power system. The intent of this paper is to demonstrate these features by means of a planned application of a STATCOM and Battery Energy Storage System (BESS) in a region with high penetration levels of wind and solar integration. Firstly, the paper describes the integration challenges of integrating intermittent renewable energy, followed by possible mitigation measures. Thirdly, a specific application of a STATCOM with a BESS is included and the different possible revenue streams are calculated.**

***Index Terms*—STATCOM, Battery Energy Storage System, Wind Farm Integration, Solar Energy Integration.**

I. Introduction

SEVERAL USA utilities are now confronted with high Renewable Portfolio Standards (RPS) proposed by their different states. RPS levels of 15 – 30% are required in most US states by 2020. Taking the low capacity factors of wind and solar generation in the existing generation pools into account, implies typical a 50 -100% increased installed capacity from these renewable resources if no mitigation is included. Furthermore, existing transmission capacity has to be increased by 100% to transport the renewable generation to the load centers without mitigation measures.

Five minute power measurements from a 60 MW wind farm and a 2 MW distributed generation roof-top PV solar facility in southern California were collected. These measurements are used to describe the intermittency issues of renewable energy generation and role of storage to interconnect these resources to the grid. A proposed STATCOM-BESS system describes the interconnection benefits and revenue options to integrate these resources.

A. Production data of wind generation in southern California

The studies presented in this paper are based on measurements from a wind power generation rich area in the southern California power system. The power output from one wind farm during seven days are presented in Figure 1. The wind power generation profiles are based on actual measurements with one sample per minute. As can be seen from Figure 2 the wind power output has fast ramping requirements during the entire week and during any given day. Furthermore, there are several other wind farms in the region with similar profiles that produce approximately 270 MW and absorbs about 100 MVAr from the bulk power system for reactive power support, during peak production times.

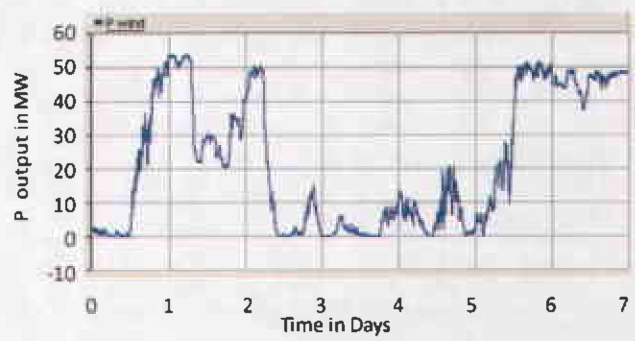

Figure 1. 60 MW wind farm generation profiles during a seven days period in southern California

Common problems in these remote wind production areas include low capacity factors for all the wind farms, impacts of line contingencies on wind farm operations, curtailment of wind farm outputs during high production times and high ramp rate requirements.

B. Production data of PV generation in southern California

In most urban regions Photovoltaic (PV) flat-plate collectors are predominately used for solar generation and can produce power production fluctuations with a sudden (seconds time-scale) loss of complete power output. With partial PV array clouding, large power fluctuations can also result at the output of the PV solar farm with large power quality impacts on distribution networks [5],[8].

The power output from a 2 MW utility scale PV power plant is presented in Figure 2. The solar power generation profiles are based on actual measurements, one sample per 5 minutes. It is clear that these types of power variations on large scale penetration levels can produce several power quality and power balancing problems.

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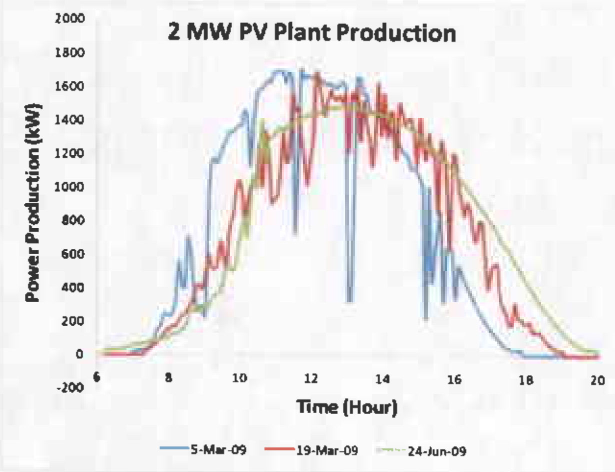


Figure 2: 2 MW PV Solar generation profiles during 3 days in southern California

As can be seen from Figure 2 cloud cover and morning fog require fast ramping and fast power balancing. Furthermore, several other solar production facilities are normally planned in close proximity on the same electrical distribution feeder, that can result in high levels of voltage fluctuations and even flicker. Reactive power and voltage profile management on these feeders are common problems in areas where high penetration levels are experienced.

II. Characterization of Renewable Energy Integration Problems

This section includes a general description of the integration issues of wind and PV solar power at high penetration levels [10].

A. *Wind power generation related problems*

Typical T&D system related problems include [7],[3]:

- Capacity factors in the range of 25 – 40 %
- Fast ramping requirements (300 - 700 MW/min)
- No wind farm dispatch capability
- Minimum reactive power support capability, especially in areas with older Type 1 and Type 2 wind turbines.
- Absorb reactive power from system
- No Low-Voltage-Ride-Through (LVRT) capability
- Non-compliant with FERC – Large Generator Interconnection Procedure (LGIP)
- Common wind farm curtailments
- N-1 contingencies are sometimes resulting in wind curtailment
- Voltage collapse may occur due to long remote lines during line trips
- Lack of coordination control of existing reactive power support

B. *PV Solar generation related problems*

Typical T&D system related problems include [6]:

- Capacity factors in the range of 10 – 20 %
- No dispatch capability of PV solar farms.
- Ultra-fast ramping requirements (400 – 1000 MW/min)
- Most existing PV inverters do not provide reactive power and voltage support capability.
- PV inverters do not have Low-Voltage-Ride-Through (LVRT) capability
- Most PV plants are non-compliant with FERC – Large Generator Interconnection Procedure (LGIP)
- IEEE-1574 provides contradicting guidance with LVRT and non-islanding requirements.
- Reactive power management of feeders are not designed with high PV production in mind
- Power Quality, especially voltage fluctuations, flicker and harmonics may be out of IEEE-519 and other standards.
- Lack of coordination control of existing reactive power support

Practical results of these phenomena will be presented in the presentation.

III. Application of STATCOM with Energy Storage

A. *STATCOM - BESS Case Study*

One of the most promising solutions to mitigate these integration issues is by implementing a hybrid fast-acting energy storage and STATCOM solution [3],[5]. Several fast energy solutions are currently available on the market, including NAS, Li-Ion, VRB, etc. battery technologies and flywheels [1],[2],[5],[9]. For mitigating the mentioned wind and solar integration problems the energy storage device needs to be fast acting and a storage capability of typical of 15 min – 4 hours and a STATCOM that is larger than the battery power requirements to have adequate dynamic reactive power capabilities. Figure 3 shows a STATCOM – BESS application for mitigating the wind farm related integration issues [11].

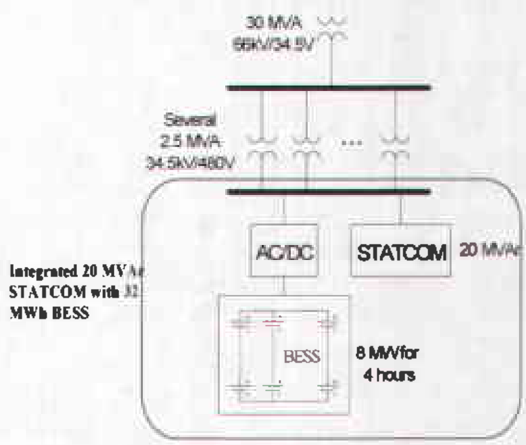


Figure 3: Basic Schematic of the STATCOM – BESS [11]

From Figure 3, the main components technical characteristics are described next.

1. 8 MW/4hr Battery.
2. 20 MVAr STATCOM.

3. Integrated Control and HMI (Human Machine Interface) of STATCOM and BESS system
4. Inverters for BESS and STATCOM.

B. Wind Farm Mitigation Provided by STATCOM – BESS

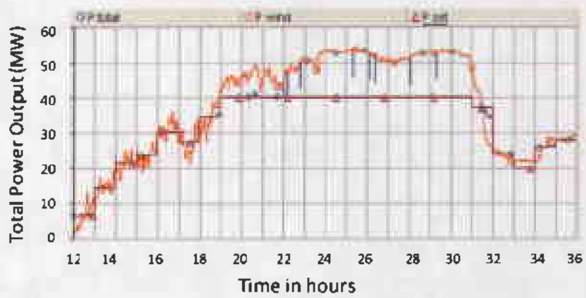
Dynamic simulations were performed to observe the behavior of the system during contingencies with and without the energy storage system [11].

1) Contingency support in terms of MW and MVAr. The STATCOM-BESS system prevents the system from collapsing for the critical contingencies.
2) Voltage regulation support. With the STATCOM-BESS system the voltage recovery is improved in about 10-15%.
3) Improved fault ride-through (LVRT) support on mostly Type 1 wind farms.
4) One of the connected wind farms can be dispatched an hour ahead.
5) Regulation ancillary services are provided
6) Large transmission upgrades to the wind facility can be postponed for several years.
7) Curtailments of the wind farm are minimized up to 4 hours

C. Hourly dispatch results

One of the mitigation applications of the hybrid STATCOM - BESS to provide 1 hour dispatch of the wind farm, is shown here [11]. Assume a forecast the average wind power output for the next hour with 10% mean absolute error of the individual wind farm (50-52 MW peak power) [4]. For this application, the BESS will compensate the differences between the hourly dispatch level, *Pset,* which comes from the forecast, and the wind farm power output, *Pwind.* The power at the battery, *Pbess*, then can be expressed as *Pbess=Pset-Pwind.* The results of dispatching the wind farm are shown in Figure 4 (a) for low wind generation and Figure 4 (b) for high wind generation.

(a)



(b)

Figure 4 Dispatching of wind farm power with BESS, Pset: desired set point, Pwind: wind power, Ptotal: net injected power (Pwind + Pbess, in MW) (a) During low wind generation (b) During high wind generation

It is seen from Figure 4 (a) that we can dispatch the wind power with the help of the BESS during low wind generation. From Figure 4 (b) the BESS can also help to absorb the excess generation when wind power is high as long as the SOC of the BESS is within its limits.

The operational modes of the battery to support a 50 MW hourly dispatch as well as for contingency support have been presented. The 32 MWh battery is capable of dispatching about 50 MW of the total capacity of the surrounding wind farms (270 MW peak power).

The other applications are discussed in more detail in reference [11].

D. Value Steams for STATCOM BESS Case Study

Several value streams can be calculated for this application. This includes the net present value (NPV) of the avoided cost in the delay of upgrading the transmission line. Having totaled the yearly avoided cost for the investment of the different value streams with respect to a possible $25 M investment in a hybrid BESS / STATCOM application can provide a return on investment (ROI) of about 13%. There are several additional other value streams that we can consider as well but did not include them here. These include voltage support, improved low voltage ride through (LVRT) and reduction of peaker generator plant maintenance costs. For example, we can link the difference in maintenance cost of a plant with respect to its variable operation and maintenance (O&M) costs primarily due to changes in plant efficiency and ramping requirements. The BESS heps to minimize start-and-stop operations of these peaker plants during regulation services.

IV. Conclusions

This paper has presented the mitigation options and associated value of utilizing dynamic reactive power support and fast acting energy storage to help alleviate some of the problems encountered with integrating intermittent wind and solar power plants on T&D systems, especially in regions with high penetration levels. The paper has characterized a number of integration issues where there is abundant wind and solar generation.

The benefits of the application of a hybrid 8 MW/4 hours Battery Energy Storage System (BESS) and 20 MVAr STATCOM to address the problems at a wind power generation rich area are presented. For this application, the ROI is calculated for the different value streams at above 13%. Several more results will be presented for both wind and solar applications.

V. Acknowledgments

The author acknowledge greatly the work from his collogues at Quanta Technology and support from his clients.

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VII. Biographies

Dr. Johan Enslin (M'85, SM'00) is Vice President of Sustainable Energy at Quanta Technology He is an expert on the interconnection issues of large-scale, on-shore and offshore wind parks and solar farms to the high and medium voltage electrical grids. These include feasibility, system impacts, interconnection options, dynamic modelling, stability, transient, network grid upgrades, power balancing and harmonic system studies for different on- and offshore grid topologies using HVDC, HVAC and energy storage technologies Previously he also designed, developed and commercialized back-to-back converters for wind and solar generators

Network Impacts of High Penetration of Photovoltaic Solar Power Systems

Johan H.R. Enslin, PhD, PrEng

Abstract—**The impacts of PV power plants are associated with voltage profiles, electrical losses, power factor, capacity planning, power quality, system operations and protection. Currently utility-scale solar PV plants have nominal capacities that are compatible with distribution substation MVA ratings e.g., between 1 MVA and 10 MVA, plans are to develop transmission interconnected PV plants in the 50 – 100 MW power range. These distribution network impacts are discussed and mitigation solutions are provided. A case study of a feeder fully loaded with PV power plants will be discussed.**

Index Terms— **Photovoltaics; Solar Energy Integration.**

I. Introduction

USA utilities are confronted with high Renewable Portfolio Standards (RPS) proposed by the different states. RPS levels of 15 – 30% are required in most US states by 2020. To avoid large expansions and associated time lags to build new transmission, there is a large likelihood that large numbers of the renewable portfolio will be connected as distributed renewable energy resources (DRER). Large penetration levels of solar photovoltaic (PV) systems will be located on customers' premises across the United States within the next decade [5],[9],[11].

Solar PV distributed generation impacts several aspects of distribution systems planning and operation. Some of the most noticeable effects concern voltage, current profiles, power quality, protection, electric losses, power factor, power balancing, reliability, power quality, protection and operability of the system. Solar PV generation impacts can be of steady state or dynamic (transient) in nature. These impacts vary in severity as a function of the degree of penetration and location of solar PV distributed generation. For instance, since traditional feeders are commonly designed for radial-unidirectional power flows, it is expected that some of the most significant impacts occur for large solar PV penetration levels, which lead feeders to become active circuits and inject power back to the transmission system. Under this condition, voltage profiles, overcurrent protection, and capacitor bank and voltage regulator operation are evidently affected [6].

On the other side, large penetration of solar PV distributed generation can be used to alleviate overloads and release capacity of feeders and substation transformers. This is an important benefit from a capacity planning perspective, since it allows utilities to defer capital investments.

Distributed Generation and network interaction problems were reported previously in literature [4],[5],[16]. The interconnection standards [7],[20],[21],[22], try to address these problems in the future. In the literature, the voltage regulation problem with the power feedback at high isolation levels and possible islanding problems are mainly discussed. The problems associated with generated harmonics and possible network resonances are seldom investigated [4].

Mitigation solutions to some of the expected problems include distributed energy storage, intelligent inverter control and dynamic reactive power support [1],[2],[3],[14],[15],[18]. Some of these mitigation solutions are discussed in this paper. A well-engineered energy storage plant can help alleviate some of the problems encountered with the integration of intermittent PV power plants and at the same time make PV power plants more cost effective in existing traditional power system. Firstly, the paper describes the integration challenges of integrating intermittent PV solar power, followed by possible mitigation measures.

II. Characteristics of PV Solar Farm Production

Taking the low capacity factors of solar generation in the existing generation pools into account, implies typical a 50 - 100% increased installed capacity from these renewable resources if no mitigation is included. Furthermore, existing transmission capacity has to be increased by 100% to transport the renewable generation to the load centers without mitigation measures.

In most urban regions Photovoltaic (PV) flat-plate collectors are predominately used for solar generation and can produce power production fluctuations with a sudden (seconds time-scale) loss of complete power output. PV generation penetration within residential and commercial feeders approaches 4 – 8 MW per feeder. With partial PV array clouding, large power fluctuations result at the output of the PV solar farm with large power quality impacts on distribution networks [5].

Some practical measurement data of the power output from utility scale PV solar farms are presented in Figure 1 and Figure 2. It is clear that these types of power variations on large-scale penetration levels can produce several power quality and power balancing problems.

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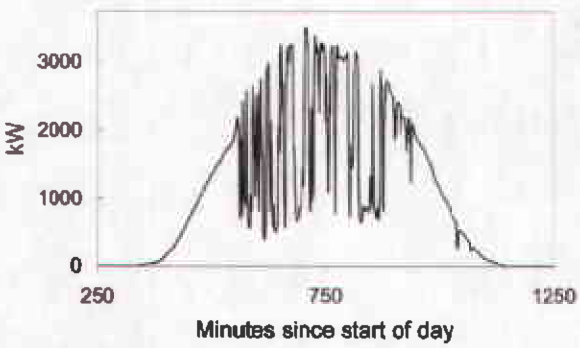

Figure 1: Daily real power output data over one full day in summer at 1 minute sampling frequency [5].

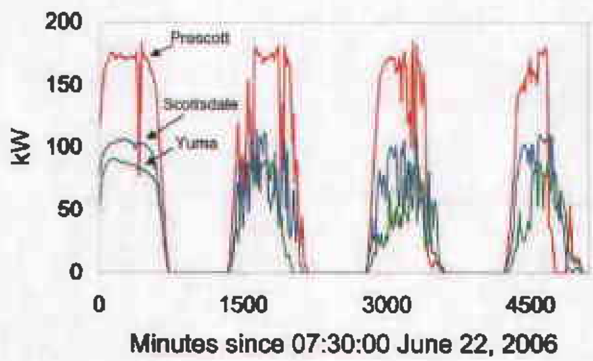

Figure 2: Daily real power output data from individual arrays over ~4 days at 10 minute resolution [5].

Recently SCE also installed large 2 MW utility scale power plants on distribution feeders [9] and provided valuable reference data.

The power output from a 2 MW utility scale PV power plant is monitored over several months and some of the individual days are presented in Figure 3. The solar power generation profiles are based on actual measurements, one sample per 5 minutes.

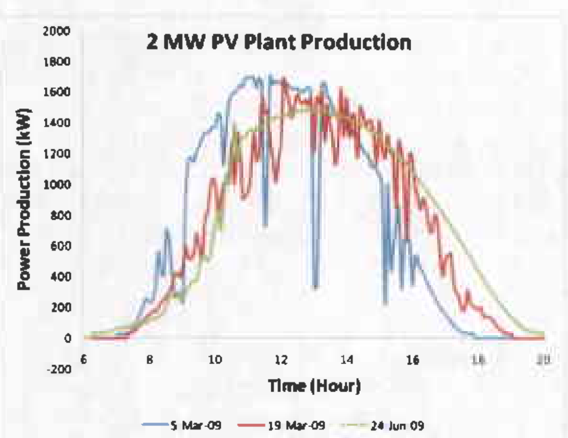

Figure 3: 2 MW PV Solar generation profiles during 3 days in southern California.

It is clear that these types of power variations on large-scale penetration levels can produce several power quality, capacity factors and power balancing problems.

As can be seen from Figure 3 cloud cover and morning fog require fast ramping and fast power balancing. Furthermore, several other solar production facilities are normally planned in close proximity on the same electrical distribution feeder that can result in high levels of voltage fluctuations and even flicker on the feeder. Reactive power and voltage profile management on these feeders are common problems in areas where high penetration levels are experienced.

III. Characterization of PV Solar Energy Integration Issues

Studies and actual operating experience indicate that it is easier to integrate PV solar energy into a power system where other generators are available to provide balancing power, regulation and precise load-following capabilities. The greater the number of solar farms operating in a given area, the less their aggregate production is variable.

This section includes a general description of the integration issues that need to be addressed in regions with high levels of PV solar production [6]. A summary is provided followed by a more in-depth description.

Typical T&D system related problems include [4]:

- Capacity factors in the range of 10 – 20 %
- No dispatch capability of PV solar farms without storage.
- Ultra-fast ramping requirements (400 – 1000 MW/min)
- Most existing PV inverters do not provide reactive power and voltage support capability.
- Existing PV inverters do not have Low-Voltage-Ride-Through (LVRT) capability [13].
- Most PV plants are non-compliant with FERC – Large Generator Interconnection Procedure (LGIP) [17].
- IEEE-1574 provides contradicting guidance with LVRT and non-islanding requirements [7].
- Reactive power management of feeders are not designed with high PV production in mind
- Power Quality, especially voltage fluctuations, flicker and harmonics may be out of IEEE-519 and other standards.
- Lack of coordination control of existing reactive power support

High penetration of intermittent resources (greater than 20% of generation meeting load) affects the network in the following ways:

1. **Power flow and reactive power:** We need to ensure that interconnected transmission and distribution lines are not over-dutied. Reactive power should be generated throughout the network, not only at the interconnection point and should be compensated locally through the

feeders. Due to PV power variations and required ramp-rates larger than 1 MW/sec, fast acting reactive power sources should be employed throughout the feeders and network.

2. **Short circuit:** Impact of additional generation sources to the short circuit current ratings of existing electrical equipment on the network should be determined. PV inverters normally do not contribute short circuit duty to the feeder networks.
3. **Transient stability:** Dynamic behavior of the system during contingencies, sudden load changes, disturbances clouds can affect stability and power quality. Voltage and angular stability during these system disturbances and production variance are very important. In most cases, fast-acting reactive-power compensation equipment, including SVCs and distributed STATCOMs, are required for improving the transient stability and power quality of the network. PV array clouding in larger PV plants may require energy storage facilities to provide smoothing for the PV plant output.
4. **Electromagnetic transients:** Ensure these fast operational switching transients have a detailed representation of the connected equipment, capacitor banks, their controls and protections, the converters, and DC links. Due to PV power fluctuations these network equipment may switch much more than originally intended.
5. **Protection and Islanding:** Investigate how unintentional islanding and reverse power flow may have a large impact on existing protection schemes, philosophy, and settings. Large levels of PV production will reverse power flows during certain times of the day and protection circuits needs to be able to protect the distribution feeders under these conditions. Problems were reported with PV inverter non-islanding circuitry in regions with high PV power production [12].
6. **Power leveling and energy balancing:** Due to the fluctuating and uncontrollable nature of wind power as well as the uncorrelated generation from PV power and load, PV power generation has to be balanced with other very fast controllable generation sources. These include gas, hydro, or renewable power generating sources, as well as fast-acting energy storage, to smooth out fluctuating power from wind generators and increase the overall reliability and efficiency of the system. The costs associated with capital, operations, maintenance and generator stop-start cycles have to be taken into account [8], [15].
7. **Power Quality:** Fluctuations in the PV power production and the strength of the T&D network at interconnection points have direct consequences to the power quality. As a result, large voltage fluctuations may result in voltage variations outside the regulation limits, as well as violations on flicker and other power quality standards.
8. **Other DER Facilities:** Several other Distributed Energy Resource (DER) technologies are currently being integrated on the distribution feeders as part of SmartGrid initiatives including Plug-in Electric Vehicles (PEV), Combined Heat and Power (CHP) generation and Distributed Energy Storage. The coordination of these DER devices is crucial to determine the combined impacts on the distribution feeders and networks.

IV. Characterization of Expected Benefits from PV Solar Energy Production

There are also several technical benefits having PV generation especially on the distribution feeders as distributed generation resources. When designed correctly, large penetration of distributed PV solar generation can be used to alleviate overloads on highly loaded distribution feeders and release capacity on these feeders and substation transformers. This allows distribution planners to defer capital investments to other areas.

Total distribution losses and reactive power requirements can also be optimized through the feeder. An example of such a case is shown below where a total of 8 PV DER plants are installed on a feeder with a combined load of 10 MW distributed throughout the feeder. From this specific result, it is clear that between 4 – 6 MW of PV generators (two – four) plants will provide optimized losses and minimize reactive power requirements.

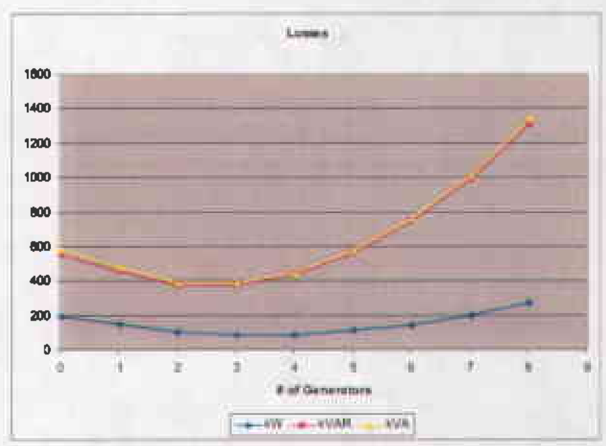

Figure 4: Feeder power losses and reactive power with increased PV production along a feeder (1 MW each). (Feeder load – 10 MW)

The real limit in this case is actually during low loading and high PV production condition. The PV plants do provide voltage support for the feeder and less capacitor banks are required. In summary, the PV power plants release feeder capacity.

In the final presentation, a wide range of possible phenomena and impacts will be presented and the results of the analysis performed for a variety of scenarios on a typical distribution feeder will be presented and discussed. These scenarios cover different degrees of penetration and location of solar PV distributed generation and several feeder-loading conditions.

V. Application of STATCOM with Energy Storage

Some of the main problems of integrating PV plants are dynamic reactive power requirements and power output smoothing during partially cloudy days, as shown in the previous figures.

One of the most promising solutions to mitigate these integration issues is by implementing a hybrid fast-acting energy storage and dynamic reactive power device (i.e. STATCOM) solution [3]. Several fast energy solutions are currently available on the market, including NAS, Li-Ion, VRB, etc. battery technologies and flywheels [1],[2]. For mitigating the mentioned PV solar integration problems the energy storage device needs to be fast acting (<1 sec response time) and a storage capability of typical of 15 min – 1 hour and a STATCOM that is larger than the battery power requirements to have adequate dynamic reactive power capabilities. Figure 5 shows a possible STATCOM with battery energy storage system (BESS) application for mitigating the PV integration issues.

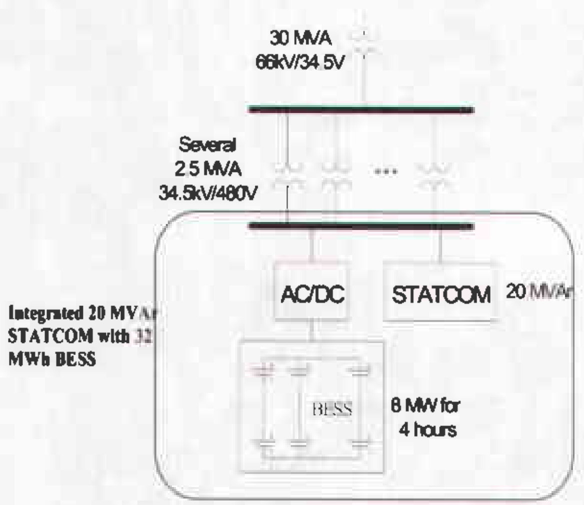

Figure 5: Basic Schematic of the STATCOM – BESS

From Figure 5, the technical characteristics of the main components are described next. This conceptional design will be adequate for providing dispatch and PV smoothing support for a 50 – 100 MW PV or wind power plant based on system strength and intermittency requirements [18].

1. 8 MW/4hr Battery.
2. 20 MVAr STATCOM.
3. Integrated Control and HMI (Human Machine Interface) of STATCOM and BESS system
4. Inverters for BESS and STATCOM.

The key functionality and possible revenue streams can be calculated for the following mitigation solutions:

1) Contingency support in terms of MW and MVAr. The STATCOM-BESS system prevents the system from collapsing for the critical contingencies.
2) Voltage regulation support. With the STATCOM-BESS system the voltage recovery is improved in about 10-15%.
3) Improved fault ride-through (LVRT) support on PV inverters.
4) A 75 MW PV Power plant can be dispatched an hour ahead.
5) Regulation ancillary services can be provided
6) Large transmission upgrades to the PV facility can be postponed for several years.
7) Curtailments of a remote PV solar farm are minimized up to 4 hours

It is important to use the BESS system to provide several value streams to make the PV power plant more cost effective. This includes the net present value (NPV) of the avoided cost in the delay of upgrading the transmission line. Having totaled the yearly avoided cost for the investment of the different value streams with respect to a possible $25 M investment in a hybrid BESS / STATCOM application can provide a return on investment (ROI) of about 13%. There are several additional other value streams that we can consider as well but did not include them here. These include voltage support, improved low voltage ride through (LVRT) and reduction of peaker generator plant maintenance costs. For example, we can link the difference in maintenance cost of a plant with respect to its variable operation and maintenance (O&M) costs primarily due to changes in plant efficiency and ramping requirements. The BESS helps to minimize start-and-stop operations of these peaker plants during regulation services.

VI. General Approach to Mitigation Solutions

To integrate high levels of intermittent renewable resources like PV power plants, several mitigation solutions and an advanced planning approach should be followed. There is no silver bullet but requires a combined effort on three major levels as is summarize in Figure 6:

- Generation Mix to utilize different complementary resources
- Advanced transmission facilities
- Demand response

Generation Mix
- Hybrid Energy Mix
- Complementary Gen.
- Advanced Power Electronics
- Generation with independent P & Q regulation
- Larger control areas
- Offshore wind
- Fast ramping
- Regulation capability

Advanced Transmission
- WAMPAC and FACTS
- Local FACTS Integration
- HVDC Transmission
- Energy Storage
- Capacity Credits
- Renewable Dispatch
- Congestion Management
- Voltage Support & LVRT
- Ancillary Services
  - Frequency Regulation
  - Control Error
  - Spinning reserves
- Strong interconnections

Demand Response
- Wind forecasting
- Off-peak loading
- Gen. - load match
- Price sensitive load
- Frequency Response
- Responsive to Wind
- SmartGrid / AMI
- Distributed Storage
  - PHEV
  - DES

Figure 6: Large-scale Renewable Integration Planning Approach.

The integrated planning approach is crucial to mitigate the system impacts of intermittent renewable resources. These approaches need to be studied in more detail and specific demonstration projects need to be integrated into the grid, demonstrating the features and advanced capabilities of these approaches. These demonstration projects will also help to maturing the new technologies.

VII. Conclusions

This paper has presented some of the integration challenges and benefits of integrating large-scale PV power plants. The value of dynamic reactive power support and fast acting energy storage to help alleviate some of the problems encountered with integrating intermittent solar power plants on T&D systems.

The benefits of the application of a hybrid 8 MW/4 hours Battery Energy Storage System (BESS) and 20 MVAr STATCOM to mitigate PV power integration issues are presented.

VIII. Acknowledgments

The author acknowledge greatly the work from his collogues at Quanta Technology and support from its clients.

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X. Biographies

Dr. Johan Enslin (M'85, SM'92) is Vice President of Sustainable Energy at Quanta Technology. He is an expert on the interconnection issues of large-scale, on-shore and offshore wind parks and solar farms to the high and medium voltage electrical grids. These include feasibility, system impacts, interconnection options, dynamic modelling, stability, transient, network grid upgrades, power balancing and harmonic system studies for different on- and offshore grid topologies using HVDC, HVAC and energy storage technologies. Previously he also designed, developed and commercialized back-to-back converters for wind and solar generators.

Integration of Micro-Scale Photovoltaic Distributed Generation on Power Distribution Systems: Dynamic Analyses

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***Abstract* — Grid-connected solar photovoltaic distributed generation (PV-DG) units offer many benefits such as clean energy, reduced emissions and creation of new green jobs. A combination of supportive legislation, incentives, technology developments and costs decrease have favored the proliferation of PV-DG plants of different capacities, ranging from a few kVA (small-scale) to several MVA (large-scale). Due to its intermittent nature, increasing penetration of large-scale PV-DG may lead to potential impacts on planning and operations of power distribution systems. Recently, highly distributed small size PV-DG (using panel-level PV inverters) and new inverter controls have emerged as an alternative to existing centralized inverter technologies. This paper discusses potential impacts and benefits of large-scale and micro-scale PV-DG based on conventional power factor control and Generator Emulator Control (GEC) for PV inverters. Impacts of interest for this paper are those of dynamic nature due to output intermittency that may lead to distribution feeder voltage fluctuations and operation of conventional automatic voltage control devices of a feeder. The paper presents results of detailed simulations conducted on a real-life 12.47 kV utility feeder and shows a comparison of the expected impacts and benefits of using different PV-DG technologies and inverter control modes.**

***Index Terms*—Distributed Generation, Solar Photovoltaic Generation, Distribution Systems, Inverter Controls**

I. Introduction

Renewable energy sources such as solar and wind power are becoming an increasing part of the electricity generation portfolio. Solar electric energy production has grown by an average 30% per annum over the past 20 years against a backdrop of rapidly declining costs and prices [1]. Notably, the number of installations of grid-connected solar photovoltaic (PV) generation systems has rapidly grown in the recent years. As of 2011, cumulative grid-connected solar electric installations have reached more than 2.85 GW, enough to power nearly 600,000 U.S. homes [2]. A large fraction of these installations are interconnected to primary (medium-voltage) and secondary (low-voltage) power distribution lines in the form of Distributed Generation (DG).

Given its output variability, high proliferation of grid-connected PV-DG affects the operation and planning of power distribution systems, since the latter are generally designed to be operated in a radial fashion. Some of the most noticeable effects of high penetration of PV-DG on distribution systems are potential voltage fluctuations, reverse power flows, power and energy losses increase, power factor modification, interaction with voltage control and regulation devices, protection system and operability issues. PV-DG impacts can be either steady-state or dynamic in nature and they vary in severity as a function of the degree of penetration and location of the PV-DG facilities [3]-[4].

PV-DG may be broadly classified as a function of its installed capacity as:

a. Small-scale PV-DG consists of few kVA-size single-phase units (e.g., 5 to 10 kW) such as the ones installed on rooftops of residential households.
b. Medium-scale PV-DG consists of larger kVA-size three-phase units (e.g., 100 to 500 kW) such as the ones installed on rooftops of small commercial buildings.
c. Large-scale PV-DG consists of MVA-size three-phase units that have nominal capacities that are manageable by distribution feeders and substations, e.g., between 500 kW and 10 MW.

Small-scale PV-DG is directly connected to secondary distribution lines (e.g., 120/240 V), and large-scale PV-DG is connected to primary distribution lines (e.g., 12.47 kV) via interconnection transformers. Depending on its installed capacity, medium-scale PV-DG may either be connected to secondary lines serving existing facilities or to primary lines via independent interconnection transformers. Recently, micro-scale PV-DG consisting of highly distributed VA-size single-phase units (e.g. 200 VA) connected to existing secondary lines, and new inverter control modes have emerged as an alternative to existing technologies [5].

This paper discusses and compares the potential dynamic impacts and benefits of two approaches to PV-DG integration. The first approach or *centralized solution* consists of a few large-scale PV-DG plants connected to existing primary distribution lines (12.47 kV) via interconnection transformers. The second approach or *distributed solution* consists of a larger number of highly-distributed micro-scale PV-DG connected to existing secondary distribution lines (120/240 V). Furthermore, this paper evaluates the performance of these two solutions under two different PV-DG inverter control

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modes: a) conventional unity power factor control and b) Generator Emulator Control (GEC) as developed by Petra Solar [[5],[6]]. This controller was developed as part of the DOE SEGIS program managed by Sandia. It is worth noting that a companion paper [7] addresses potential steady-state impacts and benefits of the aforementioned approaches to PV-DG integration and inverter control modes.

This paper outlines typical aspects of dynamic studies for a real-life utility feeder for the aforementioned integration approaches and inverter control modes. Impacts of interest are those of PV-DG output intermittency and large power fluctuations on feeder voltages and interactions with automatic switching devices. The intermittency is typically caused by cloud coverage and shading effect and/or loss and restoration of the full output of PV-DG plants. The study incorporates detailed control models of conventional voltage regulating devices and switched capacitor banks to investigate any adverse effect on number of tap changers operation and/or level of temporary under/over voltages.

The remaining sections of the paper are organized as follows. Section II includes a general description of the feeder, system models and software tools used for the study; section III describes the study results for the centralized solution; section IV discusses the results for distributed solution; and section V presents the conclusions of the study.

II. Distribution Feeder and PV-DG Modeling

As mentioned in Section I, the study consisted of the evaluation of time-varying (dynamic) impacts due to the interconnection of PV-DG plants. Impacts of interest are: a) primary feeder voltage fluctuations, and b) operation of line voltage regulators (VRs), voltage-controlled capacitor banks and substation transformer Load Tap Changer (LTC). In order to evaluate these impacts, detailed feeder and PV-DG plant models were built and calibrated to conduct a series of comprehensive simulations. The modeling and simulation of dynamic impacts were conducted by using PSCAD/EMTDC software [6], which is one of the well-known commercial software used by the power industry for these types of analyses. The data for feeder and PV-DG plant modeling were provided by the manufacturer/developer and utility. Moreover, the utility provided the characteristics and settings of existing capacitor banks, and the characteristics and settings of substation transformer LTCs.

A CYMDIST [9] model provided by the utility was utilized for building a steady-state model that included the PV-DG plants. The steady-state model was the starting point for building a detailed PSCAD model, which in turn was used for studying the dynamic impacts. The initial conditions for the dynamic simulations were calculated by using the steady-state model. These initial conditions were calculated for what is considered the worst case scenario in terms of potential impacts on the distribution system. This is expected to occur during annual minimum feeder load at maximum PV-DG output, which generally occurs around noon for the geographic location of the feeder under analysis. Hourly feeder load data (8760 hours) were analyzed to identify the minimum load at noon (P and Q) and conduct a load allocation to calibrate the steady-state model that was used to build the dynamic model. Then the steady-state and dynamic base-case models (without PV-DG) were compared to verify that they are equivalent. The comparison consisted of verifying power flows, fault duties, and voltage levels at different feeder points on the dynamic model, and then comparing their respective values on the steady-state model.

A simplified one-line diagram of the 12.47 kV feeder under analysis is shown in Figure 1. The diagram shows: a) PV-DG plant locations for centralized solution (penetration level of 2 MW consisting of four 500 kW ± j500 kVAr PV-DG plants), b) the relative position of the main feeder equipment (capacitor banks, voltage regulators, reclosers), c) active and reactive power flow values for the base case (before interconnection of PV-DG plants), and d) measurement points (red dots) for selected locations along the feeder. The measurement points are:

- F0: beginning of the feeder, after LTC
- VR1: load side of line voltage regulator
- BP1: beginning of a major branch
- RC1: recloser between substation and PV-DG site
- LC: load center point
- PV1: Location of first PV-DG plant
- PV2: Location of second PV-DG plant
- PV3: Location of third PV-DG plant
- PV4: Location of fourth PV-DG plant
- FE: feeder end point (farthest point on the feeder with respect to the substation)

In order to model the residential load, a combination of constant impedance and constant current load was used in the PSCAD model. The active component of the loads is considered as constant current and the reactive component of the loads is considered constant impedance in the model. The capacitors in the model are represented as ideal capacitors with manual or voltage control. The regulator model is a transformer having a base ratio of 1.0 with tap changer.

The detailed inverter model in PSCAD is using a PV model representing the input solar resource and irradiation as a function of number of series and parallel PV panels in a module and/or an array. The inverter model also includes under/over voltage and frequency protection schemes with default settings as specified in the IEEE 1547 Standard [10]. For evaluation and comparison purposes, highly distributed micro-scale PV-DG plants were modeled as micro-inverter clusters with an aggregated capacity of 5 kW ± 5 kVAr. Each cluster represents 25 micro-inverters with an individual capacity of 200 W ± 200 VAr. Large-scale centralized plants consist of individual PV-DG facilities with a capacity of 500 kW ± 500 kVAr and dedicated interconnection transformers.

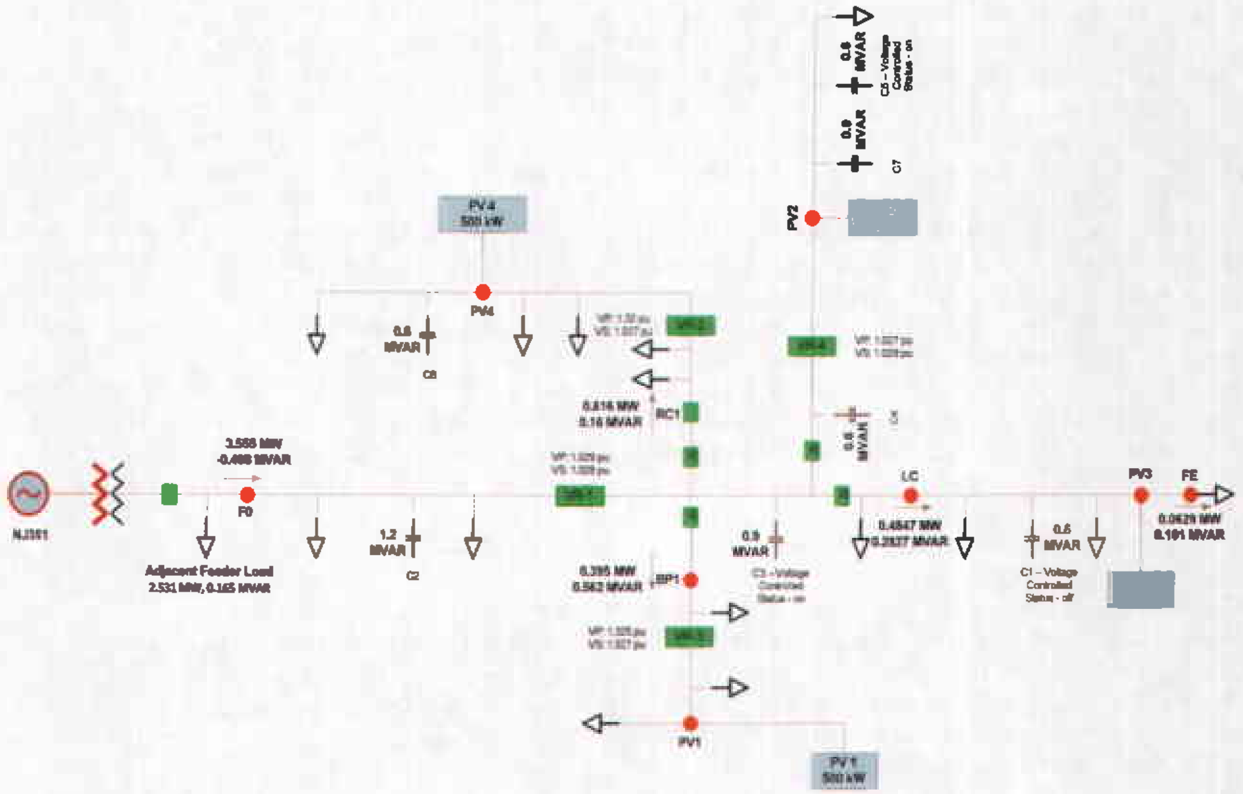

Figure 1 - Feeder configuration and power flow (MW/MVAr) in the dynamic simulation model

III. Analysis for Centralized solution

This section presents the results of the simulations for the centralized solution (four 500 kW ± j500 kVAr PV-DG plants and annual minimum feeder load at noon). Several simulation cases were studied to investigate the effect of adding PV-DG generation on feeder voltage profile under various generation conditions. Two types of PV-DG profiles were utilized to investigate worst case scenarios and effect of intermittency with variable power output by using profiles with pre-specified step changes and/or time-varying solar radiations as captured in the field. The following studies were conducted for conventional unity power factor and GEC controls:

- Conventional unity power factor control
  - Case 1 – Step change of PV-DG output from 0% to 50% to 100% under conventional control
  - Case 2 – Step-wise PV-DG profile under conventional control

- GEC control
  - Case 3 – Step change of PV-DG output from 0% to 50% to 100% with base droop control
  - Case 4 – Step change of PV-DG output from 0% to 50% to 100% with modification of droop control
  - Case 5 – Step-wise PV-DG profile with modified control

The specific utility requirements for maximum and minimum voltage levels for the primary distribution system (1.04 & 0.98 PU, respectively), as well as permissible ranges of transient voltage fluctuations (1%) were used as the evaluation criteria to assess the impact of integrating PV-DG plants on feeder voltages. As shown in Figure 2 a step-wise solar radiation profile was used to simulate the effect of changes in the solar radiation throughout a sunny day on feeder voltages and operation. The solar profile starts at 7 AM and lasts until 6 PM. The solar step changes are calculated from an ideal solar profile per 30 minute intervals. Although the profile incorporates smooth solar radiation changes, the effect of PV-DG output on line voltage regulators and LTC tap changer for an entire day can be investigated.

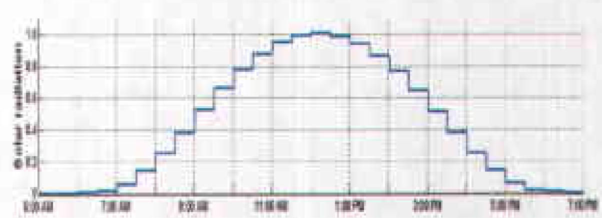

Figure 2 - A step-wise solar irradiation profile – applying a full-day solar radiation change

Figure 3 and Figure 4 show the simulation results for conventional unity power factor control. Figure 3 shows the variations in feeder voltages due to the PV-DG plants output step change from 0 to 50% to 100% when the inverters are operated at unity power factor. All the results are shown in per unit (PU) with 12.47 kV as the base voltage. The simulation results show that the maximum voltage level is exceeded at PV4 location for 100% PV generation. Then a step wise solar radiation profile was applied to study voltage variation at PV locations. Simulation results are presented in Figure 4 and they show that the maximum voltage level is exceeded at PV4 location for PV generation above 85% of the nominal rating.

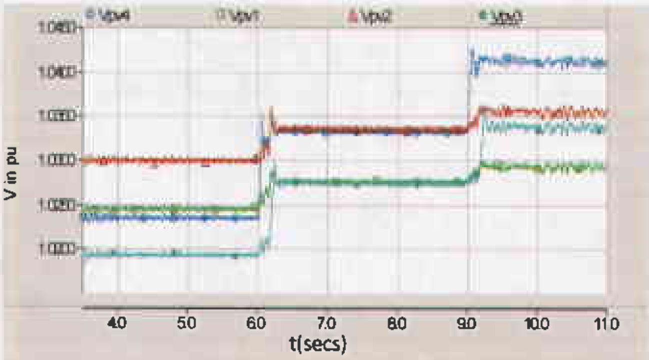

Figure 3 - Impact on feeder voltages of PV-DG output variation from 0 to 50% to 100% under conventional control

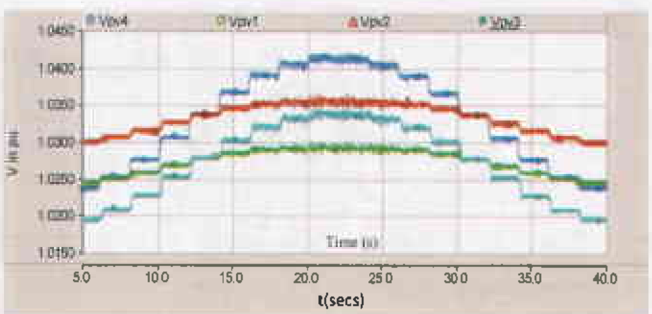

Figure 4 - Impact on feeder voltages of PV-DG output variation by applying step-wise PV profile)

As a mitigation strategy, inverters were operated on Generator Emulator Control (GEC), which allows controlling and regulating voltage of PV-DG inverters in a similar fashion as conventional synchronous generators. GEC applies voltage droop methods to determine reactive power contribution of PV inverters.

Figure 5 to Figure 8 present the results of these simulations. Figure 5 shows the results of applying radiation step changes from 0% to 50% to 100% under basic GEC control. The results show that the voltage at PV4 location was still over 1.04 PU, at high PV output. In order to overcome this issue, the droop coefficient of each inverter was increased in steps by 20%, 40%, and 60%, respectively. Figure 6 to Figure 8 show the levels of reactive power absorption of PV-DG plants for 20% (1315 kVar/PU), 40% (1534 kVar/PU), and 60% (1754 kVar/PU) increase in the droop coefficient, respectively. The results show that the voltage at PV4 location can be alleviated by increasing the droop coefficient. For this particular case, the voltage violation can be resolved by increasing the droop coefficient to 60%.

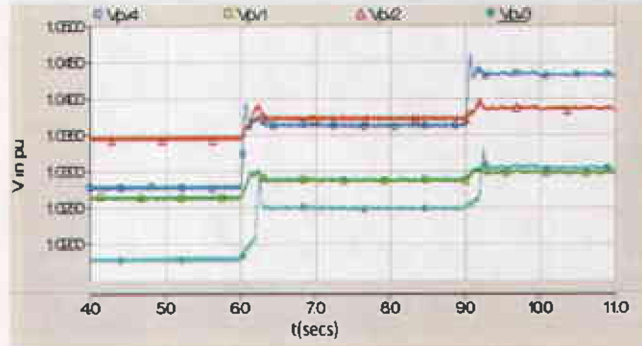

Figure 5 - Impact on feeder voltages of PV-DG output variation from 0 to 50% to 100% under basic GEC control

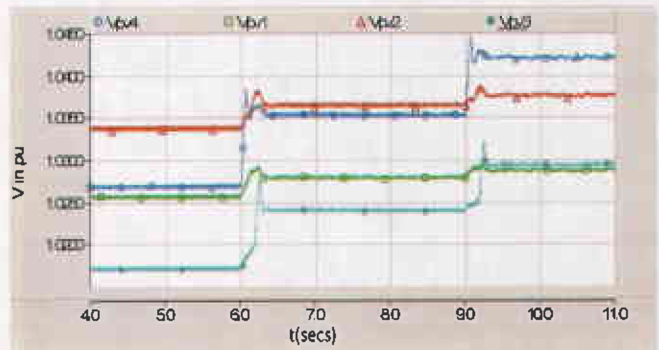

Figure 6 - Impact on feeder voltages of PV-DG output variation from 0 to 50% to 100% under GEC control with 20% increase in droop coefficient

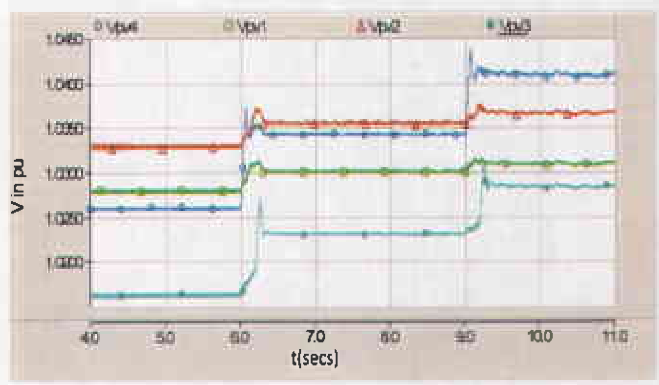

Figure 7 - Impact on feeder voltages of PV-DG output variation from 0 to 50% to 100% under GEC control with 40% increase in droop coefficient

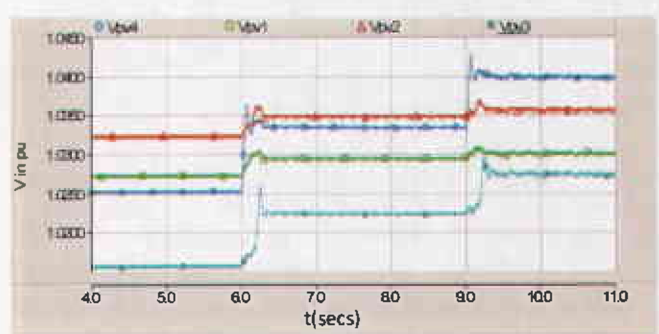

Figure 8 - Impact on feeder voltages of PV-DG output variation from 0 to 50% to 100% under GEC control with 60% increase in droop coefficient

IV. Analysis for Distributed Solution

For the distributed solution scenario it was assumed that numerous micro-scale PV-DG units (micro-inverters) are connected to the secondary system of a conventional distribution transformer. These micro-inverters can either be installed on utility poles or on residential household rooftops. In this study micro-inverter clusters with an installed capacity of 5 kW ± j5 kVAr were used. Two cases were considered for analysis: a) medium penetration, which consisted of four micro-inverter clusters, and b) high penetration case, which consisted of eight micro-inverter clusters, per a typical 50kVA pole-mounted transformer. Each 50kVA transformer supplied 5 to 8 typical houses. The houses are modeled as variable load with a 5kW maximum consumption per house. Initial simulations were conducted with PV inverters using conventional unity power factor control. GEC control was applied when voltage violations were identified.

Figure 9 shows the layout of the secondary distribution system with eight houses supplied at 240 V. Figure 10 shows the corresponding model of the secondary systems and clustered inverters (medium penetration case) for dynamic analysis in PSCAD software environment. The secondary overhead lines and underground cables are modeled by equivalent series resistive and inductive impedances representing short line lengths. The household loads are presented as dynamic loads with fixed P&Q values for this study.

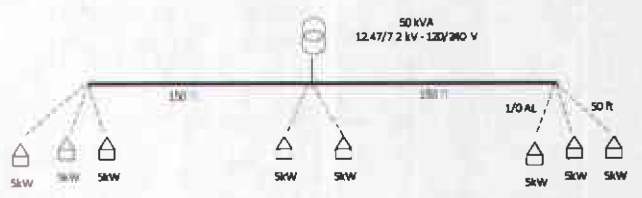

Figure 9 Layout of distributed solution

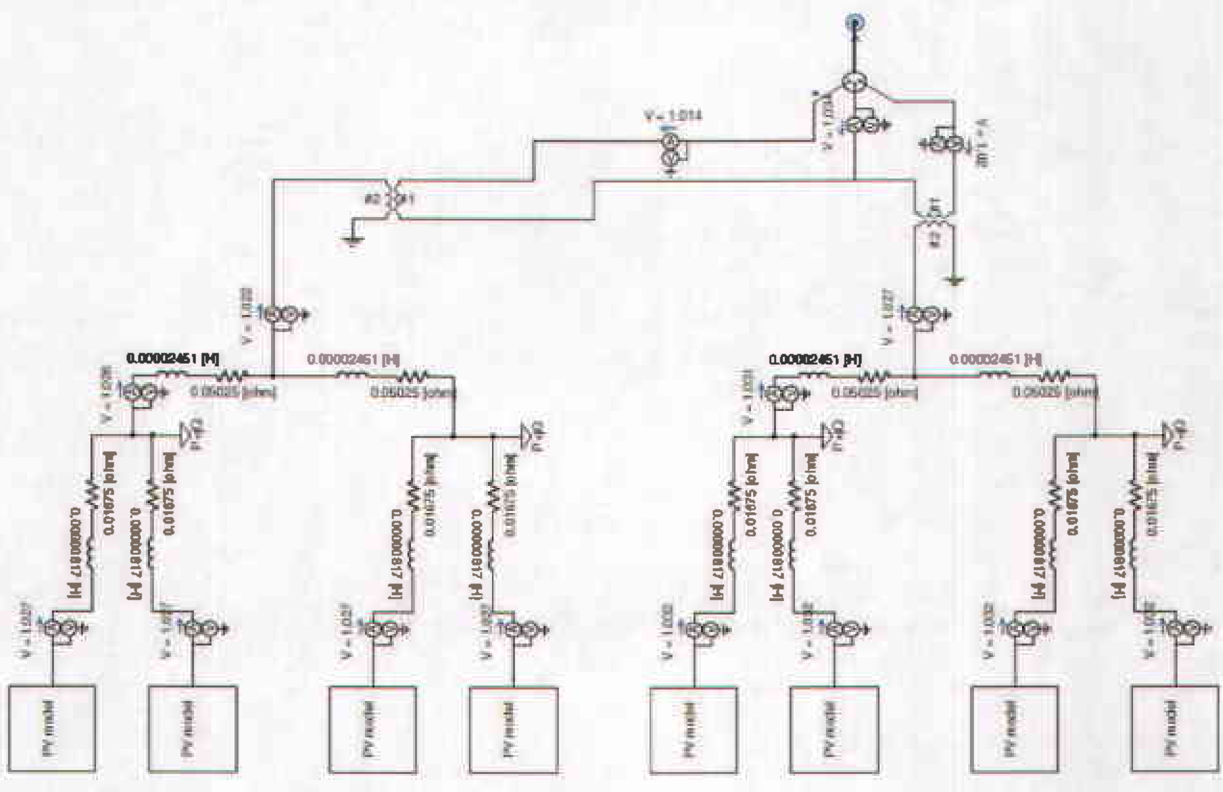

Figure 10: Secondary system model in PSCAD/EMTDC software

Figure 11 and Figure 12 show the simulation results for the medium penetration case. Figure 11 shows the phase-to-ground voltage at the primary side of the pole-mounted transformers, and Figure 12 shows the voltage at the customer sites. The results show that this case does not lead to voltage violations. Similarly, Figure 13 and Figure 14 show the simulation results for the high penetration case. Figure 13 shows the phase-to-ground voltage at the primary side of the transformers, and Figure 14 shows the voltage at customer sites. The results show that this case may lead to voltage violations at customer sites. A series of simulations were performed to investigate a possible mitigation solution to this overvoltage issue. The selected mitigation solution consisted of operating the micro-inverters under GEC control. Figure 15 and Figure 16 show the simulation results for the mitigation measure, the results demonstrate the effectiveness of the proposed solution.

The GEC method also mitigates the voltage rising effect of distributed PV generation on operation of shunt capacitors and line voltage regulators. For the voltage-controlled capacitors located at the end of the feeder and closed to the PV sites, increase in the primary voltage at high PV penetration causes disconnection of the shunt capacitors. Also, when voltage regulators tap changer controls detect the increase in the primary feeder voltages for an extended period (beyond specified delay), they decrease the tap position in an attempt to re-adjust the voltages. Any subsequent reduction in PV generation due to variations in solar radiation can eliminate the voltage rising effect of PV generation and may cause temporary under-voltage situation for the feeder, before the operation of VRs and shunt capacitors adjust the voltage again.

The studies also showed that the PV inverters with GEC controls are effective in mitigating the aforementioned issues. The GEC controls dynamically adjust the reactive power contribution of PV inverters based on variations in the voltages at PV sites (secondary) and prevent voltage rise at capacitors and/or voltage regulators locations.

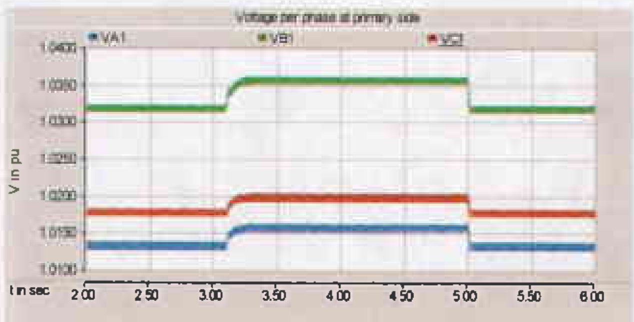

Figure 11 Phase voltage at primary side of distribution transformer (medium penetration case and unity power factor control)

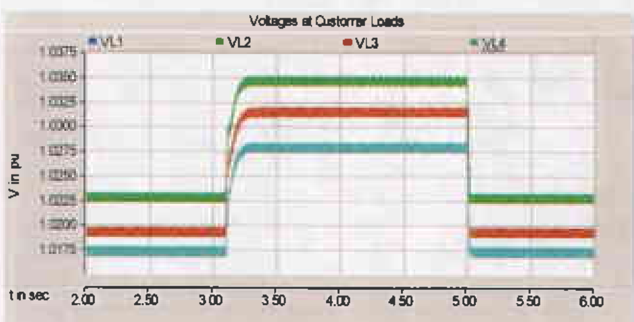

Figure 12 Voltage at customer sites (medium penetration case and unity power factor control)

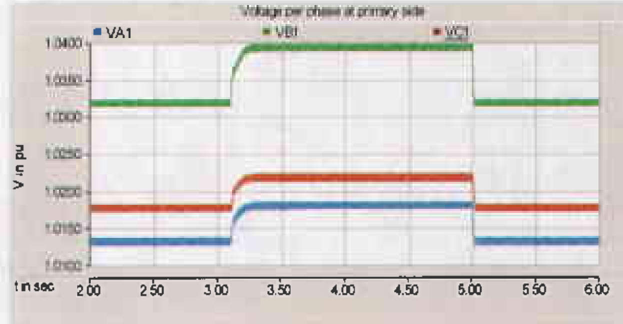

Figure 13 Phase voltage at primary side of distribution transformer (high penetration case and unity power factor control)

Figure 14: Voltage at customer sites (high penetration case and unity power factor control)

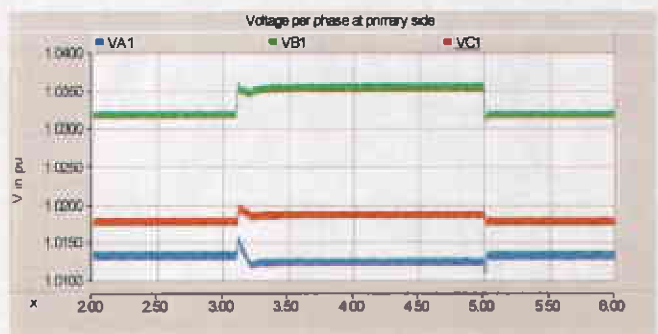

Figure 15 Phase voltage at primary side of distribution transformer (high penetration case and GEC control)

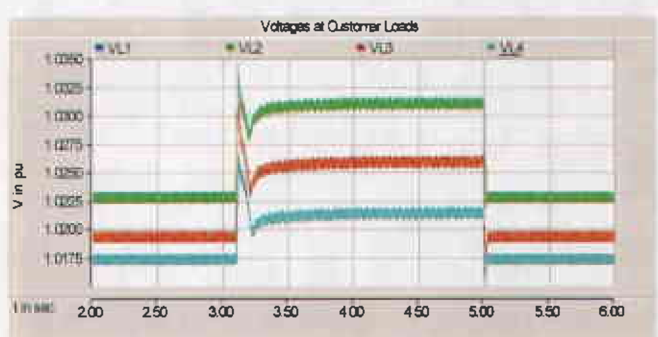

Figure 16 Voltage at customer sites (high penetration case and GEC control)

V. Conclusions

The interconnection of variable resources such as PV-DG to distribution systems may increase voltage levels along the feeder and lead to additional tap operations of LTCs and line voltage regulators. Most importantly, the steady-state voltage level increase and transient fluctuations caused by PV-DG interconnection may exceed the limits allowed by distribution utilities under medium to high penetration scenarios. Two different integration approaches for PV sources were reported and studied in this paper, namely, centralized solution and distributed solution.

The impacts of the centralized solution (500 kW +/- j 500 kVAr inverters) and the distributed solution on feeder voltages and operation of voltage regulation and control equipment under moderate penetration scenario were studied. The analysis compared the results obtained by using the conventional control (inverters operating at unity power factor) and the GEC control for variations in the PV-DG output generation. Several cases were studied to investigate possible mitigation solutions including PV-DG plant operation with the GEC control to compensate reactive power at different rates based on varying the slope of the droop curves used to control voltages. The simulation results show that inverters with GEC control capability can be very effective in mitigating the adverse voltage issues and reducing the number of tap changer operations.

The current stages of DG interconnection standards (e.g. IEEE 1547) do not allow voltage controls at DG locations. Several standard development working group have focused on modifying the standards to accommodate active participation of DG units in feeder controls and mitigation of possible impacts on system operation and increase in voltages.

VI. Acknowledgments

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VIII. Biographies

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Hussam Al-Atrash is the co-founder and controls engineering manager at Petra Solar Inc. His work is focused on digital control techniques and their application to distributed renewable energy generation systems. He is leading the design and demonstration of advanced PV inverter technologies such as Generator Emulation Controls (GEC), Volt-VAr optimization, and micro-grid operation. He received his BSc degree -with honors- from the University of Jordan, Amman, in 2003, and the MSEE and PhD degrees in Electrical Engineering from the University of Central Florida, Orlando, in 2005 and 2007, respectively.

Grid Impacts and Mitigation Measures for Increased PV Penetration Levels using Advanced PV Inverter Regulation

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***Abstract*— As part of the Renewable Systems Interconnection (RSI), exploring the impact of high levels of PV penetration on standard utility system planning methodologies is critical. In this paper, in order to evaluate the potential impacts on representative distribution feeders for a south-eastern utility that is facing the interconnection of increasing levels of Photovoltaic (PV) generation; detailed steady-state and dynamic modeling and simulation of the integrated systems are performed. The study was conducted on two representative feeders: an almost exclusively residential feeder, and a predominantly rural feeder. Multiple PV penetration levels based on Spring loading were considered: 33.3% and 75% of total feeder loading, and 75% of total connected capacity as extreme case. Steady-state and dynamic analyses were performed. Procedures used to evaluate these impacts and results and observations are discussed. Moreover, possible impact mitigation strategies and evaluation of PV inverter controllers for mitigating the negative impacts are assessed.**

I. INTRODUCTION

Due to growing concerns about climate change, the adoption of renewable portfolio standards and incentives, renewable energy technologies such as photovoltaics (PV) and wind are expected to become a larger part of our energy portfolio during the next couple of decades [1]. However, as their market share grows, concerns about potential impacts on the operation and stability of the electricity grid may create barriers to further expansion. As part of the Renewable Systems Interconnection (RSI) study conducted by the Department of Energy (DOE), one of the key areas needing immediate attention was defined to be: 'Power System Planning: Emerging Practices Suitable for Evaluating the Impact of High-Penetration Photovoltaics' [1].

From these and other research studies in the area (e.g. [2]-[6]), it is apparent that exploring the impact of high level PV penetration on standard utility systems is critical. In this paper, we evaluate the impact of PV penetration on the power distribution system in terms of: a) voltage and line loading, b) voltage and reactive power controllers, c) impacts of islanding and temporary over voltages. Also, this paper develops generic PV and grid dynamic models which contribute to PV interconnection studies as such models are not yet fully developed.

In order to evaluate the potential impacts on representative distribution feeders due to the interconnection of increasing levels of PV generation, static and dynamic models of two representative distribution feeders are developed. We present the PV and inverter models, procedures and results of a study performed to evaluate impacts of PV penetration on these representative feeders performed for a major south-eastern utility. Further possible impact mitigation strategies are presented by optimizing the PV inverter control algorithms.

Two representative feeders, an almost exclusively residential feeder and a predominantly rural feeder, with multiple PV penetration levels based on feeder Spring loading profiles were considered: 33.3% and 75% of total feeder loading, and 75% of total connected capacity as extreme case. Steady-state and dynamic analyses were performed; specifically, the analyses focused on impacts of increasing levels of PV penetration on feeder voltage profile and line section loading, as well as PV interaction with voltage regulating equipment, such as capacitor banks and voltage regulators. Finally, the dynamic impacts on feeder voltage, such as temporary over-voltages, due to PV intermittent output, loss and restoration of PV power output, and impacts of different islanding scenarios are evaluated.

The paper is organized as follows. In section II, the modeling procedure for the distribution feeders under study and the PV systems is introduced and challenges encountered are addressed. In section III, results of steady-state analyses are discussed and observations are presented; moreover, comparisons in performance of different types of inverter controllers are highlighted with respect to the operation of voltage regulating devices. Section IV focuses

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on the dynamic analyses performed, including performance during islanding scenarios. The paper then concludes with a summary of findings and suggestions for impact mitigation strategies.

II. Modeling of Distribution Feeders and PV Distributed Generators

In order to perform these studies, detailed feeder models were built and calibrated. Detailed models of the PV sources and inverters were also built and validated against manufacturer's datasheets and available field data. A series of comprehensive simulations using CYME® [7] and PSCAD® [8] were then conducted. To speed up the simulation without losing accuracy, aggregated feeder dynamic models were also developed and validated against their non-aggregated counterparts.

A. Distribution Feeder Modeling

Two representative feeders were identified for this study:

- A mostly residential feeder, the Urban Feeder, and
- A mostly rural feeder, the Rural Feeder.

The Urban Feeder has a total connected capacity of 43.7 MVA, and it's comprised of 23.9 kV L-L primary (3-phase) and 13.8 kV L-g secondary (1-phase) lines; the Rural Feeder has a total connected capacity of 30.5 MVA and 12.47 kV L-L primary and 7.2 kV L-g secondary lines.

For steady-state analyses, the two feeders were modeled in CYME. The feeder models were then validated against results obtained by Duke Energy for example load allocation studies, so as to gain confidence in the subsequent results obtained by these models.

In order to perform dynamic type of studies, PSCAD, which is a software tool used to perform Electro Magnetic Transient (EMT) Simulations, was used. Dynamic models in PSCAD for the various components have been developed and then integrated:

- Source model (i.e. the substation),
- Line models,
- Model for voltage regulators and their controllers – Figs. 1 and 2,
- Load models,
- Dynamic model for the PV generators and their controllers, which will be described in the next subsection.

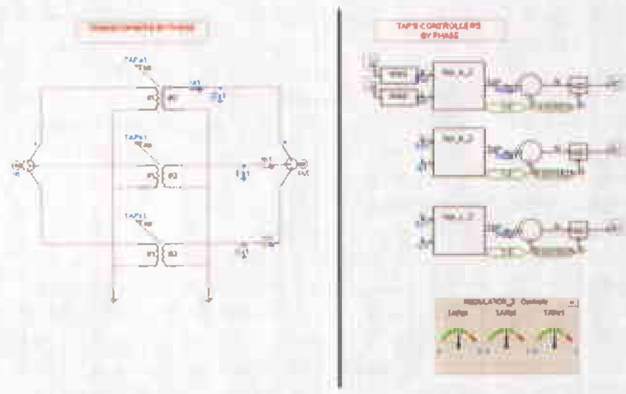

Figure 1 Dynamic model of voltage regulators (in PSCAD)

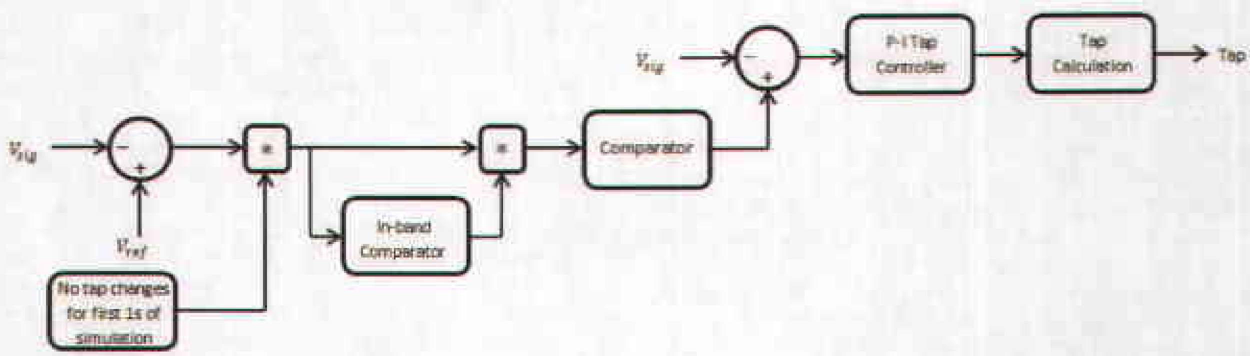

Figure 2 Dynamic model of voltage regulator controller schematic

To speed up the simulation without losing accuracy, aggregated feeder dynamic models were also developed and validated against their non-aggregated counterparts. Loads and lines were combined, i.e. aggregated, into a few single fixed loads, balanced across the three phases. The process of aggregating loads and lines consisted of placing a meter and then replacing a fixed constant load at the meter location equivalent to the meter reading, which enabled to not only aggregate the loads, but to also account for line losses. The aggregated dynamic models were then validated against the steady-state models under steady state conditions. As an example, power flow results obtained using the aggregated dynamic models and the steady-state models and their difference are shown in Table 1 for the Urban Feeder at low loading conditions.

TABLE I. URBAN FEEDER: SELECT NODE VOLTAGES AND DIFFERENCES BETWEEN STEADY-STATE AND AGGREGATED DYNAMIC MODELS

Steady-State Model Node Voltages (p.u.)	Aggregated Model Node Voltages (p.u.)	% Difference
0.9991667	0.997109	0.20596
0.9966667	0.995402	0.126922
0.9941667	0.994025	0.014239
0.9925	0.993088	-0.05923
0.9916667	0.992946	-0.12897
0.9933333	0.993364	-0.00309
0.9925	0.99341	-0.09169

B. *PV Distributed Generation Modeling*

Detailed photovoltaic system models were developed to be used in the steady-state and dynamic simulation platforms. It is noted that the modeling of the solar PV systems was based on specifications and field data obtained for a Duke Energy-owned and operated 1 MW solar installation. The PV panels were modeled based on specific manufacturers and model specifications, and were validated against manufacturer's data as well as field data. PV arrays were modeled using the Yingli Datasheet; while the inverter models were based on a SATCON inverter datasheet. Schematics of the PV generators, inverters and inverter controllers, are shown in Fig. 3.

Several control strategies for the PV inverters were taken into account to compare their performance with respect to voltage regulation. Specifically, different constant power factors and a PV with DQ control:

Case 1. constant power factor, set at 0.85

Case 2. constant power factor, set at 1.0

Case 3. dq control.

Performance in terms of operations of voltage regulators resulting from applying the three cases of inverter control strategies will be shown in the next section.

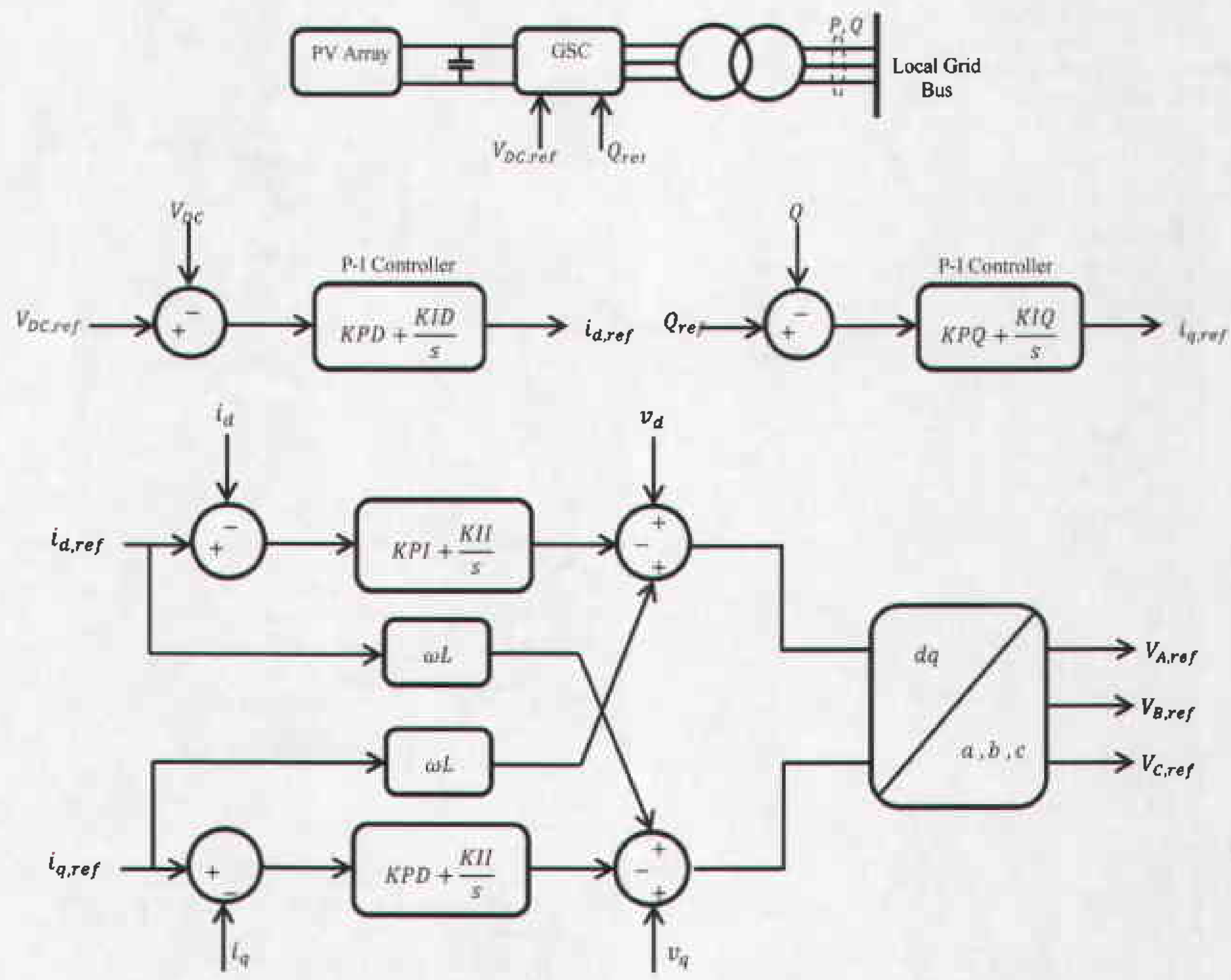

Figure 3 Schematics for PVs, inverters and their controllers

III. Steady-State PV Interconnection Studies

A. Test Setup and Scenario Description

The steady-state analyses consisted on the modeling and simulation of the two feeders under study for a typical day in April, as representative of low loading conditions, and specifically at solar noon. These analyses were conducted for solar noon given that the output of the PV distributed generators is typically at its peak at that time, which therefore represents the worst case scenario. These simulations were also conducted for the 24-hour load cycle on the same day. Multiple PV penetration levels were considered: 33.3% and 75% of total feeder loading, and 75% of total connected capacity as extreme case. Several PV locations were also taken into account. All node voltages, line section loadings and status of switched capacitors and voltage regulators were monitored and their performance analyzed.

For evaluation purposes, load profiles and PV generation as shown in fig. 4 and fig. 5 are used. Further, the operation of voltage regulators in the representative feeders are evaluated for the following scenarios with PV generation of 5106 kW and feeder loading of 4743 kW and 2839 kVAr:

1. Operation of regulators without PV generation
2. Operation of the regulator with PV generation:
    a. With constant pf PV output (1 and 0.85)
    b. With dq control (advanced control) on the PV system

Figure 4. Rural Feeder – 24-hour load profile for study on voltage regulating devices

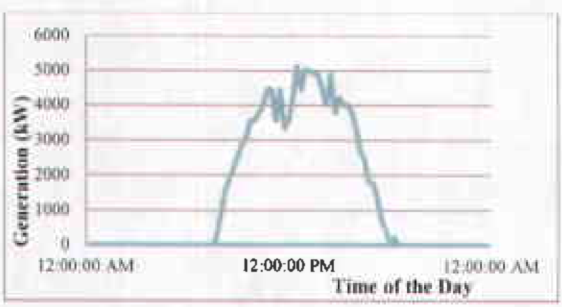

Figure 5 24-hour PV generation profile

Figs. 6 through 8 show feeder voltage profile with respect to distance from the substation without and with PV penetration and system active power.

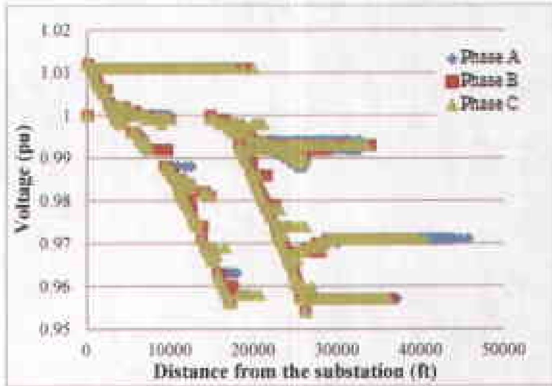

Figure 6 Rural feeder – Voltage profile without PV

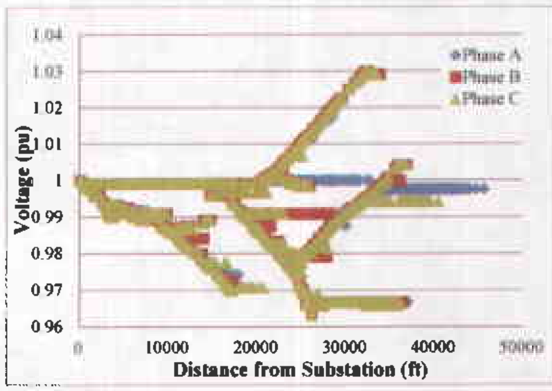

Figure 7 Rural feeder – Voltage profile with PV at solar noon (loading: 4743 kW, 2839 kVAr, PV generation: 5106 kW)

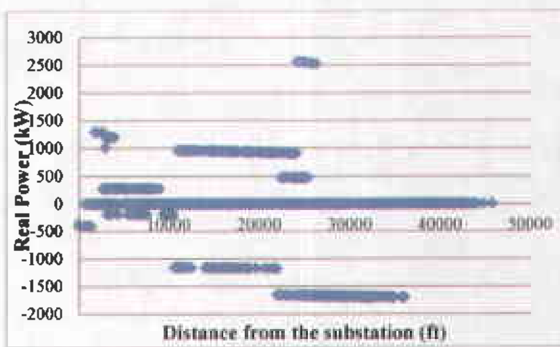

Figure 8 Rural feeder – Real Power profile with PV at solar noon (loading: 4743 kW, 2839 kVAr, PV generation: 5106 kW)

Table II shows the number of tap changes for the three voltage regulators in the rural feeder without PV and with PV and the three different control strategies. % increase in number of operations with respect to the case without PV is also shown. Actual tap settings and their changes throughout the day for one of the voltage regulators are shown in Fig. 9.

TABLE II TAP SETTINGS FOR

Regulator		# of Tap Changes	% Increase w/o vs. with PV
1	**No PV**	2	
	With PV and constant pf = 1.0	4	100%
	With PV and constant pf = 0.85	4	100%
	With DQ Control	4	100%
2	**No PV**	1	
	With PV and constant pf = 1.0	13	1200%
	With PV and constant pf = 0.85	15	1400%
	With DQ Control	10	900%
3	**No PV**	10	
	With PV and constant pf = 1.0	23	130%
	With PV and constant pf = 0.85	36	260%
	With DQ Control	24	140%

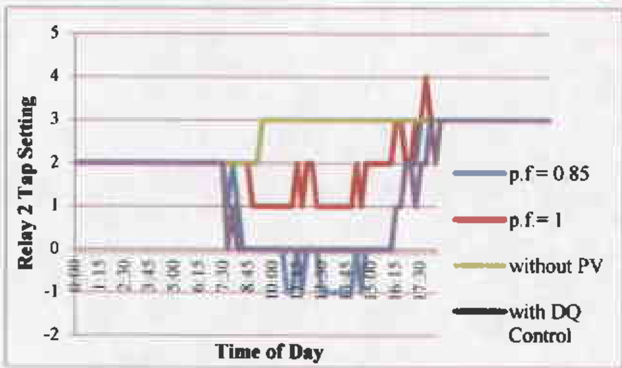

Figure 9 Relay 2 tap settings for the given 24-hr load profile

B. *Summary of Results and Observations*

A summary of the observations made follows:

- The interconnection of the PV generally has a positive impact on voltage profile, as seen for example in Fig. 7, and on feeder losses;
- The improved voltage profile can though pose problems of exceeding the upper voltage limits and increasing complexity in regulator control.
- For the residential feeder, the results of the steady-state analysis show that maximum voltage limits are not violated and distribution line section ratings are not exceeded for any of the first sets of conditions analyzed (33% and 75% penetrations, various PV locations). Some line overloads (up to 120%) are present when PV penetration is equivalent to 75% of feeder total connected capacity is assumed;
- The rural feeder presented varying voltage profile and the voltage regulator actions proved critical to maintain acceptable voltage levels; with 75% PV penetration, the voltage profile goes beyond the acceptable upper limit and distribution line section ratings are exceeded;
- Capacitors (both switched and fixed) were always ON as the trip settings currently used are not reached until the current is zero. This results in good voltage profile. However, it is suggested changing the control logics of switched capacitors to be voltage based as opposed to current, so as to provide voltage regulation even at low loading conditions;
- The number of operations of the voltage regulators is found to be much higher (up to 15 times) when PV generators are connected to the feeder as opposed to without PV; this could cause higher maintenance and faster aging of regulator controllers. For example, given the load and PV generation profiles as shown in Fig. 4 and Fig. 5, the operations of one of the voltage regulators for the case without and with PV and constant power factor of 0.85, constant power factor of 1 and with DQ control is shown in Fig. 9 for the 24-hour period. A summary of the number of operations of the three voltage regulators in the rural feeder is provided in Table 2.

IV. DYNAMIC PV INTERCONNECTION STUDIES

A. *Test Setup and Scenario Description*

The dynamic part of the studies consisted of two main analyses, both of which are focused on evaluating occurrences of temporary over-voltages: 1. the simulation of sudden disconnection and connection of PV distributed generators (PV generation step change), and 2. the islanding impact studies. These analyses were conducted using detailed models of PV generators and aggregated models of the two feeders in PSCAD. Penetration levels equivalent to 33% and 75% of feeder loadings were analyzed, and several PV locations were considered.

B. *Urban Feeder*

For system analysis during the switching transients, strategic points (buses) in the aggregated feeder model are considered, as shown in Figure 10. 0. The case study presents the following characteristics:

- A total system demand of 6774.67 kW;
- Location of PVs as indicated in Fig. 10, and penetration levels as summarized in the following table:

PV Location	Penetration Level	
	33%	75%
PV1	2236 kW	5081 kW
PV2	2236 kW	5081 kW
PV1, PV2, and PV3	745 kW each PV	1694 kW each PV

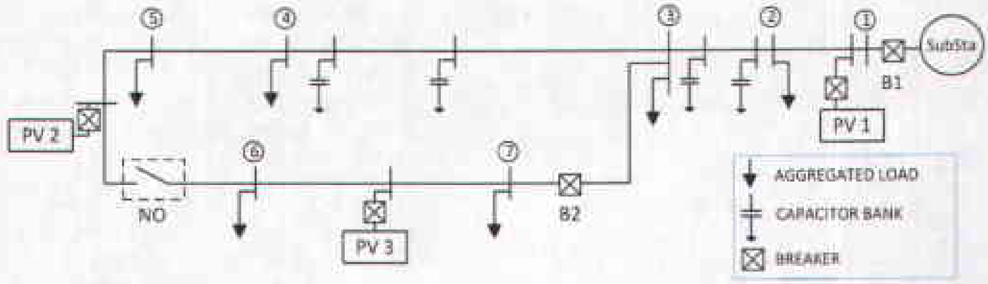

Figure 10. One-line diagram of the Urban Feeder agregated model used for dynamic studies

B.1 Connecting and Disconnecting PVs

In this study, for the two PV penetration levels (33% and 75%), the PVs are disconnected at time = 5 seconds, and then re-connected at time = 5.05 seconds using the PV breakers. Temporary overvoltages are noted after re-connection of the PVs. The highest overvoltages after reconnection of the PVs, for both the 33% and the 75% cases, are observed in the cases of PVs connected at multiple locations. These results are shown in Figs. 11 and 12 for 33% and 75% PV penetration, respectively.

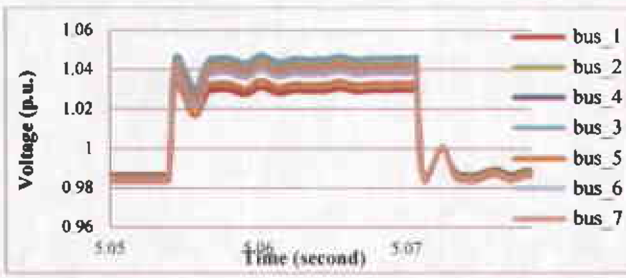

Figure 11. Urban Feeder – Connecting and Disconnecting PV: 33% PV Penetration, PV at PV1, PV2, and PV3

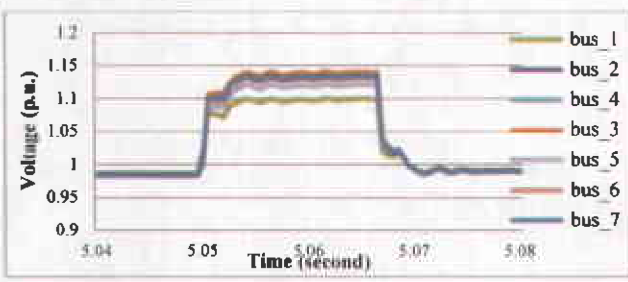

Figure 12. Urban Feeder – Connecting and Disconnecting PV: 75% PV Penetration, PV at PV1, PV2, and PV3

B.2 PV Islanding

Two possible islanding conditions were considered. In the first islanding scenario, the island is created by opening breaker B2 in Fig. 10. In the second scenario, breaker B1 is the one that opens, causing the PV to have to temporarily supply the entire feeder load. In both scenarios, the respective breakers open at simulation time = 5 seconds, creating the island, and close back at time = 5.05 seconds.

For the first islanding scenario (breaker B2 opens), in the cases in which the PV is located at PV1 and at PV2, the voltage at buses 6 and 7 (see Fig. 10 for bus numbering) drops to zero, since once the fault occurs and is isolated (breaker is opened) this area does not have any PV or source support. When the PVs are located at PV1, PV2 and PV3, the voltage at buses 6 and 7 drops by 30% as opposed to 100% because supported by PV3, as seen in Fig. 13.

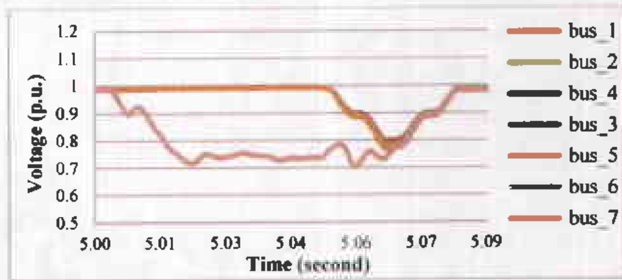

Figure 13. Urban Feeder – Islanding Scenario 1: 75% PV Penetration, PV at PV1, PV2, and PV3

In the second islanding scenario, in which breaker B1 opens, the resulting voltage profiles for 75% PV penetration and PV at PV1 is shown in Fig. 14 as an example. It is noted that during the 0.05 sec islanding condition, the system voltages drop to approximately 50%.

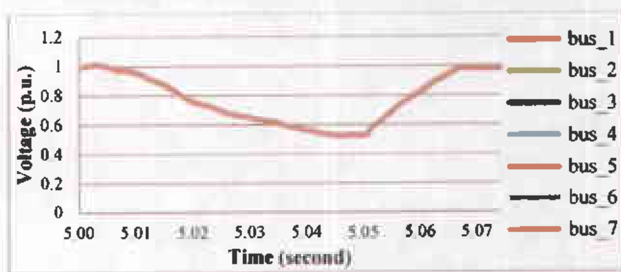

Figure 14. Urban Feeder – Islanding Scenario 2: 75% PV Penetration, PV at PV1

C. Rural Feeder

The rural feeder aggregated feeder model used in these studies is shown in Figure 10. 5. The case study presents the following characteristics:

- A total system demand of 3356 kW (which corresponds to a low loading condition characteristic of Spring loading);
- Location of PVs as indicated in Fig. 15, and penetration level as summarized below:

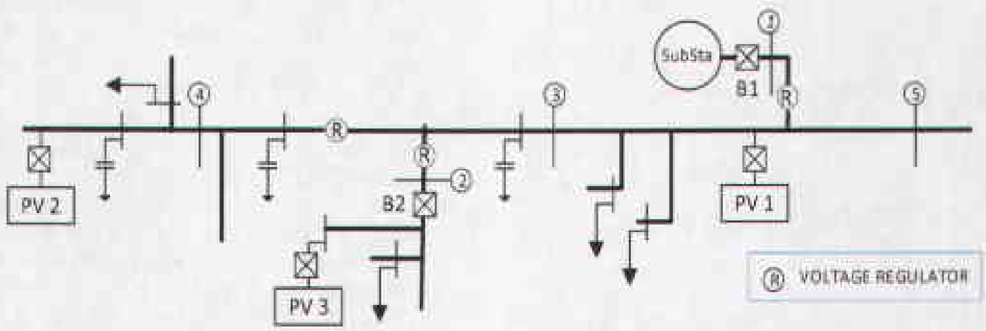

Figure 15. One-line diagram of the Rural Feeder agregated model used for dynamic studies

PV Location	Penetration Level
	75%
PV1	2517 kW
PV2	2517 kW
PV1, PV2, and PV3	839 kW each

C.1 Connecting and Disconnecting PVs

In this study, the PVs are disconnected at time = 5 seconds, and then re-connected at time = 5.05 seconds using the PV breakers. The highest overvoltages after reconnection of the PVs are observed in the case of PVs connected at multiple locations. These results are shown in Fig. 16 for Bus 4 and Table III for all buses.

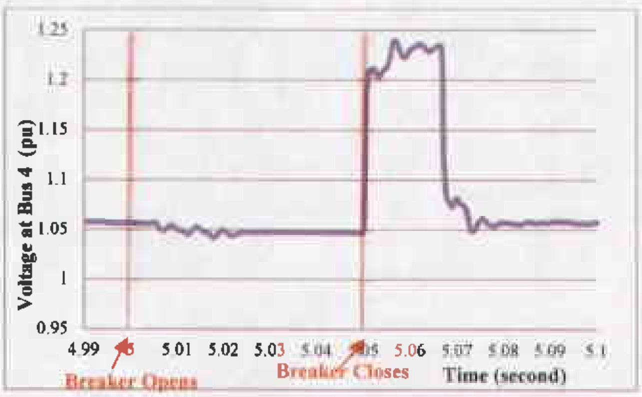

Figure 16. Rural Feeder – Connecting and Disconnecting PVs: 75% PV Penetration, PV at PV1, PV2, and PV3

TABLE III. RURAL FEEDER – CONNECTING AND DISCONNECTING PV: 75% PV PENETRATION, PV AT PV1, PV2, AND PV3 – VOLTAGE INCREASE

Time (sec)	Voltages (pu)				
	Bus 1	Bus 2	Bus 3	Bus 4	Bus 5
5	1	1.05	1.05	1.06	1.04
5.07	1.09	1.24	1.2	1.24	1.14
% Increase	9.00%	18.10%	14.29%	16.98%	9.62%

C.2 PV Islanding

Similarly to the studies performed on the urban feeder, two possible islanding conditions were considered. In the first islanding scenario, the island is created by opening breaker B2 in Fig. 15; in the second scenario, by opening breaker B1. In both scenarios, the respective breakers open at simulation time = 5 seconds, creating the island, and close back at time = 5.05 seconds.

For the first islanding scenario (breaker B2 opens), a small voltage perturbation at all buses can be observed; the main voltage rise (of approximately 0.95%) is present at bus 2, close to the breaker B1. Voltage waveform seen at Bus 2 is shown in Fig. 17.

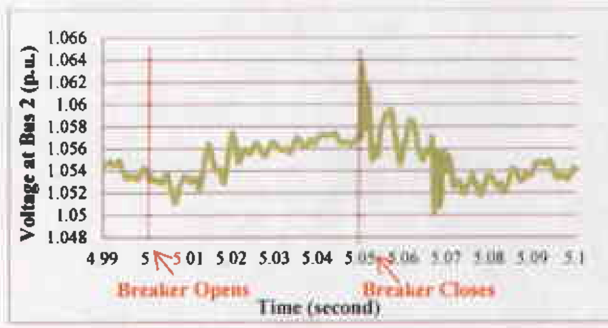

Figure 17. Rural Feeder – Islanding Scenario 1: 75% PV Penetration, PV at PV1, PV2, and PV3

In the second islanding scenario, breaker B1 opens causing the PV to have to temporarily supply the entire feeder load. The resulting voltage waveform at Bus 3 (as example) is shown in Fig. 18. Figs. 19 and 20 then show plots of active and reactive power supplied by the PVs right before, during, and right after the island.

Figure 18. Rural Feeder – Islanding Scenario 2: 75% PV Penetration, PV at PV1, PV2, and PV3

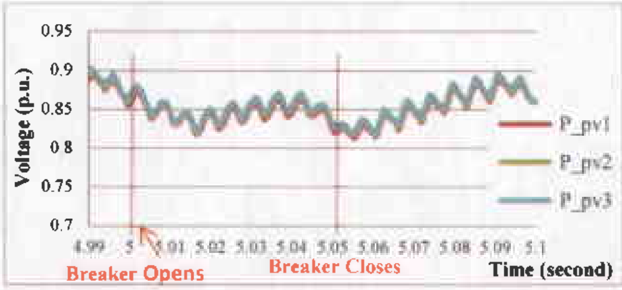

Figure 19 Rural Feeder – Islanding Scenario 2: 75% PV Penetration, PV at PV1, PV2, and PV3, Active Power Supplied by the PVs

Figure 20 Rural Feeder – Islanding Scenario 2 75% PV Penetration, PV at PV1, PV2, and PV3, Reactive Power Supplied by the PVs

It is worth noting that during the 0.05 sec islanding condition, the system voltages drop by approximately 20% in 0.015 sec, and then stabilize at the low voltage until the breaker closes back, at which point they rise back. The voltage does not collapse during the island thanks to the PQ controllers of the PVs.

D. Summary of Results and Observations

A summary of the observations made follows:

- Connection/disconnection analyses for 75% PV penetration resulted in a maximum transient voltage of 18% on average for the Rural Feeder (Fig. 16).
- It is noted that the magnitude and duration of the voltage spike would depend on the response time of the inverter internal protection scheme.
- The islanding analysis performed by suddenly opening the breaker shows that during the 0.05 islanding condition, the system voltages drop by approximately 20% in 0.015 sec, and then stabilize at the low voltage until the breaker closes back, at which point they rise back (Fig. 18). It is noted that the voltage does not collapse during islanding conditions due to the PV controllers.

V. Summary of Findings and Conclusions

In summary, strategies for impact mitigation of increased penetration level of PV distributed generation and recommendations for further investigation include:

- The use of advanced PV inverter controllers has been proven critical; detailed study of the impacts of different inverter controllers on the system will be described in the final paper;
- PV location, inverter controller configuration and dynamic control are all critical in effectively increasing PV penetration level;
- The number of operations of the voltage regulators can be reduced by optimal placement of the PV distributed generators and dynamic controllers;
- Analyzing the impacts of PV interconnection to the feeder in a real-time simulation scenario can be beneficial to evaluate details of system dynamics under a multitude of system conditions;
- Evaluation of optimal area control methods for controlling voltage regulators and PV inverters needs to be assessed.

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Generator Emulation Controls for Photovoltaic Inverters

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***Abstract*—The grid faces a number of challenges related to large-scale integration of intermittent distributed generation (DG) such as photovoltaics (PV). Power quality challenges include voltage regulation issues, flicker, and frequency volatility. Operational challenges include the need for extension of the command-and-control infrastructure to millions of devices anticipated on the low-voltage (service) side of the distribution network. This paper presents an advanced grid-tied inverter controls concept designed to address such challenges. This controls concept is based on reproducing favorable characteristics of traditional generators that result in load-following tendencies, and is accordingly dubbed Generator Emulation Controls (GEC). Traditional generators are analyzed with specific focus on such favorable characteristics as inertial dynamics and controlled impedance. Details of GEC are then presented, and its implementation is outlined based on the evolution of conventional grid-tied inverter controls. This is followed by an examination of the system impact of GEC-operated devices. GEC allows DG inverters to perform voltage regulation support, reactive power compensation, and fault ride-through. GEC also allows DG inverters to form scalable inverter-based microgrids, capable of operating in grid-tied mode or separating and supporting an islanded load. Simulation results are presented to examine the impact on voltage regulation and power losses across a distribution feeder. Two experimental test beds are used to demonstrate voltage regulation support, transient suppression, and microgridding capabilities.**

***Index Terms*—Distributed power generation, inverters, photovoltaic systems, smart grids.**

I. Introduction

IT IS TIME FOR renewables! Today, the world is facing the economic, environmental, and political consequences of its heavy dependence on fossil fuels for energy. The rapid growth of grid-tied photovoltaic (PV) installations holds many promises: clean energy, reduced emissions, energy independence locally and nationally, and the creation of new green jobs. Sunshine is an abundant resource, while PV technology is clean, quiet, and suitable for distributed installations near points of load.

Unfortunately, PV supply is intermittent in nature, and does not properly match the load profile. As a result, large-scale integration of distributed PV generation challenges the quality and stability of the grid [1], [2]. These challenges are exacerbated

Fig 1 Functions performed by the grid, and corresponding technologies

by constraining standards that govern the interconnection of PV into the grid system.

Today, the penetration of renewable DG into the grid is quite limited for economic reasons, and thus presents little challenge to grid operation and stability. As the price of wind and PV energy generation continues to decline with improved technology, their penetration into the grid will increase and thus their impact on the grid will become more tangible. This paper offers a technical approach that addresses these impacts.

A. Technology Gap

Grid functions extend far beyond the mere transport of real power to loads. A closer look at the functions performed by the electric grid reveals a seldom-addressed technology gap in the "traditional smart-grid" approach. Fig. 1 shows an overview of functions performed by the electric grid, along with traditional and emerging technologies that deliver these functions. Load-following functions are critical to grid operations, and are necessary for the proper shaping of the voltage waveforms. Load-following requires energy storage, spinning reserve, frequency stabilization, voltage stabilization, reactive power supply, and supply of harmonic currents.

Traditional generation through synchronous machines exhibits inherent electro-mechanical characteristics that facilitate the performance and coordination of load-following functions. In particular, high-inertia inherent in machine rotors is a form of short-term energy storage that results in a natural tendency for frequency and voltage stabilization. The low stator impedance of generators allows for the supply of reactive and harmonic currents required by the load. Capacitor banks are used to enhance the ability of the grid to supply reactive and harmonic currents, resulting in enhanced voltage regulation, improved voltage quality, and reduced network losses.

As PV displaces an increasing proportion of traditional generation on the grid, new technologies are necessary to ensure that all load following functions are being supplied adequately. Traditional PV systems produce energy at their own pace and

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push non-dispatchable near-unity power factor current into the grid. Distributed PV generators-often at large capacities rolling up to 50–100 MW in some regions—are currently not integrated into utility's dispatch and resource planning solutions. These installations normally require large amounts of balancing power resources, in addition to adequate levels of energy storage and spinning reserve. These resources are required to absorb load transients, clouding fluctuations and improve transient and voltage stability in response to contingencies such as the tripping of a large generator. Demand response and energy storage may be used to offset some of the slower needs for energy balancing and spinning reserve. Distributed capacitor banks may still be used to supply reactive and harmonic currents. This leaves a technology gap in the areas of frequency stabilization and voltage stabilization within the "traditional" smart grid approaches.

B. *Towards Generator Emulation*

In order to maintain grid stability and reliability, the increasing penetration of PV and DG technologies into the grid should be accompanied by a proportional increase in the grid's capacity for load-following functions. The integration of load-following functions into DG systems is a natural, scalable, and cost-effective approach to achieve this goal [3], [4].

Voltage regulation support is a prime example of load-following functions. Voltage regulation challenges have already been reported by a number of distribution utilities in the United States [5]. These challenges have generally been concentrated in certain pockets of high-penetration of PV systems. In a number of cases, this has driven these utilities to stop PV installations at these troubled circuits, or invest in costly upgrades. In this light, the challenge of voltage regulation has received particular interest in various studies [6]–[8]. Many studies point to voltage regulation support through injection of reactive power as a key component of the remedy [9], [10]. In [11] and [12], it is shown that this approach is equally effective in low-voltage (LV) circuits as it is at medium and high-voltage.

Power electronics offer remarkable flexibility that can be utilized to support more load-following functions in a comprehensive fashion. Specifically, DG inverter can be programmed to emulate the favorable characteristics of traditional generators: controlled impedance and inertia. DG inverters operating in this manner promote voltage and frequency stability in the system they are interconnected to [13]. This is a powerful concept that allows such inverters to form scalable master-less microgrids [14]–[16].

Petra Solar's Generation Emulation Controls (GEC) technology is an integrated approach for embedding load-following, grid-forming functions into PV inverters. It employs the concept of impedance emulation [14], [17], [18], to eliminate the need for a large inductor at the inverter output as in many popular implementations [13]. The GEC control strategy also accounts for the power-limited nature of PV and its effect on system dynamics.

C. *The Role of Microgrids*

Widespread adoption of DG, distributed storage, demand response, and other intelligent systems on the distribution network poses a major challenge to the command and control philosophy of the grid. It is not technically or economically feasible to extend the traditional command and control infrastructure to millions of devices anticipated on the LV side of the distribution grid. Furthermore, exerting direct control over the operation of customer-owned assets may be perceived as an encroachment on their property and privacy.

Microgrid technology is a very promising solution to many grid operations challenges. A microgrid is a coordinated group of energy sources, storage, and loads that can collectively interact with a host electrical power system (EPS) as a unified coherent system. A microgrid can operate in parallel to the host EPS, and/or disconnect and operate as an intentional island. The goals of this behavior are to maximize the value of local energy resources, enhance the reliability of energy supply to local loads, and/or support the host EPS [16], [19].

Adoption of microgrids as building blocks is an effective way of distributing intelligence throughout the grid system. A microgrid hierarchy may be created by arranging microgrids into a pre-defined chain of command and data reporting. This hierarchy will shift the communications and control burden away from a centralized grid controller and create a more "democratic" system. Local microgrid control agents will be better equipped with information about local network topology, resources, and requirements. This will also allow a small section of the grid to stay operational if it loses its power or communication connection to the grid.

The distinct ability of microgrids to create intentional islands is highly valuable to the grid operator and the end user. This can, for instance, be applied at a feeder level. It provides a means to maintain continuous power supply to local loads in the event of disturbance elsewhere in the power system. It also isolates both DG and loads within the islanded section during a power quality event. This reduces the interconnected load on the system during a contingency, and enhances the ability of the grid to perform a black-start.

This paper is focused on introducing the concept of Generator Emulation Controls (GEC). A study of the characteristics and controls of traditional synchronous generators is presented in Section II, highlighting favorable characteristics in the power system. This is followed by a study of traditional grid-tied inverter architecture and control in Section III. This provides a foundation for Section IV in which the GEC concept is introduced. Section V focuses on GEC implementation and outlines recommended design guidelines. Section VI is dedicated to an evaluation of the impact of GEC-operated PV on a distribution feeder, compared to that of traditional PV.

II. Characteristics of a Traditional Generator

The overwhelming majority of traditional generators are synchronous generators. Their prime movers vary according to the energy source, and are often heat engines driven by the energy resulting from fossil fuel combustion or a nuclear reaction. This section provides a simplified discussion of the operation and dynamics of synchronous generators. Emphasis is placed on characteristics and mechanisms that are particularly useful to mimic in DG inverters under the GEC concept. This analysis is presented in more detail in [20].

The behavior of a synchronous generator has multiple components that dominate its dynamics within different regions of the frequency domain. Fig. 2 provides an overview of these

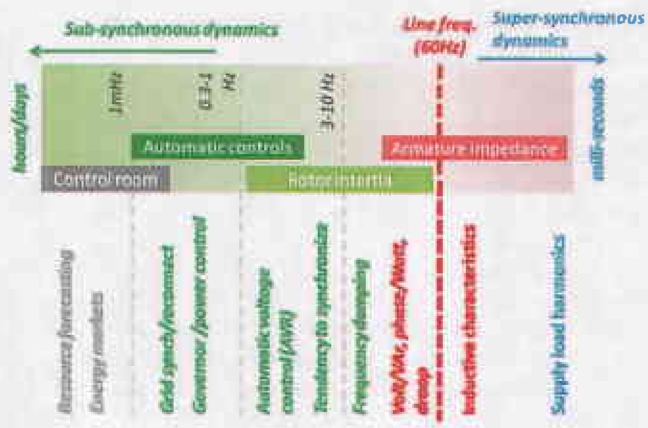

Fig. 2. Generator dynamics and controls in the frequency domain.

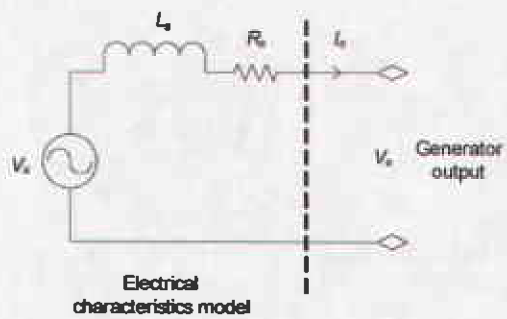

Fig. 3. Simplified model of the output characteristics of a synchronous generator.

frequency ranges, and the dynamics, controls, and subsystems dominant within each.

Electrical characteristics of the machine dominate its dynamics at line frequency and above. Fig. 3 shows a simplified model of the electrical characteristics of a synchronous generator at its ac terminals. The model consists of the induced electromotive force (EMF), V_s, in series with the self inductance and ohmic resistance of the armature windings, L_s, and R_s. Output current, I_o, flows in the windings and causes a voltage difference between the induced EMF, V_s, and the actual output voltage, V_o. Generator impedance reflects its size and capabilities. As a rule of thumb, generator impedance is inversely proportional to its power ratings. Power generator designs minimize the value of resistance, R_s, in order to limit the ohmic losses in the windings. As a result, the typical voltage drop across R_s is very small, and is neglected in analysis in this paper.

Consider a generator with an electrical model as in Fig. 3, with negligible resistance. For small values of the power angle δ, real and reactive power output, P_o and Q_o, can be expressed as

$$P_o \approx \frac{|V_o| \cdot |V_s| \cdot \delta}{\omega \cdot L_s} \tag{1}$$

$$Q_o \approx \frac{|V_o| \cdot (|V_s| - |V_o|)}{\omega \cdot L_s}. \tag{2}$$

The angle δ represents the phase of the internal induced voltage of a generator relative to that of the output voltage. It is strongly correlated to active power, and is thus dubbed the power angle or torque angle of the generator. The amount of reactive power delivered is rather strongly dependent on the difference in amplitude between the output and induced voltages, V_o and V_s.

A. Amplitude and Frequency of the Induced EMF

The amplitude, frequency, and phase of the induced EMF, V_s, are determined by the state of the rotor and magnetic excitation. They provide the main bridge between the electrical, magnetic, and mechanical characteristics of the machine.

The frequency is determined by the rotational speed of the rotor, and the construction of the machine.

$$\omega_s = n \cdot \omega_{\text{mech}} \tag{3}$$

where ω_s is the electrical frequency of the induced EMF in rad/s, ω_{mech} is the mechanical rotational speed of the rotor, and n is an integer ratio dependent on the number of poles in the machine.

The voltage amplitude is proportional to the rotor flux and operating frequency

$$|V_s| \propto \omega_{\text{mech}} \cdot \phi \tag{4}$$

where ϕ is the rotor flux.

During normal generator operation, there is very limited variation of the rotor speed. The generator's exciter controls voltage amplitude by adjusting the rotor excitation current and the resultant magnetic flux.

Energy is kinetically stored in the rotating mass of the generator system. This includes the rotating mass of the prime mover in addition to that of the synchronous machine's rotor. This energy governs and stabilizes the machine's rotating speed, and operating frequency. The machine's mechanical speed is determined by the amount of kinetic energy stored in this rotating mass.

$$E_{\text{kinetic}} = \frac{1}{2} \cdot J \cdot \omega_{\text{mech}}^2 \tag{5}$$

where E_{kinetic} is the rotational kinetic energy, and J is the moment of inertia of the rotating mass (determined by mass and geometry).

B. Power and Frequency Control of a Synchronous Generator

Real power, kinetic energy storage, and operating frequency are closely coupled. The relationships between these are examined in this section in order to identify the characteristics that need to be emulated by GEC to mimic the inertial behavior of a synchronous machine.

The rate of change of kinetic energy is equivalent to the difference in prime-mover power input, P_{in}, and electrical power output, P_o, (neglecting any losses). Considering narrow frequency fluctuations around nominal frequency, $\overline{\omega_s}$, and using (3), it can be shown that

$$\begin{aligned} \omega_s &= \frac{n^2}{J \cdot \overline{\omega_s}} \cdot \int (P_{\text{in}} - P_o) \cdot dt \\ &= k_{\text{rotor}} \cdot \int (P_{\text{in}} - P_o) \cdot dt. \end{aligned} \tag{6}$$

The power angle, δ, can be expressed as the integral of instantaneous difference between the electrical frequency of the

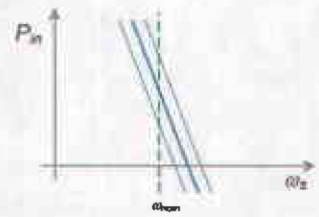

Fig. 4. A family of power-frequency droop curves.

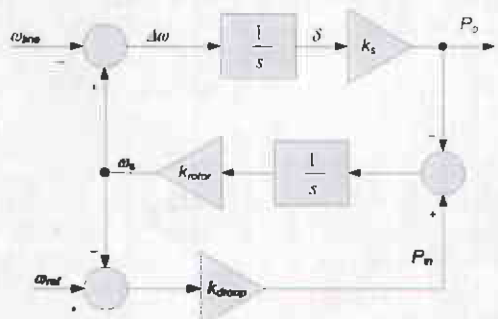

Fig. 5. Dynamic model of a synchronous generator with power-frequency droop.

induced EMF, ω_s, and that of the host EPS, ω_{line}. In this light, (2) can be rewritten as

$$P_o \approx \frac{|V_o| \cdot |V_s|}{\omega_s \cdot L_s} \cdot \int (\omega_s - \omega_{\text{line}}) \cdot dt$$
$$= k_s \cdot \int (\omega_s - \omega_{\text{line}}) \cdot dt. \qquad (7)$$

Equations (6) and (7) reveal a natural negative feedback mechanism that relates the rotor speed and real power output of the machine. A controller governs the relation between line frequency and input power according to different objectives depending on the operating mode of the machine: connected to an infinite bus, dedicated load, or paralleled with other synchronous machines.

1) Power-Frequency Droop: Power-frequency droop is an effective unified control approach for synchronous generators. Prime mover power is dynamically adjusted to follow a negative-sloped relationship to rotating speed, as shown in Fig. 4. This scheme is suitable for a synchronous generator operating under diverse operating conditions. It provides robust operating characteristics around which supervisory controls can be wrapped by modifying droop characteristics.

A simplified dynamic model of a synchronous generator with droop is shown in Fig. 5. Droop is assumed instantaneous in order to simplify the model for purposes of this paper. The significance of droop for stability is clear from this model as discussed below.

Consider a machine connected to a dedicated load with a constant power demand. Droop acts as a negative feedback mechanism that will adjust real power input to match the power output, and prevent a frequency run-away condition.

For a machine feeding a constant-frequency infinite bus, the droop path provides damping. In the absence of droop, the model is reduced to a marginally unstable feedback loop with two cascaded integrative functions.

A typical EPS (such as the grid) has a finite number of generators operating in parallel and supporting a common load. In this case, droop limits frequency deviation, provides damping, and delivers the added benefit of automatic power sharing both during transient and steady-state conditions. With droop control, generator units tend to converge at a stable operating point with some degree of power-sharing even in the absence of any coordinating controls. Droop characteristics can then be adjusted in a supervisory manner to modify the contribution of individual units.

2) Response of Power Output to EPS Frequency: The response of the power output to EPS frequency variations is an interesting formulation that offers a simplified summary of inertial dynamics when analyzed in the frequency-domain.

Consider a machine with power-frequency droop with the dynamic model shown in Fig. 5. The response of real power output to short-term EPS frequency transients is dominated by stator dynamics, and can be approximated as

$$\frac{P_o(s)}{\omega_{\text{line}}(s)} \approx \frac{-P_o(s)}{\Delta\omega(s)} = -k_s/s. \qquad (8)$$

The droop characteristics dominate the response of output power to slower variations in EPS frequency

$$\frac{P_o(s)}{\omega_{\text{line}}(s)} \approx \frac{-1}{\omega_s(s)/P_o(s)} \approx -k_{\text{droop}}. \qquad (9)$$

Equations (8) and (9) capture the inertial behavior of the synchronous machine, and represent the preferred power-frequency behavior to be emulated in PV inverter under the GEC scheme. Fig. 6 is a simplified representation of this power-frequency response at various frequency ranges. High-frequency dynamics are dominated by stator characteristics, while low-frequency dynamics are determined by the droop characteristics as outlined in these equations. A supervisory controller may be used to further shape machine operation in steady-state by manipulating the droop characteristics in real-time. For example, a machine can be operated in a constant real power mode. In such case, the frequency-to-power gain approaches zero in steady-state.

III. Traditional PV Inverter Control

This section discusses traditional PV inverter control. The objective is to outline the necessary modifications to support GEC.

A block diagram of a typical PV inverter is shown in Fig. 7 below. The pre-regulator dc-dc converter converts the variable output voltage of the PV panel to a bus voltage suitable for the inverter stage. During normal operating conditions, it is operated under Maximum Power Point Tracking (MPPT) and behaves as a constant-power source. The preregulator controller also has a built-in mechanism for limiting power flow during contingencies. The converter operates as a voltage source as a means of protection if the intermediate bus voltage level rises above normal.

A sinusoidal pulse-width modulated (SPWM) inverter stage is used to interface the host EPS. It is controlled to operate as a current-source, under the assumption that the host EPS appears as a stiff voltage source.

Fig. 8 shows the basic current-source control strategy for a traditional PV inverter. The innermost control loop directly governing the operation of the SPWM stage is the output current regulation (OCR) loop. The OCR controller shapes the output current of this stage into following a sinusoidal reference. This

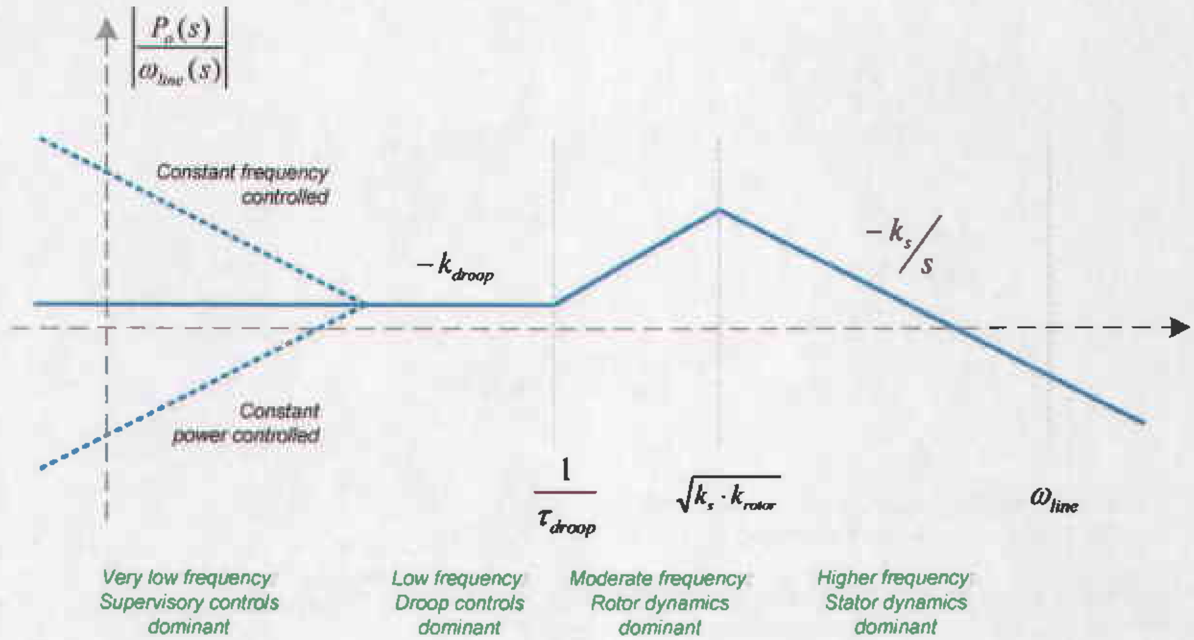

Fig. 6. Power-frequency characteristics of a synchronous generator in various frequency ranges.

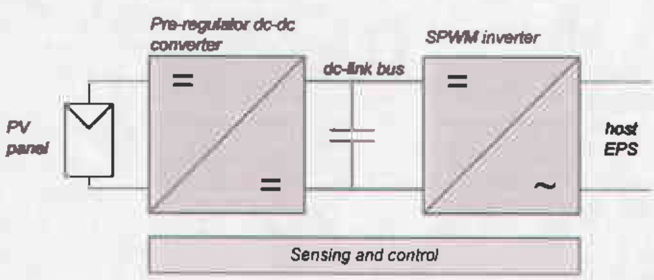

Fig. 7. Block diagram of a typical two-stage PV inverter.

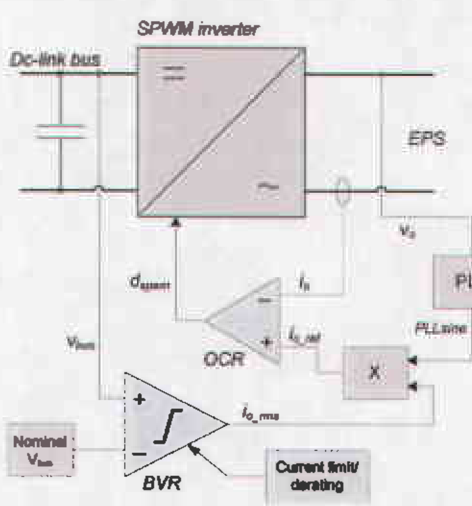

Fig. 8. Traditional current-source control strategy for a grid-tied PV inverter stage.

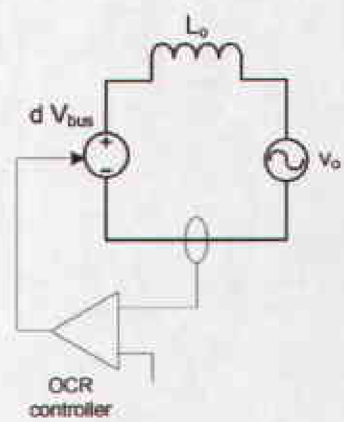

Fig. 9. Output current regulator (OCR) loop layout.

sinusoidal reference is a scaled version of the phase-locked loop (PLL) block output. The PLL is responsible for supplying a high-fidelity constant-amplitude sine wave synchronized with the host EPS.

The bus voltage regulation (BVR) controller supplies a slowly varying signal that modulates the amplitude of the output current reference in an attempt to regulate the dc-link bus voltage. The output of the BVR can be positive or negative (it can temporarily sink power from the host EPS). This output is limited from either direction, providing the current limit function. These limits may be varied based on temperature as a means of thermal derating.

A. OCR Dynamics

The dynamics of the OCR loop are of specific interest as this loop is inherited in the GEC implementation. Ideally, this loop is closed at a high bandwidth. The inverter stage is seen as a stiff current source with very high output impedance. Practically, several factors limit the bandwidth of the OCR loop, resulting in finite output impedance in the super-synchronous frequency range (above line frequency).

Fig. 9 shows the basic layout of the OCR loop. Fig. 10 shows the dynamic model of this control loop. Fig. 11 shows the Bode sketches of the frequency response of the plant, controller, and the combined loop.

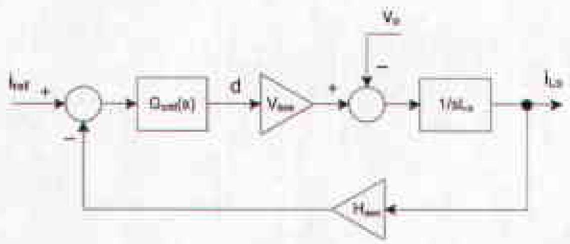

Fig. 10. Output current regulator (OCR) loop model.

In the frequency range of concern, the loop frequency response can be approximated by

$$\mathrm{Loop}_{\mathrm{OCR}}(s) = \omega_c^2/s^2 \tag{10}$$

where ω_c is determined by plant dynamics and controller design, and is generally one-to-two decades below the switching frequency.

From the model, the response of the inductor current to EPS voltage is given by

$$\frac{i_{\mathrm{Lo}}(s)}{v_o(s)} = \frac{-1/s \cdot L_o}{1 + \mathrm{Loop}_{\mathrm{OCR}}(s)} = \frac{-1}{s \cdot L_o} \cdot \frac{1}{1 + \omega_c^2/s^2} \tag{11}$$

where L_o is the output filter inductor.

In the frequency range of interest, this can be further approximated by

$$\frac{i_{\mathrm{Lo}}(s)}{v_o(s)} = \frac{-s^2/\omega_c^2}{s \cdot L_o} = \frac{-s}{\omega_c^2 \cdot L_o}. \tag{12}$$

The inductor current induced by the EPS voltage resembles that flowing in a "virtual" capacitor connected across it of the value

$$C_{\mathrm{ocr}} = 1/\omega_c^2 \cdot L_o. \tag{13}$$

As far as the host EPS is concerned, the inverter output stage can be modeled as shown in Fig. 12.

In addition to this "virtual" capacitor resultant from the control loop, the inverter output filter has a small physical capacitor. When considering current distortion, these two capacitors (actual and virtual) can simply be added

$$C_{\mathrm{total}} = C_o + C_{\mathrm{ocr}} \tag{14}$$

where C_o is the output filter capacitor of the inverter, and C_{total} represents the combined apparent capacitor.

Capturing the dynamics of the OCR loop through an equivalent circuit is a valuable tool that simplifies stability analysis of GEC controls, as will become evident in the Section V.

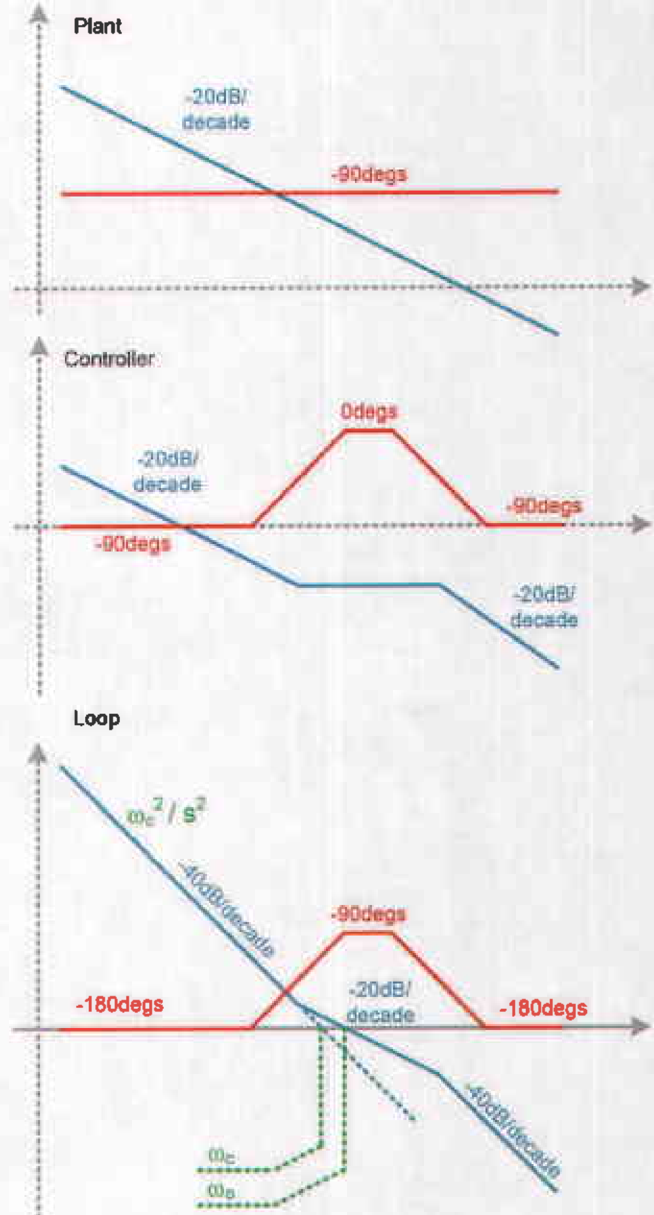

Fig. 11. Bode sketch of OCR frequency response.

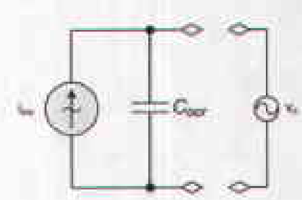

Fig. 12. Capacitive effect at the inverter output.

IV. Generator Emulation Controls

Generator Emulation Controls (GEC) is an inverter control concept designed to reproduce favorable grid-forming characteristics of a synchronous generator. This includes tendencies for voltage and frequency regulation, transient suppression, safe and master-less parallel operation, and seamless transition between grid-tied and islanded operation.

GEC is a combination of control loops that operate in a cohesive manner in various frequency ranges to shape the inverter's behavior. First, the inverter output is forced to reproduce the behavior of the basic circuit model in Fig. 3. This governs the response of the inverter to sub-cycle transients and defines droop characteristics relative to EPS voltage amplitude and phase, as

Fig. 13. A size comparison of a PV microinverter relative to an actual inductance eliminated through impedance emulation.

defined in (1) and (2). Impedance emulation is utilized to create the impedance characteristics while avoiding the cost and power losses associated with it. Secondly, a PLL is utilized derive the "emulated EMF" and serves to reproduce inertial dynamics outlined in (8) and (9). Finally, a power-flow controller is utilized to govern the steady-state power processed by the inverter. This is necessary to account for physical constraints such as limited available power from PV, its inability to sink power, or a fully charged battery system. These components are explored in detail in this section.

A. Impedance Emulation

The cornerstone of the GEC concept is to ensure that the inverter electrical characteristics mimic those of a synchronous generator as outlined in Fig. 3. While a simple H-bridge SPWM inverter can be designed with appropriately-sized components to capture such characteristics, such implementation is quite impractical. In particular, the value of series inductance required is prohibitively high. An actual inductor of this size would incur high power losses and add significant size, weight, and cost to the converter system. To put things in perspective, an inductor of such size is shown in Fig. 13 to the side of a PV microinverter that would have hosted it! Instead, it is possible to use the concept of impedance emulation to approximate such circuit characteristics without adding any additional components to this inverter.

Impedance emulation is a control method by which "virtual" components are incorporated by reproducing their electrical characteristics through computational methods. This concept is popular for enabling parallel operation of dc-dc converters [21]. For dc-dc converters, a virtual resistance is created by drooping the voltage reference in proportion to converter output current as given by

$$v_{\mathrm{ref}} = v_{\mathrm{nom}} - r_o \cdot i_o \tag{15}$$

where v_{ref} is the reference voltage setting for the converter, v_{nom} is the nominal setting at no load, r_o is the emulated resistance value, and i_o is the output current measurement.

GEC extends this concept to PV inverter controls as shown in Fig. 14. A GEC current estimator "imagines" the presence of the preferred electrical network, and utilizes a terminal voltage measurement to compute the current that should be produced

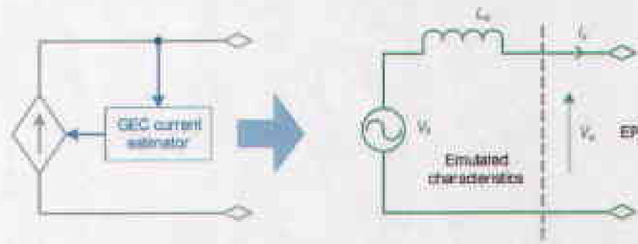

Fig. 14. A simplified representation of the impedance emulation concept.

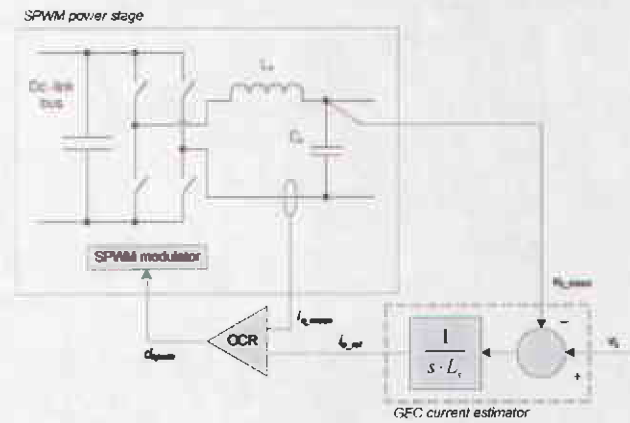

Fig. 15. Simplified diagram of GEC impedance emulation, applied to an SPWM inverter stage.

by the device. This is fed to lower-level controls responsible for forcing the inverter to generate that current.

The implementation strategy for GEC impedance emulation is summarized in Fig. 15, as applied to a typical SPWM inverter stage. The GEC current estimator emulates virtual components using basic electrical relationships. For example, the series inductor, L_s, can be emulated by forcing the output current to follow the relation in (16), as shown in Fig. 15. The implementation inherits the innermost OCR loop of a traditional PV inverter, responsible for ensuring that the output current of the inverter follows the current reference produced by the GEC current estimator.

$$i_o = \frac{1}{L_s} \cdot \int (v_s - v_o) \cdot dt. \tag{16}$$

As a direct result of impedance emulation, a GEC-operated inverter conforms to (1) and (2). In light of (1), the phase angle of the emulated EMF, V_s, has a direct effect on the real power output of the inverter. It is manipulated by the power flow controller as will be discussed in a later section.

According to (2), keeping amplitude of the emulated EMF, V_s, at a constant value results in linear Volt-VAr droop characteristics as shown in Fig. 16. The inverter provides voltage regulation support by sinking reactive power if line voltage is higher than normal and sourcing reactive power if line voltage drops. This very simple droop profile results naturally with a constant emulated EMF amplitude. The Volt-VAr profile may be modified through supervisory controls by adjusting the EMF amplitude in real time. The profile can be accordingly modified to include maximum/minimum limits, multiple segments with different slope, and/or a dead-band around nominal voltage [22].

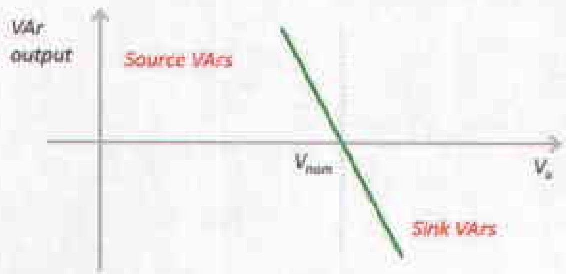

Fig. 16. Typical Volt-VAr droop characteristics of GEC-operated inverters.

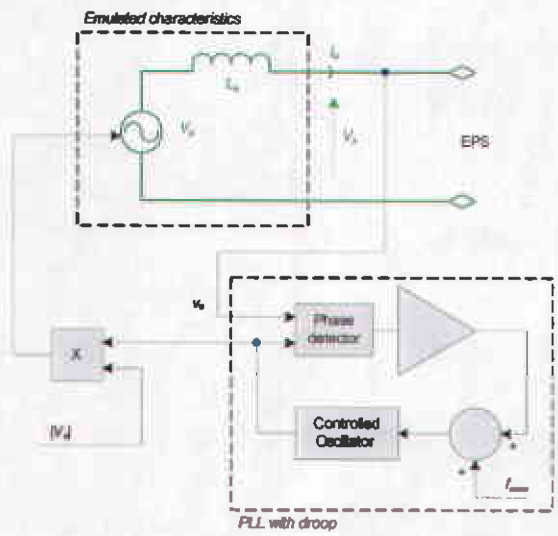

Fig. 17. Deriving the emulated EMF under GEC control.

B. Phase-Locked Loop

It is proposed that the emulated EMF be derived based on the output of a PLL locked to the output voltage, as summarized in Fig. 17. Utilizing a PLL achieves a number of important objectives. It provides a high quality sinusoidal EMF independent of distortion or amplitude variations of the terminal voltage, and provides the inverter with the tendency to synchronize to the host EPS. A PLL results in phase-continuity of the induced EMF during transients, and produces a form of "emulated inertia."

A simple PLL with finite proportional gain is naturally suited to recreate the generator power-frequency dynamics, including embedded droop. Finite controller gain results in residual phase shift proportional to the frequency deviation from the center frequency. The dynamics model of such a PLL is captured in Fig. 18. The response of output power to variations in line frequency can be expressed as

$$\frac{P_o(s)}{\omega_{\text{line}}(s)} = k_s \cdot \frac{-1/s}{1 + k_{\text{PLL}}/s} = -\frac{k_s}{k_{\text{PLL}}} \cdot \frac{1}{s/k_{\text{PLL}} + 1} \quad (17)$$

where k_{PLL} is the feedback gain of the PLL.

At—relatively—high frequency, this reduces to

$$\frac{P_o(s)}{\omega_{\text{line}}(s)} \approx -k_s/s. \quad (18)$$

At low frequency, (17) reduces to

$$\frac{P_o(s)}{\omega_{\text{line}}(s)} \approx -k_s/k_{\text{PLL}} = -k_{\text{droop}}. \quad (19)$$

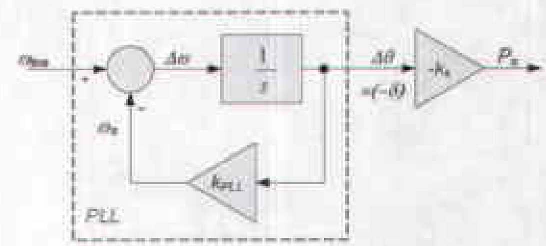

Fig. 18. A simple PLL providing natural power-frequency droop characteristics.

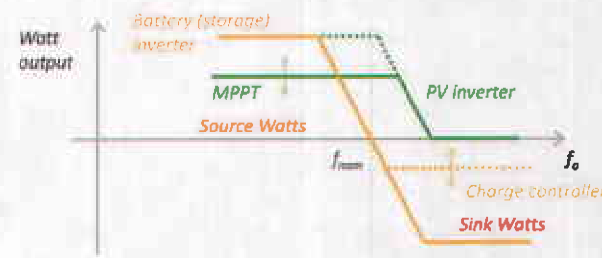

Fig. 19. Typical power-frequency characteristics of GEC-operated inverters.

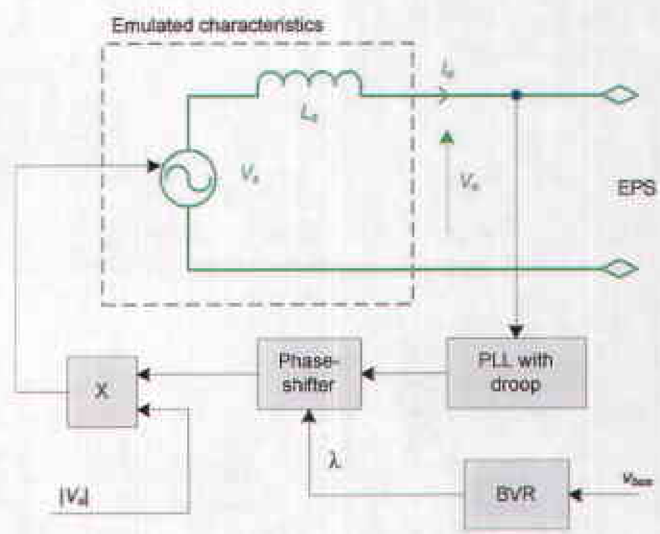

Fig. 20. GEC layout with BVR controller.

Equations (18) and (19) are reproductions of (8) and (9), respectively. A GEC-operated inverter with a simple PLL reproduces short-term transient and droop behavior that define the power-frequency characteristics of a synchronous generator. It is therefore expected to behave in a similar fashion when connected to a dedicated load, an infinite bus, or a finite EPS composed of synchronous generators and GEC-operated inverters.

The PLL center frequency can be used to influence the power output of the GEC-operated resource and prioritize resource utilization. A resource with a higher center frequency setting is drawn upon to supply real power first, and at a higher proportion.

C. Power-Frequency Characteristics

The preferred steady-state operating point of a GEC-operated inverter is heavily dependent on the nature of the energy resource, and the state of the system. Fig. 19 shows typical

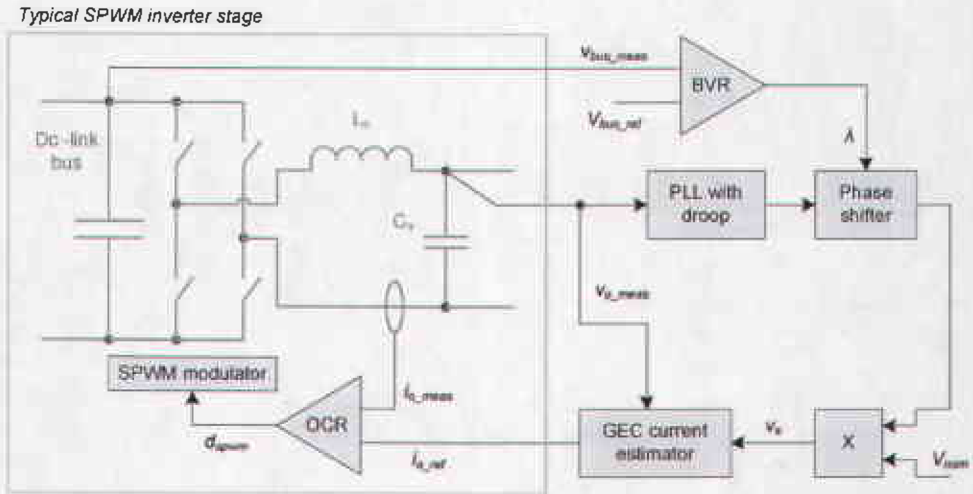

Fig. 21. GEC implementation for a typical SPWM inverter stage.

power-frequency operating profiles under GEC for a PV inverter and a battery inverter.

Under normal operating conditions, a PV inverter is expected to maximize the power injected to the power system, processing all power available as determined by the MPPT process. This is achieved by setting the PLL center frequency sufficiently above normal line frequency, as shown in Fig. 19. Droop is engaged as a power-limiting mechanism in the absence of sufficient load or storage devices to absorb this power. This prevents excessive frequency hikes in a system with too much generation. At excessively high frequency, PV power is dropped to a minimum value of zero as it is naturally unable to absorb power from the system.

A battery inverter is expected to operate along the droop characteristics in normal operating conditions. This allows a supervisory controller to modulate its power output by shifting the PLL center frequency. Maximum power sourced or sunk by a battery inverter/charger depends on inverter ratings, and the state of charge of the battery.

D. Power Flow Control

Proper operation of a two-stage DG inverter requires a mechanism to manage short-term energy storage in the dc-link bus. Power processed by both stages should be balanced in order to maintain an acceptable operating bus voltage. When operating along the power-frequency droop curve, the SPWM inverter stage governs the amount of power flow through the system. The preregulator dc-dc stage is then responsible for regulating the bus voltage.

It is evident from Fig. 19 that power-frequency droop as outlined by (19) may dictate operation at a power level beyond the capabilities of the energy resource at that point in time. Power dictated by the droop may not be achievable due to operating limitations such as in-availability of sufficient source power, or limited ratings. This results in a non-sustainable power imbalance and a shift in bus voltage. A mechanism is required for shaping the power-frequency characteristics in order to restore equilibrium. In this case, the inverter stage is required to override droop and regulate the bus voltage. A BVR controller is appended to the GEC scheme to perform this function.

The BVR controller, shown in Fig. 20, operates by modulating the phase of the PLL by the power angle command, λ, in order to deviate from the droop curve. The BVR controller output, λ, moves negative in order to limit output power if the bus voltage is falling below nominal. It drifts positive if the bus voltage increases above normal due to the inability to absorb power in an over-frequency event.

V. GEC Implementation and Design Considerations

An overview of the GEC control system is shown in Fig. 21. Voltage regulation performance and super-synchronous stability are heavily dependent on the emulated impedance characteristics. Frequency regulation performance and emulated inertia are dependent on PLL configuration, and its interaction with the BVR. A successful implementation requires careful tuning of various configuration parameters within the various control blocks. Design considerations and recommended design guidelines are outlined in this section.

A. Emulated Impedance Configuration

The sizing of the emulated series inductance, L_s, shapes the Volt-VAr droop characteristics, and the voltage regulation performance of the inverter in response to reactive loading. As a rule-of-thumb, the maximum anticipated swing between capacitive and inductive loading should result in spanning the acceptable voltage window per applicable standards

$$Z_{Ls} = \frac{\Delta V}{I_{Q\,\max} - I_{Q\,\min}} \approx \frac{\Delta V \cdot V_{\text{nom}}}{Q_{\max} - Q_{\min}}. \tag{20}$$

Consider a typical inverter in the US with an expected power factor of 0.9 lead to 0.9 lag. This corresponds to reactive loading of 44% capacitive or inductive. With a nominal voltage of 1.0 pu, and typical voltage swing of $\pm 5\%$ (10%), the recommended inductor impedance works out to 0.114 pu, or 11.4%.

The simplified circuit characteristics shown in Fig. 14 require some modifications to address practical implementation considerations. Such considerations include dc-current build-up, super-synchronous stability, and harmonic response. The modified characteristics are summarized in Fig. 22 and discussed below.

Dc-current build-up is highly undesirable in a power system. Under GEC control, dc-current build-up may result from any dc component in the EPS voltage, the associated sensor circuit, or

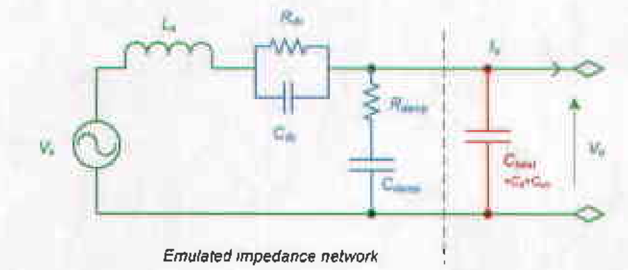

Fig. 22. Modified emulated characteristics for practical consideration.

from computational artifacts in the GEC engine. A series resistance, $R_{\rm dc}$, is introduced in order to limit dc-current run-away. To minimize the effect of this resistance at line-frequency, a large capacitor, $C_{\rm dc}$, is introduced across it.

The value of this resistance is dependent on the amount of dc voltage drift, and the dc-current injection limit. A resistance in the vicinity of 5e-3pu (0.5%) is typically sufficient to prevent any noticeable dc-current. When the inverter output is connected to an EPS with low impedance, the addition of parallel capacitor, $C_{\rm dc}$, may form a resonant tank circuit with series inductance, L_s. To avoid such effects, it is recommended that the resonant frequency, $\omega_{\rm nDC}$, be placed at least a decade below line frequency.

$$\omega_{\rm nDC} = 1/\sqrt{L_s \cdot C_{\rm dc}} \ll \omega_{\rm line}. \tag{21}$$

Furthermore, the capacitor should be sized to ensure that the resistance, $R_{\rm dc}$, provides sufficient damping. It is recommended that the damping factor for this circuit, $\xi_{\rm nDC}$, be larger or equal to unity

$$\xi_{\rm nDC} = \frac{1}{R_{\rm dc}} \cdot \sqrt{\frac{L_s}{C_{\rm dc}}} > 1. \tag{22}$$

A second consideration is to maintain super-synchronous stability in various operating conditions. In other words, it is important to prevent sustained oscillations and resonances above line frequency. Particularly challenging is maintaining stability when supporting a dedicated load of high impedance: an inductive load, a current-sink, or an open-circuit. In such conditions, the series inductance, L_s, forms a resonant tank with inverter total output capacitance, $C_{\rm total}$. As discussed in Section III, this capacitance represents the combined effect of the actual filter capacitor, C_o, installed at the inverter output, and that of the virtual capacitor introduced by the dynamics of the OCR loop, $C_{\rm ocr}$.

A series R-C damping branch is introduced to the model in order to help dampen super-synchronous resonances. This branch also helps reduce inverter impedance in the frequency range above line frequency, and enhance the inverter responsiveness to harmonic distortion in load current.

As a rule of thumb, it is recommended that the damping capacitor, $C_{\rm damp}$, be sized to obtain a resonant frequency, $\omega_{\rm ndamp}$, half-decade to a full decade above line frequency

$$3 \cdot \omega_{\rm line} \le \omega_{\rm ndamp} = 1/\sqrt{L_s \cdot C_{\rm damp}} \le 10 \cdot \omega_{\rm line}. \tag{23}$$

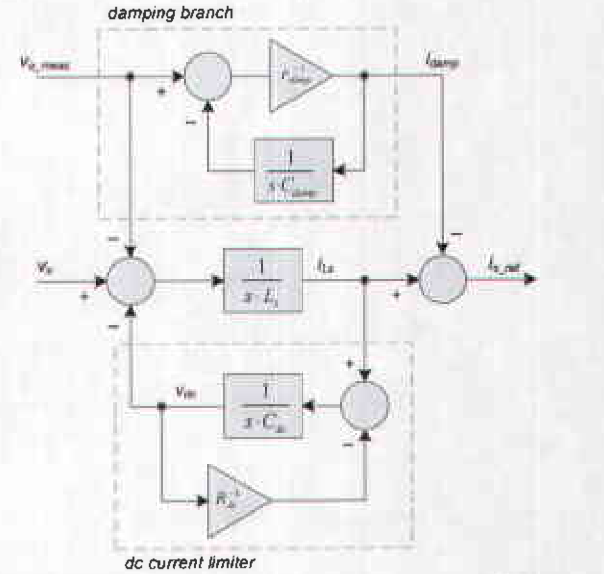

Fig. 23. Implementation of the GEC current estimator with modified impedance characteristics.

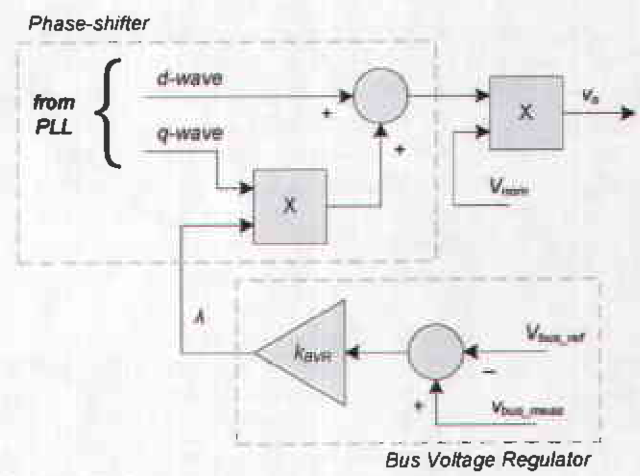

Fig. 24. BVR implementation and integration into GEC.

The damping resistor, $R_{\rm damp}$, should be sized to achieve an adequate damping factor, $\xi_{\rm ndamp}$, of the resonant tank circuit, $L_s - C_{\rm damp}$

$$\xi_{\rm ndamp} = R_{\rm damp} \cdot \sqrt{\frac{C_{\rm damp}}{L_s}} \ge 1. \tag{24}$$

Fig. 23 shows the implementation of the GEC current estimator required to emulate the characteristics in Fig. 22. The implementation results from applying basic circuit theory, where the series inductor current is an integration of the voltage drop across it with the appropriate gain

$$i_{Ls} = \frac{1}{L_s} \cdot \int (v_s - v_{\rm dc} - v_o) \cdot dt. \tag{25}$$

The bottom section in Fig. 23 represents the implementation of the dc-limiting elements. The dc-capacitor voltage is the scaled integral of the net current flowing through it, which is that of the inductor less that flowing in the dc-resistor

$$v_{\rm dc} = \frac{1}{C_{\rm dc}} \cdot \int \left(i_{Ls} - \frac{v_{\rm dc}}{R_{\rm dc}} \right) \cdot dt. \tag{26}$$

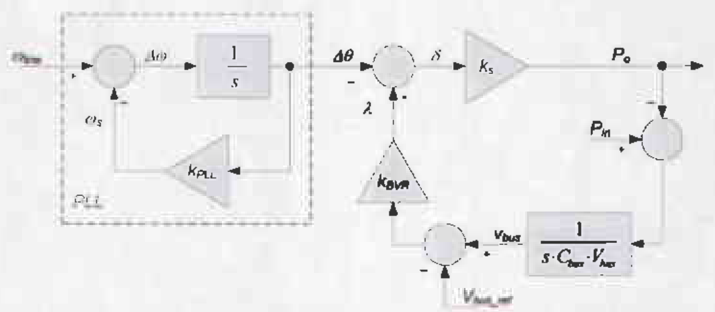

Fig. 25. Power-frequency dynamic model with BVR.

The upper section of Fig. 23 represents the implementation of the damping branch. The output current estimate is equal to the series inductor current, less the current in the damping branch, i_{damp}.

$$i_{o\_\text{ref}} = i_{Ls} - i_{\text{damp}}. \tag{27}$$

The damping branch current can be calculated by considering the voltage drop across the damping resistor. The scaled integral of this current represents the damping capacitor voltage

$$i_{\text{damp}} = \frac{v_o - v_{c\_\text{damp}}}{R_{\text{damp}}} \tag{28}$$

$$v_{c\_\text{damp}} = \frac{1}{C_{\text{damp}}} \cdot \int i_{\text{damp}} \cdot dt. \tag{29}$$

In a discrete time system such as a digital signal processor (DSP), a simple Euler implementation can be used to perform the integration functions.

B. Power-Frequency Characteristics and Power Flow Control

Steady-state power-frequency characteristics drive the frequency regulation performance of the inverters and the prioritization of energy resources within the system. It is recommended to configure power-frequency droop to prevent frequency deviation beyond the acceptable standard limits.

Consider a PV inverter design for the US. The recommended droop begins at 100% power at 60.05 Hz with a slope of -400% per Hz (-4.0 pu/Hz), dropping to 0% at 60.3 Hz. Engaging the droop at 60.05 Hz provides a margin to prevent normal non-emergency frequency deviations from limiting PV harvest. The cut-off point of 60.3 Hz is comfortably below the IEEE 1547 trip setting of 60.5 Hz for distributed generation. This ensures the PV's output is fully employed to limit the frequency hike before an emergency shut-down.

PLL configuration is dictated by the preferred power-frequency characteristics, where the steady-state phase error is tuned to produce the sloped droop section of the characteristics. The center frequency of the PLL should be set to that at which the droop points to zero power output. This is because the PLL produces no phase shift at its center frequency. The gain of the PLL controller should be set to produce the intended droop rate

$$\frac{d\theta_{\text{error}}}{d\omega_{\text{line}}} = \frac{1}{k_s} \cdot \frac{dP_o}{d\omega_{\text{line}}} \tag{30}$$

where θ_{error} is the steady-state phase error of the PLL. For an inverter with an 11.4% inductor, $k_s = 8.77$ pu/rad at nominal voltage. To achieve the recommended 4.0 pu/Hz, the PLL phase shift should droop at 0.456 rad/Hz.

Formation of the power-frequency characteristics is completed by introducing the BVR to account for energy resource limitations, as shown in Fig. 24. A simple BVR controller can be implemented as a proportional gain, whose output, λ, is used to modulate the phase shift of the PLL. The phase-shift is implemented by scaling the quadrature sinewave (q-wave) output of the PLL by λ, and summing it back to the direct wave (d-wave). The resulting sinewave is scaled by the appropriate amplitude to create the emulated EMF, v_s.

With the BVR in place, the power-frequency dynamics can be modeled as in Fig. 25. The response of output power to line frequency can then be described by

$$\frac{P_o(s)}{\omega_{\text{line}}(s)} = \frac{k_s}{1 + \frac{k_s \cdot k_{\text{BVR}}}{s \cdot C_{\text{bus}} \cdot V_{\text{bus}}}} \cdot \frac{-1/s}{1 + k_{\text{PLL}}/s} \tag{31}$$

where k_{BVR} is the gain of the BVR controller, C_{bus} is the bus capacitor value, and V_{bus} is the operating voltage of the bus.

$$\frac{P_o(s)}{\omega_{\text{line}}(s)} = -\frac{k_s}{k_{\text{PLL}}} \cdot \frac{1}{s/k_{\text{PLL}} + 1} \cdot \frac{s \cdot \tau_{\text{BVR}}}{1 + s \cdot \tau_{\text{BVR}}} \tag{32}$$

where τ_{BVR} is the time-constant of BVR loop

$$\tau_{\text{BVR}} = \frac{C_{\text{bus}} \cdot V_{\text{bus}}}{k_s \cdot k_{\text{BVR}}}. \tag{33}$$

As evident from comparing (17) and (32), the presence of the BVR introduces an additional transfer function, $s \cdot \tau_{\text{BVR}}/(1 + s \cdot \tau_{\text{BVR}})$, to the power-frequency dynamics of the inverter. This reduces the gain to zero in steady-state. In other words, the BVR controller prevents the inverter from being responsive to frequency in steady-state as expected. The inertial behavior, however, may be preserved at higher frequencies if τ_{BVR} is much larger than the time-constant of the PLL, $\tau_{\text{PLL}} = 1/k_{\text{PLL}}$. This is most effectively achieved by appropriately sizing the bus capacitor, the main energy-storage reservoir in the PV inverter. A simplified frequency response plot of a GEC-operated PV inverter is shown in Fig. 26.

VI. System Impact

Deployment of GEC technology is part of a paradigm shift, and is a cornerstone to an overall philosophy for the smart-grid. This philosophy is focused on pushing intelligence along with distributed generation assets to the periphery of the power system. Distributing intelligence throughout the power system is an effective way of alleviating the requirements for high-speed communications or massive data processing and decision-making infrastructure.

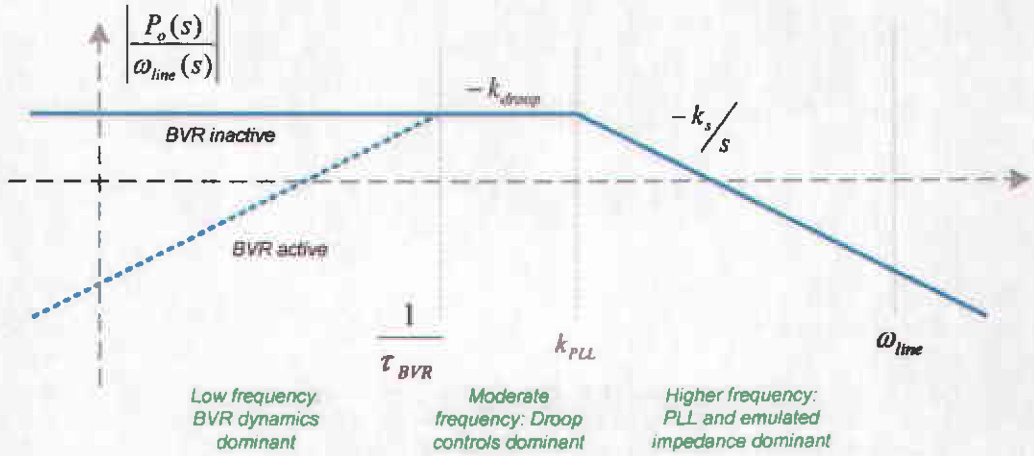

Fig. 26. Power-frequency characteristics of a GEC-operated inverter in various frequency ranges.

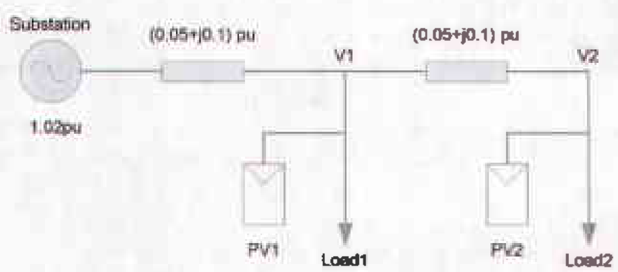

Fig. 27. Single-line diagram of simplified distribution feeder.

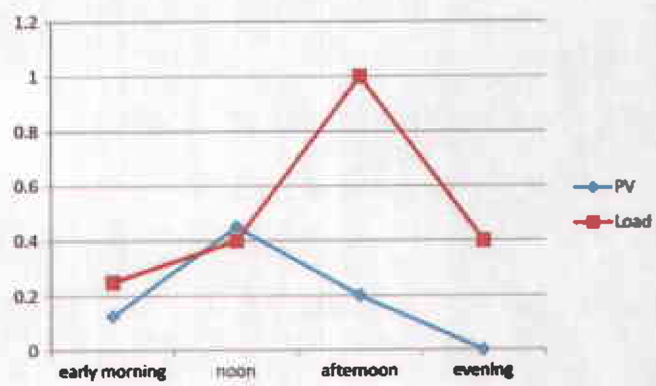

Fig. 28. Total load and PV power profiles (in per-unit) used in the simplified feeder simulation.

GEC is a natural approach to embedding load following functions into distributed generation. It results in a number of important advantages that include: enhanced power factor, reduced distribution power losses, enhanced voltage regulation, and harmonics suppression. The effectiveness of GEC in achieving these tasks is dependent upon parameters of the distribution circuit of concern, and grows with penetration level. This section is dedicated to demonstrating these effects using a simplified distribution feeder model, along with experimental results obtained from laboratory test beds.

A. Feeder Simulations

A simplified distribution feeder model was constructed in Matlab/Simulink to simulate various scenarios. The ratings for this feeder were chosen to be 12 kV, 10 MVA, and were also used as the per-unit base values for the model. The feeder is limited to two major segments and two load centers for simplification, as shown in Fig. 27. The impedance of each segment is approximately 0.112 pu with an X/R ratio of 2.0. The voltage at the substation (source) is considered constant, as it would typically be regulated through a tap-changer. The substation voltage was set at 1.02 pu, which is a typical setting used to account for voltage drop on the feeder under load.

Steady-state simulations were conducted in order to examine voltage regulation performance and power losses. Two constant-impedance loads are modeled at the end of each segment of the feeder. Each load has a peak of 5 MVA, at 0.92 power factor. A PV array is installed near each load with a peak capacity of 2.5 MVA, representing 50% penetration. Four load/PV combinations were simulated that represent various points in a typical sunny workday. Total load and PV profiles for the simulations are shown in Fig. 28.

These simulations were repeated for three different scenarios: no PV installation, traditional PV, and GEC-operated PV. GEC-operated PV inverters were programmed for a 0.11 pu impedance per guidelines in the previous section. The amplitude of the emulated EMF was set to 1.02 to help compensate the reactive part of the nearby load.

Voltage regulation performance can be observed by comparing the node voltages, V_1 and V_2, in various scenarios, as shown in Figs. 29 and 30. In the absence of PV, load current results in significant voltage drop across the feeder. The voltage at the end of the feeder drops slightly below 0.9 pu. The introduction of traditional PV, operating near unity-power factor does help raise voltage at the end-node. It, however, still introduces significant volatility apparent through the wide different between maximum and minimum node voltage. GEC-operated PV has a marked "flattening" effect: voltage variation is limited compared to both other cases due to dynamic adjustment of reactive power output, shown in Fig. 31. Reactive power injection is maximized when the load is highest, leading to the restoration of the circuit.

Improvement in power distribution losses can also be observed in the presence of PV. This is because a significant percentage of real power is locally supplied to load, reducing the rms current required in the feeder. This effect is amplified by GEC-operated PV through local supply of reactive power. This

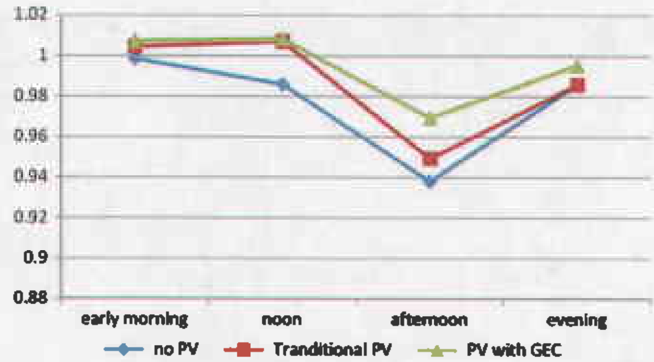

Fig. 29. Voltage at node V1, in per unit.

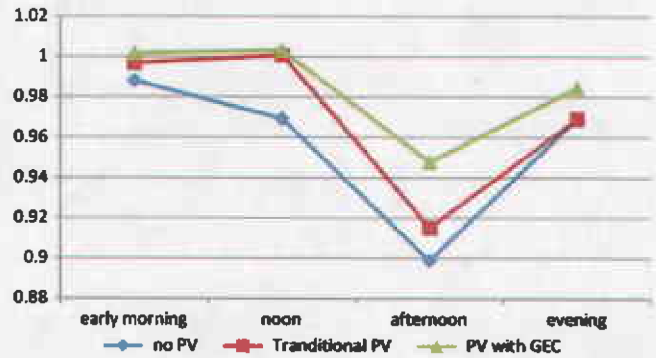

Fig. 30. Voltage at node V2, in per unit.

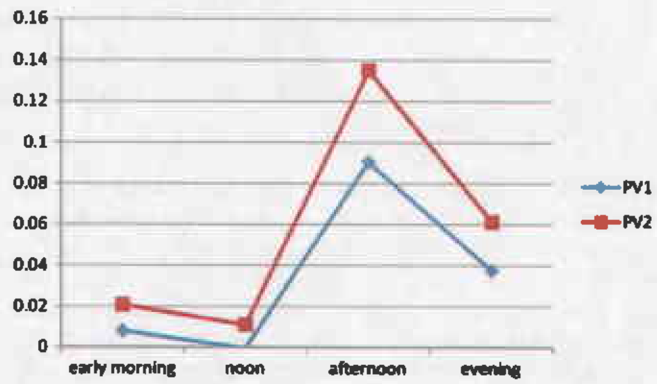

Fig. 31. Reactive power injected by GEC-operated PV (in per-unit).

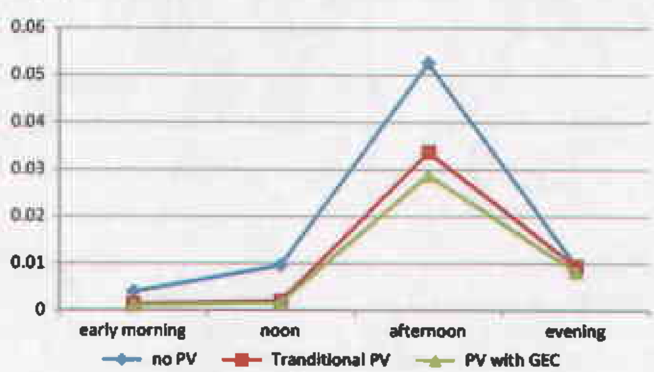

Fig. 32. Power loss during various conditions, in per unit.

is not a guaranteed effect, but generally holds true in typical scenarios where the load is inductive, and the voltage is accordingly low. The results are summarized in Fig. 32.

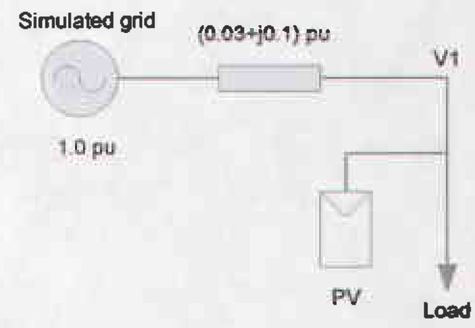

Fig. 33. Single-line diagram of first test bed.

B. Experimental Test Beds

The GEC concept has been implemented and demonstrated using Petra Solar's SunWave™ microinverters. Each microinverter is rated at 120 V/200 VA, and is capable of supplying current at a full range of power factors: unity down to zero lead or lag.

GEC parameters were chosen based on the guidelines in Section V. The emulated synchronous impedance, L_s, was chosen to be 0.12 p.u., or 23 mH. Combined with the actual filter inductor of 3.5 mH, this resulted in a simple Volt-VAr droop with a slope of 12.2 VAr/Volt. Real power output responds to the power angle at 1.47 kW/rad. The dc-limit resistor, R_{dc}, was chosen to be 0.45 Ohms, or 0.6%. The capacitor, C_{dc}, was sized at 27.5 mF. This placed the resonance frequency associated with dc-limit circuit far below line frequency at 6.4 Hz, with a damping factor of 2.0. The damping capacitor, C_{damp}, was sized at 26.9 μF. This is approximately ten times larger than the total effective output capacitance, C_{total}, sized at 2.2 μF. The damping resistor, R_{damp}, was chosen to be 29 Ohms. These values place the resonant frequency associated with the damper branch at 204 Hz, with a damping factor of 1.0.

Different power-frequency profiles were setup for PV inverters and battery inverters. Power-frequency droop was programmed at a slope of 0.8 kW/Hz, (400% per Hz) for both profiles. PV inverters were programmed with a center frequency of 60.27 Hz allowing full power delivery at 60 Hz. Battery inverters were programmed with a center frequency of 59.96 Hz, preventing discharge at 60 Hz. These profiles grant PV the priority to supply load over batteries.

The first test bed is a simple circuit consisting of a combination of PV and load connected to a simulated grid through a series impedance as shown in Fig. 33. This was geared at experimental demonstration of voltage regulation and transient suppression. The nominal voltage of the system is 120 V, and all values are specified relative to 120 V/400 VA base. Two PV inverters are incorporated that are rated at 200 W each for a total of 400 W. The load consists of two portions: a 260 VA (0.64 pu) R-L load at 0.78 lagging power factor, and a 200 W (0.50 pu) incandescent light-bulb.

The effectiveness of voltage regulation support is evaluated through measurement of the voltage, V_1, in three different scenarios: no PV, traditional PV, and GEC-operated PV. In each case, the voltage level is recorded at three loading conditions: no load, R-L load only, and R-L load combined with the bulb load. The results are shown in Fig. 34. Traditional PV results in a voltage rise on the feeder, which is helpful at heavy loads, but potentially problematic at light loads. The voltage flattening

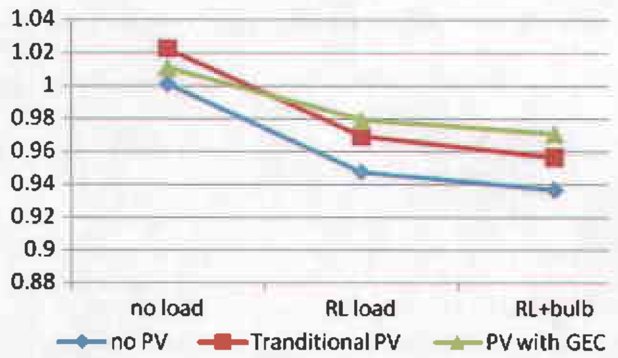

Fig. 34. Voltage regulation performance.

Fig. 35. Behavior of traditional PV during load transient. Traces: [1] Load current (2 A/div) [2] PV inverter current (2 A/div) [3] Inverter dc-bus voltage (zoomed, 10 V/div).

effect of GEC is apparent: GEC-operated PV results in better restoration of the voltage under heavy load, in addition to a lower voltage rise at light-load conditions.

This setup was also used to demonstrate the unique ability of GEC-operated inverters to suppress sharp load transients. GEC-operated inverters tend to supply part of the load transient currents locally due to inherent inertia. This reduces the magnitude and severity of the transient as seen by the rest of the power system. Fig. 36 compares the behavior of GEC-operated PV to that of traditional PV, shown in Fig. 35, during a load transient. During this experiment, the bulb load is switched in, creating a transient amplified by its inrush current. Traditional PV inverter current is virtually undisturbed, and so is its bus voltage. The current generated by GEC-operated PV inverters, however, shows an immediate—same cycle—response to the load. The disturbance is also reflected in a temporary dip in the dc-bus voltage waveform, as the transient energy is supplied from this reservoir within the PV inverter before return to steady-state operation. This naturally happens as a response to the phase disturbance created by the load transient. The reaction of GEC inverter acts as a damper that reduces the sharpness of the transient as seen by the power system.

The second test bed was focused at demonstrating microgridding features, and is depicted in Fig. 37. A 3 kVA proof-of-concept microgrid was built out of fifteen inverters: ten PV inverters (2 kVA total), and five battery inverters (1 kVA total). The microgrid was setup to support a local electronic load that was set at 2.5 kW during experiments captured below.

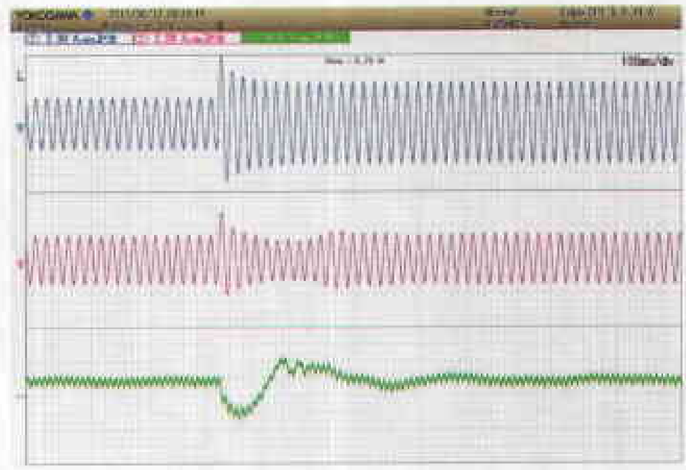

Fig. 36. Behavior of GEC-operated PV during load transient. Traces: [1] Load current (2 A/div) [2] PV inverter current (2 A/div) [3] Inverter dc-bus voltage (zoomed, 10 V/div).

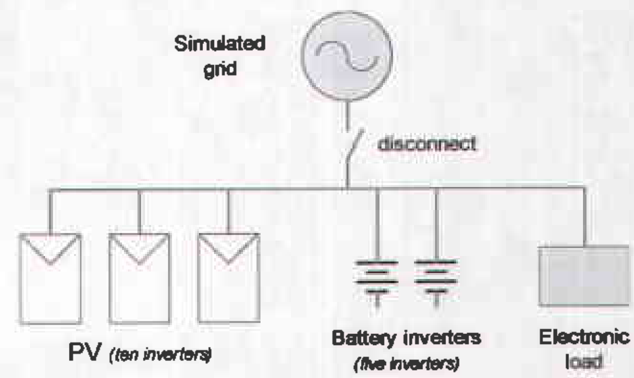

Fig. 37. Microgrid test bed diagram.

This test bed demonstrated the plug-n-play ability of GEC-operated inverters to build scalable microgrids that can perform seamless disconnection and reconnection to a host EPS. Fig. 38 shows a transition from grid-tied mode into islanded operation. During grid-tie, only PV inverters are contributing power to the load, while battery inverters are idling near zero power. Some power is imported from the grid as the local load exceeds available PV. Upon interruption of the grid-connection, emulated inertia allows the inverters to pickup voltage regulation with phase continuity. A slight frequency drop engages battery inverters to pick-up the power balance. Fig. 39 shows a transition back to grid-tied mode. The grid-connection is reestablished when the local and host voltages are acceptably synchronized. The grid forces the frequency to return to 60 Hz, prompting batteries to idle, allowing the grid to pick-up the load balance.

VII. Conclusion

Preserving grid stability and power quality at high penetration of inverter-based DG requires a proportional growth in load-following capabilities of the system. Traditional synchronous generators exhibit inertial behavior and a controlled output impedance profile that result in a natural tendency for load-following. GEC is a controls concept that is designed to capture and reproduce these characteristics in grid-tied inverters.

Controlled impedance characteristics can be "emulated" or programmed into an inverter through computational methods.

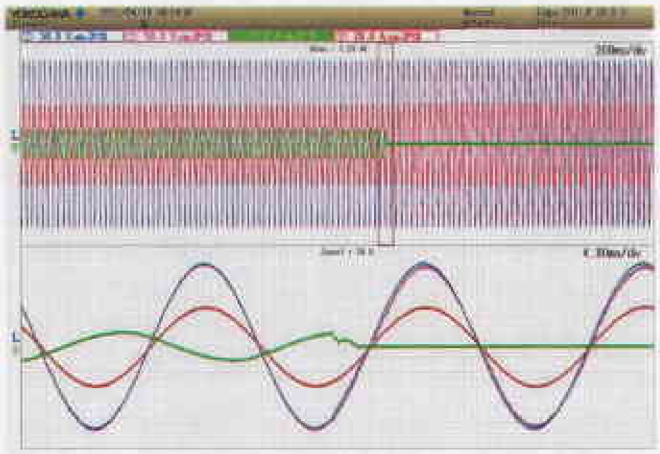

Fig. 38. Seamless microgrid transition from grid-tied to islanded mode. Traces [1-blue] Grid voltage (50 V/div) [2-magenta] Local voltage (50 V/div) [3-green] Total microgrid current exported to grid (20 A/div) [4-red] Load current (20 A/div).

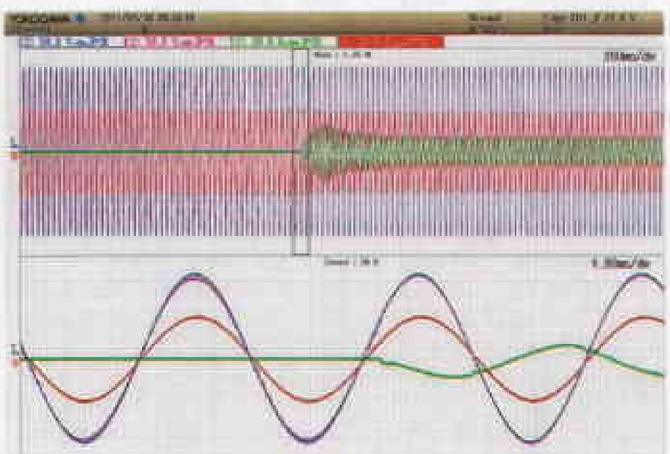

Fig. 39. Seamless microgrid transition from islanded to grid-tied mode. Traces [1-blue] Grid voltage (50 V/div) [2-magenta] Local voltage (50 V/div) [3-green] Total microgrid current exported to grid (20 A/div) [4-red] Load current (20 A/div).

This allows the inverter to operate as a part of a larger EPS, or support a dedicated load in an intentional island. Impedance emulation is a powerful approach that relieves the design of the size, weight, cost, and power-loss that would result from using actual components to create the impedance profile. A set of simple guidelines were presented to facilitate the design of the impedance network to attain appropriate damping of super-synchronous dynamics under various operating conditions.

Machine inertia can be emulated through the reproduction of the power-frequency response of a synchronous machine. Using a PLL to create the "emulated EMF" required in the inverter is an effective approach. Stable sub-synchronous dynamics can be attained by using a simple PLL to capture the responsiveness to phase transients and create droop characteristics of real power vs. frequency.

The system impact was examined through various simulation models and experimental lab-scale test beds. The results demonstrated that GEC-operated devices can reduce voltage fluctuations by dynamically adjusting reactive power output. Under typical loading conditions, this is also accompanied by the reduction of distribution power losses due to local supply of reactive power to lagging loads. Transient suppression resulting from inertial behavior was also verified experimentally. Transient energy is sourced or absorbed into the device's dc-bus capacitor which provides a form of short-term energy storage. A fifteen-inverter test bed was also used to demonstrate the ability of GEC-operated inverters to create scalable microgrids. In the absence of real-time communications, this collection of inverters was moved into an intentional island and back to grid-tie operation in a seamless fashion.

The implementation of GEC supports a design philosophy based on pushing intelligence to the periphery of the power system. It empowers distributed devices on the distribution network to take real-time decisions and shape local transients in a favorable and predictable fashion. Rules or profiles can then be used to grant supervisory control to a more-centralized controller. This philosophy dramatically reduces communications requirements and relieves the need for massive centralized data processing and decision-making operations. It allows sections of the grid to isolate and form intentional islands during contingencies.

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He is Cofounder and Manager for Controls Engineering and Advanced Technology at Petra Solar, South Plainfield, NJ, where he is responsible for the design and implementation of embedded real-time controls for PV systems He served as the technology architect for Petra Solar's work under the Solar Energy Grid Integration Systems (SEGIS) contract This effort, funded by the DoE and administered by Sandia National Labs, lead to the demonstration of Generator Emulation Controls (GEC) technology His work resulted in the integration of advanced grid-support features into the SunWave systems, such as voltage regulation support and microgrid functionality While at UCF, he served as technical lead for a number of PV-related research projects conducted with support from NASA and the U S Air Force This work laid the technical foundation for innovations embedded in Petra Solar power conversion and grid-support solutions He has authored more than 20 publications in technical conferences, scholarly journals, and trade magazines, all focused on PV power conversion

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Johan Enslin (M'83–SM'93) is the Director for the Energy Production and Infrastructure Center (EPIC) and Duke Energy Distinguished Chair in Power System Engineering at the University of North Carolina, Charlotte The main goal of this multidisciplinary Center is regional growth and advancement in the energy industry He has combined a 30 year career with leadership activities in industry and university in the United States, Europe, and South Africa He served as an executive and consultant for private business operations and as a professor in electrical and electronic engineering He initiated and managed renewable energy groups and executed multiple projects for U S and international industries in power system planning, power electronics, and the integration of large-scale solar and wind power into the grid Throughout his career, he has performed work for more than 80 U S , European, Asian, and African power utilities, governments, and industries

Dr Johan Enslin came as Chief Technology Officer from a smart grid and renewable energy technology company, Petra Solar, South Plainfield, NJ Previously he was a Vice-President with Quanta Technology, Raleigh, NC, and Vice President for the Alpha Technologies Group in Washington State, where he was the General Manager for Alpha's Renewable Energy division Previously he was also Vice President of Power System Planning at KEMA Inc , and the principal in establishing a new medium voltage, smart grid and power electronics research, development and testing laboratory in Arnhem, The Netherlands Dr Enslin, who has worked at the utility ESKOM in South Africa, Universities of Stellenbosch and Pretoria as Departmental Chair and full Professor He is an Adjunct Professor associated with North Carolina State University's Future Renewable Electric Energy Delivery and Management Systems Center (FREEDM Systems Center) He has authored and coauthored more that 250 technical journal and conference papers in the IEEE and other organizations and several chapters in scientific books. He is or has been active on several IEEE and CIGRÉ working groups and standard committees. He holds more than 15 provisional and final patents, is a Registered Professional Engineer, and a Fellow of the SAIEE

Close

Solutions for Integrating PV into the Grid

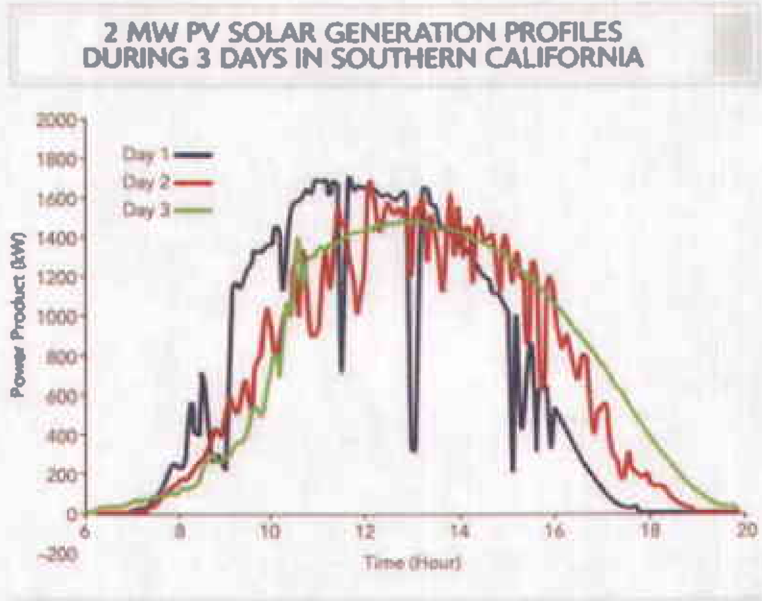
By Johan Enslin, Petra Solar

Solar power's role in the global power generation portfolio is growing year over year largely because solar generation increasingly makes economic sense.

This burgeoning economic case results from a combination of incentives such as solar renewable energy credits (SRECs) and mandates including renewable portfolio standards (RPS) and because solar solutions—especially when they have smart grid and other functionality built in—can be packaged into profitable business propositions without subsidies. As these forces grow solar power's prominence, power grids must handle far more photovoltaic (PV) input than before. To accomplish this, solar power and the grid have some growing up to do.

Large-scale solar power faces significant challenges integrating into the grid. Centralized solar generation, including large PV arrays, or solar farms, can be subject to intermittency. Even in the sunniest climates, clouds inevitably pass over solar farms, resulting in problems such as voltage fluctuations, distribution losses and reduced power quality and power balancing. In the worst case, this can result in lower power reliability for end users, and utilities feel the effect via increased wear and tear on grid hardware: Solar generation can make capacitor banks, breakers, voltage regulators, load tap changers and other power equipment work harder and wear out faster. PV's potential stress to the grid coincides with pressures from other rapidly developing technologies, such as electric vehicles, which will call for grid upgrades.

Several opportunities exist to hasten massive PV integration into the grid. Primary among them is highly distributed PV generation because higher degrees of PV distribution deliver a more stable power supply and reduce impact on grid assets. Standard PV inverters are not optimized for interfacing with the grid; maximum PV penetration requires developing the right inverters for the job. Also, PV's business case can be strengthened by adding value via smart grid and other functionality at generation points. Finally, local, state and federal policies can be designed to promote rather than inhibit PV's growth (see Figure 1).

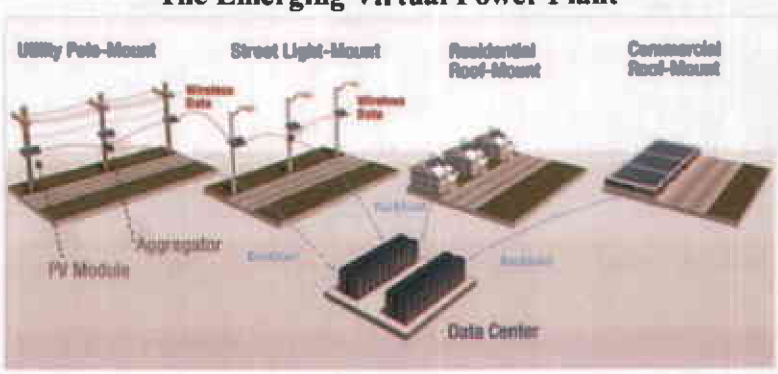


Distribution

Throughout power grid history, the most reliable strategies for providing power have relied on a diverse mix of power generation. In PV's case, that generation diversity is best manifested through geography. When generation is concentrated in one location, however, local weather such as cloud cover or snow can affect an entire solar power plant's output. With PV plants reaching 100-MW capacities, local weather can affect enormous amounts of electrical output, potentially impacting local businesses, hospitals, schools and other power consumers.

As we have seen in Public Service Electric and Gas (PSE&G)'s ongoing installation of up to 200,000 Petra Solar PV panels throughout New Jersey, when PV is installed as a virtual power plant (VPP) in a highly distributed network, weather risk attenuates. A statewide or regional network of strategically distributed PV generation offers consistent power throughout the network because weather impacting one part of the distribution region is unlikely to affect other parts of it simultaneously (see Figure 2).

The Emerging Virtual Power Plant



Such distribution also has economic benefits. While solar farms achieve some economies of scale, these land-intensive projects can fall victim to regulatory entanglement. Distributed systems, however, can be installed on available public infrastructure such as utility and lighting poles, highway infrastructure, public buildings' rooftops and publicly owned marginal land. Such installation schemes usually can be implemented faster than solar farm construction, bringing solar power online incrementally throughout an installation project rather than forcing communities to wait for project completion to reap new power. VPPs also provide opportunities to add smart grid functionality, such as power monitoring and conditioning and grid communications, from the distributed points of PV generation.

Technology

The only way PV generation will integrate with the grid on a large scale is for it to grow up and act like any other power plant. To reach this maturation point, associated technologies, especially inverters, energy storage and weather forecasting, must continue to evolve. Inverters must handle reactive power better so PV can operate in closer proximity to other generators. They must offer better ramp control to mitigate the effects of sunlight loss. Finally, these technologies must offer smart grid functionality such as power conditioning to add to their value and to add value to solar's business case.

Once PV generation functions like any other generation source, it will be dispatchable. System operators will be able to request a certain amount of power and know they will receive it. For PV, this will require better and lower-cost energy storage technology and better weather forecasting systems for centralized and distributed generation so system operators can plan more accurately around likely sunshine and resulting power output.

Cost

Because recent solar subsidies have a limited lifespan, PV also must present an enhanced business case to utilities if they are to implement solar on a large scale. Ever-cheaper solar panels are only part of making PV more affordable. More important is the ability for PV to build a comprehensive value package of which generation is only a part. Highly distributed PV systems can do this by adding value with smart grid communications, power monitoring, power conditioning and other ancillary services. In these cases, project capital costs may be higher, but with enhanced return on investment overall project payback arrives more quickly and levelized cost of electricity (LCOE) is lower. Building such a value proposition, which expands beyond power generation alone, has been core to enabling utility executives to implement systems such as integrated PV and smart grid solutions.

Understanding how peak power usage interplays with PV generation is also critical to maximizing PV's value proposition. Solar generation holds inherent advantages over wind power because solar's peak production naturally comes during peak-load use times, commanding higher rates, whereas wind generation tends to produce more at night when power is in lower demand and sells for less. Further, there are ways to maximize solar's peak-pricing advantage. For example, tilting solar panels slightly to the west can be more profitable because they generate less power overall but produce more power during peak use.

Finally, distributed systems offer cost advantages because they skirt siting, permitting and other regulatory obstacles that can hamstring centralized solar generation and add greatly to their costs. Because distributed PV generates power close to its point of use, distribution power loss is mitigated and no new distribution or transmission infrastructure, like that for accommodating centralized solar farms, must be built. Because highly distributed PV assets begin feeding power to the grid immediately upon installation, they also offer opportunity cost advantages over large solar projects that might not produce power throughout their multiyear construction.

Policy

While PV is maturing beyond the point of total reliance on government incentives, mandates and other policy, smarter standards are required for PV's integration with the grid. Many standards regulating PV's interaction with the grid were enacted 20 years ago when PV power production was small and the main objective was to ensure home solar production did not interfere with grid operations. Creating solar virtual power plants in which inverters act within the grid like traditional generation sources requires a refreshed regulatory framework based on today's technology picture. Energy efficiency policies are critical to solar development; lowering overall energy use eases overall stress on the grid and generation, while allowing PV generation to assume a higher percentage of overall production.

In coming decades, PV power will make up a substantial part of many local generation portfolios. With maximum distribution of generation, the right inverters, smart business models and realistic policy, we can look forward to welcoming solar power's clean, reliable contribution to our power supply.

Johan Enslin, who has a doctorate in psychology, is the chief technology officer at Petra Solar. In an academic and business career spanning nearly 30 years, Enslin has consulted more than 80 U.S., European, Asian and African power utilities, governments and companies, written more than 250 technical journal and conference papers and secured 14 patents. He is a registered professional engineer, Fellow of the SAIEE and Senior Member of the IEEE.

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RENEWABLE ENERGY GRID INTEGRATION STUDY TOUR

NOVEMBER 10–22, 2013 DELEGATION FROM Eskom

Delegation List

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Chief Advisor, Single Buyers Office
Eskom Holdings SOC Limited

Hendri Bower
Demand and Load Forecasting Analyst, System Operations
Eskom Holdings SOC Limited

Mobolaji Bello
Senior Engineer, Power Delivery Engineering
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Simphiwe Hashe
Middle Manager, Network Planning
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Pamela Ijumba
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Mbulelo Kibido
General Manager, Transmission Grid Planning
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Eskom

Biographical Information

Mr. Mobolaji Bello
Senior Engineer, Power Delivery Engineering

Mobolaji Bello currently serves as a Senior Engineer within Eskom's Group Technology Division. In this capacity he focuses in grid connection standardization for renewable generation within Eskom's networks. Mr. Bello has over 14 years of experience of program management and electric power utilities. He has authored and co-authored several scientific articles, journal and conference papers. He is a senior member of the Institution of Electrical and Electronic Engineers (IEEE), a Chartered Engineer (CEng), and an International Professional Engineer (Int. PE) with the Engineering Council in the United Kingdom.

He holds a Bachelor of Engineering (Hons) and a Master of Science of Engineering in Electrical Engineering, a Master of Science in Technology Management and Innovation and also a Bachelor of Science (Hons) degree in Industrial and Systems Engineering.

Mr. Keith Bowen
Chief Advisor, Single Buyers Office

Keith Bowen is the Chief Advisor for Power System Economics for Energy Planning and Market Development within Eskom's Transmission Division. In this role he supports the Integrated Resource Planning Processes (IRP) focusing on scenario development and decision support. Working in conjunction with South Africa's Department of Energy, Mr. Bowen develops wholesale pricing mechanisms, supporting internal transfers within the vertically integrated utility, and payments to independent power producers. He previously worked as a competition economics analyst at Eskom.

He has a Master in Economics from the University of Witwatersrand.

Mr. Hendri Bower
Demand and Load Forecasting Analyst, System Operations

Hendri Bower currently serves as a Demand and Load Forecasting Analyst within the System Operations Department. Before holding this position, he served as Assistant Engineer for Load Forecasting within Eskom. From 2006 to 2008 he worked in the Short Term Forecasting department while finishing his undergraduate degree.

He earned a Bachelor of Science in Mathematics and Geography in 2008 and a Bachelor of Science in Honors Mathematics in 2011 from the University of Johannesburg. He is a candidate for a Master of Science in Mathematics from the University of Johannesburg.

MR. SIMPHIWE HASHE

MIDDLE MANAGER NETWORK PLANNING, ESKOM DISTRIBUTION GROUP

Simphiwe Hashe currently serves as Middle Manager Network Planning in the Asset Creation Department of the Eskom Distribution Group in the Eastern Cape Province. In this capacity he is responsible for the optimal medium to long term electrical network expansion. Mr. Hashe focuses on investment planning and cost effectiveness of the electrical infrastructure. He is responsible for the planning and integration of Renewable Energy in the distribution grid in the Eastern Cape Province. Previously Mr. Bello worked as the *Master Planning Senior Engineer for* Eskom Distribution in the Eastern Cape Province.

He holds a Bachelor of Technology in Electrical Engineering from the Nelson Mandela Metropolitan University and a Bachelor of Science Honors degree in Electrical Engineering from Pretoria University. He is a member of the South African Institute of Electrical Engineers and professionally registered with the Engineering Council of South Africa.

MS. PAMELA IJUMBA

SENIOR ENGINEER, TRANSMISSION GRID PLANNING

Pamela Ijumba currently serves as a Senior Engineer for Transmission Grid Planning within the Infrastructure Investment Planning Department. She has also worked in the Integrated Planning Support Department to ensure the optimal integration of new load and new generation into the transmission network. She is currently involved in a strategic study to optimize the integration of Renewable Energy (RE) into the future grid. Since 2011, she has been heavily involved in the IPP integration studies for the RE IPP Procurement Program. Ms. Ijumba joined Eskom in 2008 in the Key Sales and Customer Service Department. This division is responsible for interfacing with Eskom customers that consume more than 100GWh per annum.

Ms. Ijumba studied Electrical Engineering at the University of Cape Town. She obtained her Bachelor's degree in 2005 and her Master's degree in 2008.

MR. MBULELO KIBIDO

GENERAL MANAGER, TRANSMISSION GRID PLANNING

Mbulelo Kibido has served Eskom in various capacities since 2008. Currently he serves as General Manager for Transmission where he oversees the regulatory compliance for Eskom's transmission grid and the optimal integration of their generators. In this role, he also manages the transmission investment planning. Before this role, while in Eskom, he acted as Senior Manager for Transmission.

He worked for South Africa's National Government as Chief Director for Energy until 2008, where he lead the Electricity Distribution Industry (EDI) restructuring effort and monitored Eskom's capital investment program. From 2004 to 2007 he acted as Director for Electrical Engineering Services. Mr. Kibido is also a registered engineer with the Engineering Council of South Africa (ECSA) and serves as a non-executive member in Lukhanji Technologies where he has fiduciary duties and oversight on management.

Mr. Kibido earned from the University of Witwatersrand a Master of Business Administration (MBA) in 2002 and a Graduate Diploma in Engineering in 2003. He also earned a Bachelor of Science in Electrical Engineering from the University of Cape Town in 1993.

MR. JACOB LABANE MADUMO
REGIONAL MANAGER, GRID ACCESS UNIT

Jacob Madumo is the Regional Manager for Grid Access Unit within Group Customer Services in Eskom, responsible for the overall service relationship with the Independent Power Producers. His mandate is to facilitate grid access or connection for IPPs and other generators. His unit serves as a point of contact or entry into Eskom for IPPs and services all generators' needs. Mr. Madumo provides end to end personalized service to the Independent Power Producers (IPP) and other generators in terms of consultation and advising, quotation and contracting and construction and connection of generation plants.

In 2011, prior to this position, he was the Regional Executive Manager responsible for management of Key and Large customers within Eskom. He provided customer and technical support, managed financial and revenue performance, developed and monitored Service Level Agreements with critical stakeholders.

Mr. Madumo has been part of Eskom for eighteen years and gained all his experience within Group Customer Services. In 1991 he completed his Bachelor of Arts in Humanities from University of Witwatersrand. He later obtained his BA honors degree in Industrial Sociology from the University of Rhodes, South Africa.

MS. LERATO MPUTLE
CHIEF TECHNOLOGIST, GROUP TECHNOLOGY-ENGINEERING

Lerato Mputle currently serves as the Lead Engineer for the 150MW Solar Photo Voltaic (PV) fleet projects for captive consumption involving over 50 different Eskom's power stations, office building rooftops and substations. In her capacity as Lead Engineer she gives technical and integration leadership, and also coordinates a multi-disciplinary team consisting of engineers and various mechanical disciplines. She launched her career in renewable energy within Eskom as the Lead Engineer in the first two demonstration Solar PV projects (each 600KW) in 2011.

Prior to her current role, Ms. Mputle has led various projects as acting departmental head including the Turbo-Generator Project on the 4.6 GW Medupi Power Station (one of the largest coal fired power stations in the world under construction). She joined Eskom in 2000. She is a professionally registered Electrical Technologist with Engineering Council of South Africa and also an active member of SAIEE, the South African Institute of Electrical Engineers.

MR. AKASH PRAKASH
POWER PURCHASE MANAGER, SINGLE BUYER OFFICE

Akash Prakash currently serves as the Power Purchase Manager in the Single Buyer Office. He is responsible for managing the Power Purchase Agreements (PPAs) with Independent Power Producers (IPPs) within South Africa. This includes the 47 Renewable Energy PPAs that were concluded as part of the Renewable Energy IPP Procurement Programme in South Africa and a further 17 Renewable Energy PPAs that are still to be concluded with preferred bidders that were recently announced by the Department of Energy. The portfolio of PPAs that are being managed also includes two Open Cycle Gas Turbine IPP projects which are currently in construction as well as numerous short to medium term PPAs.

Mr. Prakash has been with Eskom for the past 17 years and has served in various capacities, within the engineering, electricity tariff development and special pricing arrangement units of Eskom. In recent years, he has been instrumental in leading numerous short to medium term Power Procurement Programmes within Eskom to secure power from IPPs and generators outside of the Eskom fleet, to ensure sufficient supply to meet demand.

He obtained his Bachelor of Science Engineering Degree (Electrical) from the University of Natal (Durban). He went on to complete the Post Graduate Diploma in (Industrial) Engineering at the University of the Witwatersrand. In 2006, he completed the Masters in Business Administration (MBA) at the Gordon Institute of Business Science (GIBS) – University of Pretoria.

MR. LEHLOHONOLO TINTE
PROGRAM MANAGER-SOLAR PV PROJECTS,

Lehlohonolo Tinte currently heads Eskom's in-house Solar PV Business Unit, responsible for the development, construction and management of the ILANAGA Program, Eskom's own Solar PV Project. This Solar PV program for captive consumption involves both greenfield utility scale Solar PV projects at some of Eskom's existing power plants as well as roof top installations at its commercial building, and major electrical sub-stations around South Africa with an aggregate of 150MW of solar PV capacity. In this capacity, he leads Eskom's multi-functional project team including development, engineering, environmental permitting, siting, and turnkey EPC for construction and operations and maintenance of these facilities. Earlier he was Project Manager involved in construction of coal fired power stations, hydro pump storage projects. Prior to that he was involved with SAP roll out in Eskom. He has been with Eskom for 12 years.

He was previously with a South African chemicals company in the explosives industry. Academically, he holds a Masters degree in Business Leadership from University of South Africa and degrees in production and operations management from Technikon Witwatersrand. He is also a member of South African Institute of Industrial Engineers.

MR. ISAAC R. TSHWAGONG
CHIEF ENGINEER, ANCILLARY SERVICES, SYSTEM OPERATIONS

Isaac Tshwagong has been Chief Engineer for Ancillary Services in the System Operations unit of Eskom for last three years. In this capacity, he leads the budgeting and contracting of ancillary services and analyzes the impact to renewable energy providers. He has extensive engineering experience having served in various Eskom sites as Chief Engineer for National Operations from 2007 to 2009 and Senior Engineer from 2003 to 2007 in Gauteng; Engineer for the Operations Planning Department from 2001 to 2003 and Engineer in Training for the Distribution Network Planning & SCADA Department from 1999 to 2001 in Germiston offices.

He received a Diploma in Technology Leadership Program from the University of Warwick in 2003. He earned a Graduate Diploma in Engineering from Wits University in 2001 and a Bachelor of Science from the University of Potchefstroom in 1998. He is a registered engineer with the Engineering Council of South Africa.

MR. RAVINDRA VORA

ADVISOR-ESKOM RENEWABLE ENERGY BUSINESS

Ravindra Vora has been seconded by Black & Veatch to Eskom to serve as the Advisor to Eskom's Renewable Energy business since last two years reporting to the Senior General Manager and Head of Eskom's Renewable Energy business unit. He has been actively involved in supporting and participating in the development of Eskom's wind energy, CSP with energy storage and solar PV program including development, financing (part of negotiating team with international funders), construction and O&M management. Another focus area is development and implementation of Eskom's renewable energy strategy and organizational transformation to becoming a financial sustainably, high growth business. He is engaged in assisting all Eskom stakeholders engaged in RE integration in the South African electricity market. Further, he facilitated two very successful Solar PV and Solar Augmentation conferences for Eskom as part of their RE capacity building.

Prior to joining Eskom, he has held leadership positions with a large RE IPP (President), leading wind energy company ; with electric utility companies in USA and India and has been a strategic advisor to clean energy industry and financial institutions. He has over 20 years of experience in the electric utility, IPP, and renewable energy industries. He has been on the board of directors of two investor owned electric utility companies as well. He earned his Masters in International Management from American Graduate School of International Management (Arizona) and Masters and Bachelor's degrees in Chemical Engineering from Iowa State University.

ENTERTAINMENT OPTIONS

AUSTIN, TEXAS

Austin is a city of over 700,000 inhabitants and also the capital of Texas. Austin is also marketed as the "Live Music Capital of the World" due to the large number of venues.

Downtown Austin is the central business district of the city is home to some of the tallest condo towers in the state. Across 2nd Street from Austin City Hall is the newly re-created TV set for the long-running PBS program Austin City Limits, which is housed beneath the new 146 m W Hotel. South by Southwest (SXSW) is hosted downtown and is one of the largest digital media and consumer electronic conferences in the United States. Though it is a media industry-based event, SXSW also contains a large music component which links locally with events such as the annual Austin Music Awards show. SXSW is the highest revenue-producing special event for the Austin economy, with an estimated economic impact of at least $200 million in 2012.

Sights and Culture

Austin has a strong theater culture, with dozens of itinerant and resident companies producing a variety of work. The city also has live performance theater venues such as the Zachary Scott Theatre Center, Vortex Repertory Company, Salvage Vanguard Theater, Rude Mechanicals' the Off Center, Austin Playhouse, Scottish Rite Children's Theater, Hyde Park Theatre, the Blue Theater, the Hideout Theater, and Esther's Follies. The Victory Grill was a renowned venue on the Chitlin' circuitPublic art and performances in the parks and on bridges are popular.

South Congress (SoCo) is a neighborhood located on South Congress Avenue known as a shopping and cultural district famous for its many eclectic small retailers, restaurants, music and art venues and, more recently, food trucks. South Congress begins at the Colorado River and Ann W. Richards Congress Avenue Bridge and runs due south towards Ben White Boulevard/TX-71. Since its humble beginnings in the 1850s, South Congress Avenue has been transformed from a rural country road to the capital city gateway and, finally, to the vibrant shopping district that it is today. Many Austinites attribute its enduring popularity to the magnificent and unobstructed view of the Texas State Capitol. Other sightseeing options include:

University of Texas in Austin: Visit the Blanton Museum of Art, the Harry Ransom Center, Texas Memorial Museum of Science and History, or view the public art around the campus. The famous UT tower has reopened and it has breathtaking views and history lessons. For this tour reservations are needed.

The Texas State Capitol: A large source of pride for the city and the state, the State Capitol is a beautiful building wrapped in Texas pink granite. Texans take pride in the fact that the State Capitol is actually 14 feet taller than the U.S. Capitol in

Washington, D.C. Unlike many other state capitols in America, Texas' is completely open to the public seven days a week and has free admittance.

The State and Paramount Theaters: features a wide variety of plays and acts, from Broadway productions to unique dance companies.

Congress Avenue: Early structures along Congress Avenue included government buildings, hotels, saloons, retail stores and restaurants. By the late 1840s "The Avenue" formed a well-established business district. The mid-1870s introduced gaslight illumination and mule-driven streetcars as well as construction of a new Travis County courthouse at Eleventh Street. Notable structures along Congress Avenue north of the Colorado include the Texas State Capitol, Paramount Theatre, the Southwestern Telegraph and Telephone Building, Gethsemane Lutheran Church and the Old Bakery.

Sixth Street: Sixth Street is a historic street and entertainment district in Downtown Austin. Sixth Street itself stretches from the Mopac Expressway in Old West Austin across to Interstate 35 and beyond. The nine-block area of East Sixth Street roughly between Lavaca Street to the west and Interstate 35 to the east is recognized as the Sixth Street Historic District and was listed in the National Register of Historic Places on December 30, 1975.

The area around nearby 4th Street and 6th Street has been a major entertainment district since the 1970s. Many music venues and shopping destinations are located on E. 6th Street between Congress Avenue and Interstate 35 and many offer live music at one time or another during the week.

Dining

Eddie V's Edgewater Grill
Cuisine: International (Jazz Music available)
301 East 5th Street
Austin TX 78701
512-472-1860

Fleming's Steakhouse
Cuisine: Steakhouse
320 East 2nd Street
Austin, TX 78701
512-457-1500

Franklin Barbecue
Cuisine: Barbecue
900 E 11th St., Austin, TX 78702
(512) 653-1187

Mandola's Italian Market
Cuisine: Italian
4700 W Guadalupe St #12, Austin, TX
(512) 419-9700

Threadgill's World Headquarters
301 West Riverside Drive, Austin, Texas 78704
(512) 472-9304

HOUSTON, TEXAS

From sophisticated theaters and museums to live music events in funky bars, Houston is a city that offers a very broad range of entertainment. The motion picture industry has taken notice of what the city offers and has poured over $100 million into the local economy in recent years.

Sights and Culture

Live music venues are very popular and very varied. Some bars and nightclubs showcase live bands on weekends or specific nights, while others like the Fabulous Satellite Lounge feature live bands every night of the week. The Lounge is located in the historic Heights area and has been honored several times by the Houston Press as one of the city's best venues for live music. Popular bands play rock, blues, country and folk music to entertain sizable crowds. Billy Blues Bar & Grill is another popular nightspot that features live blues performances every night. This bar also has a full-service restaurant, where you can nibble on some tasty barbecue while you enjoy the music. If your preference is jazz and seafood, head downtown to Sambuca Jazz Cafe for nightly performances. The management at this ritzy club books at least one national act a month.

Experience a little Irish culture several times a month at The Claddagh. This bar also features authentic Irish cuisine and an open mic on Wednesday nights. The Hop books popular sock-hop entertainers to croon tunes from the 50s and 60s several times a month. Older crowds, as well as young swingers, find this nightclub very appealing. Live Latino music is a hit at Ruggles Bistro Latino on the weekends. Head downtown early and enjoy an assortment of Latin cuisines before settling in for the show. The Copacabana style and elegance of the 1940s is the main attraction at the Mercury Room, a popular hangout among a distinguished, older crowd. Swing and blues feature heavily at this downtown nightclub.

Karaoke has become a popular pastime in Houston. You will find that many nightclubs and bars offer karaoke and open-mic nights on a regular basis. Even if you are not tempted to try it yourself, watching the antics of others can be tremendously entertaining. Miller's Cave features karaoke three nights a week in addition to live rock & roll bands on Friday evenings. Dave & Busters is popular on the Strip for its unique approach to entertainment. A karaoke bar is part of its charm, along with high-tech virtual reality and video games, numerous pool tables and a full-service restaurant.

In a completely different respect, live concerts and classical performances are equally popular and entertaining. Jones Hall is home to the critically acclaimed Houston Symphony and features numerous classical concerts every month. Other artistic musical presentations also take place in this downtown music hall from time to time. Compaq Center, the Astrodome and Cynthia Woods Mitchell Pavilion all play host for famous concert tours featuring the hottest performers. If these types of live music are the ones you prefer, keep an eye on the Local Events section for upcoming performance dates and ticket information.

Houston is a city with a lot of popular attractions and a plethora of things to do. Even many of the locals have never managed to see and do everything, and most of them have spent a lifetime here.

Downtown Astrodome or the "Eighth Wonder of the World," is a must-see. Be sure to browse the museum as well. Try down home cooking at Irma's Restaurant. If you are a shopaholic or simply a lover of the unique, you will want to experience the Tunnel Walk, an amazing modern tunnel system lies under many of the most prominent buildings in the downtown area. Classical music fans will enjoy the Houston Symphony, while the Sam Houston Park is a haven from the hustle and bustle.

Montrose/Museum District: The Montrose District is also known as the Museum District for its dozens of world-class galleries and art collections. The Contemporary Arts Museum has exhibits that reflect modern art styles, while the Houston Museum of Natural Science contains interactive displays such as a live butterfly exhibit. The nearby River Cafe is a great place to stop and grab a bite to eat. Other important museums include the Houston Holocaust Museum and the Children's Museum of Houston, which is dedicated to enriching the lives of youngsters.

Clear Lake/Kemah: The area around the Kemah Boardwalk is filled with things to do. The Boardwalk itself has many interesting shops, cafes and restaurants that keep visitors busy for hours. Dine at Bonnie's Beef & Seafood. Space technology junkies, especially those who experienced first-hand the wonder and thrill of America's first moon landing, will definitely want to visit Johnson Space Center. The renowned Comedy Showcase, where many famous comics got their start, is also nearby.

West Houston: Ima Hogg is the famous philanthropist responsible for creating the Houston Symphony in the early 1900s. Her magnificent estate, Bayou Bend, is a 28-room mansion that contains over 4800 pieces of American art that represent various styles from colonial times to the mid-1900s. A wander through the nearby Buffalo Bayou Park and Memorial Park is also a nice way to break up the day. Dine at Lynn's Steakhouse.

Nearby Dining Options

The diverse industrial focus of Houston has inspired people from numerous countries to settle here. With so many cultures represented, it is no great surprise that the city's dining opportunities reflect their influences. If you are homesick, there is a good chance you will be able to find a restaurant that specializes in your native cuisine. If you are simply adventurous and like to sample the flavors of the world, you will have a lot of chances to do so while visiting. In fact, you would have to live here a very long time to exhaust the possibilities. Also there are the following nearby restaurants:

El Rancho Mexican Restaurant
Cuisine: Mexican
17754 Katy Freeway, Houston, TX 77084
(281)-492-967

The Far Seas Grill
Cuisine: Mediterranean
17756 Katy Freeway
Houston, TX 77094
(281)-578-9082

Pasta Lomonte's
Cuisine: Italian
14510 Grisby Road
Houston TX 77079
(281)-496-0030

Lupe Tortilla's
Cuisine: Mexican
15315 North Freeway
Houston, TX 77090
(281)-873-6220

Texas Land and Cattle
Cuisine: Steakhouse
12313 Katy Freeway, Houston, TX 77079
(281)-679-9900

Thai Cottage at Katy
Cuisine: Thai
19610 Katy Freeway
Houston, TX 77094
Phone number (281) 398-0701

Downtown

Beyond the realm of traditional Texan, the possibilities are equally impressive. The close proximity to the Gulf of Mexico has inspired a love of seafood, which has, in turn, inspired the birth of a large number of seafood restaurants across the city. The downtown area boasts the expertise of Massa's Seafood Grill. A variety of Asian food types are popular in Houston. If you like Japanese sushi in an upscale atmosphere, try the Sake Lounge. In addition to the tasty Tex-Mex offerings, the city also boasts a number of restaurants that specialize in traditional Mexican fare. Irma's Restaurant has been a famous Houston mainstay for years. Irma herself will come out of the kitchen and treat you like one of the family at her homey establishment.

Galleria

Steaks are considered to be a strong runner-up as a Texas tradition, and some of the finest steakhouses in the state are located in Houston. Morton's The Steakhouse is yet another former President Bush-approved restaurant It is classy and elegant, as is Capital Grille. The Galleria area also lays claim to McCormick & Schmick's. Copeland's of New Orleans is an example of a New Orleans' original that has made a mark on the spicy side of the Houston dining scene.

Houston also has its share of restaurants that specialize in contemporary, cutting-edge cuisine. Anthony's Restaurant is owned and operated by heralded restaurateur Tony Vallone. The elegance and sophistication of the décor and European/American menu are hard to beat. Rudi Lechner's Restaurant pays tribute to German and Austrian cuisine. Pizzerias are essentially Italian, of course, but the concept has been Americanized to a large extent. Fun-loving diners are drawn to the boisterous atmosphere of New York Pizzeria, while out-of-the-ordinary options, like barbecue pizza, attract a full house at California Pizza Kitchen.

Montrose/Museum District

When it comes to Tex-Mex, the city's restaurants offer a variety of atmospheres to suit every mood. You can enjoy the best at a place called Little Pappasito's. The décor is eclectic Mexican, complete with roaming mariachis, but the menu offers some sophisticated twists in addition to traditional Tex-Mex. Otto's Bar-B-Q has been around for over 50 years and has earned former President George Bush's seal of approval. Not to be outdone, Goode Company Barbecue is famous across the city for the sweet-spicy-smoky barbecue sauce they slather on a variety of meats. Brennan's of Houston specializes in Cajun and Creole creations, while Baroque offers the best in French dining with a romantic, elegant theme. You have the option of dining lavishly, and if you choose to do so, there is no better place to splurge than Aldo's.

You will be comfortable dressing up or down for your meal at Mark's American Cuisine, but don't let the name fool you. There are a lot of interesting global twists on the menu. For spicy Thai and a view of some interesting murals, visit Nit Noi.

TUCSON, ARIZONA

Tucson (pronounced TOO-sawn) is the second-largest city in the state of Arizona, and at an elevation of 730 meters, it has slightly cooler temperatures than Phoenix. The city is also situated in the Sonoran Desert. As of 2011, the population within city limits was 843,168 and 989,569 in the Greater Tucson Metropolitan Area, making the 52nd biggest city/metro area in the country and the 2nd in the state and the Southwestern US.

Sights and Culture

Similar to many other cities in the Western U.S., Tucson was developed on a grid plan starting in the late 19th century, with the city center at Stone Avenue and Broadway Boulevard. While this intersection was initially near the geographic center of Tucson, that center has shifted as the city has expanded far to the east, development to the west being effectively blocked by the Tucson Mountains. An expansive city covering substantial area, Tucson has many distinct neighborhoods.

For outdoor enthusiasts, the Sabino Canyon is perfect for hiking or explore Arizona's native cactus preserved at the Saguaro National Park. For those looking for more relaxing things to do in Tucson, the Park Place Mall, just one mile from the hotel, is Tucson's premier shopping, dining, and entertainment destination. Other sightseeing options include:

Sabino Canyon: A desert canyon cut into the south side of the Santa Catalina Mountains, now on Tucson's northern urban fringe. A tram (for a fee) will take visitors 9 stops into Sabino Canyon; a separate tram will take you into Bear Canyon and to the trailhead of the popular Seven Falls Trail.

Arizona-Sonora Desert Museum: 2021 N. Kinney Rd., Tel. (520) 883-2702. The Arizona-Sonora Desert Museum is part zoo, part natural history museum and part botanical garden all in one Tucson attraction. From tarantulas to black bears, coyotes to scorpions, the museum-zoo is an entrancing and full-contact tribute to the Sonoran desert's wildlife The Museum is also on the fringes of Saguaro National Park, home to the world's largest forests of Saguaro cacti.

Tohono Chul Park: 7366 N. Paseo del Norte, Tel. (520) 742-6455. "Tohono chul" means "desert corner" in the Tohono O'Odham's (desert people's) language, and this haven in the midst of Tucson's burgeoning north side offers a tea room, gift shop, bookstore, and art gallery in the middle of trails and gardens. There are extensive botanical exhibits explaining the native plants, and a wonderful plant-sale area in which to buy them for your own garden. Many kinds of desert birds are frequent visitors.

Mission San Xavier del Bac: 1950 W. San Xavier Rd., Tel. (520) 294-2624. The Mission San Xavier del Bac was finished in 1797 when Arizona was still New Spain. It has recently been cleaned and restored by professional art conservators who worked with, and trained members of the community.

Old Tucson Studios: 201 S. Kinney Rd., Tel. (520) 883-0100. Many of Hollywood's Old Western movies have been filmed at the Old Tucson Studios; originally built in 1939 for the making of the William Holden vehicle "Arizona." Still an active film, TV and commercial set, it's also a nostalgia-themed park, with main drag shootouts, corseted can-can dancers, educational shows, pre-Prohibition saloons, restaurants, and gift shops.

Barrio Viejo (Barrio Historico): Bounded by I-10, W Cushing St , S 6th Ave, and W 18th St. One of Tucson's oldest neighborhoods, with colorful adobe buildings housing shops, galleries, and residences.

Nearby Dining Options

Maynards
Cuisine: French
400 N. Toole Ave., Downtown, Tucson, AZ 85701
(520) 545-0577

Union Public House
Cuisine: American
4340 N Campbell Ave #103, Tucson, AZ 85718
(520) 329-8575

BJ's Brewhouse
Cuisine: Grill
5510 E Broadway Blvd, Tucson, AZ 85711
(520)-512-0330

El Charro Mexican
Cuisine: Mexican
7725 N Oracle Rd #101, Tucson, AZ 85704
(520) 229-1922

PHOENIX, ARIZONA

Phoenix is the capital of the state of Arizona as well as the most populous city in the American Southwest and sixth largest city in the United States. Founded in 1871, it has become the region's primary political, cultural, economic, and transportation center. At an elevation of 335 meters, it is situated in the biologically unique Sonoran Desert. Phoenix has an arid climate with long and very hot summers and mild winters. It has the highest average temperature of any metropolitan area in the United States. The weather varies enormously from one season to the next. While it's not as cold as in the northern states during the winter, it does freeze sometimes, and temperatures in the 30s°F (-1°C) are not unheard of.

Downtown
Downtown Phoenix is clean, with wide streets and tall, modern, solidly built buildings. Sports anchor the scene downtown, with the Suns and Mercury playing basketball, Diamondbacks playing baseball, and for a for a more cultural vibe, the Herberger Theatre Center, Symphony Hall, and the Arizona Science Center are all within walking distance. Many Downtown sites are served by the light-rail system or DASH (Downtown Area Shuttle), a free bus service.

Midtown
There are a handful of officially recognized and protected historic neighborhoods and a variety of cultural, performance, and sporting venues in this area of town. The Central Avenue Corridor is a significant stretch of north-south Central Avenue, in Phoenix, Arizona. This is one of Phoenix's most vital and heavily trafficked stretches of roadway and also one of the region's largest centers of employment, with nearly 60,000 people being employed within a three-mile (5 km) radius of this swath of Central Avenue. Major employers here include major banks and financial institutions, hi-tech companies, and several major law firms and government agencies.

North Phoenix
The Phoenix Mountains are located here and offer a plethora of hiking and outdoor activities. The Shops at Norterra is a major retail power center is located at I-17 on the north side of Happy Valley Rd. Major shopping stores are located here and a Harkins 14-screen cinema and Best Buy. Many smaller retailers and casual dining restaurants are also in the shopping center.

Camelback East
A very upscale area of town that contains the famous Biltmore Hotel, Papago Park, the Phoenix Zoo, and world class resorts. South of the mountains the roads are almost universally laid out in a grid format, with numbered streets running north/south and increasing in number as you move east towards the Scottsdale border. Leaving the area to the north generally means passing through one of two major mountain passes--the Dreamy Draw via State Route 51 or around Camelback Mountain and through the Town of Paradise Valley via 44th St. to MacDonald Dr. and then north along Tatum Blvd. Either route offers some stunning views of urban desert mountain settings.

Sights and Culture

The Phoenix Art Museum is the Southwest's largest destination for visual art from across the world. Located at 1625 North Central Avenue, the 26,500 m^2 art museum stands at the intersection of Central Avenue and McDowell Road on the historic Central Avenue corridor. Phoenix Art Museum displays international exhibitions alongside the Museum's comprehensive collection of more than 18,000 works of American, Asian, European, Latin American, Western American, modern and contemporary art, and fashion design.

Another prominent area museum is the Heard Museum just north of downtown. It has over 12,000 m^2 of gallery, classroom and performance space. Some of the signature exhibits include a full Navajo hogan, the Mareen Allen Nichols Collection containing 260 pieces of contemporary jewelry, the Barry Goldwater Collection of 437 historic Hopi Kachina dolls, and an exhibit on the 19th century boarding school experiences of Native Americans.

Other notable museums in the city include the Arizona Science Center, Hall of Flame Firefighting Museum, the Phoenix Zoo, the Pueblo Grande Museum and Cultural Park, and the Children's Museum of Phoenix. In 2010 the Musical Instrument Museum opened their doors, featuring the biggest musical instrument collection in the world.

Sports

Phoenix is home to several professional sports franchises, including representatives of all four major professional sports leagues in the U.S. – although only two of these teams actually carry the city name and play within the city limits. The Phoenix Suns of the National Basketball Association, the Arizona Cardinals of the National Football League's National Football Conference, and the Arizona Diamondbacks of Major League Baseball are three of the most prominent teams.

Nearby Dining Options

The Arrogant Butcher
Cuisine: Modern American
2 E. Jefferson St. #150, Phoenix, AZ 85004
(602) 324-8502

Blue Hound Kitchen
Cuisine: International
2 E. Jefferson St., Phoenix, AZ 85004
(602) 258-0231

Cheuvront Restaurant
Cuisine: American
1326 North Central Ave., Phoenix, AZ 85004
(602) 307-0022

Mrs. White's Golden Rule Café
Cuisine: Southern
808 E. Jefferson St, Phoenix, AZ 85034
(602) 262-9256

Gallo Blanco
Cuisine: Mexican
401 W Clarendon Ave, Phoenix, AZ 85013
(602) 327-0880

Los Dos Molinos,
Cuisine: Spanish
8646 S Central Ave, Phoenix, AZ 85034
(602)-243-9113

Los Angeles and Costa Mesa, California

Downtown
Located in the heart of downtown, the modest Pueblo de Los Angeles remains the city's oldest structure. Built in 1818, it serves as a historical monument to the mission era of California, and also provides tourists with the perfect reason to visit downtown and not miss one of the city's best-kept sightseeing secrets. Located in the middle of the historic pueblo is Olvera Street, an L.A. landmark since the early 1930s. Any day of the year the cobblestone street is alive with inexpensive Mexican delicacies, kitschy shopping and several wandering mariachi bands. If too many hours on Beverly Hills/Rodeo Drive Shopping District have strained the magnetic strip (or the limit) of your credit card, the Garment District offers a great low-cost shopping alternative. The Cooper Building and Santee Alley house designer outlet stores and clothing in all styles, labels and sizes.

Hollywood
The Griffith Observatory is one of the largest in the country. At night you can stargaze from balconies on the outside of the building, as well as from on the roof. Face north in the parking lot and you will get a spectacular view of the Hollywood Sign. Take Hollywood Boulevard approximately three blocks to Vine. At this famous intersection begins the Hollywood Walk of Fame, so named for the bronzed stars placed into the pavement that bear the name of a legendary entertainer in music, movies and television. L'Orangerie is a classy French restaurant near here. Continuing up Hollywood Boulevard you will come to Mann's Chinese Theater, more famous for the front courtyard than for any film ever shown there. The footprints and handprints outside include so many stars, and create such a stir, it's sometimes hard to squeeze your way in.

Malibu and Santa Monica
The beach community of Santa Monica offers great shopping and dining. The Third Street Promenade and The Pier are major centers of activity. Here you can ride roller coasters, shop, eat fish or just take in the ocean air. Beaurivage is a fantastic restaurant with ocean views when you're ready to hit the coast, head north on the beautiful Pacific Coast Highway. A few miles north of Malibu one can find Leo Carillo State Beach. This unique inlet features rock formations and tide pools overflowing with some of the most unusual aquatic life in the world. If you are lucky, you will also be able to see dolphins frolicking just offshore.

Mount Wilson
The 110 freeway north ends at Colorado Boulevard, where you will turn right and head into Old Town. In addition to being a quaint historical city, Old Town Pasadena Shopping District is known for world-class restaurants, thriving theater and many antique shops. One of the best features of Old Town is the architecture. An elegant dining option nearby is Bistro 45, which has contemporary French options on its menu. For those who feel confined by gravity and want to get a different perspective of Pasadena, simply follow signs to the Angeles Crest Highway and head up--straight up! This winding (and at times treacherous) mountain road takes you through the Angeles National Forest en route to the Mount Wilson Observatory, some 5000 feet above sea level.

Theaters
The creative activity in the theaters of Los Angeles proves the naysayers wrong: just because the city's more frivolous side is the most publicized, Los Angeles does indeed have a rich history of culture and soul. The Performing Arts Center of Los Angeles County complex in downtown Los Angeles houses many of the city's major theatre venues, including the Dorothy Chandler Pavilion, the Mark Taper Forum, Pantages Theatre, and the Ahmanson Theatre.

Museums
Los Angeles is indeed multi-faceted: with beautiful beaches on one end, trendy clubs on another, and amazing museums spread throughout, it is no wonder people flock here to get a taste of everything it has to offer. The Getty Center is a breathtaking architectural work before you even see the collections inside. The Los Angeles County Museum of Art has impressive permanent collections as well as top-billed shows. If contemporary art is more your cup of tea, then pay a visit to the Museum of Contemporary Art (MOCA) which has featured extremely innovative art exhibitions. L.A. is also home to many smaller, private galleries, concentrated especially in Venice and the Melrose area of Hollywood. If nature and science excite you more than a rare Van Gogh, the California Science Center is a hands-on educational facility that takes science to the extreme while the Natural History Museum has 35 galleries of environmental science displays to explore. For a more serious-minded museum visit, the Los Angeles Museum of Tolerance is a stop for the humanitarian-minded tourist. The museum offers classes in racial diversity and acceptance, and offers tours for school children and interested adults. It is a powerful, moving and informative institution.

Cinema
Mann's Chinese Theater on Hollywood Boulevard stands out as one of the most famous cinema houses ever built. Crowds descend upon the faux-Asian theater every day to measure the famous feet and hands imprinted on the sidewalk outside. Across the street from the Mann's Chinese, the Egyptian Theater stands in its Vegas-style glory.

Comedy
With countless small theaters and clubs in Los Angeles, open mic nights for struggling comedians are everywhere. For a more polished performance check out the famous Groundlings since this well-known "training camp" for television shows like Saturday Night Live has an ever-changing lineup of up-and-comers with an occasional star headliner. The Improv and the Comedy Store consistently feature well-known, professional headliners as well as budding new talent.

Disneyland
The Disneyland Resort is located in Anaheim, California. It is home to the original Disneyland Park, which opened on July 17, 1955, a favorite among visitors to Southern California from all over the world for well over half a century. It was joined in 2001 by a sister park, Disney California Adventure, which is a stylized recreation and celebration of California's rich history and culture.

The Disneyland Resort is divided into two separate theme parks, three hotels, and a shopping and entertainment district. The first park is the original Disney theme park Disneyland, which opened on July 17, 1955. Its sister park Disney California Adventure, which opened in February 2001, is located across the entry plaza on the former site of Disneyland's parking lot. Both parks are divided into "lands", or themes. At the western end of the entry plaza is Downtown Disney, the shopping and entertainment district. Please see the map included in this section.

Tickets are sold at several levels: the base ticket is the Single-Day Theme Park Ticket and enables admission to only one of the two parks for a full day. By contrast, the 1-Day Park Hopper allows you to see both parks on the same day and to move back and forth between the parks. Park Hopper tickets are also sold in increments of 2, 3, 4, and 5 days; while the ticket price increases with each day, the price per day actually decreases with each day.

The prices below are effective May 20, 2013:

Days	Ages 10+	
	1-Park	Park-Hopper
1-Day Theme Park Ticket	$92.00	$137.00
2-Day Theme Park Ticket	$175.00	$210.00

Universal Studios Hollywood
Universal Studios Hollywood is a movie studio and theme park in the unincorporated Universal City community of Los Angeles County, California. It is one of the oldest and most famous Hollywood movie studios still in use. Its official marketing headline is "The Entertainment Capital of LA. These studios were initially created to offer tours of the real Universal Studios soundstages and sets. It is the first of many full-fledged Universal Studios Theme Parks located across the world.

Universal Studios Hollywood can easily be accessed by public transportation. The Metro Red line subway train runs between Union Station in Downtown Los Angeles, Westlake, Koreatown, Los Angeles, East Hollywood, and Hollywood. The subway line runs daily between the hours of 4:55 a.m. and 12:35 a.m. The last Metro Red Line train to Downtown Los Angeles departs the Universal City station at 12:58 a.m. on Mondays-Thursdays and Sunday/Holidays. On Fridays and Saturdays, the last Metro Red Line train to Downtown Los Angeles departs the station at 2:00 a.m. Passengers can also arrive at the entrance of the theme park entrance by several Metro bus routes.

Tickets		
Category	**Details**	**Price**
Front of Line Pass	Includes park admission with one-time priority access to each ride, show & attraction. Front of Line Passes often sell out at the front gate ticket booths.	$139.00
VIP Experience	Go behind the scenes and visit closed sets on Hollywood's most famous movie-studio backlot. VIP privileges at Universal Studios Hollywood theme park, with escorted priority access to all rides, shows & attractions.	$299.00
1- Day Pass	General Admission	$84.00

Shopping
South Coast Plaza is a comprehensive shopping center in Costa Mesa. It is the largest mall on the west coast; its sales of over 1.5 billion are highest in the United States. Its 250 retailers represent the highest concentration of design fashion retail in the U.S, with the second highest sales-volume in California. The shopping center has about 260,000 m² of gross leasable area and over 250 stores, making it one of the largest shopping centers in the United States. In 2004, South Coast Plaza received the Federal Trademark as "The Ultimate Shopping Resort".

The shopping center also features restaurants such as Lawry's Carvery, Charlie Palmer at Bloomingdales, and Vie De France as opposed to a food court. Additionally, features such as valet parking, concierge services, access lounge and even courtesy umbrellas or hot beverage service continue to highlight the upscale nature of the mall. Please see the store directory and map included with this section.

Nearby Dining Options

T.G.I. Friday's
Cuisine: American
601 Anton Blvd, Costa Mesa, CA 92626
(714)-540-2227

Mastro's Steakhouse
Cuisine: American
633 Anton Blvd, Costa Mesa, CA 92626
(714)-546-7405

Z Tejas
Cuisine: Southwestern
3333 Bristol St, Costa Mesa, CA 92626
(714)-979-7469

Lawry's Carvery
Cuisine: Sandwiches
3333 Bristol St #2601, Costa Mesa, CA 92626
(714)-434-7788

Maggiano's Little Italy
Cuisine: Italian
3333 Bristol St, Costa Mesa, CA 92626
714-546-9550

Vie De France
Cuisine: French
3333 Bristol St #1420, Costa Mesa, CA 92626
714-557-1734

SAN DIEGO, CALIFORNIA

San Diego is a large coastal city in California. Located on the Pacific Ocean in Southern California, it is home to 1.3 million citizens and is the second-largest city in the state. San Diego has a strong military presence and is home to the Pacific Fleet of the United States Navy. It is also known for its ideal climate, impressive beaches, and several tourist attractions which include the SeaWorld theme park and the San Diego Zoo. The city sits just north of the Mexican border, across from Tijuana.

San Diego's commercial port and its location on the United States-Mexico border make international trade an important factor in the city's economy. The city is authorized by the United States government to operate as a Foreign Trade Zone. In addition San Diego hosts the busiest international border crossing in the world, in the San Ysidro neighborhood at the San Ysidro Port of Entry.

Sights and culture
Many popular museums, such as the San Diego Museum of Art, the San Diego Natural History Museum, the San Diego Museum of Man, the Museum of Photographic Arts, and the San Diego Air & Space Museum are located in Balboa Park. The Museum of Contemporary Art San Diego (MCASD) is located in La Jolla and has a branch located at the Santa Fe Depot downtown. The downtown one consists of two building on two opposite streets. The Columbia district downtown is home to historic ship exhibits

belonging to the San Diego Maritime Museum, headlined by the Star of India, as well as the unrelated San Diego Aircraft Carrier Museum featuring the USS Midway aircraft carrier.

The San Diego Symphony at Symphony Towers performs on a regular basis and is directed by Jahja Ling. The San Diego Opera at Civic Center Plaza, directed by Ian Campbell, was ranked by Opera America as one of the top 10 opera companies in the United States. Old Globe Theatre at Balboa Park produces about 15 plays and musicals annually. The La Jolla Playhouse at UCSD is directed by Christopher Ashley. The Joan B. Kroc Theatre at Kroc Center's Performing Arts Center is a 600-seat state-of-the-art theatre that hosts music, dance, and theatre performances. The San Diego Repertory Theatre at the Lyceum Theatres in Horton Plaza produces a variety of plays and musicals. Hundreds of movies and a dozen TV shows have been filmed in San Diego, a tradition going back as far as 1898.

For entertainment and sightseeing, there are various landmarks and entertainment localities that should be of interest. Balboa Park has an expansive campus of museums, parks, gardens and arboretums. Neo-classical Spanish architecture, flowering gardens, a beautiful clock tower and intriguing museums make visiting Balboa Park a must. The San Diego Zoo, located in Balboa Park is one of the premier zoos in North America, encompassing over 100 acres of displays and habitats. Animal shows run constantly, and there are creatures here that aren't visible in any other zoo on the planet. Definitely worth a visit, but you need a full day to really do it justice. Sea World San Diego allows visitors a chance to interact with aquatic animals in an exciting way. Through shows, displays and enclosures people can learn about the world's oceans and the creatures that inhabit them. See the Mission Beach article.

La Jolla is an upscale coastal community of San Diego that includes secluded coves, beaches and ocean cliffs to explore. There are dozens of coffee shops, restaurants and high-end shopping outlets to be explored in La Jolla. Another landmark to visit is Point Loma since from the high vantage point visitors can get a panoramic view of the Naval Air Station, downtown San Diego, the Coronado Bridge and the distant mountains. The lighthouse is a short walk and allows stunning sunset views of the Pacific Ocean and off-shore islands. Cabrillo National Monument commemorates the landing of Juan Rodriguez Cabrillo's expedition for Spain of California in 1542.

The USS Midway Museum, a former aircraft carrier of the US Navy, is open for tours and home to a collection of former naval aircraft housed on her expansive flight deck. Guided tours and displays offer the public a unique look into the life aboard a powerful, old warhorse.

San Diego's near perfect climate, unique landscape, and low-crime rate make it one of the most pleasant places in the country to enjoy outdoor exercise. Because of this, visitors and locals alike will have no trouble finding a biking, hiking, or walking trail to suit their needs. There are numerous hiking trails and bike paths to choose from - big and small, highly visible or hidden. Information on some of the most popular individual trails can be found in the district articles. Also San Diego offers some unique opportunities for rock climbing both outdoor and indoor and other sports like kayaking and biking.

Nearby Dining Options

Aqua al 2
Cuisine: Italian
322 5th Ave, San Diego, CA 92101
(619) 230-0382

Fleming's Prime Steakhouse & Wine Bar
Cuisine: Steakhouse
380 K St, San Diego, CA 92101
(619)-237-1155

The Fish Market Seafood Market & Restaurant
Cuisine: Seafood
750 N Harbor Dr.
San Diego, CA 92101

Cucina Urbana
Cuisine: Italian
505 Laurel St., San Diego, CA 92101
(619) 239-2222

Indigo Grill
Cuisine: International
1536 India St. San Diego, CA 92101
(619) 234-6802

Le Fontainebleau
Cuisine: European
1055 2nd Ave., San Diego, CA 92101
(619) 238-1818

Sacramento, California

Sacramento is the state capital of California in the United States and is the oldest incorporated city in the state, settled between the confluences of the Sacramento and American rivers. Currently it has a population of 490,000 in the city and over two million in the metropolitan area. The pace of life is somewhat slower than in other large Californian cities, and the people are generally warm and friendly According to Time magazine Sacramento is the most diverse city in the USA.

Sights and Culture

California State Capitol Museum includes the historical state capitol building and the surrounding 16 square city blocks, known as Capitol Park. Inside, tours of the capitol, its legislative chambers, and its restored historic offices are available daily. Outside, the public is free to visit the many gardens, memorials, and monuments located throughout the 40-acre park's grounds. Entrance is free. Sutter's Fort State Historic Park is the oldest restored fort in the United States. Built by John Sutter in the 1840's, the fort now hosts a collection of pioneer and early California artifacts. Self-guided audio tours are available. There is an entrance fee.

There are several museums that showcase Sacramento's diversity. The State Indian Museum contains displays of Native Californian basketry, beadwork, clothing and exhibits about the ongoing traditions of various California Indian tribes. The Crocker Art Museum is the oldest continuously operating museum in the West, home to a premier collection of California art. Free on Sundays.

The Cesar Chavez Park: Formerly known as Plaza Park, Cesar Chavez Park is a scenic park in the middle of downtown Sacramento that adjoins historic City Hall, the Public Library and Sacramento's Citizen Hotel. Folsom Lake is one of Northern California's largest lakes; Folsom Lake is where many local Sacramentans go fishing, biking, sailing, kayaking or jet-skiing during the summer. It is located 30 minutes east of downtown Sacramento off Highway 50. Finally the Dinner Detective is America's Largest Interactive Murder Mystery Dinner Show which is located in the Doubletree by Hilton

Old Sacramento

Once a thriving riverfront pioneer town, Old Sacramento now primarily exists as living historic district. The boardwalk style sidewalks and horse-drawn stagecoaches give this small section of town a unique flavor. Old Sacramento contains several museums, restaurants, and the usual assortment of souvenir shops all within walking distance of each other. Best of all, it's a five minute walk from the Amtrak station. The best time to visit is in late afternoon and early evening There's a nice, short, safe walkway between K Street Mall and Old Sacramento.

Theater

There are several major theatre venues for Sacramento. The Sacramento Convention Center Complex governs both the Community Center Theatre and Memorial Auditorium. The Wells Fargo Pavilion is the most recent addition. It is built atop the old Music Circus tent foundations. Next to that is the McClatchy Main stage, originally built as a television studio, which was renovated at the same time the pavilion was built. It is the smallest of the venues and provides seating for only 300. The Sacramento Ballet, Sacramento Philharmonic Orchestra and the Sacramento Opera perform at the Community Center Theatre.

Professional theatre is represented in Sacramento by a number of companies. California Musical Theatre and its Summer stock theatre, Music Circus, lure many directors, performers, and artists from New York to Los Angeles to work alongside a large local staff for their productions at the Wells Fargo Pavilion.

During the fall, winter and spring seasons Broadway Sacramento brings bus and truck tours to the Convention Center Theatre. The Sacramento Theatre Company provides non-musical productions as an Equity House Theatre, performing in the McClatchy Main stage. At the B Street Theatre, smaller and more intimate professional productions are performed as well as a children's theatre that will soon be opening a larger theatre complex in the heart of midtown in 2014. The Sacramento area has one of the largest collections of community theatres in California. Some of these include the Thistle Dew Dessert Theatre and Playwrights Workshop, 24th Street Theatre, Davis Musical Thatre Co., El Dorado Musical Theatre, Runaway Stage Productions, River City Theatre Company, Flying Monkey Productions, The Actor's Theatre, KOLT Run Productions, Kookaburra Productions, Big Idea Theatre, Celebration Arts, Lambda Player, Light Opera Theatre of Sacramento, Synergy Stage and the historic Eagle Theatre.

Museums

Sacramento has several major museums. The Crocker Art Museum, the oldest public art museum west of the Mississippi River, is one of the finest. On July 26, 2007, the Museum broke ground for an expansion that more than tripled the Museum's floor space. The modern architecture is very different from the Museum's original Victorian style building. Construction was completed in 2010.

Also of interest is the Governor's Mansion State Historic Park, a large Victorian Mansion that was home to 13 of California's Governors. The Leland Stanford Mansion State Historic Park, which was completely restored in 2006, serves as the State's official address for diplomatic and business receptions. Guided public tours are available. The California Museum for History, Women, and the Arts, home of the California Hall of Fame, is a cultural destination dedicated to telling the rich history of California and it is unique.

Nearby Dining Options

Taro's By Mikuni
Cuisine: Asian
1735 Arden Way, Sacramento, CA 95815
(916)-564-2114

Cheesecake Factory
Cuisine: American
1771 Arden Way, Sacramento, CA 95815
(916)-567-0606

Elephant Bar
Cuisine: European
1500 Arden Way, Sacramento, CA 95815
(916)-564-2526

Seasons 52
Cuisine: Vegetarian
1689 Arden Way, Sacramento, CA 95815
(916) 692-0089

The Green Boheme
Cuisine: American
1825 Del Paso Blvd., Sacramento, CA 95815
(916) 920-4278

DENVER, COLORADO

Denver is the capital and largest city of Colorado. Known as "The Mile-High City", Denver sits at an altitude of 1,600 meters above sea level and lies where the Great Plains give way to the Rocky Mountains. Denver is a large city and one of the fastest growing in the United States.

Denver is a bustling city of more than 600,000 people supporting a fast-growing metropolitan area of nearly 3 million people. The city embraces its cowboy and mining past but also looks toward the future with a vibrant arts and performing arts scene, dozens of great outdoor festivals, and distinct neighborhoods each offering a unique experience. There is everything a cosmopolitan city has to offer including a spectacular view of and easy access to the beautiful Rocky Mountains, which are only 12 miles west of town.

Sights and Culture

As of 2006, Denver had over 200 parks, from small mini-parks all over the city to the giant 1.27 km^2 City Park. Denver also has 29 recreation centers providing places and programming for resident's recreation and relaxation.

In addition to the parks within Denver itself, the city acquired land for mountain parks starting in the 1911s. Over the years, Denver has acquired, built and maintained approximately 57 km^2 of mountain parks, including Red Rocks Park, which is known for its scenery and musical history revolving around the unique Red Rocks Amphitheatre. City parks are important places for both Denverites and visitors, inciting controversy with every change. Denver continues to grow its park system with the development of many new parks along the Platte River through the city, and with Central Park and Bluff Lake Nature Center in the Stapleton neighborhood redevelopment. All of these parks are important gathering places for residents and allow what was once a dry plain to be lush, active, and green. Denver is also home to a large network of public community gardens, most of which are managed by Denver Urban Gardens, a non-profit organization.

Denver is home to many nationally recognized museums, including a new wing for the Denver Art Museum by world-renowned architect Daniel Libeskind, the second largest Performing arts center in the nation after Lincoln Center in New York City and bustling neighborhoods such as LoDo, filled with art galleries, restaurants, bars and clubs. Denver's neighborhoods also continue their influx of diverse people and businesses while the city's cultural institutions grow and prosper. The city acquired the estate of abstract expressionist painter Clyfford Still in 2004 and plans to build a museum to exhibit his works near the Denver Art Museum by 2010. The Denver Museum of Nature and Science currently has an aquamarine specimen valued at over one million dollars, as well as specimens of the state mineral, rhodochrosite. Every September the Colorado Convention Center at 451 E. 58th Avenue hosts a gem and mineral show.

While Denver may not be as recognized for historical musical prominence as some other American cities, it still manages to have a very active pop, jazz, jam, folk, and classical music scene, which has nurtured several artists and genres to regional, national, and even international attention. Of particular note is Denver's importance in the folk scene of the 1960s and 1970s. Well-known folk artists such as Bob Dylan, Judy Collins and John Denver lived in Denver at various points during this time, and performed at local clubs.

Denver has many beautiful parks that are full of colorful gardens, meandering paths, crystal clear lakes, abundant wildlife and recreation opportunities. The city has a rich pioneer history, and there are plenty of museums where you can learn all about it. It's also a very environmentally conscious city, with one of the nation's first municipal "Green Fleets", public transit vehicles using hybrid and alternative fuel and a city tree-planting initiative.

There are a number of shopping areas in Denver. The 16th Street Mall runs the near entire length of 16th St in downtown Denver. It is home to a number of chain stores, as well as novelty shops. It is dominated by the Denver Pavilions, an "urban mall," on the southeast end of the street. The Cherry Creek Shopping District sits southeast of downtown Denver, and hosts some of the most expensive stores in the metropolitan area. The Cherry Creek Shopping Mall is the epicenter of this district. LoDo (Lower Downtown) is immediately west of the Financial District of Denver and is connected directly to Larimer Square. Like Larimer, it is home to rich old architecture (as well as a few modern pieces). It is anchored by the Tattered Cover and hosts a ton of shops, mostly in fashion, furniture, and big chains. Larimer Square offers some of the best shopping districts in the city and was one of the first urban shopping concepts, dating back to the 1960's. The area is full of all kinds of stuff from clothing to furniture. Colfax Avenue and Capitol Hill offer some of the most eclectic retailers.

Dining

Rioja
Cuisine: Mediterranean
1431 Larimer St., Denver, CO 80202
(303)-820-2282

Sushi Sasa
Cuisine: Japanese
2401 15th St., Denver, CO 80202
(303)-433-7272

Elway's
Cuisine: American
1881 Curtis St., Denver, CO 80202
Phone number (303) 312-3107

Sam's #3
Cuisine: Southwestern
1500 Curtis St., Denver, CO 80202
(303)-534-1927

Osteria Marco
Cuisine: Italian
1453 Larimer St., Denver, CO 80202
(303) 534-5855

Vesta Dipping Grill
Cuisine: International
1822 Blake St., Denver, CO 80202
(303) 296-1970


Main Street, U.S.A.
ATTRACTIONS
DISNEY DINING
Adventureland
ATTRACTIONS
DISNEY DINING
New Orleans Square
ATTRACTIONS
DISNEY DINING
Critter Country
ATTRACTIONS
DISNEY DINING
Frontierland
ATTRACTIONS
DISNEY DINING
Fantasyland
ATTRACTIONS
DISNEY DINING
Hamburgers, pizza and salads
Mickey's Toontown
44 Disneyland Railroad
45 Goofy's Playhouse
46 Donald's Boat
47 Gadget's Go Coaster presented by Sparkle®.
49 Mickey's House and Meet Mickey
50 Minnie's House
51 Roger Rabbit's Car Toon Spin
DISNEY DINING
V Toontown Dining Hot dogs, salads, sandwiches, pizza and ice cream treats.
Tomorrowland
ATTRACTIONS
52 Finding Nemo Submarine Voyage
53 Disneyland Monorail
54 Autopia
55 Disneyland Railroad
56 Innoventions With experiences presented by Honda, HP, Microsoft, SCE, Siemens, Taylor Morrison, Xbox and Yamaha Music.
57 Space Mountain
58 Captain EO
59 Starcade
60 Star Tours–The Adventures Continue
61 Astro Orbitor
62 Buzz Lightyear Astro Blasters
DISNEY DINING
W Tomorrowland Terrace Breakfast, sandwiches, burgers, salads, desserts and drinks
X The Spirit of Refreshment hosted by Coca-Cola®.
Y Redd Rockett's Pizza Port Pizza, pasta and salads
Critter Country
New Orleans Square
Frontierland
Adventureland
Fantasyland
Tomorrowland
Main Street, U.S.A.
Mickey's Toontown
N
CALIFORNIA
Restrooms
First Aid
ATM Locations
Pay Phones
Baby Care Center
Locker Rentals
Wheelchair Rentals
Height Requirement
Smoking Area
Parade Route


SOUTH
COAST
PLAZA

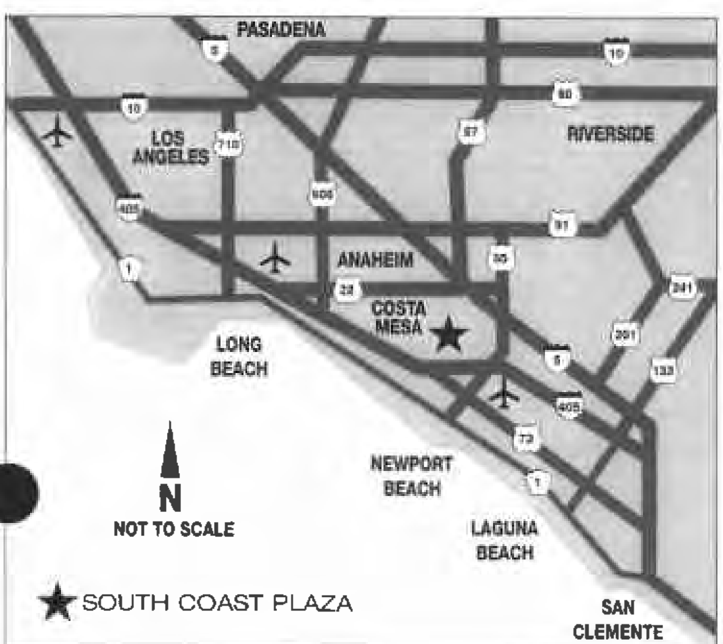
SOUTH COAST PLAZA SERVICES

MONEY EXCHANGE
For your convenience, Travelex Worldwide Money foreign exchange converts foreign currency into U.S. dollars at current posted rates and buys or converts traveler's checks. Located on South Coast Plaza's first level, near Carousel Court.

VIP PASSPORT
Out-of-town visitors receive a South Coast Plaza VIP Savings Passport (with appropriate ID) with special benefits and discounts at over 160 stores and restaurants. Available at all South Coast Plaza Concierge locations.

CONCIERGE
As a helpful assist, gift certificates, package check, store information and referrals, restaurant and theater reservations, hotel shuttle, Orange County attraction information, complimentary strollers and wheelchairs, computerized gift search, tourism assistance, lost and found and foreign language assistance are available.

VALET PARKING
- Bear Street between Macy's and Macy's Men's Store
- Sunflower Avenue in the north parking structure, by Nordstrom
- The Capital Grille/Seasons 52 restaurants, off Bristol Street
- Claim Jumper restaurant, off Bristol Street, near Sears (Seasonal)



SOUTH COAST PLAZA AREA MAP

The Bridge of Gardens

The Bridge of Gardens crosses Bear Street, offering a spectacular view as it connects the two sides of South Coast Plaza.

ALPHABETICAL LISTING

Store	Section/Level	Phone

A

[illegible]

B

[illegible]

C

[illegible]

Store	Section/Level	Phone

[illegible]

D

[illegible]

E

[illegible]

F

[illegible]

Store	Section/Level	Phone

G

[illegible]

H

[illegible]

I

[illegible]

J

[illegible]

K

[illegible]

L

[illegible]

ALPHABETICAL LISTING

Store	Section/Level	Phone
M		
M•A•C	F-1	714.751.2142
N		
O		
P		
Q		
R		
S		
T		
U		
V		
W		
Y		
Z		

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San Joaquin Corridor (73) at Bear Street

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