ADVANCED ENERGY ECONOMY

THIS IS ADVANCED ENERGY

52 Technologies That Are Powering the U.S. Economy, Modernizing Our Energy System, and Lowering Costs for Consumers

ADVANCED ENERGY ECONOMY
the business voice of advanced energy

ABOUT ADVANCED ENERGY ECONOMY

Advanced Energy Economy is a national association of businesses that are making the energy we use secure, clean, and affordable. Advanced energy encompasses a broad range of products and services that constitute the best available technologies for meeting energy needs today and tomorrow. AEE's mission is to transform public policy to enable rapid growth of advanced energy businesses. AEE and its State and Regional Partner organizations are active in 26 states across the country, representing more than 1,000 companies and organizations in the advanced energy industry. Visit AEE online at www.aee.net.

Advanced Energy Economy
the business voice of advanced energy

LEADERSHIP COUNCIL

AES we are the energy

CLEAResult

Competitive Power Ventures, Inc.

E4 THE FUTURE

ENERNOC

enphase ENERGY

First Solar

General Catalyst Partners

GE

GRIDCO SYSTEMS

JM Johns Manville A Berkshire Hathaway Company

Johnson Controls

Landis+Gyr

Microsoft

OPOWER

RECURRENT ENERGY

SunEdison

SUNPOWER

Vestas

VEOLIA

Advanced Energy Economy

the business voice of advanced energy

BUSINESS COUNCIL

Abundant Power – Energy Efficiency Made Simple
Aclara
@lta energy
Ambri
Apex Clean Energy
beneficial state bank
Bergey WindPower
Bloomenergy
Bloomberg
Blue Delta Energy
Bosch
Bridge Energy Group
brightergy
CalCEF
California ISO
Clean Fuel Partners – Renewable Energy Ecosystems
Doosan
EnergySavvy
Enerparc
FirstFuel – Analytics | Building Science | Software
genZe by Mahindra
GoodCents – The power to perform.
Hannon Armstrong
Harvest
Houze – The Zero Energy Home
Ice Energy
intel
Invenergy
Itron
lime
Mintz Levin – Mintz Levin Cohn Ferris Glovsky and Popeo PC
Natel Energy
Navigant
nest
nextility – Energy Friendly
next step living – home energy solutions
OneRoof Energy
OwnEnergy
Pattern
Philips
Regatta Solutions – Smart Power
Retroficiency
res Americas – powering change
RenovateAmerica
Siemens
Silver Spring Networks
Simple energy
Siva power
SmartWatt Energy Inc.
Smart Wires
SolarCity
Southern Current
spruce
stem
Sullivan & Worcester
SunConnect
Sungevity – Generate Positive
Teltech Communications
WaterSmart Software

ADVANCED ENERGY ECONOMY

the business voice of advanced energy

the business voice of advanced energy

INTRODUCTION

Access to affordable, reliable energy is fundamental to modern life and commerce, as consumers and businesses alike depend on uninterrupted power, unrestricted mobility, and constant connectivity. The increased need for reliability, the rising economic cost of blackouts, and the growing threat of cyber attacks can all be addressed through a more flexible and responsive energy system that draws on a variety of resources and gives all participants a role in energy decisions. By updating the aging infrastructure that has supported American prosperity for decades, and by moving toward a more diverse and dynamic energy system, we can also foster competition and innovation that will drive down costs while meeting our evolving energy needs. Fortunately, the technologies needed to build a modern, high-performing, and affordable energy system already exist, and bring with them huge opportunities for businesses to grow in the U.S. and lead global innovations in energy.

This report provides an overview of the technologies available to transform our energy system. Collectively, we call the 52 technologies included in this report "advanced energy," and together they are already modernizing and streamlining the ways we produce, manage, and consume energy.

Many of these technologies are already in use, delivering proven solutions that bring much-needed innovation to the energy sector. Other technologies described here are in an earlier stage of development or just beginning commercial deployment, but they are likewise poised to accelerate the transformation of our energy system as they gain traction in the market. Today and in the future, advanced energy can:

- **Improve the reliability and resilience of our energy system** – Diverse energy solutions enhance our energy security, ensuring ample resources for electricity, heating and cooling, industrial processes, and transportation. Particularly on the electric grid, reliability and resilience involve not just long-term resource security, but also constant management. The technologies in this report provide grid operators with more sophisticated tools and a greater variety of resources than ever before, allowing them to manage the grid with more precise control and flexibility, ensuring that the lights stay on every minute of every day.
- **Lower costs for consumers** – Reducing losses and waste across the energy system through more efficient production, delivery, and use of energy saves both energy and money. With average U.S. residential electricity prices at 12.5 cents/kWh in 2014, up almost 40% over the last decade, saving money is a priority.[1] These savings come not only from reductions in consumption of fuel or electricity, but also from avoided or deferred infrastructure needs, which lower capital costs. At the same time, prices for advanced energy technologies are competitive and dropping rapidly with increased deployment and improved performance. In addition, by diversifying our energy mix to include inexpensive and domestically abundant fuels such as natural gas alongside energy technologies that do not require fuel at all, we can hedge exposure to fuel price uncertainty and insulate consumers from volatile commodity markets. Together, these improvements mean lower utility bills and savings at the pump.
- **Empower customers with unprecedented choice and control** – Advances in energy technology have not just changed the supply of electricity. They are also transforming the way businesses and individuals obtain and use energy. From technologies providing on-site energy to tools and technologies that

1.) https://www.eia.gov/electricity/monthly/epm_table_grapher.cfm?t=epmt_5_3 control energy demand and increase energy efficiency to new options for personal mobility and the transport of goods and services, advanced energy is giving consumers and businesses the same choice and control over their energy use that they have come to expect in other sectors of the economy.

- **Increase competition in the energy marketplace** – More choice means more competition, as advanced energy technologies increase the options available to utilities, grid operators, businesses, households, and individuals with regard to energy production, delivery, and consumption. Working together even as they compete in the marketplace, these technologies are already transforming the energy system of yesterday into an increasingly diverse, dynamic, responsive, and flexible system.

Advanced energy is not just a contributor to our energy future; it is an economic engine as well. In 2014, advanced energy was a $200 billion industry in the United States and a $1.3 trillion market globally. The U.S. advanced energy industry is larger than the airline industry and on par with the pharmaceutical industry.[2] Transforming the U.S. energy system with advanced energy also means growth and prosperity.

Overview of "This Is Advanced Energy"

The energy system is not just a collection of power plants and transmission lines, automobiles and gas stations, refineries and pipelines. It is a dynamic and complex assortment of resources, technologies, and services. For the purposes of this report on advanced energy technologies, we have broken the energy system into six main categories:

1. **Electricity Generation** – The power plants, big and small, that generate electricity to reliably light our homes and power our industries. This section includes the growing suite of distributed generation resources that provide on-site energy and give customers unprecedented control over their energy use.
2. **Electricity Delivery & Management** – The poles and wires that deliver our electricity, and the increasingly sophisticated hardware and software used to manage power supply and power quality with greater flexibility and precision.
3. **Building Efficiency** – The tools and technologies to reduce and manage building energy costs and consumption while also improving building performance and comfort.
4. **Water Efficiency** – The technologies and services available to reduce water use, and thereby reduce the amount of energy that goes into extracting, transporting, treating, and disposing of the water we need for domestic use, agriculture, industry, and power generation.
5. **Transportation** – The technologies to efficiently and cheaply power cars, trucks, trains, and boats, including innovations and improvements in traditional vehicles.
6. **Fuel Production & Delivery** – The growing variety of feedstocks, conversion processes, and delivery infrastructure used mainly in our transportation system, but also in some cases used in electricity generation, such as with fuel cells or microturbines.

The pages of this report are filled with technologies that deliver a variety of benefits to our energy system and enable a transformation that will result in reliability, affordability, consumer choice, and innovation across the board. This transformation is well underway in every state across the country as utilities, businesses, and customers embrace the advantages of advanced energy.

2.) http://info.aee.net/aen-2015-market-report

ADVANCED ENERGY ECONOMY
the business voice of advanced energy

ELECTRICITY GENERATION

The U.S. power generation fleet is a dynamic and flexible system comprised of a diverse set of technologies. Advanced energy technologies are already a critical part of this mix, with reliable nuclear plants, increasingly powerful wind turbines, cost-effective solar panels, and highly efficient and flexible natural gas turbines all working to keep the lights on. In 2014, almost all new generating capacity additions were advanced energy, including new natural gas (49%), wind (27%), and solar (20%) installations.[1,2] In the first three quarters of 2015, advanced energy accounted for 95% of capacity additions: 38% natural gas, 43% wind, and 14% solar.[3] Even with advanced energy consistently dominating new power generation additions, none of these technologies has come close to reaching its technical or economic potential, leaving room for significant growth.

Distributed generation (DG), or electricity produced at or near the point where it is used, such as at residential, commercial, industrial, and municipal buildings or facilities, is also growing rapidly. Expansion of DG further diversifies power sources while empowering consumers, driving economic growth and local employment, and bringing increased competition to the electricity market.

While each advanced energy technology provides its own benefits, a key characteristic of these technologies is how they work together, providing greater value than if any one were used in isolation. The result is an increasingly flexible and diverse generation fleet that meets the needs of all electricity consumers.[4] Some of the key benefits of an electricity system powered by advanced energy technologies include:

- **Reliability** – The wide range of advanced energy technologies for electricity generation provides resource diversity for long-term energy security while also contributing to the day-to-day reliability of the grid. The technologies profiled in this section contribute to meeting electricity system needs according to their individual characteristics, variously providing baseload capacity, flexible ramping generation, and ancillary services such as voltage control, frequency control, and automatic generation control (regulation) — often on timescales much faster than conventional generation.[5] This allows variable renewable generation to be integrated into the current electricity system at high levels without sacrificing the high reliability we have come to need and expect (see "The Agile Grid," p.4).
- **Price hedging** – Electricity prices are heavily influenced by fuel prices, which themselves are subject to volatility and uncertainty. Many advanced energy technologies for electricity production do not require any fuel to produce power or use fuels more efficiently, and therefore offer an important hedge against commodity price uncertainty and volatility. Fuel-free generating sources also serve to suppress wholesale prices by pushing out higher-priced generation.
- **Consumer choice and control** – As DG technologies such as fuel cells, solar photovoltaics, combined heat and power, small-scale wind turbines, and microturbines proliferate and drop in price, they are empowering consumers to take control over their energy use and costs and exercise unprecedented consumer choice. Along with energy storage, energy management technologies, and energy efficiency, DG is helping electricity customers to move from passive buyer to engaged market participants.

1.) http://www.eia.gov/todayinenergy/detail.cfm?id=2070 **2.)** http://www.ferc.gov/legal/staff-reports/2014/dec-infrastructure.pdf. Data excludes most distributed generation. **3.)** http://www.ferc.gov/legal/staff-reports/2015/sep-infrastructure.pdf **4.)** http://www.nrel.gov/docs/fy13osti/56324.pdf **5.)** http://www.nrel.gov/docs/fy14osti/60574.pdf

- **Market competition and innovation** – In the 1990s, gas turbine technology was a key driver of increased competition in wholesale electricity markets. Today, an array of advanced energy technologies are boosting competition and sparking innovation in grid operations and customer engagement. These innovations are, in turn, transforming the grid into an increasingly dynamic, competitive, and open marketplace.
- **Falling costs** – Many advanced energy options are already competitive with incumbent technologies, and costs are projected to fall further. Particularly for technologies not subject to fluctuating fuel costs, prices are linked to technology performance and operations and maintenance costs – metrics that consistently improve as deployment ramps up.

The Agile Grid: Integrating Renewable Generation

Large-scale variable resources — particularly wind and solar — present certain challenges to the operation of the bulk power system because their output varies throughout the day and cannot be controlled as readily as other sources. However, an array of existing technologies and operational practices are successfully integrating ever-rising levels of renewable generation. These solutions include ancillary services, demand response (p.34), improved forecasting for wind and solar generation, greater coordination between balancing areas, energy storage (p.28), ramping capabilities from flexible gas turbines (p.9), and grid management technologies such as distribution automation (p.30), synchrophasors (p.27), and flexible alternating current transmission systems (p.24). Thanks to these technologies, grid operators and utilities are already integrating high levels of variable renewable energy while maintaining grid reliability.[6,7] Advances in renewable technologies themselves also contribute to seamless integration. Given appropriate market signals, wind or solar farms with advanced controls are able to provide services such as dynamic voltage regulation, ramp-rate control, frequency or governor response, inertial control, and active power regulation without support from grid-supplied ancillary services.[8,9]

At the same time, new and existing technologies and services are enabling the deployment of ever-higher levels of variable distributed generation (DG) such as distributed solar photovoltaics (p.16). Technologies such as smart inverters and distributed control systems, behind-the-meter energy storage, data analytics (p.39), demand response, advanced distribution management systems (ADMS; p.32), voltage and volt-ampere reactive (VAR) optimization (p.35), distribution automation, and advanced metering infrastructure (p.31) enable increasingly seamless grid integration of these resources while offering customers additional control and, in many cases, cost savings.[10] Moreover, as DG becomes more interactive with the grid in the future, these same integration technologies and strategies will increasingly enable this DG to serve as a capacity resource, defer other grid investments, and provide essential grid services such as voltage control. As DG capacity grows, these increased capabilities will not only ensure that the bulk power system is able to see and adjust to load changes from behind-the-meter generation, but also allow distributed energy resources to resolve power quality issues at the edge of the grid.[11]

6.) http://info.aee.net/integrating-renewable-energy-into-the-electricity-grid **7.)** http://synapse-energy.com/sites/default/files/A-Solved-Problem-15-088.pdf **8.)** http://ieeexplore.ieee.org/xpl/login.jsp?reload=true&tp=&arnumber=5589787&url=http%3A%2F%2Fieeexplore.ieee.org%2Fxpls%2Fabs_all.jsp%3Farnumber%3D5589787 **9.)** http://www.firstsolar.com/en/Technologies-and-Capabilities/Grid-Integration/Documents/Grid%20Integration%20White%20Paper.aspx?dl=1 **10.)** https://www1.eere.energy.gov/solar/pdfs/segis-es_concept_paper.pdf **11.)** http://energy.gov/sites/prod/files/2014/01/f7/47927_chapter6.pdf

Anaerobic Digestion

Anaerobic digestion (AD) is a process by which organic materials, such as livestock manure, food scraps, and municipal or industrial wastewater, are broken down by microorganisms in the absence of oxygen. The product of AD is biogas, a gas mixture comprised primarily of methane and carbon dioxide. AD is one of several options for converting organic matter into useful energy. Different digester types can be used, from simple covered lagoons at animal farms to more sophisticated above-ground steel or concrete tanks. Today, most biogas is burned to generate electricity on-site, but it can also be purified and made into a pipeline-quality substitute for natural gas, including compressed natural gas (CNG) for vehicles (p.67).[12] Fats, oils, and grease can be added to manure or wastewater (co-digestion) to enhance energy production. AD is often used in conjunction with combined heat and power (CHP, p.7) for efficient electricity and heat generation, such as on dairy farms and at wastewater treatment plants.

In the United States, AD is most commonly used at municipal wastewater treatment facilities but is also found on farms, at industrial sites (e.g., food and beverage processing plants), and other locations. As of early 2015, there were over 240 anaerobic digesters operating at livestock facilities across the country, with much potential remaining for expanding the use of AD on commercial farms.[13] A third-generation swine farm in Ashley, Ohio, uses an anaerobic digester installed by Quasar Energy Group to produce electricity, heat, and compressed natural gas (CNG) for on-site use, with some electricity also being sold to the grid.[14] Interest in using AD for food waste is also on the rise, especially as states look to reduce the amount of municipal waste going to landfills. For example, in Orlando, Florida, food waste sourced primarily from the Walt Disney World Resort is fed through an anaerobic digester owned and operated by Harvest Power, producing enough electricity to meet the needs of 16,000 homes.[15]

AD facilities improve waste management while also producing fuel for electricity or other uses and providing new revenue streams. For example, many farmers who deploy AD are able to reduce manure odors while meeting their electricity and heating demands, avoiding the need to purchase electricity or fuels. In addition, the residual biosolids from AD make excellent fertilizer, which can be used onsite or sold. AD can also improve water quality by preventing disease-causing bacteria from entering the groundwater.[16] Use of AD can make wastewater treatment facilities energy neutral or even energy positive, translating to huge cost savings for municipalities: While wastewater treatment accounts for just 0.8% of national electricity use, water treatment can amount to about 35% of total energy spending for municipal governments.[17] Municipalities also benefit from reduced pipe-clogging fats, oils, and grease in their waste streams.

12.) http://www.epa.gov/agstar/anaerobic/index.html **13.)** http://www.epa.gov/climatechange/Downloads/Biogas-Roadmap.pdf **14.)** http://www.epa.gov/sites/production/files/2014-12/documents/ringler_farms_alex_ringler.pdf **15.)** http://www.harvestpower.com/clean-energy/ **16.)** http://www.epa.gov/agstar/documents/digester_status_report2010.pdf **17.)** http://www.epa.gov/region9/organics/ad/epa-600-R-14-240-food-waste-to-energy.pdf

Biomass Power

Power generation from biomass (organic matter) covers a range of options. The most common technology is direct combustion, in which solid biomass is burned in a boiler to generate high-pressure steam that turns a steam turbine generator. Biomass resources used for this technology include logging and agricultural residues, forest product residues (e.g., bark, sawdust), agricultural field crop residues, and dedicated energy crops. Biomass co-firing is a similar technology in which biomass is burned along with fossil fuels, typically coal, in the same unit. Plants built with this capability can usually burn any mixture of biomass and coal, while retrofitted coal plants can co-fire up to about 2% biomass without major modifications, or up to about 15% if equipped with a separate biomass handling and feed system.[18] Wood chips are the most common fuel for co-firing, but torrefied biomass is gaining attention.[19] As an alternative to co-firing, old coal-fired power plants can be fully converted (repowered) to burn biomass. Gasification (p.21) is an alternative to direct combustion whereby solid biomass is converted into a synthesis gas that can be co-fired with coal or used in a gas turbine.

Electricity generated from wood and wood-derived fuels constituted approximately 6% of electricity from non-hydro renewable sources in the United States in 2014, or about 0.4% of total net electricity generation.[20] Biomass is used to generate electricity in 47 states, such as at the 75 MW Burgess BioPower facility in New Hampshire, which produces electricity from woody biomass and sells the power under a 20-year power purchase agreement to Public Service of New Hampshire.[21,22] Biomass is often deployed as combined heat and power (CHP, p.7), and many plants make use of agricultural byproducts, such as Koda Energy, a 23 MW CHP facility in Minnesota fueled, in part, by waste oat hulls from General Mills cereal production.[23] Biomass power facilities can also be co-located with biofuel production facilities, as at Abengoa's cellulosic ethanol plant in Hugoton, Kansas, which began commercial operation in 2014. The plant generates 21 MW of electricity using biomass residues from ethanol production to power the facility and supply electricity to the local community.[24]

Biomass power provides reliable baseload electricity essential for grid reliability. At the same time, the production and transport of biomass feedstocks drive economic activity, particularly in rural areas where it can be an important source of employment. The Abengoa plant in Kansas is expected to generate $17 million annually in revenue for local farmers from feedstock purchases. In 2014, the market for new biomass power installations generated nearly $900 million in revenue — a figure that does not include economic activity associated with existing facilities and their feedstock supply chains.[25] The consumption of biomass feedstock can also improve waste management and land management by making use of otherwise discarded byproducts from logging and agriculture, and by removing fuel buildup on the forest floor, thereby reducing wildfire risk.

18.) http://www.irena.org/DocumentDownloads/Publications/IRENA-ETSAP%20Tech%20Brief%20E21%20Biomass%20Co-firing.pdf **19.)** Torrefied biomass is produced by heating biomass to reduce its moisture content and give it physical properties similar to coal (http://biomassmagazine.com/articles/5750/glorified-torrefied-cofired). **20.)** http://www.eia.gov/totalenergy/data/monthly/pdf/sec7_6.pdf **21.)** http://www.eia.gov/electricity/annual/html/epa_03_18.html **22.)** http://catecapital.com/Home/RenewableEnergy **23.)** http://www.kodaenergy.com/about-us/facts **24.)** http://biomassmagazine.com/articles/11068/abengoa-celebrates-grand-opening-of-cellulosic-ethanol-plant **25.)** http://info.aee.net/aen-2015-market-report

Combined Heat and Power

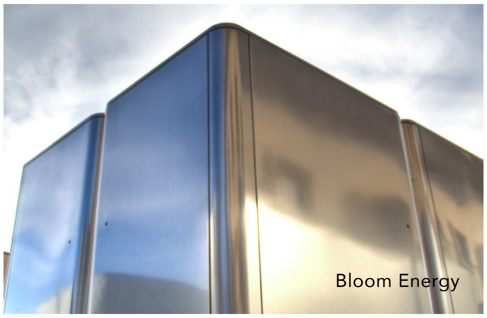
Combined Heat and Power (CHP), also known as cogeneration, produces electricity and useful heat from the same fuel source in an integrated system. CHP systems recover exhaust or waste heat from electricity generation for use in industrial processes, space heating, and water heating. CHP technology achieves greater levels of overall efficiency than using separate thermal and power systems. Any fuel type can be used, including fossil fuels and renewable fuels. Because thermal energy (steam, hot water) is more difficult to transport than electricity, CHP systems are typically installed at sites with large, steady thermal loads, such as industrial facilities, college campuses, hospitals, and military bases. CHP systems can also power district energy plants, which produce steam, hot water, and/or chilled water at central plants, then distribute the steam or water to multiple buildings through a network of insulated pipes generally located underground. Combined cooling, heating, and power (CCHP) is a variation of CHP often deployed in hot climates, which uses the waste heat to drive a cooling system (via an absorption chiller) in addition to generating heat and power. CHP is closely related to industrial waste energy recovery (p.48), where industrial waste heat or other energy that is normally lost is captured to produce electricity or useful thermal energy in industrial processes.

The United States has benefited from CHP for over a century, with a CHP district heating system operating in New York City since 1882. At 83 GW nationally, CHP currently makes up about 8% of the country's generation capacity, leaving ample opportunities for increased deployment.[26] Hospitals and college campuses are good candidates because CHP systems can continue to generate power during grid outages. During Hurricane Sandy, several CHP systems in New York, New Jersey, and elsewhere continued to provide reliable electricity and heat for several days while the grid around them was offline.[27] In Wisconsin, Gundersen Health System's Onalaska campus became the first "energy independent" hospital in the country in 2014 by installing a CHP system that uses landfill gas (p.12) from a local landfill.[28] Similarly, the University of Texas at Austin, has relied on CHP and district energy systems for 100% of its power, heating, and cooling needs for its campus since 1929. Moreover, UT Austin recently reduced its energy consumption to 1977 levels by expanding and improving these systems for greater efficiency.[29] District Energy systems can serve much more than a college campus — a natural gas-fired CHP facility run by Veolia uses a 26 mile pipe network to provide heat for much of Boston and Cambridge.[30]

In the United States, average power plant electrical efficiency is about 34%, meaning that roughly two-thirds of the energy content of the fuel is wasted. While best-in-class power plants have efficiencies of about 50% to 55%, CHP plants can typically achieve overall fuel efficiencies (electricity plus heat) of 75% to 85%, and sometimes even higher.[31] Higher efficiency translates to cost savings. A $3.5 million initial investment is expected to save Gundersen Health System approximately $400,000 in energy costs annually while providing the county with $200,000 in annual revenue, and UT Austin saves an estimated $10 million annually relative to energy purchased from the grid.[32,33]

26.) http://info.aee.net/aen-2015-market-report **27.)** http://www.forbes.com/sites/williampentland/2012/10/31/where-the-lights-stayed-on-during-hurricane-sandy/ **28.)** http://www.gundersenenvision.org/energy-conservation/combined-heat-and-power **29.)** http://www.districtenergy.org/assets/University-of-Texas-at-Austin-Case-StudyFINAL9.4.2.pdf **30.)** http://www.veolianorthamerica.com/sites/g/files/dvc596/f/assets/documents/2015/07/Veolia-Kendall-Station-brochure-and-CHP-graphics.pdf **31.)** http://www.c2es.org/technology/factsheet/CogenerationCHP **32.)** http://www.midwestchptap.org/profiles/ProjectProfiles/GundersenLutheran.pdf **33.)** http://www.districtenergy.org/assets/pdfs/CHP_Case_Studies/UTAustin.pdf

Fuel Cells


Bloom Energy

A fuel cell generates electricity via an electrochemical reaction, converting the chemical energy in fuel directly into electricity without combustion. Much like a battery, a fuel cell consists of three parts: an electrolyte, an anode, and a cathode. Unlike a battery, in a fuel cell hydrogen and oxygen react across the electrolyte to produce a continuous supply of electricity. Most fuel cells utilize natural gas or hydrogen as fuel (see p.68), but landfill gas (p.12) and biogas from anaerobic digestion (p.5) can also be used; for transportation or portable applications, methanol, ethanol, and even gasoline and diesel can be used. Fuel cell power plants are considered a form of distributed generation because they are small compared to traditional central generating stations, ranging from a few kilowatts for residential applications to tens of MW for larger industrial or grid-sited applications. With net electrical efficiencies of 60% or higher, fuel cells are more efficient than comparably sized onsite diesel or natural gas internal combustion engines.

Fuel cells are currently used to provide reliable, efficient onsite power (and thermal energy if used with combined heat and power) for many different industries, including computing and software, media, construction, food and beverage processing, grocery stores, hotels, warehouses, and distribution centers. They can also be placed on a utility's distribution system to provide power and ancillary services to the grid. Walmart has installed over 12 MW of Bloom Energy fuel cell systems across more than 40 retail stores and distribution centers around the country, while Delmarva Power has installed fuel cell systems totaling 30 MW to meet the needs of utility customers in Delaware.[34] The technology is mature but still at an early stage of commercialization, with high growth potential; Navigant Research projects that the global market for stationary fuel cells will increase from $1.4 billion in 2013 to $40 billion in 2022.[35] U.S. fuel cell capacity totaled nearly 250 MW in late 2015, with California, Connecticut, and New York leading in total installations.[36]

Because they are quiet and produce almost no emissions, fuel cells are well suited for onsite generation. In many states, fuel cell solutions are already cost competitive with power from the grid, with Bloom Energy fuel cells producing electricity at 8-10 cents per kWh.[37] Costs are expected to fall as the market grows and manufacturing scales up. Fuel cells are an attractive option for onsite generation at facilities that place a high value on 100% reliable electricity. Microsoft is using anaerobic digestion to create fuel to power fuel cells at a data center in Wyoming; Apple is using fuel cells in combination with solar power to support its operations in North Carolina; and eBay, Inc. is using Bloom Energy fuel cells to power its data center in Utah.[38, 39, 40] Fuel cells provide these companies not only with the reliability they need, but also choice of energy sources. In addition, fuel cells strategically sited on a utility network can provide grid support, delivering important services to improve reliability or defer costly grid upgrades. Delmarva Power in Delaware and Connecticut Power & Light and NRG Energy in Connecticut are all adding fuel cell capacity to deliver reliable power to their grid networks.[41]

34.) http://energy.gov/sites/prod/files/2014/11/f19/fcto_2013_market_report.pdf. **35.)** http://www.navigantresearch.com/research/stationary-fuel-cells **36.)** http://hydrogen.pnl.gov/hydrogen-data/hydrogen-consumption **37.)** http://www.fuelcells.org/pdfs/2013BusinessCaseforFuelCells.pdf **38.)** http://inr.synapticdigital.com/siemens/CheyenneDataCenter/ **39.)** https://gigaom.com/2013/11/18/apple-solar-farm-fuel-cell-farms-exclusive-photos-investigative-report/ **40.)** http://tech.ebay.com/blog-post/introducing-our-salt-lake-city-data-center-advancing-our-commitment-cleaner-greener **41.)** http://www.fuelcells.org/pdfs/2013BusinessCaseforFuelCells.pdf

Gas Turbines


-Siemens

Gas turbine technology is mature and widely used, with innovations driving new improvements in efficiency, performance, and cost. In its most basic configuration, the simple cycle gas turbine (SCGT), air is compressed and mixed with fuel (usually natural gas), then the mixture is burned in a combustor. The resulting hot, pressurized gases expand through the turbine section that drives the compressor and an electric generator. In a combined cycle gas turbine (CCGT) plant, also called a natural gas combined cycle (NGCC) plant, the hot exhaust gases leaving the turbine pass through a heat recovery steam generator, producing steam that is used to generate more electricity with no additional fuel. This process can increase efficiency to 60%, compared to about 40% for SCGTs. Most gas turbine plants in operation use so-called "heavy duty" or "industrial" turbines, with units ranging from about 1 MW to over 300 MW.[42] The other main type of machine, an aeroderivative gas turbine, ranges in size up to about 90 MW. These turbines are more lightweight, compact, and even more efficient.[43] Another class of machines, microturbines, have lower efficiencies than the larger turbines, but are well suited for onsite power and CHP (p.7) due to their compact footprint and smaller size (25 kW to 500 kW).[44]

In 2013, there were 1,725 natural gas-fired plants operating across the United States, such as the 785 MW CCGT Towantic Energy Center in Oxford, Connecticut owned and operated by Competitive Power Ventures.[45,46] The availability of low-priced natural gas (much of it produced domestically) has increased the utilization rates of existing SCGT and CCGT capacity while also driving investment in new units, such as Invenergy's 584 MW CCGT plant in Rock Falls, Illinois, completed in 2015.[47] As a result, the share of electricity generated from natural gas has increased rapidly in the United States, up to 32% in 2015 (through Q3) compared to 18% in 2004.[48] This electricity is generated by ever-more efficient plants, with GE's recently released H class combined-cycle turbines achieving over 61% net electrical efficiency.[49]

Natural gas-fired generation is an important contributor to electric reliability, with turbine technologies exceling in a range of applications. Rapid startup and ramping capabilities make SCGTs ideal for meeting peak demand and integrating variable renewable generation. Highly efficient CCGTs are primarily used to provide intermediate and baseload power. As the needs of the grid evolve, new gas turbine models are being deployed. For example, the intercooled aeroderivative is well suited to variable renewable integration due to its flat efficiency profile over a wide load range. Smaller industrial turbines, aeroderivative turbines, and microturbines also give commercial and industrial energy consumers additional onsite energy choices. Coupled with inexpensive natural gas, CCGTs in particular are cost-effective new-build options. The levelized cost for CCGTs is estimated at $61-$87/MWh, while that of gas peaking plants is estimated at $179-$230/MWh. For comparison, the levelized cost of coal generation is approximately $66-$151/MWh.[50] With such favorable economics, natural gas accounted for 49% of new generating capacity in 2014, and 55% in the first three quarters of 2015.[51,52]

42.) http://www.epa.gov/chp/documents/catalog_chptech_3.pdf **43.)** http://energy.gov/fe/how-gas-turbine-power-plants-work **44.)** http://www.wbdg.org/resources/microturbines.php **45.)** http://www.eia.gov/electricity/annual/html/epa_04_01.html **46.)** http://www.cpv.com/cpvprojects.html# **47.)** http://www.invenergyllc.com/ProjectsbyCountry/UnitedStates/Nelson.aspx **48.)** http://www.eia.gov/electricity/monthly/epm_table_grapher.cfm?t=epmt_1_1 **49.)** https://powergen.gepower.com/plan-build/products/gas-turbines/9ha-gas-turbine.html **50.)** http://www.lazard.com/PDF/Levelized%20Cost%20of%20Energy%20-%20Version%208.0.pdf **51.)** http://www.ferc.gov/legal/staff-reports/2014/dec-infrastructure.pdf. Data excludes most distributed generation. **52.)** http://www.ferc.gov/legal/staff-reports/2015/sep-infrastructure.pdf

Geothermal Power

Geothermal power taps into the high-temperature hydrothermal resources of the earth to generate electricity. There are three main types of geothermal technologies: dry steam, flash steam, and binary. Dry steam plants withdraw steam directly to drive a turbine. Flash steam, the most common geothermal technology used today, pumps high-temperature geothermal fluids at high pressure into a low-pressure tank, which causes the fluids to vaporize (or "flash") so they can be used to drive a turbine. A binary cycle is a closed-loop process where low-temperature geothermal fluids are used to heat a second fluid with a low boiling point (e.g., refrigerants or propane), which in turn drives a turbine. Binary cycle power plants are expected to dominate future markets because low-temperature resources are more plentiful and generally easier to access.[53] Another technology, enhanced geothermal system (EGS), is still in development but has the potential to unlock more than 100 GW of geothermal power in the United States, enough to meet about 20% of current electricity needs. EGS can be more widely deployed than other geothermal technologies because it does not require the presence of a naturally occurring geothermal fluid. With EGS, deep wells are drilled to reach temperatures sufficient for binary geothermal systems. Fluid is then introduced underground, heated by the surrounding rock, and recovered to drive a binary power plant.[54]

At the end of 2014, there was 3.5 GW of geothermal capacity in the United States, with an additional 1.3 GW under development, mostly in Nevada, California, Oregon, and Utah.[55] With a net operating capacity of 725 MW, enough to power 725,000 homes, The Geysers in California is the world's largest complex of geothermal power plants. Thanks to plants such as this, California generates 6% of its total electricity from geothermal resources.[56] After California, Nevada is the second-largest producer of geothermal power in the country, with a capacity of 566 MW across 22 operating plants.[57]

New geothermal plants have relatively high capital costs, as well as ongoing costs for drilling new wells to maintain output. However, they have no fuel costs and operate at very high capacity factors, making geothermal power an excellent source of baseload electricity. The levelized cost of geothermal production is estimated at approximately $89-$142/MWh, making it competitive with technologies such as coal ($66-$151/MWh) and nuclear ($92-$132/MWh).[58] Depending on local conditions, geothermal can be very cost-effective. For example, Cheno Hot Springs in Alaska has decreased energy costs for the community by 80%, from 37 cents to 7 cents per kWh.[59]

53.) http://energy.gov/eere/geothermal/electricity-generation **54.)** http://energy.gov/sites/prod/files/2015/03/f20/GTO_2014_Annual-web.pdf **55.)** http://geo-energy.org/reports/2015/2015%20Annual%20US%20%20Global%20Geothermal%20Power%20Production%20Report%20Draft%20final.pdf **56.)** http://www.calpine.com/media/Geysers_Factsheet.pdf **57.)** http://energy.gov/sites/prod/files/2015/03/f20/GTO_2014_Annual-web.pdf **58.)** http://www.lazard.com/PDF/Levelized%20Cost%20of%20Energy%20-%20Version%208.0.pdf **59.)** http://energy.gov/sites/prod/files/2015/03/f20/GTO_2014_Annual-web.pdf

Hydroelectric Power

Hydroelectric power plants use turbines and generators to convert the kinetic energy of moving water into electricity. There are three major types of hydroelectric power plants: impoundment, run-of-river (diversion), and pumped storage. An impoundment facility uses a dam to store river water in a reservoir, which it then releases through turbines to generate electricity. The height differential ("hydraulic head") between the reservoir surface and the turbine outlet is what provides the energy for power generation. A run-of-river facility takes advantage of natural elevation changes along a river, diverting a portion of the river flow via pipes or underground conduits to drive turbines and generate power without a dam. Because of this design, the output from run-of-river plants can fluctuate throughout the year, whereas impoundment plants generally have steadier output. Pumped hydro storage is a form of bulk energy storage that generates electricity when demand is high (see p.28). In addition to these three major variants, there is a niche application called in-conduit hydropower, which uses hydro turbines to harness energy from water supply infrastructure such as tunnels, irrigation canals, and pipes.[60]

Hydroelectric power currently constitutes the largest and oldest source of renewable electricity in the United States, producing 51% of renewable electricity and 7% of total electricity from all sources in 2013, not including pumped hydro.[61] This energy comes from over 2,500 hydroelectric facilities in the United States with a total capacity of approximately 78 GW. Although the country's major hydroelectric resource is largely developed, there was a net capacity increase of nearly 1.5 GW from 2005 to 2013, and there is the potential to increase capacity by about 12 GW by adding generation at existing dams that do not currently generate electricity.[62] The Pacific Northwest, California, and the Southeast are particularly rich in hydroelectric power.[63] Southern Company, the largest electricity producer in the country, operates 34 hydroelectric facilities in Alabama and Georgia alone, which generate enough power to meet the needs of over 200,000 customers.[64]

The U.S. hydroelectric power industry currently employs approximately 300,000 workers through project development, manufacturing, and facility operations and maintenance.[65] An estimated $4 billion has been invested over the past four years to repower or upgrade existing plants, develop small projects, and add pumped storage. Hydroelectric power also offers many reliability benefits, providing both baseload power and flexible generation that can respond very rapidly to changes in demand. In addition, hydroelectric plants can provide what is known as a "black start capability," or the ability to resume operation in isolation from the rest of the grid to enable the entire system to come back online, as happened during a blackout in 2003 that affected 50 million people from New York to Michigan.[66]

60.) http://www.hydro.org/tech-and-policy/technology/conduit/ **61.)** http://www.eia.gov/totalenergy/data/annual/index.cfm **62.)** http://energy.gov/sites/prod/files/2015/04/f22/Hydropower-Market-Report-Highlights.pdf **63.)** http://www1.eere.energy.gov/water/pdfs/npd_report.pdf **64.)** http://www.hydro.org/why-hydro/available/hydro-in-the-states/south/ **65.)** http://www.hydro.org/why-hydro/job-creation/ **66.)** http://www.hydro.org/why-hydro/reliable/

Landfill Gas

Waste Management

Landfill gas (LFG) is a form of biogas produced by decomposition of organic waste in landfills. This gas is a roughly 50:50 mixture of methane and carbon dioxide, with smaller amounts of nitrogen and other compounds. LFG is produced naturally in all landfills, and can be captured and used for productive purposes instead of being vented or flared.[67] In order to capture LFG, perforated tubes are inserted into the landfill. With existing landfills, the collection system must be added, but with new landfills the system can be installed as part of normal operations. After being extracted from the landfill using vacuum pumps, the LFG is compressed, dried, cleaned of certain contaminants, and used to power a gas turbine, a gas engine, such as GE's Jenbacher landfill gas engine, or in some cases a boiler or steam turbine. As a rough rule-of-thumb, 1 million tons of municipal solid waste (MSW) in a landfill will produce enough LFG to produce 1 MW of electricity for about 20 years.[68] LFG can also be used in combined heat and power systems (CHP, p.7), or used directly as an industrial process fuel if a suitable site exists near a landfill.[69] With addition purification, LFG can be upgraded to a pipeline-quality substitute for natural gas, including compressed natural gas (CNG) for vehicles (p.67).

Most landfill gas projects are small — from less than 1 MW up to about 20 MW. Exelon's 60 MW Fairless Hills Steam Generating Station in Pennsylvania is one of the largest generators in the country running on LFG, sourcing its fuel from nearby landfills.[70] As of early 2015, there were 645 LFG energy projects across 48 states with a total capacity of 2,066 MW, including over 430 electricity generation projects as well as CHP and direct use projects.[71] However, with approximately 2,400 operating or recently closed landfills in the United States, there are opportunities across the country for increased use of LFG. Taking advantage of just 440 of these landfills would provide an additional 855 MW of capacity, enough to generate electricity to power over 600,000 homes.[72]

LFG is generally used in baseload generating facilities but can be used in more flexible peaking units; both are essential for grid reliability.[73] At the same time, capturing LFG improves landfill management, reduces odor, and eliminates the need to flare or vent the gas.[74] LFG projects also create local jobs while creating an additional revenue stream for the landfill.

67.) http://www.epa.gov/lmop/faq/landfill-gas.html **68.)** https://www.ge-distributedpower.com/solutions-applications/power-generation/landfill-gas **69.)** http://www.epa.gov/lmop/faq/lfg.html **70.)** http://www.exeloncorp.com/PowerPlants/fairlesshills/Pages/profile.aspx **71.)** http://www.epa.gov/lmop/projects-candidates/index.html **72.)** http://www3.epa.gov/lmop/projects-candidates/index.html; http://www.eia.gov/tools/faqs/faq.cfm?id=97&t=3 **73.)** http://www.sciencedirect.com/science/article/pii/S104061901500024X **74.)** http://www.epa.gov/lmop/faq/lfg.html#05

Marine and Hydrokinetic Power

Marine and hydrokinetic power technologies generate electricity from the kinetic energy of moving water, including waves, currents, and tides. Wave energy devices are designed to capture energy from the rising and falling of waves or their forward movement. For example, the relative motion between a buoy at the surface and a fixed tether on the sea floor can be used to drive a generator. Tidal energy can be captured in two ways. First, in places with the right undersea topography, daily currents created by ocean tides can be used to drive underwater turbines. Similar technology can exploit the constant flow of water in rivers or in large-scale ocean currents like the Gulf Stream. Second, in places with large tidal ranges, tidal barrages (dams or barriers) can be built across bays or estuaries to capture energy from the receding tide via turbines as water flows out to sea. Within each category, there are many different technologies in development, particularly for wave energy capture. Proximity to shore, ocean depth, and expected sea conditions are all major considerations for these technologies.[75] Another type of marine energy, called Ocean Thermal Energy Conversion (OTEC), exploits temperature and/or salinity gradients between surface waters and deeper water to drive various power cycles.

Marine and hydrokinetic power is an emerging technology with great potential. Capturing 0.3% of the energy of the Gulf Stream would be enough to supply all of Florida's electricity needs.[76] The Department of Energy estimates that the United States has the potential to develop about 50 GW of tidal power alone.[77] At present, marine projects in the United States are principally for demonstration and testing purposes, but there is substantial interest in the technology. As of March 2015, the Federal Energy Regulatory Commission (FERC) had issued eight preliminary permits for 104 MW of electricity, while four pilot projects had received licenses for over 2 MW of capacity.[78] When completed, the world's first grid-connected tidal project, the Roosevelt Island Tidal Energy (RITE) facility in New York City, will provide 1 MW of electricity.[79]

Although marine and hydrokinetic energy resources are variable, they are very predictable, making grid integration relatively easy. Tides are extremely regular, and even wave conditions can be forecast with reasonable accuracy several days in advance. When complete, the RITE project will generate electricity for about four hours at a time every six hours, following the regular flow of New York's East River.[80] Furthermore, marine and hydrokinetic power generates this reliable electricity at no fuel cost, offering great potential for cost reductions as the technology develops and the industry scales up production. Along with falling costs, increased deployment will create construction, operation, and maintenance jobs that can bring new economic activity to coastal industries such as ports and shipbuilding.

75.) http://www.c2es.org/technology/factsheet/Hydrokinetic **76.)** http://www.ucsusa.org/clean_energy/our-energy-choices/renewable-energy/how-hydrokinetic-energy-works.html **77.)** http://www1.eere.energy.gov/water/pdfs/1023527.pdf **78.)** http://www.ferc.gov/industries/hydropower/gen-info/licensing/hydrokinetics.asp **79.)** http://www.verdantpower.com/rite-project.html **80.)** Ibid.

Large-Scale Nuclear Power

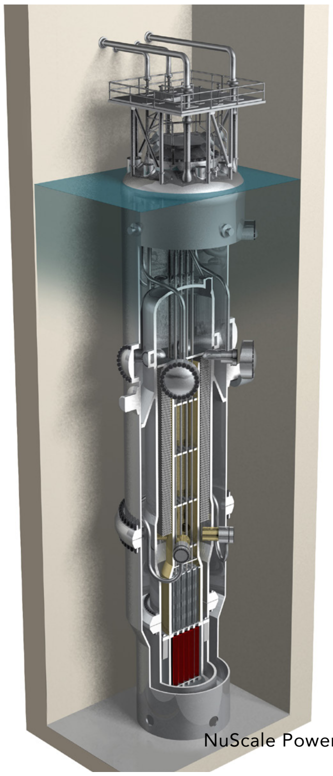
Nuclear power plants in operation today rely on nuclear fission (the splitting of heavy atomic nuclei) to produce electricity. Fission releases heat in the plant's reactor core. This heat is used to generate steam, which then spins a steam turbine attached to an electric generator. Nuclear power plants are large facilities with individual reactors typically sized in the 1 GW range. The three-unit, 4 GW Palo Verde Nuclear Generating Station in Arizona is the country's largest, generating enough power to meet the needs of 4 million homes and supplying electricity to customers of seven utilities across three states.[81] Nuclear power is typically used for baseload generation, as the technology is not easy to start and stop or cycle up and down. Currently, the Pressurized Water Reactor (PWR) and the Boiling Water Reactor (BWR) are the only two types of reactors in operation in the United States.[82] Newer technologies (known as "Generation III" or "III+") offer greater reliability and enhanced safety features, as well as higher efficiency.

Nuclear power is a mature technology, with 99 licensed reactors operating across 30 states totaling 115 GW of capacity and producing about 20% of the country's electricity. The United States remains the world's largest producer of nuclear energy, accounting for more than 30% of global generation. As of 2015, there were five new reactors under construction in the United States in Tennessee, Georgia, and South Carolina: one PWR and four Generation III+ reactors by Westinghouse.[83] In addition to the Westinghouse Gen III+ model currently under construction, the Nuclear Regulatory Commission (NRC) has certified two new designs by General Electric-Hitachi: the Gen III Advanced Boiling Water Reactor (ABWR) (1,350-1,600 MW) and the Gen III+ Economically Simplified Boiling Water Reactor (1,520 MW).[84] The ABWR, which is operational in Japan, is the first and only Gen III reactor in operation.[85]

As a major source of baseload power, nuclear energy helps to maintain resource adequacy and ensure reliable electricity as part of a diverse energy portfolio. The estimated average generating cost (capital, fuel, & operating costs) for existing U.S. nuclear plants is $44/MWh.[86] However, due to high capital costs, the levelized cost of generation by new-build nuclear facilities is generally higher than other conventional baseload power sources, with an estimated levelized cost of $92-$132/MWh, as compared to coal ($66-$151/MWh) and gas combined cycle ($61-$87/MWh).[87] The nuclear power industry currently supports over 100,000 jobs nationally.[88]

81.) http://www.srpnet.com/about/stations/paloverde.aspx **82.)** http://www.nrc.gov/reactors/power.html **83.)** http://www.world-nuclear.org/info/Country-Profiles/Countries-T-Z/USA--Nuclear-Power/ **84.)** http://www.nei.org/Issues-Policy/New-Nuclear-Energy-Facilities/New-Reactor-Designs **85.)** https://nuclear.ge-power.com/build-a-plant.html **86.)** http://www.world-nuclear.org/info/Economic-Aspects/Economics-of-Nuclear-Power/ **87.)** http://www.eia.gov/forecasts/aeo/electricity_generation.cfm **88.)** http://www.nei.org/Issues-Policy/Economics/Cost-Benefits-Analyses

Modular Nuclear Power


NuScale Power, LLC

Small modular reactors (SMRs) are small-footprint nuclear power plants that can be sized between 10 MW and 300 MW. There are numerous SMR plant designs, although SMRs all rely on the same nuclear fission technology used by larger plants. Nuclear fission releases heat in the reactor core that is used to produce steam, which spins a steam turbine attached to an electric generator. Unlike utility-scale plants, which are difficult to site and can take years to construct, SMRs are designed to have many components fabricated and assembled offsite, thus reducing the time and complexity of plant construction and increasing potential plant locations.[89] SMR designs generally have their reactors buried in the ground away from weather hazards, and are often designed to use passive cooling systems that are not vulnerable to power outages, further increasing the safety of the plant.

The basic design for SMRs is similar to the nuclear reactors that have been powering submarines for decades. While only four projects have reached the construction phase worldwide, there are projects under consideration in the United States, such as a potential Tennessee Valley Authority development in Oak Ridge, Tennessee.[90,91] NuScale is engaging with the Nuclear Regulatory Commission (NRC) to put 12 SMRs into operation with a total capacity of 540 MW. The company estimates that its first SMR plant will be online in 2023.[92] In addition, Holtec SMR is in the pre-application process with the NRC to deploy its SMR-160 model, which has an output of 160 MW.[93] General Electric and Hitachi have partnered to commercialize a 311 MW SMR called the Power Reactor Innovative Small Modular, or PRISM, which will utilize nuclear waste as a fuel source.[94]

SMRs could ease congestion and provide grid reliability if strategically sited to meet grid needs. The use of factory fabrication for most major components and the potential for shorter and less complex construction compared to large-scale plants may reduce capital costs relative to large nuclear reactors. The Department of Energy has estimated the levelized cost of electricity (LCOE) from SMRs could eventually be as low as $55/MWh.[95] For comparison, Lazard estimates a LCOE of $92-132/MWh for new large-scale nuclear plants and $66-151/MWh for new coal-fired units, including carbon capture at the upper bound.[96] Financing for large-scale plants has proven a challenge due to the large investments needed (several billion dollars per plant) and the long timeframe (about a decade). SMRs would require smaller investments and have shorter development times, which would reduce investment risk and make financing easier.

89.) http://www.energy.gov/ne/nuclear-reactor-technologies/small-modular-nuclear-reactors **90.)** http://www.iaea.org/NuclearPower/Downloadable/SMR/files/IAEA_SMR_Booklet_2014.pdf **91.)** http://www.tva.com/environment/technology/smr.htm **92.)** http://www.nuscalepower.com/nrcinteraction.aspx
93.) http://www.nrc.gov/reactors/advanced/holtec.html **94.)** http://gehitachiprism.com/what-is-prism/how-prism-works/ **95.)** http://www.energy.gov/sites/prod/files/2014/06/f16/Electricity%20Generating%20Portfolios%20with%20SMRs.pdf **96.)** https://www.lazard.com/media/1777/levelized_cost_of_energy_-_version_80.pdf

Distributed Solar Power

Distributed solar power uses the same photovoltaic (PV) technology as large-scale plants (p.17), but specifically refers to distributed generation (DG), i.e., electricity produced at or near the point where it is used, such as at residential, commercial, industrial, and municipal buildings or facilities. Most distributed systems are roof-mounted, but some are ground-mounted, either in open fields, atop closed landfills, or on canopies at parking facilities. There are several types of solar panels distinguished by the semiconductor material used to convert sunlight into electricity, with crystalline silicon as the preferred choice for space-limited distributed applications due to its high efficiency. The technical potential of residential and commercial rooftop solar is estimated to be nearly 600 GW, enough to produce approximately one quarter of the electricity generated in the United States in 2014.[97]

Distributed solar power has achieved remarkable growth over the past five years, becoming a popular choice for business and residential consumers in every market where it has been readily available. By the middle of 2015, nearly 800,000 homes and businesses had installed over 9 GW of onsite solar capacity, a 12-fold increase since 2009. The industry added 1.2 GW in residential capacity and over 1 GW in non-residential distributed solar PV in 2014, and 1.3 GW of residential and non-residential distributed PV in the first half of 2015.[98,99,100] Drops in total installed system prices are driven by a combination of falling equipment costs, increasing efficiency, growing economies of scale, and declining "soft costs" associated with sales and marketing, permitting, and installation. System prices for residential and commercial PV declined 6% to 8% per year, on average, from 1998 to 2013, and are expected to keep dropping.[101] A 2015 Deutsche Bank report predicts that installed solar prices in the United States will see a further 40% reduction to achieve grid parity in 41 states by 2017, driving installed DG solar capacity to 20-30 GW by the end of 2017.[102]

Distributed, or "rooftop," solar allows consumers to lower their electricity costs and exercise the choice to generate their own electricity. Options such as third-party financing allow customers to lease a PV system or purchase the output under a long-term power purchase agreement (PPA), removing a key obstacle: the up-front cost of the system. Businesses, municipalities, educational institutions and other entities are also taking advantage of cost savings; for example, Verizon has become a leader in onsite solar by partnering with SunPower to install over 20 MW of PV to secure long-term access to affordable energy.[103] Improvements in technology and grid operations are also increasingly enabling distributed solar to contribute positively to the grid (see "The Agile Grid," p.4). For example, companies like Enphase have developed smart-grid compatible (p.31) advanced microinverters that maximize energy production, allow for remote monitoring, and enable the system to respond to changing grid needs.[104]

97.) Based on an average capacity factor for rooftop PV of 23% http://www.lazard.com/PDF/Levelized%20Cost%20of%20Energy%20-%20Version%208.0.pdf; http://www.nrel.gov/docs/fy10osti/45832.pdf **98.)** https://emp.lbl.gov/sites/all/files/lbnl-188238_1.pdf **99.)** All figures are reported in GWDC; converting to GWAC reduces the capacity figure by about 20%. http://www.seia.org/research-resources/solar-market-insight-report-2014-q4 **100.)** https://www.seia.org/research-resources/solar-market-insight-report-2015-q1 ; http://www.seia.org/research-resources/solar-industry-data **101.)** http://www.nrel.gov/docs/fy14osti/62558.pdf **102.)** https://www.db.com/cr/en/docs/solar_report_full_length.pdf **103.)** http://www.verizon.com/about/news/verizon-plans-major-expansion-its-site-green-energy-program/ **104.)** https://enphase.com/en-us/products-and-services

Large-Scale Solar Photovoltaics

Solar photovoltaic (PV) power systems convert sunlight directly into electricity. PV modules (panels) produce direct current (DC), which is converted to grid-compatible alternating current (AC) through an inverter. Utility-scale PV installations are typically connected to the transmission grid, and range from about 1 MW to several hundred MW. Since PV can make use of diffuse or direct sunlight it can be installed anywhere. The majority of large solar farms use ground-mounted flat-plate PV panels, which can be installed at a fixed-tilt or can use single-axis or dual-axis tracking systems that follow the sun. Tracking increases electricity production over the course of the day, but also increases costs. Concentrating PV (CPV) is a variation on flat plate PV that uses arrays of lenses mounted in front of small PV cells to concentrate the sunlight reaching the cells. CPV requires dual-axis tracking and is more efficient, but more expensive, than regular flat plate PV, so it is best suited to very sunny locations.

Installed large-scale PV capacity in the United States reached over 11 GW by July of 2015, with a record 3.9 GW installed in 2014 alone.[105,106] New facilities include two of the world's largest solar projects, the Topaz and Desert Sunlight Solar Farms by First Solar in California, each with a capacity of 550 MW, enough to power approximately 160,000 homes.[107] Recurrent Energy began installing a 150 MW plant in Texas, which will be that state's largest solar plant.[108] While dry and sunny states are ideal for solar power, utility-scale installations are widely deployed in markets across the country, with North Carolina ranking second behind California for utility-scale installations in 2014.[109] When completed in 2016, the 156 MW Comanche Solar project in Pueblo, Colorado, built by SunEdison and managed by Renewable Energy Systems (RES) Americas Inc., will be the largest solar project east of the Rocky Mountains.[110]

Large-scale solar power represents a significant and growing source of domestic economic activity. Installations brought online in 2014 alone represent a total investment value of about $8 billion, boosting local businesses and tax revenue. At a broader level, job creation in the solar industry has expanded at or near 20% annually since 2010, reaching nearly 174,000 workers in 2014 and far outpacing job growth in the U.S. economy.[111] Prices of power purchase agreements (PPAs) for solar-generated electricity have fallen by more than 60% in the past six years, from an average of $175/MWh in 2008 to $50-$70/MWh in 2014, making electricity from utility-scale projects broadly competitive with other new sources of generation.[112] In 2015, Austin Energy received bids for over 1 GW of solar capacity below $40/MWh.[113] Because solar generation is not subject to fuel costs and has very low operating and maintenance costs, prices will continue to fall as deployment increases and the technology advances. Already, the proliferation of solar energy has developed alongside a number of tools and techniques that enable utilities and grid operators to integrate high levels of solar generation without compromising reliability (see "The Agile Grid," p.4).

105.) http://www.greentechmedia.com/articles/read/installing-1393-mw-of-pv-in-q2-2015-us-solar-market-surpasses-20-gw **106.)** http://www.seia.org/news/us-installs-62-gw-solar-pv-2014-30-over-2013 **107.)** http://www.firstsolar.com/en/about-us/projects **108.)** http://recurrentenergy.com/blog/recurrent-energy-wins-150mw-with-austin-energy/ **109.)** http://cleantechnica.com/2015/03/10/us-pv-installations-reach-6-gw-2014-gtm/ **110.)** http://investors.sunedison.com/phoenix.zhtml?c=106680&p=irol-newsArticle&ID=2080886 **111.)** This data is for the entire solar industry; http://www.thesolarfoundation.org/factsheet-national-solar-jobs-census-2014/ **112.)** http://energy.gov/sites/prod/files/2015/02/f19/DOE_LPO_Utility-Scale_PV_Solar_Markets_February2015.pdf **113.)** http://www.greentechmedia.com/articles/read/cheapest-solar-ever-austin-energy-gets-1.2-gigawatts-of-solar-bids-for-less?utm_source=feedburner&utm_medium=-feed&utm_campaign=Feed%3A+GreentechMedia+%28Greentech+Media%29

Solar Thermal Electric (STE)


Solana Solar Platform
(Proprietary technology of Abengoa Solar, S.A.)

Solar Thermal Electric (STE), often called concentrating solar power (CSP), uses mirrors or lenses to concentrate sunlight, generating temperatures high enough to produce steam and drive steam turbines. There are three configurations of STE systems in commercial use: power towers focus sunlight at a point, while parabolic troughs and Fresnel reflectors focus sunlight onto linear receiver tubes.[114] Parabolic troughs and power towers are the most commonly used STE technologies today, and along with linear Fresnel configurations are deployed in large-scale projects that generally range in capacity from tens to hundreds of MW. STE plants can incorporate thermal energy storage, typically using molten salt, allowing them to generate electricity when it is needed even if the sun is not shining.[115] A number of commercial and demonstration projects have also been built to integrate STE technology into natural gas and coal power plants, reducing the fuel inputs needed for the same energy output.

Large-scale STE projects were first installed in the United States starting in the 1980s, and deployments have accelerated in the past few years. Installed capacity of STE in the United States reached 1.7 GW by the end of 2014, nearly half of which (0.8 GW) was added in 2014 alone.[116,117] STE is best suited to arid areas with strong solar resources, and there are projects installed or under development in Arizona, California, Florida, Hawaii, Nevada, and Utah.[118] For example, the 280 MW dispatchable Solana STE project by Abengoa in Arizona uses a parabolic trough configuration and molten-salt thermal storage, producing enough electricity to power approximately 70,000 homes and providing up to 6 hours of storage.[119] Utilities are also making use of STE at gas and coal units. At its Martin gas plant, Florida Power and Light (FPL) has an integrated trough solar field that can generate 70 MW of solar electricity, and Xcel's Cameo project in Colorado uses a trough field alongside a coal-fueled steam turbine.[120]

While STE is a proven technology, it is currently more expensive on an energy basis than other conventional and advanced energy technologies, but costs are expected to continue to drop as deployment ramps up. Adding thermal energy storage raises capital costs, but also increases a project's firmness and flexibility, allowing the project to provide essential grid needs while also providing dispatchable energy that helps integrate variable renewable generation. STE plants can also be backed up with natural gas, biofuels, or even hydrogen to cover extended periods of cloudy weather. The flexibility of STE plants allows them to be designed either as a peaker or as a flexible baseload unit.

114.) http://energy.gov/eere/sunshot/concentrating-solar-power **115.)** https://www.irena.org/DocumentDownloads/Publications/IRENA-ETSAP%20Tech%20Brief%20E10%20Concentrating%20Solar%20Power.pdf **116.)** http://energy.gov/sites/prod/files/2015/02/f19/DOE_LPO_Utility-Scale_PV_Solar_Markets_February2015.pdf **117.)** http://www.seia.org/news/us-installs-62-gw-solar-pv-2014-30-over-2013 **118.)** http://www.nrel.gov/csp/solarpaces/by_country_detail.cfm/country=US%20(%22_self%22) **119.)** http://www.abengoasolar.com/export/sites/abengoasolar/resources/pdf/Solana_factsheet_09092013.pdf **120.)** http://www.nrel.gov/csp/solarpaces/project_detail.cfm/projectID=75

Onshore Wind Power

Wind turbines convert the kinetic energy of wind into electricity. With more than 46,000 operating turbines totaling over 62 GW of wind capacity, the United States ranks first globally in wind power generation and second in installed capacity.[121,122] Large-scale turbines typical of wind farms range in size from 100 kW to several MW each, while distributed wind turbines range from a few hundred watts to about 100 kW, and typically power homes, farms, or small businesses. The upwind three-blade design dominates the industry for large-scale wind, while some smaller turbines feature novel designs.[123]

Wind power is a mature technology used at over 900 wind farms across 39 states.[124] Most wind power capacity is in large-scale installations, such as the 300 MW Minco wind farm in Oklahoma operated by NextEra Energy Resources.[125] With 36 million MWh of electricity generated by wind in 2014, Texas ranks first for total wind generation.[126] RES Americas has constructed nearly 18% of the wind capacity in Texas, including the Keechi Wind Farm, pictured, which is owned by Enbridge and under a power contract with Microsoft. In 2013, wind-rich Iowa and South Dakota each produced more than 25% of their electricity from wind energy, demonstrating that high levels of wind generation can be integrated without jeopardizing reliability.[127] Outside the wind-rich prairie states, OwnEnergy is constructing a 100 MW wind farm in Louisiana and developing an 80 MW project in North Carolina, the first wind farm in each state.[128] Next-generation wind turbines with taller hub heights are expected to make wind a viable resource in all 50 states.[129]

Wind is a free and abundant energy resource, and electricity generated from wind has very low marginal costs. As turbine efficiency has more than tripled in the past 15 years and the industry has scaled up, the cost of wind power has decreased by more than 90% since the 1980s and continues to decline.[130] The levelized cost of new-build wind is estimated between $37-$81/MWh without subsidies, in comparison to coal ($66-$151/MWh) and gas combined cycle ($61-$87/MWh).[131] Generators often sell wind power via fixed-price long-term contracts, or power purchase agreements (PPAs), which dropped to a national average of $25/MWh in 2013.[132] Businesses are taking advantage of these locked-in low prices. Amazon Web Services signed a 13-year PPA for 150 MW of wind under construction in 2015 in Indiana by Pattern Energy.[133] Wind power also supports over 73,000 jobs across the country, brings investment to rural communities, and provides an additional income stream to farmers and other landowners.[134] Technology and market innovations have enabled ever-higher penetrations of wind energy without compromising grid reliability (see "The Agile Grid," p.4).

121.) http://www.awea.org/MediaCenter/pressrelease.aspx?ItemNumber=6965 **122.)** www.awea.org/Resources/Content.aspx?ItemNumber=5059&navItem-Number=742 **123.)** http://energy.gov/eere/wind/how-do-wind-turbines-work **124.)** http://www.awea.org/Resources/industrystatistics.aspx **125.)** http://webtest.nexteraenergyresources.com/pdf_redesign/MincoWind.pdf **126.)** http://www.eia.gov/todayinenergy/detail.cfm?id=20051 **127.)** http://www.awea.org/Annual-MarketReport.aspx?ItemNumber=6305 **128.)** http://www.ownenergy.net/project-development/our-projects **129.)** http://energy.gov/sites/prod/files/2015/05/f22/Enabling-Wind-Power-Nationwide_18MAY2015_FINAL.pdf **130.)** http://energy.gov/sites/prod/files/2013/09/f2/200130917-revolution-now.pdf. **131.)** https://www.lazard.com/media/1777/levelized_cost_of_energy_-_version_80.pdf **132.)** http://energy.gov/sites/prod/files/2014/08/f18/2013%20Wind%20Tech-nologies%20Market%20Report_1.pdf **133.)** http://patternenergy.com/en/operations/facilities/amazon-wind-farm-fowler-ridge/
134.) http://www.awea.org/Resources/Content.aspx?ItemNumber=5059&navItemNumber=742

Offshore Wind Power

Offshore wind turbines are very similar in design to land-based large-scale turbines (p.19). They are located in bodies of water where there is access to stronger, steadier wind resources than are typically available on land. Generally, the turbines are fixed directly to the bottom of a lake or ocean, although technologies are being developed to mount turbines on floating platforms, which will enable deployment in deeper water or farther offshore. Because of the higher expense of foundations and installation compared to land-based wind turbines, offshore wind farms generally feature larger turbines to minimize infrastructure requirements. Offshore wind turbines are typically 3-5 MW in size, but Vestas has installed 8 MW turbines, and even bigger turbines (10-15 MW) are under development.[135]

As of 2014, there were 104 operational offshore wind farms worldwide with a total capacity of 7 GW.[136] Recent data suggests that U.S. offshore wind potential along the coasts and in the Great Lakes is more than 4,000 GW – approximately four times total current U.S. electricity generation capacity.[137,138] While there are no operational offshore wind farms in the United States, in April 2015, Deepwater Wind, a U.S.-based offshore wind company, began construction of the first U.S. offshore wind farm off the coast of Rhode Island. The project will include five turbines totaling 30 MW of capacity, and is expected to produce enough electricity to meet the needs of about 17,000 homes.[139] Including Deepwater Wind, there are 14 projects with a planned total capacity of nearly 4.9 GW at an advanced stage of development in the United States.[140]

Offshore wind farms are more expensive to install than land-based projects, resulting in a higher estimated levelized cost of energy ($162/MWh compared to $37-$81/MWh for onshore wind).[141] However, offshore wind farms generally capitalize on stronger and more reliable wind resources and are often located closer to large coastal population centers, reducing the need for long-distance transmission. In the United States, the shallower waters in the Atlantic make the East Coast more economical and attractive for offshore wind development in comparison to the Gulf of Mexico and the Pacific Coast, where deeper waters make it more difficult to build.[142] As with marine and hydrokinetic power (p.13), offshore wind power offers the potential to bring new economic activity to coastal industries, such as ports and shipbuilding, during all phases of a project, from development to construction to operation.

135.) http://energy.gov/sites/prod/files/2014/09/f18/2014%20Navigant%20Offshore%20Wind%20Market%20%26%20Economic%20Analysis.pdf **136.)** http://energy.gov/sites/prod/files/2014/09/f18/2014%20Navigant%20Offshore%20Wind%20Market%20%26%20Economic%20Analysis.pdf **137.)** http://energy.gov/eere/wind/offshore-wind-research-and-development **138.)** http://www.eia.gov/cfapps/ipdbproject/iedindex3.cfm?tid=2&pid=2&aid=7&cid=r1,&syid=2008&eyid=2012&unit=MK **139.)** http://dwwind.com/block-island/block-island-project-overview **140.)** http://energy.gov/sites/prod/files/2014/08/f18/2014%20Navigant%20Offshore%20Wind%20Market%20%26%20Economic%20Analysis.pdf **141.)** http://www.lazard.com/PDF/Levelized%20Cost%20of%20Energy%20-%20Version%208.0.pdf **142.)** http://www.boem.gov/renewable-energy-program/renewable-energy-guide/offshore-wind-energy.aspx

Waste-to-Energy


Joe W.

Waste-to-energy (WTE) is the process of generating electricity and/or heat by combusting municipal solid waste (MSW). The most common form of WTE is mass-burn combustion, in which MSW is burned "as is" to produce steam that spins a turbine attached to an electric generator. There is a small amount of ash (typically 5% to 15% of the volume of the processed trash) left over as a byproduct that is sent to a landfill. Some WTE facilities sort out as many recyclable materials as possible prior to combustion, whereas others recover metals post combustion. There are other WTE technologies as well, including modular systems (which are essentially the same as mass-burn combustion, only smaller), and refuse derived fuel (RDF) systems (which shred the MSW prior to burning and remove non-combustible materials).[143] Gasification is an alternative to direct combustion that offers some benefits with respect to emissions and efficiency. The technology is well developed, but not in widespread use.

As of 2014, there were 84 WTE facilities in the United States. Located across 23 states, primarily in the Northeast, these facilities have a generating capacity of over 2.7 GW and process more than 30 million tons of municipal trash annually.[144] Analysts estimate that WTE could replace nearly 5% of coal-fired generation capacity if all MSW were used for electricity generation.[145] Non-utility companies, typically subsidiaries of waste management companies, develop, own, and operate most WTE facilities. These companies use power purchase agreements (PPAs) to sell electricity to utilities and contract with trash collectors to provide the waste feedstock. For example, Covanta Energy, one of the largest WTE companies in the United States, owns and operates the I-95 Energy/Resource Recovery Facility, located in Lorton, Virginia, which processes more than 3,000 tons of MSW per day. The 80 MW facility sells enough electricity to Dominion Virginia Power to serve the equivalent of 80,000 homes.[146] Coal-fired generating units can also be retrofitted to burn MSW. For example, the Elk River Energy Recovery Station in Minnesota, originally built to burn coal and oil, now processes 1,500 tons of MSW each day.[147]

Though providing electricity to the U.S. grid since the 1970s, WTE still has opportunities to expand. With over 63% of waste still sent to landfills each year, MSW is an underused source of energy capable of producing baseload power. Recent analysis estimates the total national economic impact of WTE to be $5.6 billion with nearly 14,000 jobs created by the industry. WTE facilities can play a strong role in local community economic development by providing high-paying jobs, enabling long-term savings in disposal fees, and injecting money into local economies.[148]

143.) http://www.epa.gov/waste/nonhaz/municipal/wte/basic.htm **144.)** http://www.energyrecoverycouncil.org/userfiles/files/ERC_2014_Directory.pdf **145.)** http://pubs.acs.org/doi/pdfplus/10.1021/es802395e **146.)** http://www.covanta.com/facilities/facility-by-location/fairfax.aspx **147.)** http://www.greatriverenergy.com/makingelectricity/biomass/elkriverstation.html **148.)** http://www.wte.org/userfiles/files/130820%20Berenyi%20Nat%27l%20WTE%20Economic%20Benefits.pdf

ELECTRICITY DELIVERY & MANAGEMENT

The electricity grid we rely on today appears to have much in common with the one that was developed over 100 years ago: electricity flows from centralized power plants over a high-voltage transmission system to a low-voltage distribution system that delivers electricity to end-use customers. But beyond this basic structure, the electricity system of today — and especially of the future — is far different.

With our economy running on a foundation of information technology, manufacturing, and other electricity-intensive industries, reliable and high-quality electricity has never been more critical. At the same time, new technologies are also finding their way into the grid, promising new and better ways to manage the flow of electricity, including two-way flows resulting from power generation installed at homes and businesses. Customers are already enjoying the benefits of the electricity produced onsite, but there is even more value that can come from services offered on the grid among and between grid operators, utilities, generators, third-party product and service providers, and customers.

For instance, Electricity Delivery and Management (ED&M) technologies provide opportunities to capitalize on granular system and customer data, new analytical capabilities, and load management throughout the electric grid. The market for these technologies is growing, with investment in ED&M technologies rising to $13.1 billion in the United States in 2014 in (up 23% from 2013) and totaling $67.9 billion worldwide.[1]

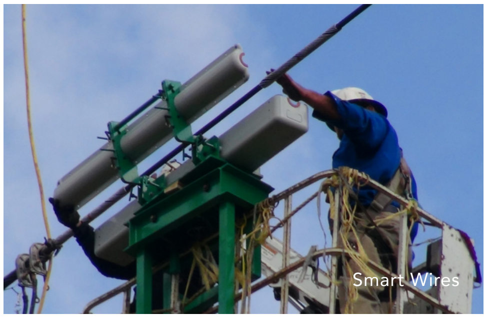
ED&M systems have a wide variety of configurations and deployment options, but their benefits can be grouped into four categories:

- **Operational savings** – More precise management of electrical flows and power conditions mean significant savings for consumers from reduced transmission and distribution losses. Advanced warning of equipment malfunction, the ability to pinpoint fault locations, and automated prioritization of repair crew dispatch can amount to significant operations and maintenance savings for utilities and customers.
- **Infrastructure savings** – Much of the capacity of the grid goes unutilized even under peak demand conditions due in part to a lack of real-time information, which forces operators to rely on models that assume worst-case scenarios. Using more of the operational range of equipment and optimizing the flow of power allows grid operators to carry power over existing equipment, reducing the investments needed to replace or supplement infrastructure. This can deliver significant savings and also extend the life of existing equipment.
- **Reliability** – Due to a lack of real-time information, grid operators often are not aware of developing problems until something fails. ED&M provides granular data that can be used to detect problems before failures occur and pinpoint faults more rapidly to minimize disruptions. As the dependence of the economy on reliable electric power has grown — especially for such facilities as data centers and hospital equipment — so has the impact of power disruptions, which have an estimated annual cost to the U.S. economy of $150 billion.[2]

1.) http://info.aee.net/aen-2015-market-report **2.)** http://electricalsector.eaton.com/forms/BlackoutTrackerAnnualReport

- **Integration of new technologies** – Customer-sited distributed energy resources can provide significant value to the grid, but also pose operational challenges to a utility that cannot monitor or manage them. Additionally, it is difficult to provide economic signals to customers when there is a lack of information on the impacts of different resources and the value they provide to the grid. Accurate assessment of how distributed energy resources impact the system allows utilities, third-party technology and service providers, and customers to realize the full value of these new technologies. By providing increased visibility and control of distributed energy resources, ED&M technologies enable new markets to spur innovation and unlock significant value for customers (see "The Agile Grid," p.4).

Flexible Alternating Current Transmission Systems


Smart Wires

Flexible Alternating Current Transmissions Systems (FACTS) include technologies that increase transmission system efficiency, maintain power quality, and respond quickly to disruptions to maintain reliability of the bulk power system. FACTS can be used to manipulate the conditions on transmission lines to keep AC power in balance by maintaining voltage stability, keeping current and voltage "in sync," and dampening distortions. Transmission operators have always had to perform these functions, but in the past they used devices that relied on mechanical switches that performed more slowly, less efficiently, and less reliably. By dynamically managing AC power and line conditions, FACTS can raise the carrying capacity of existing lines, route power more efficiently, and direct power flow along contractual paths. Additionally, in regions with high renewable power penetration, FACTS can provide frequency response that traditionally required inefficient spinning generators (see "The Agile Grid," p.4).

The first FACTS technologies were deployed in the 1970s, starting with Static VAR Compensators (SVCs). Since then FACTS technologies have continued to grow in variety and sophistication; Navigant Research estimates that $42 billion will be invested in FACTS globally between 2014 and 2023.[3,4] The U.S. grid already relies to some extent on FACTS to provide reliability, power quality, and control. In Texas, leading FACTS provider ABB installed four SVCs to allow existing transmission lines to carry more wind power and compensate for changes in voltage and power flow that can occur with variable output of wind generation.[5] ABB also installed an SVC and two mechanically switched capacitors (MSCs) in Alaska to provide dynamic voltage control to a remote area of the grid subject to reliability challenges.[6] FACTS technology can also be deployed incrementally as required to monitor line current and augment line impedance. The Tennessee Valley Authority and Southern Company are both using devices from SmartWires to manage power flow, maintain reliability, and integrate higher levels of renewable generation.[7]

By improving the performance of the existing grid, FACTS avoid the need to invest in costly new infrastructure subject to siting and permitting challenges. FACTS are also able to integrate variable renewable generation while delivering the reliability and power quality that are increasingly important in our IT-driven economy. Finally, by extending the operating range and capacity of transmission lines and enabling power to flow along contractual paths, FACTS can help increase competition and allow power markets to function more effectively.

3.) http://www.energy.siemens.com/us/en/power-transmission/facts/static-var-compensator-classic/#content=References **4.)** https://www.navigantresearch.com/research/flexible-ac-transmission-systems **5.)** http://www.abb.com/cawp/seitp202/c11d285a37093ec4c1257d9a00335542.aspx **6.)** http://new.abb.com/facts/references/reference-jarvis-creek **7.)** http://www.smartwires.com/2015/04/30/greentech-media-smart-wires-clears-congestion-and-allows-more-renewables-on-the-transmission-grid/

High Voltage Direct Current Transmission

Siemens AG

There are two types of currents that can be used when transmitting electricity: Alternating Current (AC) and Direct Current (DC). The electric grid originally developed around AC power because it was easier to manipulate and transport efficiently over long distances compared to DC power. Technological advancements have now made high voltage DC (HVDC) lines a viable option for long distance transmission. With HVDC, converters draw AC power from the grid and convert it to DC power. The DC power flows over the transmission line, then goes through a second conversion back into AC power before it is injected into the grid. Converters at both ends allow HVDC lines to transfer power between regional grid interconnections without disruption.[8]

HVDC has been used for decades in underwater and underground transmission projects where AC use is impractical. Its use in aboveground transmission is now increasing, primarily for moving large amounts of remote wind, solar, and hydroelectric power to distant load centers. The planned TransWest transmission project is expected to save California customers $600 million per year by delivering low-cost wind power from Wyoming.[9] In 2014, global investment in HVDC systems amounted to $6.1 billion, a 61% increase over 2013.[10]

HVDC transmission has important advantages over comparable AC lines. The higher power density of HVDC lines allows them to carry the same amount of energy as AC lines while using narrower rights-of-way and fewer towers, which reduces land requirements and eases siting considerations. HVDC lines do have fixed upfront costs regardless of line length, as the lines require converters to tie into the AC grid. However, energy losses are lower on HVDC lines than for comparable AC lines. An 800 kiloVolt (kV) HVDC power line over 1,000 miles loses less than half the power of a comparable 765 kV AC transmission line, including the conversion at both ends.[11] The lower line losses and need for fewer substations to correct for power quality result in cost savings over longer distances, such that HVDC transmission is competitive when spanning more than 250 miles.[12] HVDC lines can also provide support to the existing AC grid without adding to transmission congestion.

8.) The U.S. power grid is divided into three major interconnections, one in the east, one on the west and one covering most of Texas. The frequencies in these interconnections are not in sync and therefore AC power cannot flow between them. **9.)** http://wyia.org/wp-content/uploads/2011/09/news-release-wecc-10-yr-study-favors-wyoming-wind1.pdf **10.)** http://info.aee.net/aen-2015-market-report **11.)** https://www.irwaonline.org/eweb/upload/may_web_SuperConductor.pdf **12.)** http://www.abb.com/industries/db0003db004333/678bb83d3421169dc1257481004a4284.aspx

High Temperature Superconducting Transmission

Long Island Power Authority (LIPA) is utilizing a cable system manufactured by Nexans that utilizes AMSC's HTS wire and an Air Liquide cooling system. Energized in April of 2008, this is the world's first superconductor transmission-voltage cable system and is capable of transmitting up to 574 megawatts (MW) of electricity and powering 300,000 homes.

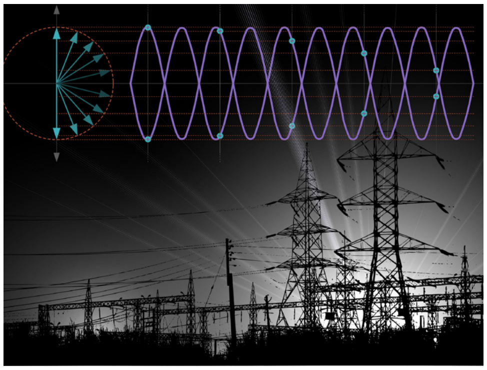
Superconductivity is a property of certain materials whereby electrical resistance, which normally decreases gradually with decreasing temperature, suddenly drops to zero at a critical temperature, allowing greater current to flow and eliminating resistive losses. Advances in material science have created high-temperature superconductors (HTS), with relatively "warm" critical temperatures of -315°F to -230°F that allow for the use of less expensive and easier to handle coolants such as liquid nitrogen. HTS systems transmit electricity through a superconducting cable that is insulated with liquid nitrogen pumped by refrigeration equipment. This allows HTS cables to carry 10 times the power of a standard cable of similar thickness with almost no losses. These lines can connect directly to the existing AC transmission system to add highly efficient transmission capacity that can relieve congestion without the need for high voltages.

Several utilities have begun to use HTS equipment for projects in urban areas that do not have space for large transmission towers or additional transformer equipment. For example, using technology from American Superconductor and Nexans, the Long Island Power Authority (LIPA) installed a superconducting AC transmission cable with 574 MW of capacity in a right-of-way only one meter wide. Because of the high energy density of the cables, LIPA was able to substantially increase transmission capacity while utilizing existing underground utility conduits.[13] Other utility HTS projects are underway in Albany, New York, and Columbus, Ohio.[14]

The ability of HTS equipment to relieve transmission bottlenecks allows for more efficient operation of the transmission system and more efficient generator dispatch, which saves money by reducing transmission energy losses and allowing more competitively priced power to reach transmission-constrained areas. In addition, because HTS lines do not emit or receive interference, placing transmission lines in close proximity to each other does not hinder their operation or create electromagnetic fields. This means that HTS cables can be packed tightly underground, thus allowing for the use of much narrower rights-of-way, reducing land requirements, minimizing the impact of eminent domain on landowners, and enabling the siting of lines in otherwise difficult or impossible locations.

13.) http://tdworld.com/overhead-transmission/lipa-energizes-worlds-first-transmission-voltage-superconductor **14.)** http://energy.gov/sites/prod/files/oeprod/DocumentsandMedia/cable_overview2.pdf

Synchrophasors



Due to a lack of real-time data, grid operators have traditionally based grid management decisions on worst-case scenarios, resulting in inefficient performance. Over the past few years, transmission system operators have deployed synchrophasors to address this inefficiency. Synchrophasors are devices that measure the frequency, magnitude, and power factors (the alignment of voltage and current) of the grid with high speed and accuracy, then send the data back to control centers. Utilizing data time-stamped from GPS satellites, synchrophasors detect shifts in grid conditions in real time to improve management.

Synchrophasors began significant deployment in 2009, but today there are already around 1,700 synchrophasors in use in North America, providing data coverage of a significant portion of the bulk power system.[15] Utilities and grid operators across the country have installed synchrophasors, from Idaho Power in Idaho and Oregon to American Transmission Co. in Wisconsin to Entergy in Arkansas, Louisiana, and Mississippi.[16] Navigant Research estimates that global annual investment in synchrophasors and other technologies to improve situational awareness of the electric grid will grow from $8.5 billion in 2014 to $16.7 billion in 2023.[17]

Synchrophasor data can be used to improve reliability and resilience by reducing the likelihood of grid disturbances. Dramatic shifts in power conditions between measurement points can signal to grid operators that something is going wrong and corrective measures are needed. When a grid disturbance does occur, accurate data help pinpoint the cause and enable a more effective response. The California Independent System Operator was able to bring a transmission line between California and Arizona back online in contradiction to standing protocol because synchrophasor data showed that conditions were safe.[18] In post-event analyses, synchrophasor data can help assemble accurate, granular timelines of events and reactions.

Synchrophasor data can also improve day-to-day grid operations by enabling better utilization of system assets. In turn, this improved utilization allows operators to safely use a greater portion of the operational range of existing equipment, thus avoiding unnecessary upgrades. Good data can also help manage the flow of energy more efficiently to avoid congestion and minimize line losses, saving customers money. Finally, synchrophasors can help with system planning by improving the accuracy of system modeling.

15.) https://www.naspi.org/File.aspx?fileID=1326 **16.)** https://www.smartgrid.gov/sites/default/files/doc/files/Synchrophasor%20Report%2008%2009%20 2013%20DOE%20%282%29%20version_0.pdf **17.)** http://www.navigantresearch.com/research/synchrophasors-and-wide-area-situational-awareness **18.)** https:// www.smartgrid.gov/sites/default/files/doc/files/WISP-Tie_Line_Reclosing-09-168-2014.pdf

Energy Storage


Stem, Inc.

Without energy storage, electricity must be produced and consumed instantaneously, requiring generating capacity to be built and available to meet peak demand no matter how rarely peaks occur. To relieve this requirement, several energy storage technologies are currently mature and commercially available, including pumped hydro, compressed air energy storage (CAES), flywheel systems, electrochemical batteries such as sodium-sulfur batteries and lithium-ion batteries, flow batteries, and thermal storage. These technologies take in electrical energy when it is produced and store it as kinetic, chemical, thermal, or potential energy for conversion back to electricity when needed.[19]

While pumped hydro accounts for 95% of the 25 GW of existing energy storage capacity on the U.S. grid, most new storage capacity being added to the grid at the transmission and distribution level relies on other technologies, with 62 MW of non-hydro storage capacity added in 2014 and nearly 200 MW in 2015. In 2020 cumulative installed capacity of non-hydro energy storage is expected to reach 2 GW, growing to a $2 billion market.[20] A variety of technologies are already operational throughout the country, such as a 32 MW lithium-ion battery system by AES Energy Storage in Belington, West Virginia; a 110 MW CAES system in McIntosh, Alabama; and a 20 MW flywheel system in Hazle Township, Pennsylvania.[21] In addition, energy storage is increasingly being deployed behind the meter, giving residential, commercial, and industrial consumers new options for managing their energy use and costs while providing valuable grid services.

As part of a modernized, flexible grid, energy storage is taking on increasingly important and diverse roles, with the different types of energy storage providing grid benefits ranging from peak load shaving to ancillary services to cost-effective renewable integration (see "The Agile Grid," p.4). Pumped hydro is a bulk storage technology particularly well suited to meeting daily peak demand; lithium-ion batteries can aid in peak load shaving, smoothing out variable renewable generation, and meeting behind-the-meter energy management needs; and flywheels provide rapid-response ancillary services such as frequency regulation, inertial response, voltage support, and reactive power.[22] Aggregators enable smaller behind-the-meter systems to bid into markets to provide peak capacity resources or grid optimization services, as Stem Inc. has done in California.[23]

Energy storage can also be used to defer or avoid infrastructure investments. In New York, ConEdison expects to defer a $1 billion transmission and distribution upgrade by investing $200 million in a combination of traditional solutions and distributed energy resources, including energy storage installed on its distribution system.[24] Similarly, deploying a battery system instead of transmission upgrades lowered infrastructure costs to ratepayers of Central Maine Power from $18 million to $6 million.[25] Energy storage is also an important component of microgrid systems (p.33), and behind-the-meter energy storage can be used by residential and commercial customers to reduce peak electricity costs and demand charges while helping utilities to manage system-wide peak demand to benefit all customers.[26]

19.) http://www.iec.ch/whitepaper/pdf/iecWP-energystorage-LR-en.pdf **20.)** http://www.nrel.gov/docs/fy13osti/58655.pdf; http://www.greentechmedia.com/research/us-energy-storage-monitor **21.)** http://www.energystorageexchange.org/ **22.)** http://www.sandia.gov/ess/publications/SAND2013-5131.pdf **23.)** http://www.tmcnet.com/usubmit/2014/06/24/7891699.htm **24.)** http://documents.dps.ny.gov/public/MatterManagement/CaseMaster.aspx?MatterSeq=45800&MNO=14-E-0302 **25.)** http://www.pressherald.com/2015/06/08/grid-feeding-battery-system-of-the-future-humming-in-boothbay/ **26.)** http://www.nrel.gov/news/press/2015/16481.html; http://www.stem.com/systems-2-0

Electric Vehicle Charging Infrastructure

Image courtesy of ChargePoint, Inc.

Electric vehicle charging infrastructure has developed quickly over the past few years as the number of plug-in electric vehicles (PEV) on the road has risen significantly (see p.58). Most EV charging infrastructure uses "Level 1" charging (standard outlet voltage, which requires no additional equipment) or "Level 2" stations (charging at higher voltage, which is faster but requires special equipment). In addition, there are a small number of "Level 3" direct current (DC) fast-charging stations, such as Tesla's "Supercharger" stations, which can charge vehicles in a matter of minutes.[27] Most PEV owners have charging equipment at home, but public charging infrastructure is becoming more prevalent.

As of late 2015, there were 27,474 public EV charging outlets in the United States.[28] In 2014, the market size of electric vehicle charging infrastructure in the United States was $200 million, representing a 31% increase over 2013. Market growth in EV infrastructure in the United States has outpaced the global market, with total market share increasing from 21% in 2011 to almost 34% in 2014.[29] Charging stations can be located anywhere from public streets to retail stores to private homes. Recognizing the growing demand for charging infrastructure, Brookfield Office Properties installed 40 ChargePoint charging stations in multiple locations throughout Washington, California, Colorado, and Texas.[30]

As PEVs grow in number, utilities and grid operators will need new tools to manage the incremental demand from vehicle charging. EV charging infrastructure can be integrated with intelligent controls to provide "smart charging" capabilities. In its simplest form, this involves controlling when vehicles charge their batteries, either to reduce load during peak times or to add consumption during times of high renewable energy generation. In the future, the batteries in PEVs can be used as energy storage to optimize grid operations. So-called "vehicle-to-grid" (V2G) technology is currently being demonstrated by several research projects, including a collaboration between the National Renewable Energy Laboratory and Xcel Energy.[31] The Department of Defense has also started to deploy V2G technology through a pilot project in Los Angeles, with preliminary testing indicating that revenue from electricity regulation services provided to the grid can exceed energy consumption costs under certain conditions.[32,33] With smart charging, analyses have shown that PEVs can reduce their electricity use by up to 95% during demand response events (DR; p.34) without impacting mobility, indicating that there can be significant deployment of PEVs with minimal need for new generating capacity or grid upgrades.[34] Smart charging with DR capabilities is being deployed through a pilot program by ClipperCreek and Itron in conjunction with the electric utility Pepco Holdings, Inc., in Maryland and Washington, D.C.[35]

27.) http://www.afdc.energy.gov/fuels/electricity_infrastructure.html **28.)** http://www.afdc.energy.gov/fuels/electricity_locations.html **29.)** http://info.aee.net/aen-2015-market-report **30.)** http://www.chargepoint.com/files/casestudies/73-001062-01-2-CS-Prpownr-BrooklfieldOfficeProperties-01.pdf **31.)** http://www.nrel.gov/electricity/distribution/projects_vehicle_grid.html **32.)** http://www.energy.ca.gov/2014_energypolicy/documents/2014-06-23_workshop/presentations/05_Gorguinpour_CEC_IEPR_Presentation_06232014.pdf **33.)** http://www.energy.ca.gov/research/notices/2014-11-19_workshop/presentations/Doug_Black_CEC-VGI-Workshop-LBNL-DOD-V2G_2014-11-19.pdf **34.)** http://papers.sae.org/2015-01-0304/ **35.)** https://www.itron.com/na/newsAndEvents/Pages/Pepco-Deploys-Itron-and-ClipperCreek-Electric-Vehicle-Smart-Charging-Solution.aspx

Distribution Automation


General Electric

In recent years, the transmission system in many places has been upgraded with new sensors and automated control equipment, allowing for more data collection and efficient control. The distribution system, however, is further behind in deploying similar technologies, which could improve system operations. Distribution automation technologies include a combination of line sensors, control equipment, and software tools that constantly optimize distribution equipment, such as transformers, capacitor banks, and reclosers. Together, these tools and technologies improve reliability and efficiency. Substation automation systems – a component of distribution automation – collect data about consumption and load and transmit the data to grid operators in real time. Distribution automation uses a combination of centralized control and decision-making alongside localized automated functionality.

Utilities use distribution automation technologies to reduce operating and maintenance costs, prevent outages, and enable crews to respond to outages more quickly and effectively. Distribution automation systems can improve response times from hours to minutes or even seconds. The power usage data delivered by these systems also allow for better load forecasting and more efficient use of generation resources. After installing distribution automation controls as part of a smart grid upgrade project, the Electric Power Board of Chattanooga in Tennessee and Georgia realized $1.6 million in annual operating savings, as well as $2 million in wholesale demand savings due to improved voltage control.[36] Navigant Research estimates that global revenue from distribution automation systems will grow from $6.3 billion in 2013 to $11.3 billion in 2020.[37]

Distribution automation also helps optimize voltage and reactive power, integrate more distributed generation, and increase energy efficiency throughout the system without needing action on the part of customers, which saves on costs. Still, the primary benefit of distribution automation is a more flexible grid that can anticipate and prevent outages and other problems. A Department of Energy survey found that distribution automation resulted in better reliability for utilities.[38] Distribution automation technologies provide enhanced data collection and control capabilities that allow utilities to implement more sophisticated distribution system control and management schemes.

36.) https://www.smartgrid.gov/sites/default/files/doc/files/EPB%20Final%20Project%20Description%20-%2020140422%20reformatted.pdf **37.)** https://www.navigantresearch.com/research/distribution-automation **38.)** https://www.smartgrid.gov/sites/default/files/doc/files/Distribution Reliability Report - Final.pdf

Advanced Metering Infrastructure


Landis+Gyr

Advanced metering infrastructure (AMI) is an integrated system of smart meters, communications networks, and data management systems that enables two-way communication between utilities and customers. While traditional meters that are read monthly, smart meters record electricity in intervals of an hour or less (typically 15 minutes), and transmit this information along with data on power outages and power quality to utilities for monitoring and billing purposes, usually over a secure communication network. Two-way communication with smart meters allows utilities to relay detailed energy usage and pricing information back to the customer, enabling active energy management.[39] AMI is part of the broader "smart grid" that is enabling more efficient and reliable operation of the grid and facilitating the deployment of new products and services such as smart appliances and thermostats (p.44), in-home displays, and energy management systems (EMS, p.45).

Smart meter deployment by utilities has become commonplace, with over 50 million smart meters installed in the United States as of mid-2014, covering about 43% of households.[40] By deploying more than 2.2 million Itron smart meters, CenterPoint Energy's Houston Electric in Texas achieved much faster customer service and saved 3.5 million truck rolls and service visits from 2009-2012, even before reaching full deployment of smart meters in 2012.[41] Advanced meters can also inform utility investments. Western Indiana Energy, a cooperative utility, used over 16,000 Landis+Gyr smart meters to locate line losses, guiding future infrastructure decisions.[42] Kansas City Power & Light in Kansas City, Missouri, introduced AMI as part of a larger smart grid project that also incorporated energy storage (p.28), distribution automation (p.30), residential EMS, and distributed solar photovoltaics (p.16).[43] The market for AMI was $1.3 billion in the United States and $6.5 billion globally in 2014.[44]

As a foundational component of the smart grid, AMI sets the stage for other grid management technologies and customer choices. Using data provided by AMI to improve the efficiency and reliability of its electric system, a utility with a service territory of 1 million households would achieve an estimated $77-$208 million in operational savings, $100-$150 million in consumer-driven savings, and $21-$64 million in net benefits over a 20-year period.[45] Additionally, AMI gives customers more useful information, enabling customer savings while also lowering energy usage both overall and during peak times, which can reduce outages, lower energy prices for all consumers, and avoid or delay infrastructure investments.[46] AMI data have also driven software innovations that are improving grid performance and energy management (see p.39) and utilities, using AMI data, are working with third-party providers to engage customers and offer new services. In California utilities are working with FirstFuel to leverage AMI data and increase customer engagement in the commercial and industrial sectors through intuitive data dashboards and a self-serve platform highlighting demand-side management programs.[47]

39.) http://www.cpuc.ca.gov/PUC/energy/Demand+Response/benefits.htm **40.)** http://www.edisonfoundation.net/iei/Documents/IEI_SmartMeterUpdate_0914.pdf **41.)** https://www.itron.com/na/newsAndEvents/Pages/CenterPoint-Energy-Completes-Itron-Smart-Meter-Roll-Out.aspx **42.)** http://www.landisgyr.com/webfoo/wp-content/uploads/2013/01/LAN-11038_CS_WIN-LineLoss.pdf **43.)** http://psc.mo.gov/CMSInternetData/Electric/Missouri%20Smart%20Grid%20Report%20-%20February%202014.pdf **44.)** http://info.aee.net/hs-fs/hub/211732/file-2583825259-pdf/PDF/aen-2015-market-report.pdf **45.)** http://www.edison-foundation.net/iei/Documents/IEE_BenefitsofSmartMeters_Final.pdf **46.)** https://www.smartgrid.gov/sites/default/files/doc/files/B4-revised-10-03-2014-100614.pdf **47.)** http://www.firstfuel.com/solutions/regulated-utilities/

Advanced Distribution Management Systems

General Electric

Building on new tools such as distribution automation (p.30) and advanced metering infrastructure (p.31), utilities have begun to harness a number of advances in software and IT to improve the management and operation of the distribution system. These include Distribution Management Systems (DMS), which synchronize automated reclosers, capacitors, and other systems that manage the flow and quality of power on the distribution system; Outage Management Systems (OMS), which pinpoint faults and dispatch repair crews quickly; and Geographic Information Systems (GIS), which plot equipment, lines, and faults. These systems often run on different platforms from different vendors, requiring operators to use multiple interfaces and manually compile information. Advanced Distribution Management Systems (ADMS) combine all of these functions on a single, integrated software platform that also makes use of other systems such as AMI. ADMS provides the "brain" that ensures new IT-enabled system controls are harnessed in a way that optimizes the management and operation of the entire distribution system. For instance, in the event of a power outage, ADMS can detect the location of the fault, determine which customers are without power, reroute power to bring as many customers back online as quickly as possible, institute measures such as voltage reduction to protect reliability, and dispatch repair crews to bring remaining customers back online. Without an ADMS and supporting systems, this process is lengthy and cumbersome.

ADMS is a relatively new platform. Early deployments include PPL Electric Utilities in Pennsylvania; Austin Energy in Texas; CenterPoint in Texas; Entergy in Louisiana, Arkansas, Mississippi, and Texas; and Oklahoma Gas and Electric in Arkansas and Oklahoma.[48] ADMS helped shave time off of restoration efforts in the wake of Hurricane Irene, one of the largest outage events in PPL's history.[49] At CenterPoint Energy, ADMS has saved customers from over 100 million minutes of outages since deployment began in 2011. CenterPoint saw its reliability metrics improve by 28% in a single year, while more efficient operations and maintenance lowered costs.[50] Navigant Research estimates that the global market for ADMS will grow from an annual $681 million in 2015 to $3.3 billion in 2024.[51]

By optimizing grid operations, ADMS can increase the amount of efficiency obtained through Volt-VAR Optimization (VVO; p.35), directly dispatch demand response resources (DR; p.34), avoid or defer costly infrastructure upgrades, and help utilities plan for and manage customer-controlled resources on the grid, such as microgrids (p.33) and distributed generation (see "The Agile Grid," p.4). Utilities that have deployed ADMS have found that they are better able to forecast load and generation on the grid because they are now able to monitor and plan for DG as actual generation rather than treat it as a load reduction, as is the case now in most utility systems.[52]

48.) https://www.smartgrid.gov/sites/default/files/doc/files/sgig-progress-report-final-submitted-07-16-12.pdf **49.)** https://www.smartgrid.gov/sites/default/files/doc/files/PPL_Case%20Study_electric_utilities_SGIG.pdf **50.)** http://www.abb.com/cawp/seitp202/0bc2fe9631003173c1257e21005d1f26.aspx
51.) https://www.navigantresearch.com/research/advanced-distribution-management-systems **52.)** https://www.smartgrid.gov/sites/default/files/doc/files/ADMS-Guide_2-11.2015.pdf

Microgrids

A microgrid is a network of connected electricity generation assets, controls, and loads that can operate independently from a utility grid and/or easily connect to or disconnect from a utility grid. Microgrids usually range in capacity from less than 1 MW to 40 MW, and can generally be classified as customer microgrids, utility or community microgrids, or remote microgrids. Virtual microgrids link distributed generation (DG) at multiple sites. Remote and customer-owned microgrids are well-established applications, while utility, community, and virtual microgrids are emerging alongside intelligent grid technologies.[53] In all cases, microgrids can generate, distribute, and regulate the flow of electricity to consumers at a local level.

Remote microgrids provide power to communities far from utility networks, as is common in remote villages in Alaska. Customer-owned microgrids typically refer to those at large facilities owned by a single customer, such as military bases, college campuses, and hospital complexes. Customer-owned microgrids are interconnected to the utility system, but they can disconnect (or "island") to provide electricity when the utility grid is down. Utility or community microgrids refer to portions of the grid within the utility system that are configured to function independently. These microgrids rely on software and other technologies to synchronize and operate in parallel to the larger grid, yet can also act as a microgrid when called upon to do so, such as during a widespread power outage.

The United States is the leader in microgrid adoption, with nearly 1,500 MW installed and another 1,100 MW in planning, according to Navigant Research.[54] Most of these installations are customer-owned, such as the microgrid used at the U.S. Food and Drug Administration's research facility in White Oak, Maryland. This microgrid allowed the facility to maintain operations for two and a half days during Hurricane Sandy, while the utility grid was down.[55] Microgrids can incorporate a variety of advanced energy technologies. A microgrid at the commercial-residential Mesa del Sol development in Albuquerque, New Mexico makes use of a 50 kW solar PV system (p.16), an 80 kW fuel cell (p.8), a 240 kW natural gas generator (p.9), an absorption chiller, and energy storage (p.28) from lead-acid batteries and cold thermal storage.[56]

Microgrids offer increased resilience and reliability. During blackouts or extreme weather events, microgrids can continue to generate and deliver electricity to connected loads independent of the utility grid. Microgrids are particularly attractive for secure buildings and campuses that require high-reliability power, including military bases. Many remote and customer-owned microgrids use combined heat and power systems (CHP; p.7), providing customers with year-round energy cost savings. Utilities may choose to deploy microgrids on their networks to achieve cost savings relative to traditional "poles and wires" solutions, or to meet the needs of customers with requirements for high-reliability power. Third parties are also beginning to offer microgrid options, such as SolarCity's GridLogic "microgrid-as-a-service," which provides turnkey solutions combining solar PV, batteries, and backup generators in a grid-tied microgrid.[57]

53.) https://building-microgrid.lbl.gov/types-microgrids **54.)** http://www.iaee.org/documents/2013EnergyForum4qtr.pdf **55.)** http://www.technologyreview.com/view/507106/microgrids-keep-power-flowing-through-sandy-outages/ **56.)** https://building-microgrid.lbl.gov/mesa-del-sol **57.)** http://www.solarcity.com/commercial/sustainable-energy-solution

Demand Response

Demand Response (DR) is a grid management tool through which utilities and grid operators provide information and/or incentives to customers to encourage them to reduce energy use at specific times. DR can use control technology that automatically responds to prices or other signals, or customers may respond to a DR request manually. Load reduction is typically achieved by temporarily switching off or reducing usage from cooling or lighting or by postponing energy-using activities, although some customers may switch to onsite generation. Storage-backed DR is a growing application that enables load reduction without a shift in energy use.

The United States DR market reached 1.25 billion in 2014, up 14% over 2013, and now accounts for almost two-thirds of the global DR market.[58] The estimated potential peak load reduction from DR technology in independent system operator (ISO) regions in 2013 was almost 29 GW, up 9% from 2012.[59] DR programs have traditionally targeted commercial and industrial customers, participating through aggregators.

EnerNOC works with dozens of utilities to incorporate the latest DR technologies, such as sub-second DR dispatches and automated DR, or AutoDR, into their programs. EnerNOC worked with Louisville Gas & Electric and Kentucky Utility Co. to incorporate AutoDR into their commercial and industrial DR program. Many utilities also offer DR programs to residential customers, incentivizing load curtailment through one or more of the following: time varying electricity rates, behavioral communications, participant incentives, and rebates for enabling technologies. Opower, a provider of energy efficiency and DR, is partnering with Baltimore Gas and Electric (BGE) in Maryland to deliver highly personalized communications to over 1 million residential customers, offering a rebate to customers who reduce energy consumption during peak hours.[60]

Demand response allows customers to be compensated for providing a valuable service to grid operators and also gives them more control over their own energy usage and costs. EnerNOC enabled Midwest Energy, Inc., of Kansas to reduce peak demand by targeting agricultural customers, with an annual payment of $1,000 providing additional income for participating farmers.[61] At the same time, DR improves reliability, helps to integrate renewable generation, and moderates energy prices for everyone by lowering demand at critical times and offering a lower cost alternative to expensive and rarely used peak generating capacity and transmission and distribution (T&D) infrastructure. When coupled with automated load controls, DR can provide sub-second dispatches and is increasingly being used by utilities at the distribution system level to manage more local grid issues, while also providing wholesale market ancillary services such as spinning reserves or regulation services.[62]

58.) http://info.aee.net/hs-fs/hub/211732/file-2583825259-pdf/PDF/aen-2015-market-report.pdf **59.)** http://www.ferc.gov/legal/staff-reports/2014/demand-response.pdf **60.)** http://opower.com/company/news-press/press_releases/126 **61.)** http://www.enernoc.com/our-resources/case-studies/547-midwest-energy-grows-new-energy-supply-with-enernoc-agricultural-demand-response **62.)** http://www.enernoc.com/our-resources/white-papers/demand-response-a-multi-purpose-resource-for-utilities-and-grid-operators

Voltage and Volt-Ampere Reactive Optimization


Gridco Systems

Voltage and Volt-Ampere Reactive (VAR) Optimization (VVO) is a smart grid-enabled utility application. VVO controls the flow of power on the distribution system to increase efficiency and reliability, reduce distribution energy losses, and accommodate new power flows, such as those originating from distributed generation. By providing more precise voltage control, VVO reduces total energy consumption without compromising service quality.

Distribution line voltage drops gradually with distance from the substation due to resistive losses in the wires. Historically, utilities have had to use estimates to ensure that all customers receive power within the voltage limits required to operate electric devices. This requires starting with higher than optimal levels to keep voltage from dropping below minimum thresholds by the time it reaches the customers farthest from the substation. By using dynamic control, VVO allows distribution lines to maintain lower overall voltage without impacting service quality. Power regulators, like those from Gridco Systems (pictured), can boost secondary voltage and prop up low voltage points, providing a significant opportunity for incremental VVO savings.

Increased market penetration of VVO is expected as applications verify the benefits.[63] The Snohomish County Public Utility District in Washington State invested $4.6 million in a Conservation Voltage Reduction system (an application of VVO), which resulted in better voltage quality and energy savings of approximately $600,000 per year.[64] Similarly, Dominion Power in Virginia was able to reduce total energy use by 2.8% through voltage optimization.[65] North American shipments of VVO control systems are projected to increase from 50,000 units in 2013 to over 100,000 units by 2018.[66]

In addition to energy and cost savings, VVO provides better control, creating a more intelligent, efficient, and stable distribution system. An impact analysis by the National Electrical Manufacturers Association found that VVO is able to reduce distribution line losses by 2%-5%, and a Department of Energy study of VVO concluded that the technology could reduce distribution line losses by more than 5%.[67,68] Commonwealth Edison, an Illinois utility, found that voltage optimization could reduce electricity consumption by 2%, with a levelized cost of saved energy of less than 2 cents per kWh, well below the cost of purchased energy.[69] For every 1% reduction in voltage, VVO reduces overall system demand by roughly 1%. This not only reduces energy demand, but also defers investments in new generation, transmission, and distribution capacity.[70]

63.) http://tdworld.com/test-monitor-amp-control/market-voltvar-optimization-set-transform **64.)** http://www.nema.org/Policy/Energy/Smartgrid/Documents/VoltVAR-Optimazation-Improves%20Grid-Efficiency.pdf **65.)** http://www.michigan.gov/documents/energy/Powell_418130_7.pdf **66.)** http://tdworld.com/test-monitor-amp-control/market-voltvar-optimization-set-transform **67.)** http://www.nema.org/Policy/Energy/Smartgrid/Documents/VoltVAR-Optimazation-Improves%20Grid-Efficiency.pdf **68.)** https://www.smartgrid.gov/sites/default/files/doc/files/VVO%20Report%20-%20Final.pdf **69.)** http://blogs.edf.org/energyexchange/files/2015/04/ComEd-study.pdf **70.)** http://www.nema.org/Policy/Energy/Smartgrid/Documents/VoltVAR-Optimazation-Improves%20Grid-Efficiency.pdf

BUILDING EFFICIENCY

Residential and commercial buildings accounted for approximately 41% of total U.S. energy use and 74% of electricity consumption in 2014.[1] This translates to over $400 billion in annual energy spending, which means that building efficiency holds the potential for large cost savings. A 20% reduction in building energy use would yield $80 billion in annual energy cost savings.[2] Fortunately, we now have unprecedented opportunities to meet and exceed these savings, including simple steps like upgrading appliances or lighting, more comprehensive building-level changes in envelope design or materials, and new technologies for managing building energy use. With building efficiency, it is not a question of doing "less with less" but doing "more with less." Efficient technologies and practices save energy and money while providing superior comfort, convenience, and performance.

Generally speaking, efficient building technologies and services require some sort of incremental investment over conventional options, with that investment recouped over time via lower energy use. Payback periods of a few months to a few years are typical. Overall, the total cost of saved energy is lower than the cost of procuring energy.[3] Moreover, efficient building technologies and services are coming down in price even as electricity prices rise, making energy savings even more valuable. With an existing building stock that still has many opportunities for energy savings, plus over 1 million new buildings expected to be built annually in the United States, opportunities for building efficiency are vast.[4] Investment in advanced energy technologies and services for building efficiency brings many benefits, including:

- **Cost savings** – Energy efficiency upgrades could deliver an estimated annual savings of $750 to the average U.S. household, reducing electricity bills by approximately one-third.[5] Meanwhile, efficiency upgrades at industrial facilities and retail or commercial businesses can cut operating costs. These savings are increasingly accessible without large upfront capital expenditures thanks to utility-administered efficiency programs, innovative financing vehicles, and private-sector energy service company (ESCO) services, all of which reduce barriers to investment in building efficiency improvements.
- **Consumer empowerment** – Energy efficiency technologies and services give customers the information and tools they need to take control of their energy use and spending. By investing in efficient appliances and building materials, enrolling in demand response programs (p.34), and making use of interactive software, consumers can save electricity and money. With automated hardware and software tools, consumers can choose how engaged they want to be, and can increasingly reap these benefits without putting much time or thought into their energy use.
- **Improved building performance and comfort** – While reducing energy use, many building efficiency technologies and services also improve building performance. For example, the technologies covered in this section can reduce drafts, set and control optimal lighting and temperature levels, and even help to manage and control operations across a large campus or a complex industrial facility.

1.) http://www.eia.gov/totalenergy/data/monthly/#consumption **2.)** http://energy.gov/eere/buildings/about-building-technologies-office **3.)** For example, see: http://emp.lbl.gov/sites/all/files/total-cost-of-saved-energy.pdf **4.)** http://energy.gov/sites/prod/files/2014/02/f8/BTO_windows_and_envelope_report_3.pd **5.)** http://www.energystar.gov/ia/partners/publications/pubdocs/2008%204%20pager%203-12-09.pdf

- **Improved grid performance** – In addition to building-level benefits, energy efficiency helps all electricity customers by reducing demand for electricity. Lower demand reduces the need for expensive capital investments in new power plants (including costly peaking units that run only at times of high demand) and other energy infrastructure, which ultimately saves all customers money by improving capital asset utilization. These system-wide benefits of energy efficiency will only increase as intelligent energy management coupled with responsive technologies such as smart appliances provides new opportunities for "load shifting" in response to time-of-use price signals.
- **Job creation and market growth** – Investment in energy efficiency drives job creation in a wide variety of fields, including research and development, manufacturing, software development, construction and installation, and customer service. At $60 billion in revenue in 2014, up 38% from 2013, the building efficiency market is the largest advanced energy market segment in the United States.[6]

6.) http://info.aee.net/aen-2015-market-report

Behavioral Energy Efficiency


Opower

Behavioral energy efficiency (BEE) employs messaging grounded in behavioral science to produce simple, actionable messages that are relevant to customers and motivate them to save energy. The average utility customer spends just nine minutes per year interacting with their utility or electricity provider.[7] When they do, they are likely to have one basic question: How can I save money? BEE answers this question with communications delivered through multiple channels – e.g., web, mobile, mail – to help customers get engaged and focused on reducing energy consumption and saving money. These messages include information such as how the customer's energy use compares to that of similar homes in the same neighborhood, as well as personalized energy efficiency tips, providing customers with voluntary ways to save. BEE programs consistently produce savings of 1.5% to 2.5% per household.[8] For context, every 1% reduction in residential electricity use nationally is roughly equivalent to the electricity used by 1.3 million homes, or nearly $1.7 billion annually.[9]

Behavioral energy efficiency programs are deployed by utilities or third parties acting as contracted agents of the utility. For example, Opower works with 95 utility partners in 35 states and 9 countries, including 28 of the 50 largest U.S. utilities. Opower's programs reach over 50 million households and businesses and have saved 8 terawatthours of energy – the equivalent of taking all the homes in New Mexico off the grid for a year.[10,11] Because Opower's BEE programs are administered as randomly controlled trials – much like drug trials – utilities can measure and verify every kilowatt-hour saved. Arizona's largest investor-owned utility, Arizona Public Service (APS), achieved 41 GWh of total savings from 2011 to 2013 through an Opower BEE program. One important outcome was that households with limited income achieved above-average savings.[12] Historically, low- and moderate-income customers have been harder to reach with energy efficiency programs, even though they stand to benefit the most.

The cost effectiveness of BEE makes it an attractive option for utilities and their customers. In a recent study, researchers at MIT and Harvard found that the cost to the utility is approximately 2.5 cents per kWh saved, which is far less than the cost of acquiring or generating electricity from a new power plant.[13] For customers, BEE delivers free energy savings via actionable information about energy use. Worldwide, Opower's programs have saved customers over $1 billion in utility bill savings.[14] McKinsey & Company recently estimated that BEE, if deployed to all households in the United States for which it is cost effective, could save almost 19 TWh of energy per year, which translates to $2.3 billion in avoided annual energy spending.[15,16] BEE also provides system-wide benefits, such as enabling utilities to defer or avoid costly capital investments in new generating capacity or transmission and distribution infrastructure.

7.) https://www.accenture.com/us-en/insight-actionable-new-energy-consumer.aspx **8.)** http://www.cadmusgroup.com/papers-reports/long-run-savings-cost-effectiveness-home-energy-report-programs/ **9.)** http://www.eia.gov/electricity/sales_revenue_price/ **10.)** http://www.opower.com/company **11.)** http://tdworld.com/smarter-grid/opower-and-utility-partners-save-over-eight-terawatt-hours-energy **12.)** http://blog.opower.com/2013/10/in-webinar-arizona-public-service-explains-how-to-bring-energy-savings-opportunities-to-all-customers/ **13.)** https://files.nyu.edu/ha32/public/research/Allcott%20and%20Mullainathan%202010%20-%20Behavior%20and%20Energy%20Policy.pdf **14.)** http://tdworld.com/smarter-grid/opower-and-utility-partners-save-over-eight-terawatt-hours-energy **15.)** http://www.mckinsey.com/~/media/mckinsey/dotcom/client_service/epng/pdfs/savings_from_behavioral_energy_efficiency.ashx **16.)** Based on average retail electricity price in 2013. http://www.eia.gov/electricity/annual/html/epa_02_04.html

Energy Data Analytics


WaterSmart Software

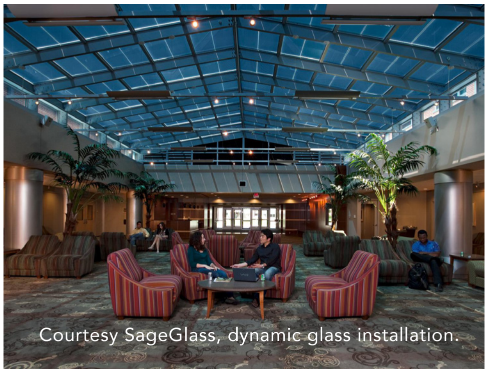
Building on new technologies such as advanced metering infrastructure (AMI; p.31) and building energy management systems (BEMS; p.45), private companies have begun to harness newly available energy data to deliver software solutions that drive greater energy savings than are possible through hardware solutions alone. These data analytics applications include automated monitoring and valuation (M&V) of efficiency savings, remote energy audits, automated and/or storage-enabled demand response (DR; p.34), energy intelligence software (EIS) that interfaces with BEMS solutions, and intelligent vehicle-to-grid (V2G) charging capabilities (p.29). Working in concert with hardware devices such as AMI, BEMS, energy storage (p.28), distributed generation, and electric vehicles (p.58), these data analytics solutions make use of information such as electricity tariffs, customer energy use, and grid conditions to optimize cost, comfort, and/or grid performance outcomes.

While some of these data analytics applications are just emerging, many are in use today. Data analytics using cloud-based EIS enables efficient building energy management across multiple properties by tracking and analyzing real-time energy data. Since deploying EnerNOC's EIS at more than 40 properties in California, Colorado, Nevada, and Florida in 2012, commercial real estate firm Equity Office Properties has identified approximately $800,000 in low- and no-cost operational savings opportunities.[17] Remote energy audits can also identify efficiency or demand-side resource investments that pay off. Automated M&V software is an extension of this idea, combining traditional evaluation processes with a software-enabled measure-as-you-go approach that allows program administrators to understand and use performance data to inform decisions. By streamlining and simplifying the process of quantifying energy savings, EnergySavvy's Optix Quantify software enables program administrators to detect and address issues nine months sooner than under traditional M&V.[18] Another emerging data analytics solution is intelligent energy storage such as Stem's PowerScope software, which reduces energy spending by controlling when a battery cycles on and off based on data such as predictable customer loads, weather conditions, and utility billing structures.[19]

Software can integrate multiple advanced energy solutions, using data analytics to optimize performance and integration of energy efficiency, demand-side resources, energy storage, and demand response.[20] Data-enabled software solutions deliver both scalable cost savings and building performance improvements. Using EnergySavvy's Optix Engage software, San Antonio municipal utility CPS Energy reduced retrofit costs by over 80% compared to an in-home audit while also delivering higher energy savings. At the same time, by making savings more accessible and more convenient, the online audits tripled the number of completed retrofits.[21] For businesses, data aggregation and visibility from EIS solutions or intelligent energy storage allow financial decision makers to make more informed choices about their operations. As data analytics solutions develop and proliferate, they will also help guide investment decisions for optimal grid performance.

17.) http://www.enernoc.com/our-resources/case-studies/equity-office **18.)** http://assets.cdnma.com/7083/assets/EnergySavvy_Optix_Quantify.pdf **19.)** http://www.stem.com/systems-2-0 **20.)** http://www.navigant.com/~/media/WWW/Site/Insights/Energy/2015/AESPMagazine_EvaluationDViolette.ashx **21.)** http://assets.cdnma.com/7083/assets/Case_Study_CPS_FINAL.pdf

Efficient Building Envelope Systems


Courtesy SageGlass, dynamic glass installation.

The building envelope consists of all the elements of a building that separate its interior from the exterior environment: external walls, insulation, windows, and roofing. Advanced building envelope materials can reduce building energy use and costs by lowering heating and cooling loads, which account for roughly 50% of energy consumed by a typical U.S. home and 40% in commercial buildings.[22,23] Heating and cooling loads can be reduced by as much as 40% simply by using efficient building envelope technologies. Roof and attic insulation alone can reduce heating and cooling needs by 10% to 15%.[24]

Opportunities for energy savings from specific technologies vary across the United States. In warm climates, reflective roofs and walls, exterior shades, and window coatings and films reduce the energy consumption required for cooling; in cold climates, improved air sealing, high-performance insulation, and advanced windows reduce energy consumed for heating. Building envelope solutions can be tailored to meet a building's specific needs. In addition to these established technologies, innovations are constantly being developed and introduced. At St. Petersburg College in Florida, leading efficient building materials manufacturer Johns Manville adhered thin-film solar photovoltaics (PV) directly to an advanced "cool roof." This roofing system generates electricity and reduces cooling and heating needs while being able to withstand hurricane-force winds.[25]

Given that space heating and cooling is the largest energy expenditure for many buildings, efficient building envelope technologies can deliver significant cost savings. A 20% reduction in building energy use — which could be accomplished by advanced building envelope technologies alone — would save an estimated $80 billion in the United States annually.[26] This translates to huge savings for individual households; for example, insulation installed by Next Step Living at a home in Connecticut is expected to deliver $500 in annual savings, with a payback period to the homeowner of just over six years.[27] These applications also improve comfort by reducing drafts. Less expensive technologies, such as air-sealing systems and efficient windows, have payback periods of less than five years.[28]

Efficient building envelope materials in new buildings can also reduce upfront capital costs for heating, ventilation, and air conditioning (HVAC) systems (p.41), because smaller HVAC systems are needed. These technologies improve building comfort and enable residential consumers and commercial or industrial building managers to make better energy decisions. Advanced building envelope technologies and installations represent a major market in the United States, where they produced an estimated $15.2 billion in revenue in 2014, up 28% over 2013. The related building design market reached $3.9 billion in revenue in the United States in 2014.[29]

22.) http://energy.gov/public-services/homes/heating-cooling **23.)** http://www.sba.gov/content/hvac-systems **24.)** http://www.iea.org/publications/freepublications/publication/TechnologyRoadmapEnergyEfficientBuildingEnvelopes.pdf **25.)** http://www.jm.com/content/dam/jm/global/en/commercial-roofing/Case%20Studies/RS-8822_St-Petersburg-College.pdf **26.)** http://energy.gov/eere/buildings/about-building-technologies-office **27.)** http://www.nextstepliving.com/success-stories/customers/customer-review-energy-evaluation-insulation-save-homeowner-hundreds **28.)** http://energy.gov/sites/prod/files/2014/02/f8/BTO_windows_and_envelope_report_3.pdf **29.)** http://info.aee.net/aen-2015-market-report

ADVANCED ENERGY ECONOMY
the business voice of advanced energy

Efficient Heating, Ventilation, and Air Conditioning


Colt Group

Heating, ventilation, and air conditioning (HVAC) systems consist of air conditioners, heat pumps, boilers, furnaces, and chillers, as well as the associated controls, air handlers, ductwork, and piping. Heating and cooling represent the largest source of energy consumption in the residential and commercial sectors, accounting for roughly 50% of energy consumed by a typical U.S. home and 40% in commercial buildings.[30,31] Chillers alone can account for 35% to 50% of a commercial building's energy use.[32] Improvements in efficiency derive from various technological innovations, such as variable speed drives (which reduce energy use by electric motors) and increased heat exchanger surface area (which improves overall energy transfer to the conditioned space). Advanced HVAC systems also have sensors and controls that communicate with sophisticated energy management systems (p.45) to further reduce energy use, improve comfort, and cut maintenance costs. Residential customers can also reduce home energy use through equipment upgrades and by using programmable thermostats such as a Nest Learning Thermostat, which can reduce heating and cooling costs by more than 20%.[33]

Because HVAC systems are major capital investments, upgrades typically coincide with normal replacement cycles (20 to 40 years). However, accelerated replacement can capture early savings, and efficient HVAC systems are a large and growing market: $13.1 billion in the United States in 2014, an increase of 7% over 2013.[34] Efficient HVAC systems can result in major energy savings, and are in wide use today in the commercial, industrial, and residential sectors. Emory University in Georgia installed two high-efficiency chillers in a medical facility, which lowered energy use for space cooling by nearly 50%. The project also included installation of variable-speed drives that reduced electricity use by the building's HVAC pumping systems by 40%.[35] Similarly, an evaporative cooling system delivered by CLEAResult reduced data center cooling energy use at Recreation Equipment, Inc. (REI), in Washington by 93%.[36]

These energy savings translate to significant cost savings that can add up quickly — REI achieved a one-year return on its investment. Similarly, efficient HVAC systems installed by Johnson Controls resulted in $1 million in energy savings in less than a decade for the Marine Military Academy in Harlingen, Texas, and $50,000 in annual savings to the Waldo County General Hospital in Belfast, Maine.[37] Because HVAC represents a significant portion of building energy use it is also a good candidate for energy management. A number of utilities offer direct load control programs or demand response (p.34) programs, in which customers shed load from an HVAC system by precooling the building or by raising the set point a few degrees when called upon. Such programs improve overall grid performance and reduce the need for expensive peaking power plants, saving money for all customers.[38,39] When integrated with intelligent controls, HVAC systems enable customers to take advantage of real-time pricing, resulting in cost savings while also providing benefits to the utility system as whole.[40]

30.) http://energy.gov/public-services/homes/heating-cooling **31.)** http://www.sba.gov/content/hvac-systems **32.)** http://www.epa.gov/region9/waste/p2/pdf/EnergyFinalOct12.pdf **33.)** https://nest.com/thermostat/saving-energy/ **34.)** http://info.aee.net/aen-2015-market-report **35.)** http://www.epa.gov/region9/waste/p2/pdf/EnergyFinalOct12.pdf **36.)** http://www.forbes.com/sites/peterdetwiler/2013/11/25/rei-points-the-way-to-huge-savings-in-data-center-power-costs/ **37.)** http://www.johnsoncontrols.com/content/us/en/products/building_efficiency/case_studies2/HVAC-Equipment.html **38.)** https://www.clearlyenergy.com/residential-demand-response-programs **39.)** http://www.elp.com/articles/powergrid_international/print/volume-16/issue-7/features/new-wave-of-direct-load-control-update-on-dlc-systems-technology.html **40.)** http://www.demandresponsesmartgrid.org/Resources/Documents/NTM%20Presentations/Eugene%20Smithart%20(Trane)%20-%20NTM%20A-2.pdf

Efficient Water Heating


David Dodge, Green Energy Futures

Water heating technology spans a range of options, from conventional technologies to renewable systems. Conventional storage water heaters typically use natural gas or electricity to keep water hot in an insulated tank, ready for use at any time. They have a simple design and are relatively inexpensive, but they also have standby losses associated with storing hot water for long periods of time. High-efficiency models increase heat transfer efficiency and reduce standby losses with more insulation. Tankless (instantaneous) water heaters eliminate standby losses by heating a stream of water on demand, though simultaneous use of hot water devices may be limited. Heat pump water heaters are electric water heaters that use heat pump technology (usually used for space heating/ cooling) instead of electric resistance coils to heat hot water. Like air conditioners and refrigerators, heat pumps move heat from one place to another instead of generating heat directly – in this case, from the surrounding air into the hot water tank. They are typically 2-3 times more efficient than conventional electric resistance units. Solar hot water systems harness the sun's energy using solar thermal collectors. They typically require a larger storage tank and a backup fuel (such as electricity or natural gas) for times when the sun cannot produce enough hot water.[41]

ENERGY STAR rated water heaters made up 11% of the gas water heating market and 1% of the electric water heating market in 2011, leaving significant room for further market penetration.[42] Customers in many areas can get rebates from their electric utilities for the purchase of an efficient water heater. Energy savings from efficient water heating is not limited to the residential sector. By installing a solar pool heating system recommended by Johnson Controls, the Glen Hills Middle School in Wisconsin will save $5,000 annually, with a payback period of just 3.5 years.[43] The U.S. market for high-efficiency water heaters was an estimated $2.1 billion in 2014, an increase of 61% over 2013.[44]

The average U.S. household spends $400 to $600 on water heating each year.[45] Efficient water heaters can use 10% to 50% less energy than standard models, with actual savings varying by the size and location of the heater and water pipes.[46] Dating back to 1990, the Department of Energy has promulgated energy efficiency standards for water heaters. The latest standards went into effect in 2015, and are expected to deliver an estimated $63 billion in cumulative savings for products shipped from 2015 to 2044.[47]

41.) http://www.energystar.gov/ia/new_homes/features/WaterHtrs_062906.pdf **42.)** https://www.energystar.gov/ia/partners/downloads/U.S._EPA-Ryan_and_Stephens-Booker.pdf **43.)** http://www.johnsoncontrols.com/content/dam/WWW/jci/be/case_studies/FINAL_CSST_09_104_Glen_Hills_5402.pdf **44.)** http://info.aee.net/aen-2015-market-report **45.)** http://energy.gov/articles/new-infographic-and-projects-keep-your-energy-bills-out-hot-water **46.)** http://www.energystar.gov/ia/new_homes/features/WaterHtrs_062906.pdf **47.)** http://www1.eere.energy.gov/buildings/appliance_standards/product.aspx/productid/27

Efficient Lighting and Intelligent Lighting Controls

Philips

Lighting accounts for 20% of energy use in commercial buildings and 10% of energy use in residential buildings. Installing efficient lighting is one of the lowest cost, fastest payoff energy efficiency improvements available today.[48] Advanced lighting technology includes light-emitting diodes (LEDs), energy-saving incandescent bulbs, and compact fluorescent lamps (CFLs). LEDs, especially, are transforming lighting markets today — once limited to niche applications, they can now be used in virtually any lighting application. LED lighting is five to six times more efficient than incandescent bulbs and up to 1.5 times more efficient than CFLs.[49] LEDs are typically dimmable and especially well suited for use with intelligent lighting controls, which use sensors to collect environmental information such as occupancy or ambient light and automatically adjust light levels, cutting lighting energy use by 80% to 90%.[50] The market for high-efficiency bulbs is well developed, with demand for conventional incandescent lights dropping by half from 2007 to 2012 as efficient bulbs have come to dominate the market.[51]

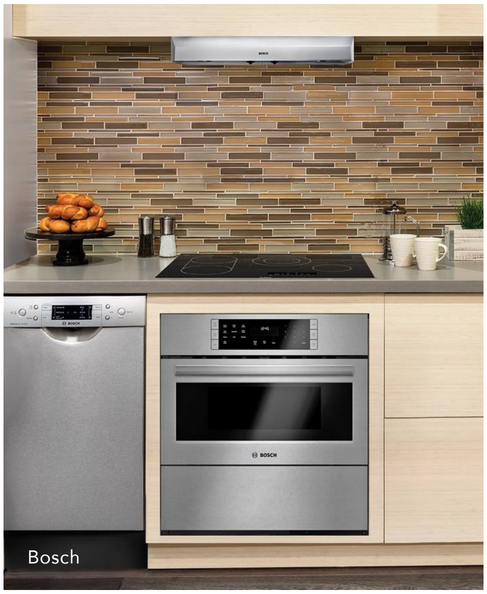
LEDs are rapidly becoming the technology of choice for street lighting due to their efficiency and extremely long life. In Los Angeles, the installation of 140,000 LED streetlights reduced lighting electricity costs by more than 60%, resulting in over $5 million in annual savings.[52] Smart street lighting can be managed remotely, and during emergencies or weather events burned out lamps can be easily detected and lights can be automatically adjusted or set to flash.

Efficient lighting for the residential sector is also growing rapidly, and remote control of connected lights is on the cusp of becoming commonplace. Total revenue from residential energy efficient lighting was estimated at $9.7 billion in 2014.[53] While LEDs are still more expensive than traditional lighting or CFLs, prices are falling rapidly, driving growth in the residential market. A McKinsey & Company study estimates that payback time for LED lighting will be around two years for the commercial and residential sectors by 2016.[54]

Depending on the bulbs they are replacing, high-efficiency bulbs reduce lighting electricity use by 25% to 80%, resulting in significant cost savings. Replacing a traditional 60-watt incandescent bulb with an equivalent 10-watt LED light by General Electric or Philips Lighting will deliver estimated electricity savings of $150 dollars, not including savings from avoided replacements over the bulb's 22-year rated life.[55] Efficient lighting also lowers space-cooling costs because it produces less heat for a given light output. If every home in the United States replaced just one incandescent light bulb with a CFL or LED, it would save enough energy to light 2 million homes for a year, which translates to $460 million in energy savings.[56]

48.) http://energy.gov/sites/prod/files/2014/02/f8/BTO_windows_and_envelope_report_3.pdf **49.)** http://energy.gov/eere/ssl/led-basics **50.)** http://www.digitallumens.com/resources/case-studies/ **51.)** http://www.gelighting.com/LightingWeb/na/consumer/images/GE-Transforming-Global-Lighting-Industry.pdf **52.)** http://www.forbes.com/sites/justingerdes/2013/01/25/los-angeles-saves-millions-with-led-street-light-deployment/ **53.)** http://info.aee.net/aen-2015-market-report **54.)** https://www.mckinsey.com/~/media/mckinsey/dotcom/client_service/Automotive%20and%20Assembly/Lighting_the_way_Perspectives_on_global_lighting_market_2012.ashx **55.)** http://www.gelighting.com/LightingWeb/na/consumer/images/GE-Light-Output-Comparison-Chart.pdf **56.)** https://www.energystar.gov/products/certified-products/detail/light-bulbs

Efficient Appliances and Electronics


Bosch

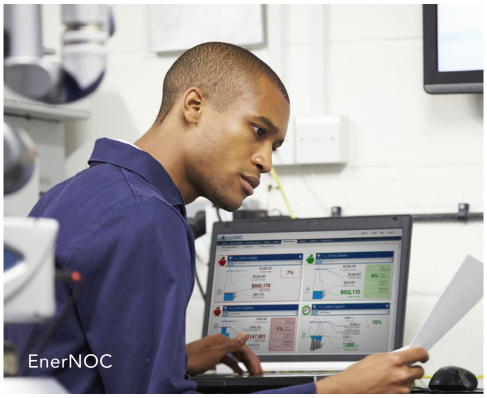
Efficient appliances and electronics reduce energy use while delivering the same or superior performance. Together, appliances and electronics comprise 28% of annual energy costs for the average U.S. household, with large appliances such as refrigerators, dishwashers, and clothes washers and dryers consuming nearly half of this energy.[57] Energy use can be cut significantly by using efficient ENERGY STAR certified appliances and electronics, which consume 10% to 50% less energy than standard models.[58] Some appliances exceed these savings: Efficient Bosch clothes washers use 60% less energy than the industry average while also cutting water use and thereby reducing water-related energy use (p.49).[59] Increasingly, consumers can also choose smart appliances and electronics that are capable of responding to price and demand signals, such as programmable thermostats, smart refrigerators and other appliances, and smart power strips that turn off devices when they are not in use to avoid standby losses.

Even though average energy consumption per U.S. home has decreased 21% from 1980 to 2009, there is still significant room for efficiency upgrades, especially as the number and types of devices have proliferated.[60] High efficiency appliances and electronic equipment had an estimated market size of $2.7 billion in 2014, an increase of 93% from 2013.[61] ENERGY STAR certified products generally account for the top 25% most efficient products across 60 product categories, from refrigerators to DVD players.[62] Smart appliances have grown a remarkable 927% since 2011 to reach $465 million in 2014. This accounts for an estimated 17% of the 2014 global market for smart appliances, which is expected to reach almost $35 billion in 2020.[63,64]

Efficient appliances and electronics deliver considerable cost savings. For example, the 690,000 ENERGY STAR qualified refrigerators sold by General Electric in 2009 alone will save customers an estimated $9.5 million in annual energy costs compared to non-ENERGY STAR refrigerators. If all clothes washers and dryers sold in the United States passed ENERGY STAR standards for efficiency, electricity costs would decrease by $5.5 billion annually.[65] Industry-leading electronics have also made great strides. Apple desktop computers today consume 97% less energy in sleep mode than original models, and the Mac Mini exceeds ENERGY STAR efficiency requirements four times over.[66] In aggregate, the reduced electricity usage from these and other efficient appliances and electronics allows utilities to avoid expensive investments in new generating units and grid upgrades. Meanwhile, smart appliances and electronics can enable savvy consumers to manage their electricity usage in response to market signals, which can lead to significant cost savings and additional grid benefits.

57.) https://www.energystar.gov/index.cfm?c=products.pr_where_money&s=mega **58.)** https://www.energystar.gov/index.cfm?c=products.pr_save_energy_at_home **59.)** http://www.energystar.gov/index.cfm?fuseaction=pt_awards.showAwardDetails&esa_id=3681 **60.)** http://www.eia.gov/consumption/residential/data/2009/index.cfm?view=consumption **61.)** http://info.aee.net/aen-2015-market-report **62.)** http://www.epa.gov/statelocalclimate/local/topics/residential.html **63.)** http://info.aee.net/aen-2015-market-report **64.)** http://www.navigantresearch.com/newsroom/smart-appliance-market-to-reach-nearly-35-billion-annually-by-2020 **65.)** https://www.energystar.gov/products/certified-products/detail/clothes-washers, and https://www.energystar.gov/products/certified-products/detail/clothes_dryers **66.)** https://www.apple.com/environment/climate-change/

Building Energy Management Systems



EnerNOC

A Building Energy Management System (BEMS) is an integrated system of software, hardware, and services that monitors, automates, and controls energy use through information and communication technology. Used primarily in commercial and industrial buildings, BEMS technology increases building efficiency and comfort by controlling building systems such as heating, cooling, and lighting. Institution-wide energy management systems, often called enterprise energy management systems (EEMS), are being deployed by universities, governments, and retail chains. BEMS can also be combined with software-based data analytics (p.39) to provide more information and control, particularly across multiple properties.

BEMS technology has brought energy savings to a broad range of building types across the country. By installing a Johnson Controls Metasys BEMS and implementing efficient technologies, the Bank of America Plaza in Columbia, South Carolina, reduced its energy use by 15%, resulting in $43,000 in annual energy savings.[67] In addition to energy costs savings, BEMS can also improve productivity and building performance. By installing Schneider Electric's SE7600 wireless room controllers in their warehouses, operating plants, and offices, Allagash Brewing Company of Portland, Maine, was able to set up automatic alerts and alarms, track energy use, and integrate temperature controls with other systems — all of which are critical for quality brewing.[68] Similarly, for Mercedes-Benz Headquarters in New Jersey, installing a Trane Building Automation System from Ingersoll Rand not only delivered cost savings, but also increased reliability and building comfort.[69]

The global BEMS market is expected to grow from $2.8 billion in 2014 to $10.8 billion by 2024. At $1.1 billion in 2014, up 13% from 2013, the U.S. market for BEMS accounted for 38% of the global market.[70]

As BEMS becomes more sophisticated, it is being integrated with demand response (DR, p.34) to provide targeted energy reductions when grid prices are high or the grid needs demand reductions to maintain reliability. This provides additional value to the customer and to the grid as a whole, as utilities and grid operators increasingly look to demand response as a cost-effective tool for maintaining system reliability while avoiding costly investments in peaking capacity and traditional "poles and wires" upgrades.

67.) http://www.johnsoncontrols.com/content/dam/WWW/jci/be/case_studies/Bank_of_America_Case_Study.pdf **68.)** http://download.schneider-electric.com/files?p_Reference=998-1284-12-22-14CR0_EN&p_EnDocType=Customer%20success%20story&p_File_Id=681023839&p_File_Name=998-1284-12-22-14CR0_EN.pdf **69.)** http://www.trane.com/commercial/north-america/us/en/about-us/newsroom/case-studies/industrial/mercedes-benz.html **70.)** http://info.aee.net/aen-2015-market-report

Energy Service Company (ESCO) Services


—Philips

Energy Service Companies (ESCOs) reduce customers' energy use and costs by implementing comprehensive energy efficiency solutions. This typically involves retrofitting existing buildings with energy efficient equipment such as high-efficiency lighting (p.43), heating, ventilation, and air conditioning (HVAC; p.41), and energy management and control systems. In addition, ESCOs often provide equipment and services related to onsite power generation, such as combined heat and power (p.7) and distributed solar (p.16), and may also offer energy procurement services. ESCOs typically handle all aspects of a project, including financing, design, installation, maintenance, and monitoring. ESCOs pioneered the use of a business model called *energy savings performance contracting* or *guaranteed energy savings contracting*. With performance contracts, the energy cost savings are used to pay for the capital improvements of the project over time, with the ESCO assuming the risk. Performance contracts therefore eliminate one of the key barriers to energy efficiency deployment: raising capital.[71]

ESCO services are widely used today, and the industry is growing at a steady pace. ESCOs currently serve mainly public and institutional customers, often called the MUSH market (municipalities, universities, schools, and hospitals). Together with the federal market, MUSH accounted for 84% of the ESCO market in 2011.[72] These entities can take a long-term view on energy investments and operating savings, and can utilize ESCO financing for large projects, such as in Pennsylvania, where ESCO services have reduced energy consumption in state buildings by 18%.[73] On a smaller scale, Johnson Controls worked with the public school system in Wyandotte, Michigan, to deliver $6.9 million in energy savings through the installation of new windows and HVAC systems as well as a building energy management system.[74]

To ensure that the promised savings are achieved, ESCOs often install "extra" efficiency measures, resulting in savings beyond expectations. In fact, lifetime energy savings for federal performance contracting projects have achieved an estimated 174% to 197% of guaranteed savings, including significant cost reductions beyond the contract period.[75] The Central Piedmont Community College in Charlotte, North Carolina, saved nearly $800,000 in the first two years of a performance contract with Trane, a subsidiary of Ingersoll Rand, exceeding contracted savings by 11% and 19% in years one and two, respectively.[76] Nationally, Lawrence Berkeley National Lab estimates that ESCOs delivered 34 TWh of electricity savings in 2012, equal to approximately 2.5% of commercial electricity retail sales.[77] Along with energy savings, since 1990, ESCOs have delivered an estimated $30 billion in infrastructure investments and 425,000 person-years of employment.[78] Up 7% from 2013, the U.S. ESCO market produced approximately $4.7 billion in revenue in 2014, including ESCO-installed HVAC equipment.[79] With an estimated 17 billion square feet of "ESCO-addressable" building space in the United States, the entire ESCO market is expected to double or triple in revenue by 2020.[80]

71.) http://www.naesco.org/what-is-an-espc **72.)** http://emp.lbl.gov/sites/all/files/lbnl-6300e_0.pdf **73.)** http://www.ncsl.org/research/energy/state-energy-savings-performance-contracting.aspx **74.)** http://www.johnsoncontrols.com/content/dam/WWW/jci/be/white_papers/GIWhitepaper.pdf **75.)** http://btric.ornl.gov/publications/Publication%2041816.pdf **76.)** http://www.trane.com/commercial/north-america/us/en/about-us/newsroom/case-studies/higher-education/central-piedmont-community-college.html **77.)** https://emp.lbl.gov/sites/all/files/lbnl-6877e.pdf **78.)** http://www.naesco.org/what-is-an-esco **79.)** http://info.aee.net/aen-2015-market-report **80.)** http://emp.lbl.gov/sites/all/files/lbnl-6300e_0.pdf

Utility Energy Efficiency Programs and Services

Utilities across the country run energy efficiency programs that provide rebates, loans, information, and services to residential, commercial, and industrial customers to help them reduce their energy use and save money. Energy efficiency improvements provided through utility programs include technologies and building systems that reduce energy use while still delivering the same or superior service, such as lighting (p.43), appliances (p.44), behavioral energy efficiency (p.38), heating and cooling equipment (p.41), and building materials and systems (p.40). Many utility programs also offer services, such as energy audits, to help customers identify and understand potential savings. While these programs are administered by utilities, the services are typically delivered by private sector companies such as Lime Energy, Next Step Living, and CLEAResult. Thanks to energy efficiency improvements, energy consumption by the average U.S. home has decreased over time, dropping 21% from 1980 to 2009 even as the size of homes has grown and the number of electronic devices has proliferated.[81,82]

Utility energy efficiency programs date back to the 1970s and the oil embargo. Now, most utilities, both large investor-owned utilities (IOUs) and smaller cooperatives and municipal utilities, offer efficiency programs or services to their customers. CLEAResult manages over 700 programs for utilities across North America, including several programs for Consumers Energy in Michigan.[83] In 2013, Massachusetts and Vermont both achieved utility program savings equivalent to 2% of electricity consumption for the year; Arizona, Hawaii, and Michigan follow as the leading states for utility energy savings.[84] These high levels of savings are being achieved even in states that have a long history of utility energy efficiency programs, demonstrating that there are savings still available long after the "low hanging fruit" has been plucked.

Despite the fact that utility energy efficiency programs are cost effective, implementation varies across the country. As a result, there remains a large stock of buildings with significant untapped potential for energy savings. At an average levelized cost of saved energy of 2.8 cents/kWh, energy efficiency is 30% to 50% cheaper than additional generation.[85] Utility energy efficiency programs give consumers more control and choice regarding their energy use and costs, while also benefiting the system as a whole by providing a cost-effective alternative to investments in new generation, transmission, and distribution facilities. Many utilities have started deploying advanced analytics (p.39) and advanced metering infrastructure (p.31) to further optimize their customers' energy use. Building efficiency has also emerged as an important sector in the U.S. economy, with an estimated $60 billion in revenue in 2014, much of it driven by utility-run programs and services.[86]

81.) http://www.eia.gov/consumption/residential/reports/2009/consumption-down.cfm?src=%25E2%2580%25B9%20Consumption **82.)** https://www.census.gov/construction/chars/pdf/medavgsqft.pdf **83.)** http://www.clearesult.com/news-events/clearesult-closes-contract-consumers-energy-implement-additional-residential-energy **84.)** http://aceee.org/research-report/u1408 **85.)** http://aceee.org/research-report/u1402 **86.)** http://info.aee.net/aen-2015-market-report

Waste Energy Recovery


Ormat

Waste Energy Recovery (WER) describes any process in which energy that would typically be "thrown away" is captured and put to use. In broad terms, there are three types of waste energy sources suitable for recovery: waste heat, excess pressure in steam and other industrial processes that is normally dissipated, and residual fuel value in industrial process streams (purge gases, off-gases, etc.). WER can be used to generate electricity or to produce thermal energy for industrial processes. Some applications of WER are similar to combined heat and power (CHP; p.7), except that instead of the fuel used by CHP systems, WER uses recovered energy that is otherwise considered waste.

Some examples of WER that generate electricity include waste heat recovery (WHR) from industrial processes and boilers; WHR from mainline natural gas pipeline compressor stations; pressure recovery from industrial steam use; pressure recovery from non-steam, high-pressure industrial processes; and pressure recovery from natural gas pipeline pressure-letdown stations. One example of WER in action is the Port Arthur Steam project in Texas, which uses heat recovered from petroleum coke kilns to produce high-pressure steam. Most of the steam is sold to a neighboring refinery, displacing natural gas use. The rest of the steam is used to produce up to 5 MW of electricity used at the calcining facility.[87] Similarly, Basin Electric Power Cooperative relies on baseload power from WER projects totaling 44 MW in North Dakota, South Dakota, and Montana.[88] Other applications of WER can be found in chemical, petroleum, and forest product industries, drying processes, and metals and mineral manufacturing.

With the industrial sector accounting for approximately one-third of all energy used in the United States, there is ample opportunity for WER to reduce energy usage. In industrial processes, 20% to 50% of the energy is ultimately lost as waste. WER can improve efficiency of industrial processes by as much as 10% to 50%, while generating electricity and useful thermal output that can be used onsite.[89] WER displaces the need for purchased fuels and electricity, thus resulting in fuel cost savings while providing industrial end-users with more control over their total energy use.

87.) http://www.chpcenterpr.org/wasteheat2power07/WH2P07_TOUR.pdf **88.)** http://www.basinelectric.com/Facilities/Recovered-Energy/index.html
89.) https://www1.eere.energy.gov/manufacturing/intensiveprocesses/pdfs/waste_heat_recovery.pdf

WATER EFFICIENCY

Any assessment of advanced energy would be incomplete without also considering the important connections between our energy and water systems. This section briefly explores advanced energy technologies and services that straddle the water-energy nexus. Water is an essential ingredient of daily life, necessary not only for drinking and domestic uses, but also for agriculture, industry, and mining. It is also needed for many forms of power generation, mainly as cooling water for thermal power plants. But that is just one of the ways water and energy are closely connected. Water needs to be pumped or collected, transported, treated, heated or cooled, and collected again and treated after use. These processes require vast amounts of energy, which can be reduced through end-use energy efficiency (e.g., more efficient water heaters, p.42), water use efficiency, and water infrastructure energy efficiency. This section focuses on the latter options, exploring different options for using less energy by using less water, and for saving energy in water treatment and delivery systems. As with building efficiency (p.36), this does not mean sacrificing performance or comfort, but rather maintaining or improving performance while saving water, energy, and money.

Total energy use related to water use is significant, equating to an estimated 3% to 3.5% of total U.S. electricity consumption, not including energy consumed by the end use of water, such as water heating, which brings the figure up to as high as 13%.[1,2] In some areas, water-related energy use is even higher. For example, California's water conveyance needs and high agricultural water use drive water-related energy up to an estimated 19% of electricity consumption; the California Energy Commission estimates that water accounts for 30% of natural gas consumption in the state and approximately 88 million gallons of diesel fuel.[3]

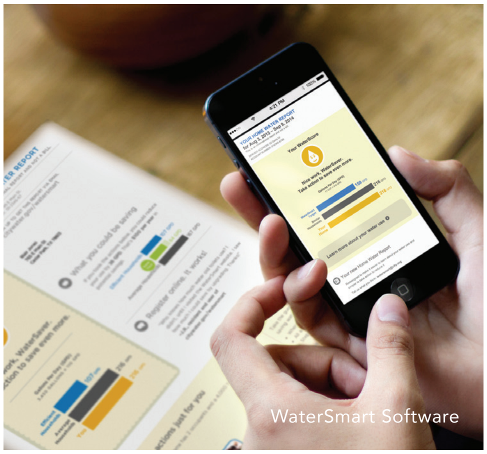
Reducing water-related energy use delivers a number of key benefits to end users of water, as well as to the energy and water systems as a whole. Among other benefits, water efficiency can deliver:

- **Relief for tight municipal budgets** – Energy for potable water and wastewater treatment accounts for about 35% of municipal energy spending.[4] Nationally, this translates to approximately $4 billion in annual spending on energy for drinking water and wastewater treatment — taxpayer money that could be spent on other needs.[5]
- **Cost savings for consumers** – In addition to indirectly benefitting from reduced municipal budgets and directly benefitting from lower water costs, consumers who reduce their water use also save on energy spending. Water heating, in particular, accounts for an estimated 15% of domestic energy consumption.[6] Beyond installing efficient water heating technology, reducing water use also cuts these costs.
- **Preservation of water resources** – Population growth in water-scarce regions has raised concerns about future water supplies, particularly in the southwest. Efficient use of water resources will preserve existing water supplies and extend the useful life of water infrastructure.

1.) http://www.energy.gov/sites/prod/files/2014/07/f17/Water%20Energy%20Nexus%20Full%20Report%20July%202014.pdf **2.)** This estimate by the River Network is based on 2005 water energy use and electricity use data from the EIA and EPRI. http://www.rivernetwork.org/sites/default/files/The%20Carbon%20Footprint%20of%20Water-River%20Network-2009.pdf **3.)** http://www.energy.ca.gov/2005publications/CEC-700-2005-011/CEC-700-2005-011-SF.PDF
4.) http://www.epa.gov/statelocalclimate/documents/pdf/wastewater-guide.pdf **5.)** http://water.epa.gov/infrastructure/sustain/waterefficiency.cfm
6.) http://www.energystar.gov/ia/new_homes/features/WaterHtrs_062906.pdf

- **Reliability and affordability for the electricity system** – Because reduced water infrastructure energy use and reduced water usage also reduce energy demand, water efficiency provides benefits across the electricity system due to lower demand for electricity. These benefits include enhanced energy security, reduced transmission congestion, and avoided infrastructure investments.

Water Conservation


WaterSmart Software

As droughts and population growth have sharpened the focus on water use, water efficiency solutions have emerged across multiple sectors and technologies. The following is an overview of some key solutions for efficient water use:

- **Installing efficient appliances and devices, including low-flow plumbing fixtures, in homes and other buildings** – By using less water, water-efficient appliances and devices reduce the energy required to deliver clean water, and also reduce the energy required to heat and use water on site. If just 10% of homes replaced existing fixtures with water-efficient versions, this would save 1 billion kWh of electricity per year, enough to power nearly 100,000 homes.[7]

- **Deploying water-use monitoring and customer engagement software to realize savings** – Utilizing the data collected at customer meters, water utilities can engage customers and achieve an average of 5% improvement in water efficiency through voluntary actions ranging from shorter showers to reduced lawn and garden irrigation.[8]

- **Reducing reliance on water-intensive electricity generation technologies** – Thermal power plants, which include coal, nuclear, and natural gas facilities, are the single largest source of withdrawals from waterways, reservoirs, and groundwater in the United States, accounting for 161 billion gallons/day in 2010, or 45% of all withdrawals.[9] Water used by these facilities requires energy for pumping, transport, and treatment. Water use by a thermal power plant depends on the cooling system used and the efficiency of the plant, with efficient natural gas combined cycle power plants (p.9) using less water than coal-fired plants. Non-thermal technologies such as wind turbines (p.19) and solar PV (p.17) require no water to generate electricity.[10] As U.S. reliance on natural gas combined cycle, wind, and solar PV surged from 2005 to 2012, water use by thermal power plants dropped 36%.[11]

- **Recycling and reusing wastewater, generally on-site** – Rather than discharging used water for treatment by a centralized facility such as a municipal wastewater treatment plant, wastewater can be treated and re-used on-site. This water is often called gray water, and can meet needs such as irrigation of non-food crops, industrial cooling processes, toilet flushing, and irrigation of food crops, depending on the level of treatment it receives. Recycling water cuts down on energy to transport and treat water both before and after use.[12]

- **Installing advanced irrigation systems and implementing on-site water management** – At 115 billion gallons/day, irrigation is the second largest source of water withdrawals in the United States, and the largest consumer of water, accounting for 80% to 90% of consumptive water use.[13,14] While investment in

7.) http://water.epa.gov/infrastructure/sustain/waterefficiency.cfm **8.)** http://www.watersmart.com/media/behavioral-water-efficiency-report/?code=850DK275&-submissionGuid=9f2d1441-561d-4004-b557-f3ca8e575994 **9.)** http://pubs.usgs.gov/circ/1405/ **10.)** http://water.worldbank.org/sites/water.worldbank.org/files/publication/World-Bank-Presentation-Anna-Delgado-UNWater-Thirsty-Energy-2014.pdf **11.)** http://www.climatecentral.org/news/water-use-declines-as-natural-gas-grows-19162?utm_source=feedburner&utm_medium=feed&utm_campaign=Feed%3A+climatecentral%2FdjOO+Climate+Central+-+Full+Feed **12.)** http://www.epa.gov/region9/water/recycling/ **13.)** http://pubs.usgs.gov/circ/1405/ **14.)** http://www.ers.usda.gov/media/884158/eib99.pdf advanced irrigation systems is growing — up 92% from 2003 to 2008 — over half of irrigated cropland in the United States still relies on less-efficient, older irrigation systems, and only 10% of farms utilize advanced water management tools.[15] Pumping irrigation water accounted for $2.7 billion in on-farm spending in the United States in 2012, and reducing the amount of water pumped would cut back on these costs.[16]

- **Using rainwater collection systems** – Rainwater harvesting (RWH) involves capturing, diverting, storing, treating, and distributing rainwater for use. RWH can be used to meet a variety of water needs, including in-home use, landscaping, livestock, and fire protection.[17]
- **Investing in infrastructure improvements and repairs** – On average, water treatment and distribution systems lose 14% of water through leaks — in some systems this figure is as high as 60%.[18] By conducting a water audit, utilizing leak detection equipment, repairing leaks, and implementing effective operations and maintenance programs, municipalities can minimize these losses and reduce energy use for treating and transporting water that is lost along the way.[19]

Water utilities, businesses, farmers, and consumers across the country are already taking advantage of these solutions. After increasing steadily from mid-century (when the United States Geological Survey began tracking water use), total water use has remained relatively constant since 1985, and from 2005 to 2010 dropped 13% to reach pre-1970 levels.[20] These water savings translate to energy and cost savings. The small town of Gallitzin, Pennsylvania, saved a total of $25,000 annually — a 60% reduction in energy costs and a 50% drop in chemical costs — when it reduced water use by 60% over the course of four years through leak detection alone. In Massachusetts, a more comprehensive conservation program including not only leak detection but also home retrofits, water management programs, improved metering infrastructure, and updated plumbing codes, resulted in estimated savings of $111 million to $153 million at upfront costs of $20 million. The savings came from deferred investments in water supply and treatment infrastructure.[21] Despite progress in some municipalities, there is still potential for dramatic improvement across the country.

Data and management technologies used to reduce energy use, such as advanced metering infrastructure (AMI; p.31), are also increasingly used to control and reduce water use. For example, using AMI in conjunction with WaterSmart Software, a data analytics platform for water utilities, Park City Water in Utah is now able to provide real-time leak alerts to customers; in three months, the utility delivered over 150 alerts, and 70% were resolved within 10 days.[22] Using the same software, the city of Greeley, Colorado, was able to reduce water use by 4% during a time of drought through voluntary actions alone.[23] The Pacific Institute estimates that cost-effective measures can reduce urban water use by 30% in California.[24] Applying these savings across the country would result in nearly 54,000 million kWh saved, representing over $5 billion in cost savings and enough electricity to power nearly 5 million homes.[25,26] Reducing agricultural, industrial, and power sector water use would deliver even higher energy savings. In addition to reducing water use, reusing water also delivers huge savings. Under a public-private partnership with Veolia Water, Oklahoma City has saved residents over $150 million since 1985 through a water reuse program. At the same time, the program saves money for large water users including two local electric utilities by supplying them with reuse water, which is 33% cheaper than drinking water.[27]

15.) http://www.ers.usda.gov/media/884158/eib99.pdf **16.)** http://www.agcensus.usda.gov/Publications/2012/Online_Resources/Farm_and_Ranch_Irriga-tion_Survey/fris13.pdf **17.)** http://rainwaterharvesting.tamu.edu/ **18.)** http://water.epa.gov/infrastructure/sustain/wec_wp.cfm **19.)** http://water.epa.gov/type/drink/pws/smallsystems/upload/Water_Loss_Control_508_FINALDEc.pdf **20.)** http://water.usgs.gov/watuse/wutrends.html **21.)** http://nepis.epa.gov/Exe/ZyPDF.cgi/200041CI.PDF?Dockey=200041CI.PDF **22.)** http://www.watersmart.com/partner-story/park-city-utah-leveraging-ami-real-time-leak-alerts/ **23.)** http://www.watersmart.com/partner-story/right-sizing-water-budgets-with-analytics/ **24.)** http://www.pacinst.org/wp-content/uploads/sites/21/2013/02/waste_not_want_not_full_report3.pdf **25.)** http://aceee.org/sites/default/files/watts-in-drops.pdf **26.)** Cost and home equivalents based on EIA data for average electricity price across all sectors (9.84 cents/kWh in 2013, EIA-861; http://www.eia.gov/electricity/sales_revenue_price/) and average household energy use (10,908 kWh in 2013; http://www.eia.gov/tools/faqs/faq.cfm?id=97&t=3). **27.)** http://www.veolianorthamerica.com/en/news/boost-savings-water-reuse

Water Infrastructure Energy Efficiency


U.S. Army Corps of Engineers Chicago District

Drinking water treatment systems and wastewater treatment plants account for approximately 3% of electricity use in the United States, or 100 billion kWh annually — enough to power over 9 million homes. These facilities have several options to reduce their electricity use, with potential savings estimated at 15% to 30% nationally. In water treatment systems, approximately 80% of electricity is used for pumping, so savings come mostly from pumps, motors, and variable-frequency drives.[28] By allowing motors to adjust to fluctuating pumping needs, variable-frequency drives can reduce electricity use by up to 50% while also extending motor life.[29] In wastewater treatment plants, electricity is used mostly for aeration, pumping, and solids processing, while thermal energy is required for digesters. Here, too, variable frequency drives can reduce energy use for pumping and aeration, while technologies such as fine-bubble diffusers can reduce energy needed for aeration.[30]

Facilities can also reduce electricity purchased from the grid by using on-site generating technologies such as solar (p.16), wind (p.19), in-conduit hydro (p.11), or combined heat and power (CHP, p.7), which in wastewater treatment plants is often fueled by biogas produced as part of the treatment process.[31] Deer Island Wastewater Treatment Plant in Massachusetts uses all these technologies.[32]

There are approximately 200,000 drinking water treatment systems and 15,000 wastewater treatment facilities across the country, not including industrial facilities, and some have already achieved significant progress in energy management.[33] By using variable-frequency drives from ABB for aeration, the Beloit Water Pollution Control Facility in Wisconsin reduced its electricity consumption by 15%.[34] The Encina Wastewater Authority in California achieved even greater savings, using fine-bubble diffusers for aeration, variable-frequency drives, energy-efficient motors, CHP, and off-peak pumping.[35] In New York, the City of Rome partnered with Johnson Controls to install a fine bubble aeration system and variable speed drives.[36]

Energy for potable water and wastewater treatment can account for 30% to 40% of energy use for municipalities that operate these facilities.[37] Energy efficiency and on-site generation bring huge cost savings: in Beloit, Wisconsin, the water pollution control facility expects to save $75,000 annually; the changes in Encina are estimated to save the facility over $600,000 each year; by making use of a performance contract (p.46), the City of Rome will achieve $8.6 million in benefits over 15 years without raising taxes; the Deer Island plant in Massachusetts saves $3.5 million in electricity costs and $15 million in fuel oil costs annually, and generates $500,000 in revenue from participating in demand response markets, reducing pumping at times of peak demand.

28.) http://library.cee1.org/sites/default/files/library/2650/ww-init-des.pdf **29.)** http://www.energy.ca.gov/process/pubs/vfds.pdf **30.)** http://library.cee1.org/sites/default/files/library/2650/ww-init-des.pdf **31.)** http://www3.epa.gov/statelocalclimate/documents/pdf/wastewater-guide.pdf **32.)** http://www.mwra.com/03sewer/html/renewableenergydi.htm **33.)** https://www.fas.org/sgp/crs/misc/R43200.pdf **34.)** https://library.e.abb.com/public/ab4ba554eaebaeb-8c1257a0f002796f8/CN_City%20of%20Beloit_lowres.pdf **35.)** http://www.energy.ca.gov/process/pubs/encina.pdf **36.)** http://www.johnsoncontrols.com/content/dam/WWW/jci/be/case_studies/cityofrome.pdf **37.)** http://www3.epa.gov/statelocalclimate/local/topics/water.html

TRANSPORTATION

Since its invention, the automobile has defined the American way of life. The basic enabling technology — the internal combustion engine (ICE) — has allowed for the efficient transport of goods and services that is key to American prosperity. The fact that the majority of our transport needs are still met with the same basic engine technology installed on Henry Ford's production line over 100 years ago is a testament to the versatility of the ICE, which has seen huge advances in performance and fuel economy over the years. Even as such improvements continue, new technologies are gaining momentum, with companies such as Tesla, BMW, Nissan, and others introducing alternatives using different technologies.

These innovations have made advanced transportation the second largest advanced energy segment globally, with an estimated $373 billion in revenue worldwide in 2014.[1] Progress and innovation in advanced transportation are reducing many of the barriers that have, until now, prevented more widespread adoption of these technologies, such as range anxiety, higher upfront costs, and refueling infrastructure.

Advanced transportation covers six vehicle platforms. Each of these choices has unique advantages and benefits, allowing consumers and companies to select transportation options that fit their individual needs. Clean diesel vehicles offer high efficiency without sacrificing performance, enabling cost savings across different transport applications. Hybrid electric vehicles offer significant fuel savings and a longer driving range compared with conventional gasoline vehicles. Plug-in electric vehicles can achieve greater than 100 mpg-equivalent fuel economy while offering excellent performance and improved range over earlier electric vehicles. Hydrogen vehicles eliminate the need for gasoline, and provide a long driving range and short refueling time. Advanced gasoline engine vehicles incorporate a variety of enhancements that provide increased fuel economy, and serve as an alternative to hybrid electric vehicles, offering consumers more choices when looking for higher fuel economy. Natural gas vehicles run on cheap and abundant natural gas, providing high performance and cost savings. In addition to these six platforms, autonomous or "self-driving" vehicles have the potential to transform the entire transportation system by improving fuel economy due to more efficient handling and reduced congestion while boosting economic activity by providing more time for work or entertainment.[2]

While each advanced transportation technology has its own distinct advantages, the suite of technologies covered here together provide a number of benefits:

- **Consumer choice** – Rather than choosing a vehicle just based on size or performance, consumers can now also consider fuel economy, fuel source, and fuel cost.
- **Cost savings** – While some advanced transportation options have higher upfront costs, their lower fuel costs and higher fuel economy can quickly generate net savings — even within the first two or three years.
- **Energy security** – Advanced transportation technologies bolster energy security by offering alternatives to petroleum-based fuels or by using these fuels more sparingly. Transportation accounts for over 70% of total U.S. petroleum consumption, and even with domestic production on the rise we still import

1.) http://info.aee.net/aen-2015-market-report **2.)** https://www.kpmg.com/US/en/IssuesAndInsights/ArticlesPublications/Documents/self-driving-cars-next-revolution.pdf about one-third of the petroleum we consume.[3] Advanced vehicle technologies help to diversify our fuel portfolio, decrease reliance on petroleum, and insulate American consumers from the economic rollercoaster that is the global oil market.

- **Market competition** – As advanced transportation options grow in market share, the transport sector is becoming increasingly diverse, driving competition and improvement in both conventional and new technologies.

3.) http://www1.eere.energy.gov/analysis/transportationenergyfutures/

Clean Diesel Vehicles

Ford Motor Company

Diesel engines are compression-ignition engines, meaning that they work by compressing air in the cylinders to heat it beyond the auto-ignition temperature of diesel fuel. When fuel is injected, combustion occurs without an external ignition source (such as a spark plug). Due to the higher compression ratio used in diesel engines and the higher energy content of diesel fuel, diesel engines can achieve 35% higher fuel economy than gasoline engines. Clean diesel engines are quieter, more efficient, more reliable, and cleaner than older diesel vehicles, thanks to innovations such as allowing for higher fuel-air mixing prior to combustion and the addition of re-circulated exhaust gas to the intake air stream.[4] In addition, electronic controls and sensors throughout the vehicle ensure that just enough fuel is injected exactly when it is needed, improving efficiency.[5] Using ultra-low-sulfur diesel fuel and exhaust treatment mechanisms such as on-board particulate traps and catalytic converters, clean diesel vehicles can achieve tailpipe emissions comparable to gasoline vehicles.[6] The revelation of a “defeat device” in Volkswagen diesel cars in 2015 has called into question the emissions performance of clean diesel cars, though there is currently no evidence that other manufacturers have used similar tactics to circumvent U.S. tailpipe emission standards. [7] The use of this device by one manufacturer does not negate the significant improvements in recent years with diesel vehicles of all classes.

Over 90% of heavy-duty vehicles in the United States are powered by diesel, and of these approximately one-third are clean diesel vehicles. Indiana, Utah, Oklahoma, Texas, and Wyoming lead the nation with clean diesel vehicles accounting for over 40% of heavy-duty trucks in those states.[8] Diesel is not as popular for passenger vehicles, accounting for less than 3% of the U.S. market; however, this is expected to grow to 7% by 2020.[9] Numerous clean diesel light-duty and medium-duty vehicles are now available, including models by BMW, Jeep, Ford, GMC, and Chevrolet.[10] Outside the major automobile manufacturers, companies like Bosch have contributed improvements in various components of clean diesel trucks, vans, busses, and cars, from electronic engine controls to web-enabled operating efficiency to high-pressure injection systems.[11] In addition, clean diesel technology can be used in rail and marine propulsion. For example, General Electric has introduced clean diesel locomotive and marine engines.[12]

Because clean diesel engines improve fuel efficiency, they can contribute to significant cost savings over the life of a vehicle; a 2013 study estimated the three to five year total cost of ownership for light-duty diesel vehicles was typically $2,000 to $6,000 lower than that of equivalent gasoline-fueled vehicles, even after accounting for the higher initial cost.[13] While cost savings are beneficial for owners, fuel savings also promote national energy security. If just one-third of U.S. passenger cars had diesel engines, petroleum consumption would decrease by up to 1.4 million barrels per day, equal to the amount of oil imported from Saudi Arabia.[14]

4.) http://energy.gov/eere/vehicles/vehicle-technologies-office-advanced-combustion-strategies#clean_diesel **5.)** http://www.economist.com/blogs/babbage/2013/07/diesels?fsrc=nlw|newe|7-8-2013|6081501|35681664| **6.)** http://www.dieselforum.org/about-clean-diesel/what-is-clean-diesel- **7.)** http://www.nytimes.com/2015/09/27/business/as-vw-pushed-to-be-no-1-ambitions-fueled-a-scandal.html?_r=0 **8.)** http://www.dieselforum.org/index.cfm?objectid=090207D5-01F9-11E4-91B7000C296BA163 **9.)** http://www.prnewswire.com/news-releases/california-texas--florida-continue-to-lead-us-in-fuel-efficient-clean-diesel--hybrid-vehicle-registrations-300053147.html **10.)** http://www.dieselforum.org/resources/clean-diesel-vehicles-currently-available-in-the-u-s- **11.)** http://www.bosch-mobility-solutions.us/en_us/us/powertrain_1/powertrain_systems_for_passenger_cars_2/diesel_3/diesel_3.html# **12.)** http://www.getransportation.com **13.)** http://www.dieselforum.org/news/new-study-finds-u-s-diesel-vehicles-have-lower-total-cost-of-ownership-than-gasoline-vehicles **14.)** http://www.dieselforum.org/files/dmfile/EnergyEfficiencyEnergyIndependence.pdf

Hybrid Electric Vehicles


Ford Motor Company

Hybrid electric vehicles (HEVs), commonly called "hybrids," are powered by a combination of a conventional internal combustion engine (typically gasoline-fueled) and a battery-powered electric motor, usually featuring a nickel-metal hydride or lithium-ion battery. The hybrid drivetrain works in several ways to improve fuel economy. Having a larger battery than a conventional vehicle allows the engine to turn off at low speeds, when driving downhill, and while idling. Since the electric motor can assist with acceleration, a smaller gasoline engine is used, which reduces fuel consumption. The integrated system also allows the gasoline engine to operate in a more efficient power range. When braking, the electric motor can run "backward" and act as a generator in a process called regenerative braking. This feature extends the vehicle's electric capacity by charging the battery with energy that is normally lost to friction in the brakes. HEVs do not plug in to recharge the batteries, and the batteries are not sized to provide significant electric-only range. Instead, the combination of regenerative braking and overall drivetrain optimization result in improved fuel economy.[15] Some of the best selling hybrids include the Toyota Prius, Honda Accord Hybrid, Ford Fusion, and the Lexus GS Hybrid, and new hybrid models are introduced by automakers every year.[16]

In 2014 there was strong worldwide growth in revenue from hybrid vehicle sales, which rose by more than 40% to $74 billion. The United States was an early adopter of HEV technology and in 2014 accounted for 16% of the total market.[17] HEV sales in the United States have increased from almost zero a decade ago to a little over 450,000 units in 2014, or about 2.7% of total vehicle sales.[18] HEVs today cost slightly more than traditional vehicles, but as battery costs decline and manufacturing scales up, vehicle costs are expected to fall. Hybrid vehicles offer significant benefits for stop-and-go traffic, which lends the technology to commercial applications such as city buses and local delivery trucks. The United Parcel Service (UPS) has deployed 380 HEVs in states across the country, including Alabama, New Jersey, Minnesota, and Kentucky. These vehicles deliver a 35% improvement in fuel efficiency.[19] Global sales of electric and hybrid electric buses (with hybrid diesel engines) are expected to increase from 16,000 units in 2014 to nearly 163,000 by 2023.[20]

HEVs offer significant economic benefits via fuel savings, with the most efficient light-duty HEV getting 50 mpg.[21] Average fuel costs for a 100-mile trip are estimated at 65% of a conventional vehicle.[22] These fuel savings mean that HEVs also help to decrease domestic reliance on imported petroleum.

15.) http://www.afdc.energy.gov/vehicles/electric_basics_hev.html **16.)** http://usnews.rankingsandreviews.com/cars-trucks/rankings/Hybrid-Cars/ **17.)** http://info.aee.net/hs-fs/hub/211732/file-2583825259-pdf/PDF/aen-2015-market-report.pdf **18.)** http://electricdrive.org/index.php?ht=d/sp/i/20952/pid/20952 **19.)** http://pressroom.ups.com/Fact+Sheets/Saving+Fuel%3A+Alternative+Fuels+Drive+UPS+to+Innovative+Solutions **20.)** http://www.navigantresearch.com/research/electric-drive-trucks-and-buses **21.)** http://www.fueleconomy.gov/feg/hybridCompare.jsp **22.)** http://www.afdc.energy.gov/vehicles/electric_emissions.php

Plug-in Electric Vehicles


genZe and Chevrolet Volt

Plug-in electric vehicles (PEVs) are emerging as an important vehicle platform in the United States and globally. PEVs are powered completely or in part by batteries (typically lithium-ion) that can be recharged with power from the electric grid. PEVs include 100% battery electric vehicles (BEVs) such as the Nissan Leaf and Tesla Model S, and plug-in hybrid electric vehicles (PHEVs) such as the Chevy Volt and Toyota Prius Plug-in, which contain both a battery and a gasoline-powered engine. BEVs typically have ranges of about 80 to 250 miles, while PHEVs have electric-only ranges of about 20 to 40 miles, after which they operate on gasoline, giving them a driving range equivalent to any gasoline-powered vehicle. As with hybrid electric vehicles (p.57), all PEVs take advantage of regenerative braking to extend electric range.

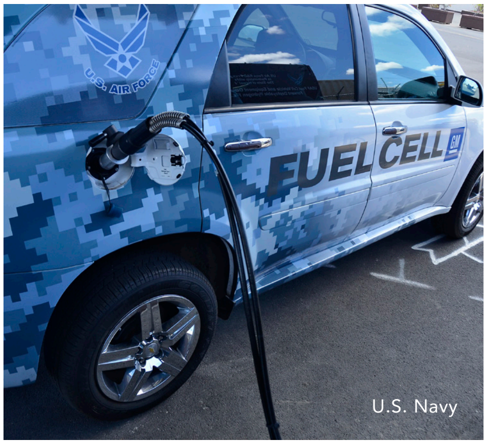
Although sales of PEVs are relatively small, the market is growing. U.S. sales were just under 120,000 units in 2014, or about 0.7% of total vehicle sales, up from approximately 96,000 in 2013.[23] These sales represent significant market growth, with U.S. revenue jumping from $700 million to $4.8 billion between 2011 and 2014, including a 34% increase between 2013 and 2014 alone. The United States remains the leading country for PEV sales, with an estimated 39% of the global market share.[24]

The upfront cost of PEVs is higher than traditional vehicles, with battery cost the main driver of the higher purchase price. As battery costs decline and manufacturing scales up, vehicle costs are expected to fall. Higher upfront costs are offset by the very high efficiency of electric drivetrains, which can achieve gasoline-equivalent fuel economy in excess of 100 mpg.[25] Both PHEVs and BEVs provide economic benefits from fuel cost savings, with BEVs also offering reduced maintenance costs resulting from the overall simplicity of an all-electric drive train. In addition, electric drive trains are smoother and quieter, and provide faster acceleration than conventional mechanical drive trains.[26]

As PEV markets grow, consideration must be given to the impacts of vehicle charging on the electricity grid. Smart integration of vehicle charging with the grid can avoid capacity shortfalls and save customers money by facilitating charging with lower-cost off-peak power. With eventual full, bi-directional integration with the grid, PEVs can also be used for energy storage, providing grid support functions such as peak shaving, load shape smoothing, renewables integration, and power quality services (see p.29). As the size of the PEV fleet grows, the ability to aggregate and manage vehicles in a coordinated fashion has the potential to amplify these benefits. Using PEV batteries as storage for grid support is currently in deployment in a number of pilot projects around the country, including work by the U.S. Army and the National Renewable Energy Laboratory at Fort Carson, Colorado, and by the University of Maryland in partnership with NRG and BMW.[27]

23.) http://electricdrive.org/index.php?ht=d/sp/i/20952/pid/20952 **24.)** http://info.aee.net/hs-fs/hub/211732/file-2583825259-pdf/PDF/aen-2015-market-report.pdf **25.)** http://www.epa.gov/fueleconomy/overall-high.htm **26.)** https://www.fueleconomy.gov/feg/evtech.shtml **27.)** http://www.nytimes.com/2013/04/26/business/energy-environment/electric-vehicles-begin-to-earn-money-from-the-grid.html?_r=1

Hydrogen Vehicles



U.S. Navy

Hydrogen vehicles are either fuel cell vehicles (FCVs) or internal combustion engine (ICE) vehicles designed to burn hydrogen instead of gasoline. FCVs are actually electric vehicles in which the electricity is produced on board by fuel cells — electrochemical devices that convert hydrogen and oxygen (in the air) directly into electricity without combustion (p.8). Pure hydrogen gas (p.68) is stored onboard the vehicle in pressurized tanks or other means. FCVs can be refilled within 10 minutes at a hydrogen fueling station. FCVs have a range of approximately 300 miles, similar to conventional ICE vehicles, and produce only water as a byproduct. There has also been some development of hydrogen-fueled ICE vehicles, which offer high fuel efficiency and very low tailpipe emissions.

Major auto manufacturers including Toyota, Mercedes-Benz, Hyundai, Honda, and General Motors have developed passenger FCVs for pilot deployment. In addition, there are several medium- and heavy-duty hydrogen FCVs available on the market, including transit buses and tractors.[28] However, before FCVs or hydrogen ICE vehicles can reach widespread commercial use, fueling infrastructure must be developed. Currently, there are 48 public and private hydrogen fueling stations spread across 17 states, with public stations in California, South Carolina, and Connecticut.[29] While FCVs have not reached widespread deployment for passenger vehicle applications, the technology is road-ready, with some of GM's test fleet vehicles exceeding 120,000 miles and enduring winter conditions.[30]

FCVs offer some advantages over plug-in electric vehicles (PEVs); namely, their longer driving range and short refueling time. Like PEVs, hydrogen-fueled vehicles provide consumers with alternatives to petroleum, and if deployed widely FCVs would enhance fuel diversity and energy security. Hydrogen FCVs are more expensive than gasoline-powered vehicles but are rapidly becoming more competitive, with fuel cell system costs for FCVs dropping 56% from 2006 to 2012.[31] Companies including Walmart, Sysco, Coca-Cola, and Kroger are already investing in fuel cell technology for their operational needs, using hydrogen to power forklifts, which has emerged as a cost-effective early application. Sysco has over 600 hydrogen fuel cell forklifts in its Texas, Virginia, and Pennsylvania facilities, reducing maintenance costs on its forklift fleet. In the first year, 100 fuel cell forklifts also saved the company $100,000 in labor costs due to short refueling times compared with the former fleet of battery-operated forklifts.[32]

28.) http://cta.ornl.gov/vtmarketreport/pdf/2014_vtmarketreport_full_doc.pdf **29.)** http://www.afdc.energy.gov/fuels/stations_counts.html **30.)** http://media.gm.com/media/us/en/gm/news.detail.html/content/Pages/news/us/en/2014/May/0507-fuel-cell.html **31.)** http://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/accomplishments.pdf **32.)** http://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/business_case_fuel_cells_2011.pdf

Advanced Gasoline Internal Combustion Engine Vehicles

As the dominant technology for passenger vehicles for over 100 years, gasoline-powered internal combustion engine (ICE) vehicles continue to improve their fuel efficiency and performance in dramatic ways. In addition to general improvements to reduce vehicle weight and improve drivetrain efficiency, several engine innovations are at various stages of development and commercial deployment. Three of these innovations are covered here: low-temperature combustion (LTC), lean burn gasoline combustion, and direct fuel injection.

LTC is a staged, flameless, lower-temperature combustion process that works by compressing a diluted fuel-air mixture until it auto-ignites. The mixture uses less fuel than normal because it is diluted with intake air or recycled exhaust gases. In addition, the lower temperature and staged combustion results in less wasted heat. Lean-burn gasoline combustion — in which fuel is burned with excess air — uses a similar diluted fuel mixture along with direct fuel injection, spraying fuel into the engine instead of through an intake port.[33] Direct fuel injection reduces fuel use and improves efficiency and power.

There are currently no light-duty LTC engines on the market, but Nissan and Toyota have both developed heavy-duty diesel-fueled LTC engines.[34] Lean-burn gasoline engines have also been slow to market, partly because lean-burn technology is not compatible with current catalytic converters, which require a near one-to-one air-fuel ratio. In 2006, Mercedes-Benz and BMW both introduced lean burn engines in Europe that achieved fuel economy improvements of up to 20%.[35] Direct fuel injection is already common with diesel engines and is becoming more popular with gasoline engines.[36]

Advanced gasoline ICE vehicles are considerably more efficient than conventional vehicles and have been shown to improve fuel economy by up to 75%.[37] Direct fuel injection alone can improve fuel economy by up to 20% and in combination with lean burn technology can improve fuel economy by up to 35%.[38,39] Advanced gasoline ICE vehicles provide one more option for consumers looking for higher fuel economy. Because they represent incremental improvements to a well-developed vehicle platform, they are a seamless and cost-effective option to increase energy security and save consumers money. Moreover, innovations made here can eventually find their way into other vehicles platforms, such as hybrid vehicles, resulting in even greater fuel economy overall.

33.) In a typical gasoline engine, fuel and air are mixed in a proportion very close to the precise amounts needed to fully combust the fuel, such that after combustion there is almost no oxygen left in the exhaust gases. In lean burn engines, "excess air" means that more air is mixed with the fuel than is required to fully combust the fuel. **34.)** http://www1.eere.energy.gov/vehiclesandfuels/pdfs/program/acec_roadmap_june2013.pdf **35.)** http://www1.eere.energy.gov/vehiclesandfuels/pdfs/program/acec_roadmap_june2013.pdf **36.)** http://www.cnet.com/news/whats-so-great-about-direct-injection-abcs-of-car-tech/ **37.)** http://energy.gov/eere/vehicles/vehicle-technologies-office-advanced-combustion-engines **38.)** http://www.autos.ca/auto-tech/auto-tech-direct-fuel-injection-vs-port-fuel-injection/ **39.)** http://energy.gov/eere/vehicles/vehicle-technologies-office-advanced-combustion-strategies

Natural Gas Vehicles

Ford Motor Company

Natural gas vehicles (NGVs) are internal combustion engine vehicles designed to run on either Compressed Natural Gas (CNG) or Liquefied Natural Gas (LNG) (see p.67). There are three basic categories of NGVs: dedicated, bi-fuel, and dual-fuel. Dedicated NGVs are the most efficient as they are designed from the ground up to run only on natural gas. In contrast, both bi-fuel and dual-fuel NGVs have two separate tanks, one for natural gas and another for diesel or gasoline. Bi-fuel NGVs can run on either natural gas or a petroleum fuel (either diesel or gasoline), switching automatically when one fuel runs out. Bi-fuel technology is typically used in light-duty vehicles. Dual-fuel NGVs run on a mixture of natural gas and diesel. They rely mostly on natural gas, but use a small amount of diesel to aid in fuel ignition. Dual-fuel NGVs are more expensive, but their higher efficiency makes them an attractive option for heavy-duty vehicles. Most NGVs rely on less-expensive CNG, but some vehicles used for long-haul trucking run on LNG because its higher energy density increases driving range.[40]

There are an estimated 150,000 NGVs in use in the United States today.[41] Because both CNG and LNG vehicles rely on dedicated fueling infrastructure, NGV technology is most commonly used for vehicles operating within a limited geographic area (transit buses, taxis and delivery vehicles) or along predictable routes (long-haul trucks). Several U.S. cities have introduced CNG transit bus fleets, including Phoenix, Los Angeles, Fort Worth, Dallas, and Atlanta.[42] Now that natural gas prices have fallen, several vehicle manufacturers, including Honda, Ford, General Motors, and Chrysler, are also beginning to offer NGV versions of popular light-duty models. In addition to fueling on-road vehicles, natural gas can also power rail and marine vehicles. General Electric (GE) offers a natural gas retrofit kit that enables locomotives to run on both diesel and LNG using dual-fuel technology.[43]

While NGVs are more expensive than equivalent gasoline or diesel vehicles, they can deliver significant lifetime savings due to lower fuel costs; for example, GE's LNG dual-fuel locomotives can reduce fuel costs by 50%. Especially for heavy-duty vehicles with high annual mileage, even a relatively small fuel price differential adds up, resulting in payback periods as short as 12 to 15 months and significant savings over the life of a vehicle.[44] The Dallas Area Rapid Transit (DART) system expects to save $120 million in fuel costs over 10 years by switching to CNG buses fueled by locally sourced natural gas.[45] In addition, both new and retrofitted NGVs provide consumers and businesses with alternative fuel options. In particular, bi-fuel NGVs allow operators to switch between fuels according to price, fuel availability, and other criteria. On a national scale, the adoption of NGVs also increases fuel diversity, boosts energy security, and delivers cost savings.

40.) http://www.afdc.energy.gov/vehicles/natural_gas.html **41.)** http://www.afdc.energy.gov/vehicles/natural_gas.html **42.)** http://www.cngnow.com/vehicles/fleets/Pages/information.aspx **43.)** http://www.getransportation.com/blog/nextfuel%E2%84%A2-natural-gas-retrofit-kit-future-here **44.)** For example, a long-haul truck averaging 6mpg may travel 120,000 miles per year, consuming 20,000 gallons of diesel per year. If diesel costs $3.06/gallon and CNG, $2.11/GGE, then the annual saving would be $19,000. Incremental costs for natural gas-powered trucks can be as low as $15,000-$20,000. http://www.truckinginfo.com/article/story/2012/10/natural-gas-what-fleets-need-to-know-part-3-whats-the-payback.aspx **45.)** http://www.metro-magazine.com/blogpost/240275/switching-fleet-to-cng-was-carefully-weighed-decision-for-dart

FUEL PRODUCTION & DELIVERY

Movement of people and goods is critical to the smooth functioning of our economy, and personal transportation is central to our way of life. This mobility requires a lot of energy, with transportation accounting for approximately 27% of total primary energy use in the United States, most of which is petroleum.[1] Nevertheless, several alternatives to petroleum have reached a high level of technological maturity, with some options now displacing meaningful quantities of petroleum-based fuels. In the United States today, the total annual production of these alternative fuels is approximately 12 billion gallons of gasoline equivalent,[2] which represents about 6.5% of total transportation fuel (gasoline and diesel) consumption. These fuel options provide enhanced energy security, greater opportunities to manage price volatility, a more competitive market for fuel and transportation technologies, and greater consumer choice.

The fuels covered in this section include both liquid and gaseous fuels that provide energy for transportation, though some are also used in stationary applications, such as space heating and electricity generation. Some of these fuels have properties that differ from conventional fuels and require dedicated infrastructure for transportation and refueling, although the technologies and systems used in that infrastructure are largely the same as those used for conventional fuels.

Fuel production is best discussed in terms of the fuel pathway. There are three main characteristics that define a fuel pathway: the feedstock (resource), conversion process, and fuel type. For example: corn-fermentation-ethanol, natural gas-liquefaction-LNG, or electricity-electrolysis-hydrogen. For biofuels, depending on the combination of the three, a pathway can either be considered "first generation," "second generation," or "third generation." Natural gas is also a growing source of transportation fuel that is particularly well suited to fleets (compressed natural gas - CNG) and long-haul trucking (liquefied natural gas - LNG). Finally, hydrogen has been in development as a fuel because it can be produced from any energy resource and can be used with high efficiency and no emissions (other than water) in fuel cell vehicles.

The advanced fuels covered in this section provide several benefits to our transportation system and economy as a whole, including:

- **Energy security** – Despite the strategic importance of a stable supply of energy for transport, the United States remains approximately 90% dependent on petroleum, a global commodity subject to significant geopolitical risk. Advanced fuels are typically made from renewable biomass (plant matter) or natural gas, both of which are abundant and produced domestically, and are much less vulnerable to global supply risks than petroleum.
- **Buffer against price volatility** – In addition to geopolitical risk, the petroleum market is subject to global supply and demand fluctuations. While increasing domestic petroleum production is helping to reduce prices and increase supplies, the risk of price spikes and supply disruptions persists. The fuels covered in this section provide a hedge against these risks.

1.) http://www.eia.gov/totalenergy/data/monthly/index.cfm#consumption **2.)** Because different fuels have different energy content, it is common to express quantities in gallons of gasoline equivalent. Where this is done in this report, the term "gge" is used. Otherwise, the volumes given are actual gallons. For example, one gallon of ethanol (84,530 Btu/gallon) is approximately equal to 0.68 gge, where conventional gasoline contains about 124,340 Btu/gallon.

- **Increased competition** – As the share of non-petroleum fuels increases, the diverse marketplace of fuel choices is enhancing competition and driving further innovation.
- **Greater consumer choice** – In a sector dominated for decades by gasoline and diesel, advanced fuels have given consumers new choices for transport fuels and technologies (p.54).
- **Jobs and economic growth** – While the United States has historically relied on imported petroleum for a significant share of transportation energy, the fuels outlined in this section are homegrown and locally produced. Biofuels, in particular, bring jobs and economic growth to rural areas, while hydrogen can be produced at scales ranging from large central plants down to individual homes.

First Generation Biofuels (Ethanol and Biodiesel)


Siouxland Ethanol plant on U.S. Highway 20 west of Jackson, Nebraska.

First generation biofuels are liquid transportation fuels produced from existing food crops. In the United States, these are ethanol, derived mainly from corn via fermentation, and biodiesel, produced mainly from soybeans via transesterification. Both of these fuel pathways are well integrated into the agricultural economy, producing a range of co-products such as high-protein animal feed. These two fuels have well-developed production technologies and supply chains, and incremental improvements have increased yields and reduced costs. In particular, the ethanol yield (measured in gallons per bushel) has steadily increased over the years, and the energy inputs (typically electricity and natural gas) required to produce a gallon of ethanol have fallen by more than one third in the past 20 years.[3] Other innovations, such as using field crop residues and other sources of biomass in place of natural gas, have further increased the "energy yield" of corn ethanol (the energy produced as ethanol compared to the fossil fuel inputs to the process). Small amounts of biodiesel are also made from waste cooking oil collected from commercial food establishments.

First generation biofuels account for a meaningful share of transport fuel use. By volume, ethanol represents approximately 10% of the U.S. gasoline pool, and biodiesel about 3% of the diesel pool. Total production in 2014 was 14.3 billion gallons of ethanol and 1.4 billion gallons of biodiesel.[4,5] The market for first generation biofuels has been relatively flat the past few years due to practical limitations on how much biofuel can be blended with conventional fuel without requiring vehicle modifications. Ethanol can be used in existing gasoline internal combustion engines in blends up to 10% (E10), although extensive testing on blends up to 15% (E15) has shown that cars built in 2001 or later can use this higher blend. So-called flex-fuel vehicles (FFVs) can burn a mixture as high as 85% ethanol (E85), and over 17 million FFVs are on the road today.[6] Biodiesel is typically used in blends with conventional diesel in mixtures up to 20% (B20), for both vehicles and in home heating oil (called "bioheat").

First generation biofuels offer a range of benefits. First, they diversify the transportation fuel pool, providing a hedge against petroleum price volatility and enhancing energy security. Second, ethanol and biodiesel have desirable fuel properties that help reduce harmful emissions from fuel combustion. Ethanol is a high-octane gasoline blendstock, whereas biodiesel has a high-cetane number (the diesel equivalent to octane rating) and also provides lubricity, an important diesel fuel property. Consumers with FFVs benefit from additional fuel purchase options where E85 is available at the pump. Third, because most of the production takes place in "grain belt" states, biofuels provide a source of investment and employment in rural economies. In Nebraska, the second highest ethanol-producing state (after Iowa), the ethanol industry has achieved tenfold growth in production over the past 20 years, and averaged $5 billion in annual revenue from 2010 to 2014.[7] Many biorefineries benefitting from this economic activity are owned by farmer cooperatives, such as Chippewa Valley Ethanol Company in Benson, Minnesota.[8]

3.) Ethanol yield has increased approximately 12% since 1995, to 2.82 gallons per bushel in 2014. Thermal energy (natural gas) required to produce a gallon of ethanol has fallen 36% since 1995, while electricity use has fallen 38%. http://ethanolrfa.3cdn.net/c5088b8e8e6b427bb3_cwm626ws2.pdf **4.)** http://www.epa.gov/otaq/fuels/rfsdata/2014emts.htm **5.)** http://www.eia.gov/dnav/pet/pet_cons_821dsta_dcu_nus_a.htm **6.)** http://www.afdc.energy.gov/vehicles/flexible_fuel.html?0/E85/ **7.)** https://agecon.unl.edu/ethanolimpacts **8.)** http://www.cvec.com/history

Second and Third Generation Biofuels

Second generation biofuels describes a wide range of fuel pathways that offer one or more advantages over first generation biofuels. The distinguishing characteristics of second generation biofuels are: (a) they use a non-food feedstock (so-called lignocellulosic biomass, such as field crops residues, forest products residues, or fast-growing dedicated energy crops), and (b) the fuel is a "drop-in" replacement for conventional petroleum-based fuels, meaning there are no limits on blending, or they can be used as is (without blending) in existing vehicles. Some second generation biofuels feature both characteristics, whereas others offer just one. The following are the main types of second generation biofuels in use or under development:[9]

- **Cellulosic Ethanol** is produced via fermentation of sugars derived from the cellulose and hemicellulose fractions of lignocellulosic biomass.
- **Biobutanol** is made in a process similar to ethanol but with different microorganisms. Currently the fuel yield is lower than with ethanol, but biobutanol can be used as a drop-in replacement for gasoline without blending limits.
- **Biomass to Liquids (BtL)** technology starts with gasification to produce a synthesis gas (syngas) followed by Fischer-Tropsch catalytic synthesis to gasoline, diesel, and jet fuel.
- **Methanol, Dimethyl Ether (DME),**[10] and mixed alcohols can also be made from syngas via catalytic synthesis. There are also specialized microorganisms that can ferment syngas into alcohols.
- **Biosynthetic Natural Gas (BioSNG),** sometimes called renewable natural gas, can also be made via gasification followed by catalytic methanation and purification. Anaerobic digestion (p.5) with microorganisms produces a biogas comprised mainly of methane and carbon dioxide that can be purified to produce BioSNG. BioSNG can then be used as compressed natural gas (CNG) or liquefied natural gas (LNG) in vehicles or injected into the existing natural gas pipeline network (p.67).
- **Hydrotreated Vegetable Oil** is a drop-in diesel substitute that has very desirable fuel properties (high cetane, no aromatics, no sulfur).
- **Pyrolysis Oils** (sometimes called "biocrude") are produced by flash pyrolysis (rapid heating to about 1,000°F followed by rapid cooling). Refining and upgrading produces liquid fuels for transportation or stationary applications (boilers, turbines).
- **Hydrogen** can be produced from biomass using various conversion technologies, with gasification being the most developed (see also p.68).

9.) https://www.iea.org/publications/freepublications/publication/2nd_Biofuel_Gen.pdf **10.)** DME has physical properties similar to propane. It is an excellent diesel substitute, but it is not a "drop-in" replacement for diesel.

Production of second generation biofuels remains small compared to first generation biofuels. In 2014, total production was about 500 million gallons, compared to about 15.5 billion gallons for first generation biofuels.[11] However, there is a burgeoning industry building up around second generation biofuels, with facilities such as Quasar Energy's anaerobic digester in Columbus, Ohio, producing 3,600 gge of CNG each day using regional food waste and waste bio-solids from the city of Columbus.[12]

Third generation biofuels are less developed than second generation biofuels but offer some potential advantages. Two examples are algal biofuels and synthetic biology. Algal biofuel production is at the early stages of commercialization and scale-up. With algae, the inputs are sunlight, water, carbon dioxide, and nutrients. The algae is grown in large ponds then harvested, de-watered, and crushed to extract algal oils, which are then converted into biofuels using transesterification (as with first generation biodiesel) or hydrotreating, as described above. The two key advantages of algal biofuels are the high yield per acre (up to 10 times higher than with other biofuels), and the fact that algae do not compete for land or potable water with agriculture or forestry, as non-arable lands and non-potable water can be used. In fact, the best locations are in the desert near sources of carbon dioxide, such as adjacent to existing fossil fuel-fired power plants, where the CO_2-rich stack gases feed the algae farm.[13] Synthetic biology is at an earlier stage of development. The concept is to use genetic modifications to develop plants or microorganisms that can synthesize drop-in fuels directly in their cells.

Second and third generation biofuels offer the same benefits as first generation biofuels, with some additional advantages. Lignocellulosic feedstocks are generally less expensive than food crops and also ameliorate concerns over competition with food supplies and the potential to raise food prices. These feedstocks are abundant, come from a wide range of sources, and can be grown on more marginal land that may not be well suited to traditional food crops. More generally, growth in biofuels markets offers the potential for rural economic development. Finally, "drop-in" fuels reduce the need for investment in new infrastructure and vehicles, and their market potential is not limited by blend-wall restrictions.

11.) http://www.epa.gov/otaq/fuels/rfsdata/2014emts.htm **12.)** http://www.quasarenergygroup.com/pages/profile_columbus.pdf
13.) http://energy.gov/eere/bioenergy/production

Compressed Natural Gas and Liquefied Natural Gas

Compressed Natural Gas (CNG) and Liquefied Natural Gas (LNG) are gaining market share as transportation fuels (p.61). The technologies for producing, storing and using both CNG and LNG are well developed. With CNG, pipeline natural gas is compressed to 3,000 to 4,000 pounds per square inch (psi) and stored in a pressurized tank on board the vehicle. CNG fueling stations include all the equipment necessary to take natural gas from the local distribution system, compress it, and refuel the vehicles. With LNG, the natural gas must be cooled to about -260°F at which point the methane (the main constituent of natural gas) turns to a liquid.[14] The LNG is stored in insulated cryogenic tanks at the refueling station and on board the vehicle.

There are about 150,000 vehicles in the United States powered by natural gas, predominantly CNG vehicles, served by 723 private CNG stations and 819 public stations across the country.[15,16] LNG takes more energy to produce than CNG but offers greater range as it has a higher volumetric energy density. As such it is mainly used for long-haul trucking, where trucks follow well-established routes. In this case, it is possible to serve a large number of trucks with a relatively small number of refueling stations (numbering a few hundred), There are currently 71 public LNG fueling stations across 25 states, including many along the I-35 corridor in Texas and along I-5 in California.[17] The private sector has initiated this build-out, with nearly 70% of fueling stations, including both private and public stations, built by Clean Energy Fuels.[18] Because LNG production is more energy intensive and complex than CNG production, LNG is typically produced at a few large-scale plants and delivered by truck to the refueling stations, as is done today with gasoline and diesel fuel.

Fuel cost is the main driver for considering a vehicle powered by CNG or LNG over gasoline or diesel. Since these fuels are consistently available at lower prices, the incremental cost of the vehicle and refueling equipment can be made back over time. The average retail fuel price for CNG in April 2015 was $2.09 per gasoline gallon equivalent (gge), lower than both gasoline ($2.42/gallon) and diesel ($2.56/gallon).[19] Now that natural gas is relatively inexpensive and abundant, more fleet operators and consumers are considering switching to CNG or LNG. This increases fuel diversity in the transportation sector, which benefits energy security and also brings added choices to the marketplace.

14.) http://www.afdc.energy.gov/fuels/natural_gas_basics.html#cng **15.)** http://www.afdc.energy.gov/locator/stations/ **16.)** http://www.afdc.energy.gov/vehicles/natural_gas.html **17.)** http://www.afdc.energy.gov/locator/stations/ **18.)** https://www.cleanenergyfuels.com/services/engineering-and-construction/ **19.)** http://www.afdc.energy.gov/fuels/prices.html

Hydrogen

Roo Reynolds

Hydrogen is a gaseous fuel that is used mainly in industry. U.S. hydrogen production in is approximately 10.5 million kg/day, primarily for petroleum refining, ammonia production, and methanol production.[20] Hydrogen is also being developed as a fuel for both light-duty and heavy-duty vehicles and as an option for energy storage on the electricity grid (p.28). The most common hydrogen production pathway is steam-methane reforming (SMR), in which natural gas is reformed with steam over a catalyst at high temperatures (about 700-1000°C) to produce a synthesis gas composed mainly of hydrogen (H_2) and carbon monoxide (CO).[21] The CO is then converted to additional H_2 by the water-gas shift reaction.[22] After removing CO_2 and water and polishing the gas to remove residual CO, the high-purity hydrogen is ready for compression or liquefaction. A less common option is water electrolysis, which uses electricity to operate an electrochemical cell, or electrolyzer, in which water is split into pure hydrogen and oxygen.[23] Hydrogen can also be made from other fossil fuels or biomass, starting with gasification or partial oxidation. The subsequent steps are then similar to SMR, although these pathways are not in widespread commercial use. Other, more novel approaches are also in development, including the use of specialized microorganisms that produce hydrogen via metabolic pathways.[24]

Hydrogen is in limited commercial use as a transportation fuel, primarily in fuel cell vehicles (p.59). For stationary applications, there are some niche industrial applications where industrial processes produce excess hydrogen (such as chlor-alkali plants). In this case the hydrogen can use used on-site in fuel cells to generate electricity (p.8). Hydrogen is also being considered as an option for storing grid electricity; an electrolyzer would convert excess electricity into hydrogen during off-peak periods and a fuel cell would generate electricity from the hydrogen when it is needed. To date, most hydrogen for transportation is produced on-site in small-scale plants using either SMR or electrolysis. Despite misconceptions, hydrogen fuel is very safe. Hydrogen is non-toxic and, as the lightest element, leaks tend to disperse quickly. Its extensive use as an industrial gas has provided the necessary technology and experience to expand its use as a transportation fuel, including storage technologies and the use of pipelines for long-distance transport, such as the 180-mile pipeline system linking 22 hydrogen plants in Louisiana and Texas.[25]

Hydrogen is unique among fuels in that its production does not require a carbon-based feedstock, so it can be made from any energy source, including electricity. The methods of production lend themselves to both large-scale and distributed applications. Thus, a hydrogen economy, were it to develop, would likely be characterized by a diversity of energy resources and scales of production, even down to the household level. The use of hydrogen as a fuel would offer increased energy security, new options for consumers to meet their household and transportation energy needs, and ready integration with other technologies, such as smart grid and on-site distributed electricity generation.

20.) http://hydrogen.pnl.gov/hydrogen-data/hydrogen-production **21.)** http://energy.gov/eere/fuelcells/hydrogen-production-natural-gas-reforming
22.) The reforming reaction is $CH_4 + H_2O \rightarrow 3H_2 + CO$; the water-gas shift reaction is $CO + H_2O \rightarrow CO_2 + H_2$. Thus, the net reaction is $CH_4 + 2H_2O \rightarrow CO_2 + 4H_2$. **23.)** http://energy.gov/eere/fuelcells/hydrogen-production-electrolysis **24.)** http://energy.gov/eere/fuelcells/hydrogen-production-microbial-biomass-conversion **25.)** http://www.airproducts.com/~/media/Files/PDF/microsites/presentation-h2-pipeline-gulf-coast-pipeline-backgrounder.pdf

www.aee.net
@aeenet