

# ADVANCED ENERGY TECHNOLOGIES FOR GREENHOUSE GAS REDUCTION

40 Solutions for Cutting Carbon Emissions from Electricity Generation



## About Advanced Energy Economy

Advanced Energy Economy is a national association of businesses and business leaders who are making the global energy system more 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 Partner organizations are active in 23 states across the country, representing roughly 1,000 companies and organizations in the advanced energy industry. Visit Advanced Energy Economy online at: [www.aee.net](http://www.aee.net).



Advanced Energy Technologies for Greenhouse Gas Reduction

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## Introduction and Overview

**The U.S. Environmental Protection Agency's (EPA's) plan to regulate carbon emissions is just the latest challenge to the U.S. electric power system. Technological innovation is disrupting old ways of doing business, infrastructure is showing its age, and customers are demanding new forms of service. Advanced energy offers a wide range of technologies and services that can help meet all these challenges. From zero- and low-emission forms of electricity generation to sophisticated grid management tools and demand reduction, investment in advanced energy solutions can modernize the electric power system, provide economic benefits, and reduce carbon emissions at the same time. As states develop plans to meet EPA's carbon emission standard, Advanced Energy Economy offers this compendium of 40 different advanced energy technologies that can be used to create a modern electric power system that is secure, clean, and affordable.**

The U.S. electric power system, an engineering marvel of the 20th century, has entered the 21st century in a state of flux. Technology is bringing to bear energy resources, such as wind, natural gas, and solar, at historically low prices. Energy efficiency, demand response, and smart grid technologies are providing ways to meet growing energy needs with greater reliability and resiliency without more resources. Distributed generation is making property owners into power producers, meeting their own needs and contributing excess generation to the grid. The hundred-year-old system of central power plants delivering ever-greater quantities of electricity to customers through a one-way distribution network is morphing into one that is more variable, complex, and multidirectional.

But even as our lives and our economy have become increasingly dependent on electronic devices that work around the clock, the delivery system for the power they run on has shown itself to be vulnerable to disruption. The U.S. Department of Energy (DOE) identified 679 widespread power outages due to severe weather between 2003 and 2012 – at a cost of \$18 billion to \$33 billion in inflation-adjusted annual losses.<sup>1</sup> Routine (i.e., non-weather related) outages are on the rise, with average time without power up 15% since 2002, reaching 112 minutes per year in 2011.<sup>2</sup> In a worst-case scenario, disruption of just nine critical substations by coordinated attack would reportedly be enough to bring down the entire U.S. power grid.<sup>3</sup>

At the same time, environmental standards are forcing change in electric generating facilities. U.S. Environmental Protection Agency's Cross-State Air Pollution Rule, recently reinstated by the Supreme Court, requires power plants to reduce nitrogen oxide (NOx) and sulfur dioxide (SO<sub>2</sub>) emissions that move across state lines.<sup>4,5</sup> Not long before, the Court upheld EPA's Mercury and Air Toxics (MATS) rule, which requires power plants to increase controls on mercury, arsenic, and metals.<sup>6,7</sup> These environmental regulations will likely result in retirement of many older, inefficient power plants that are uneconomic to bring up to current standards, requiring new solutions for meeting energy needs.

1. [http://energy.gov/sites/prod/files/2013/08/f2/Grid%20Resiliency%20Report\\_FINAL.pdf](http://energy.gov/sites/prod/files/2013/08/f2/Grid%20Resiliency%20Report_FINAL.pdf)
2. <http://www.washingtonpost.com/blogs/wonkblog/wp/2013/03/08/surprise-the-u-s-power-grid-is-getting-prier-less-reliable/>
3. <http://online.wsj.com/news/articles/SB10001424052702304020104579433670284061220>
4. <http://www.epa.gov/airtransport/CSAPR/basic.html>
5. <http://www.reuters.com/article/2014/04/29/usa-court-environment-idUSL2N0NL0V320140429>
6. <http://www.nationaljournal.com/energy/obama-s-epa-notches-big-win-in-court-on-power-plant-rule-20140415>
7. <http://www.epa.gov/mats/>

On top of all this, customer expectations are changing. No longer are they content to turn the lights on, rack up the kilowatt-hours, and pay the bill, no questions asked. Customers are looking for more self-generation, better control over energy use and costs, and a more resilient electricity system that they can count on. The convergence of energy and information technology is presenting the prospect of sophisticated energy management of the home and office building. Just as they have come to expect new products that deliver new value in smartphones, video, and internet services, customers are starting to look for the same in energy.

The latest development is EPA's regulation of carbon emissions from the electric power sector under Section 111(d) of the Clean Air Act. On the one hand, this is simply an environmental regulation like any other. But because carbon dioxide is the unavoidable product of fossil-fuel combustion, the road to lower carbon emissions from the electric power sector appears especially daunting. In fact, however, meeting EPA's carbon emissions standard provides an opportunity to meet all of the challenges facing the electric power sector and create a modern electric power system for the 21st century. It is an opportunity that should be embraced.

### **Technologies with Proven Value**

Many of the technologies that are already changing the U.S. electric power system also help to reduce carbon emissions. Deploying these technologies even more widely in electricity generation, management, and usage will help in meeting the new EPA carbon standards – all while making the electric power system more resilient and reliable, more efficient and responsive, and less vulnerable to fuel price hikes.

This report details 40 different advanced energy technologies and services that states can consider as they develop compliance plans to reduce emissions under EPA's Section 111(d) carbon standard. These solutions do not constitute a comprehensive list, but rather demonstrate the breadth of options that states have at their disposal today.

While some of these technologies are just approaching commercial scale, many are well established in the marketplace. AEE's Advanced Energy Now 2014 Market Report shows that advanced energy is a \$1.1 trillion global market, as big as pharmaceuticals worldwide.<sup>8</sup> The nearly \$170 billion annual U.S. advanced energy market is equal in revenue to the U.S. airline industry. Advanced energy technologies are already providing value to customers, to the electricity system as a whole, and to local economies.

***Advanced energy technologies are already providing value to customers, to the electricity system as a whole, and to local economies.***

States have many years of experience incorporating these technologies and services into the electricity system through policy mechanisms that are well known and understood. In short, these are energy solutions that can be readily mobilized, state by state, to make the U.S. electric power system higher performing and lower emitting, while producing economic benefits at the same time.

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8. [info.aee.net/advanced-energy-now-2014-market-report](http://info.aee.net/advanced-energy-now-2014-market-report)



Examples of broad advanced energy policy initiatives and their impacts are provided by state below:

- Ohio: Researchers from the Ohio State University found that Ohio's renewable energy and energy efficiency standards have reduced electricity bills for Ohio ratepayers by 1.4% since their inception in 2008 while stimulating the Ohio economy by \$160 million and creating over 3,200 Ohio jobs. The combination of decreased demand and increased emission-free generation reduced greenhouse gas emissions by 1.9%.<sup>9</sup>
- Massachusetts: Analysis Group found that the first five years of the state's Green Communities Act, which expanded energy efficiency and renewable energy efforts by utilities and municipalities, produced \$1.2 billion in net economic benefits (including \$155 million in state and local tax revenue), created 16,000 jobs, and reduced carbon emissions by 31 million metric tons.<sup>10</sup>
- North Carolina: RTI International and LaCapra Associates found that investment spurred by the state's renewable energy and energy efficiency requirements saved 8.2 million megawatt-hours of energy between 2007 and 2012, plus \$427 million in savings from government energy efficiency projects, with no appreciable impact on electricity rates. The state's programs spurred \$1.4 billion in project investment over the five-year period, contributing \$1.7 billion to Gross State Product and created or retained over 21,000 jobs.<sup>11</sup>

The 40 technologies and services described in this report are grouped under three broad categories: Buildings and Industry; Electricity Generation; and Electricity Delivery and Grid Management.

Technologies in Buildings and Industry increase end-use efficiency and capture energy waste in facilities that are the biggest users of electricity, reducing emissions and cutting costs. Advanced materials like quality insulation along with efficient heating, ventilation, and cooling equipment keep building occupants comfortable while reducing power consumption. Behavioral energy efficiency allows utilities to help their customers understand energy usage and find ways to save money. Combined heat and power (CHP) systems help university and hospital campuses and industrial users alike meet both their electricity and heating requirements. Demand response allows utilities and transmission organizations to keep the grid operating during peak usage times, while reducing energy usage and generating revenue for customers. With approaches to energy efficiency like these, McKinsey & Co. has found potential to reduce U.S. consumer energy demand 23% by 2020 and cut carbon emissions by 1.1 gigatons each year, at net savings of \$680 billion.<sup>12</sup>

Electricity Generation technologies include zero-emission, fuel-free resources like wind, solar, and hydropower, which also protect against fuel price hikes, as well as nuclear power, with incumbent plants already providing nearly 20% of U.S. electricity with no carbon emissions. It also includes high efficiency, lower emission sources like natural gas power generation and fuel cells. Wind power costs have come down to historically low levels as installations have hit 61 gigawatts, a capacity sufficient to avoid 4% of total U.S. power sector emissions.<sup>13,14</sup> With falling costs and no-upfront-cost financing models – residential solar leases are available now in 14 states – solar power is booming.<sup>15</sup> Using the full range of these diverse energy resources also protects against over-reliance on any one source, for greater energy security.

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9. [http://irawaynehenry.com/oaee/wp-content/uploads/2014/01/DEEPS\\_Sept25\\_2013\\_Model\\_Results.pdf](http://irawaynehenry.com/oaee/wp-content/uploads/2014/01/DEEPS_Sept25_2013_Model_Results.pdf)

10. [http://www.analysisgroup.com/uploadedFiles/Publishing/Articles/Analysis\\_Group\\_GCA\\_Study\\_Exec\\_Summary.pdf#page=2](http://www.analysisgroup.com/uploadedFiles/Publishing/Articles/Analysis_Group_GCA_Study_Exec_Summary.pdf#page=2)

11. <http://energync.org/assets/files/RTI%20Study%202013.pdf>

12. [http://www.mckinsey.com/client\\_service/electric\\_power\\_and\\_natural\\_gas/latest\\_thinking/unlocking\\_energy\\_efficiency\\_in\\_the\\_us\\_economy](http://www.mckinsey.com/client_service/electric_power_and_natural_gas/latest_thinking/unlocking_energy_efficiency_in_the_us_economy)

13. <http://www.awea.org/4Q2013>

14. [http://www1.eere.energy.gov/wind/pdfs/2012\\_wind\\_technologies\\_market\\_report.pdf](http://www1.eere.energy.gov/wind/pdfs/2012_wind_technologies_market_report.pdf)

15. <http://www.greentechmedia.com/articles/read/us-residential-solar-financing-to-reach-5.7-billion-by-2016>



Electricity Delivery and Grid Management technologies allow electricity distribution to be managed more effectively, reducing losses, minimizing outages, and giving grid operators and customers alike valuable data for managing electricity use and reducing associated emissions. This category includes microgrids, which combine onsite power generation (e.g., CHP or solar installations) with the ability to keep the lights on even when there is disruption in the surrounding power grid. It also includes energy storage, which promises ultimately to free the electric power system from the tyranny of real-time matching of generation and load – that forces massive capital investment in peak generating capacity that is required just a few hours per year. The Electric Power Research Institute calculates that net investment of roughly \$400 billion over 20 years to deploy smart grid technology nationwide would produce net benefits of \$1.3 trillion to \$2 trillion.<sup>16</sup>

## Benefits of Building a Modern Electricity System

What is hard to capture in this technology-by-technology review is the added value that comes from using these advanced energy technologies together, creating a system that makes electric power and its use more efficient, nimble, and consumer focused. With its quick ramp character, natural gas generation is the perfect complement to variable sources like wind and solar. Similarly, energy storage could capture excess capacity of wind or nuclear power generation for use at times of peak demand. Today's first plug-in electric vehicles (PEVs) simply take power from the grid, displacing carbon emissions from gasoline use, but tomorrow's PEVs could store power for the grid as well, to be dispatched as needed to avoid additional generation. Energy efficiency technologies, from building retrofits to appliance upgrades, are not only low cost ways to meet energy needs, they reduce strain on all components of the electric power system.

As advanced energy is unleashed throughout the electric power system, there will be more benefits to come. A study produced by Google.org, the philanthropic arm of Google Inc., found that select advanced energy technologies could, by 2030, save consumers over \$900 annually per household, reduce U.S. greenhouse gas emissions 13%, create 1.1 million net new jobs, and increase U.S. GDP by \$155 billion per year.<sup>17</sup>

With advanced energy technologies and services, state plans to meet EPA's carbon emission standards can be vehicles for creating a higher performing electric power system for all. Deploying advanced energy will create jobs and stimulate economic growth from investments in modernizing the electric power system. New consumer value will be created in a long-stagnant electricity sector by introducing competition, choice, and innovation for new products and services both known today and not yet imagined. To see the breadth of advanced energy technologies that are currently at states' disposal as they set out to reduce carbon emissions at lowest cost and greatest benefit, read on.

*With advanced energy technologies and services, state plans to meet EPA's carbon emission standards can be vehicles for creating a higher performing electric power system for all.*

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16. <http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=00000000001022519&Mode=download>

17. [http://www.google.org/energyinnovation/The\\_Impact\\_of\\_Clean\\_Energy\\_Innovation.pdf](http://www.google.org/energyinnovation/The_Impact_of_Clean_Energy_Innovation.pdf)



## BEHAVIORAL ENERGY EFFICIENCY



Opower

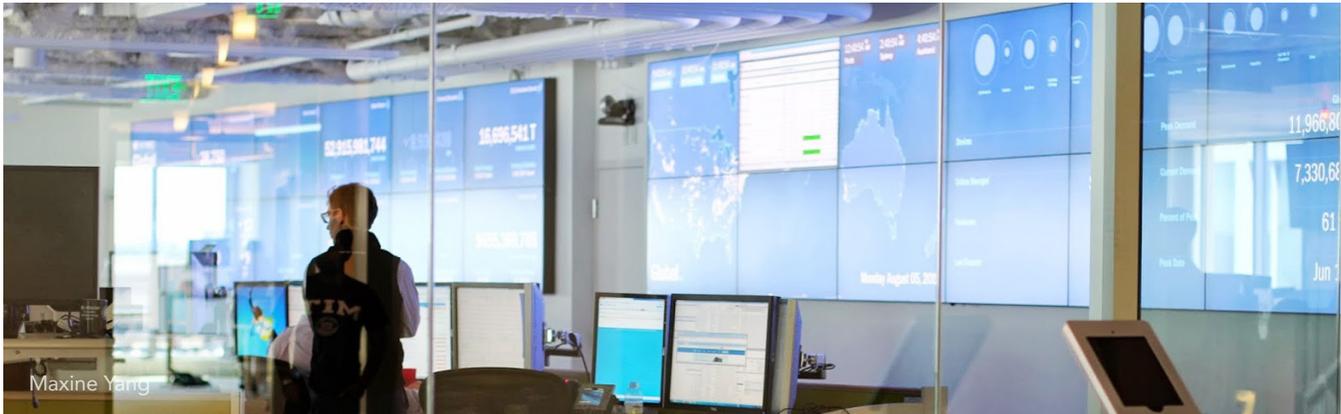
Behavioral energy efficiency (BEE) employs messaging grounded in behavioral science to produce simple, actionable messages that are relevant to customers and motivate them to save energy. Extensive research has found that the average utility customer spends nine minutes per year thinking about their energy use.<sup>1</sup> When they do, they have two basic questions: How am I using energy and what can I do to save energy and money? BEE answers this question. Utilities opt customers into BEE programs, meaning savings can scale rapidly. Communications are delivered through multiple channels – e.g. web, mobile, mail – ensuring customers are engaged and focused on reducing energy consumption. Dozens of independent evaluations have found BEE programs consistently produce savings of 1.5% to 3.5% per household.<sup>2</sup>

Behavioral energy efficiency programs are deployed by utilities or by third parties. Opower, a behavioral efficiency company, works with 93 utility partners in 35 states and eight countries around the world, from North America to Europe, Asia and Oceania, to reach over 32 million households and businesses. To date, their programs have saved over 4 terawatt-hours of energy – the equivalent of taking all the homes in a city the size of San Francisco off the grid for a year. A key component of the company's BEE programs are Home Energy Reports (HERs). HERs contextualize energy information – for example, how your energy use compares to that of similar homes – in a way that's relevant to customers. And they provide personalized energy efficiency tips, motivating customers with clear ways to save. What's more, because Opower's BEE programs are administered as randomly controlled trials – much like drug trials – utilities can measure and verify every kilowatt-hour saved.

The cost effectiveness of behavioral energy efficiency makes it an attractive compliance strategy. Utilities that need new capacity must either increase supply or reduce demand. In a recent study, researchers at MIT and Harvard found BEE "costs an electric utility \$0.025 per kWh saved," far less than the cost of a new power plant.<sup>3</sup> McKinsey & Company, recently estimated that behavioral energy efficiency, if deployed to all households in the U.S. for which it is cost effective, could save almost 19 TWh of energy per year, leading to avoided emissions of 10.2 million metric tons of CO<sub>2</sub>.<sup>4</sup>

1. <http://www.accenture.com/us-en/Pages/insight-actionable-new-energy-consumer.aspx>
2. <http://www.energyandresources.vic.gov.au/energy/about/legislation-and-regulation/energy-saver-incentive-scheme-management/ris/submissions/opower-submission>
3. <https://files.nyu.edu/ha32/public/research/Allcott%20and%20Mullainathan%202010%20-%20Behavior%20and%20Energy%20Policy.pdf>
4. Using state-by-state savings estimates, Opower calculated potential emissions reductions utilizing the individual carbon intensity of each state. That intensity estimate was drawn from the Carbon Monitoring in Action database, comprised of plant-level emissions data from the EPA & EIA.

## BUILDING ENERGY MANAGEMENT SYSTEMS



A Building Energy Management System (BEMS) is an integrated system of software, hardware and services that controls energy use through information and communication technology. Used primarily in commercial buildings, BEMS technology works by monitoring, automating, and controlling building systems such as heating, ventilation, air conditioning, thermostats, and lighting to increase building energy efficiency and improve comfort. Adoption of cloud technology has expanded BEMS from traditional energy visualization and energy analytics to include demand response and property management.<sup>5</sup> Campus-wide energy management systems, often called enterprise energy management systems (EEMS) are being deployed by universities, governments, and store chains. The state of Massachusetts invested in an EnerNOC EEMS system in 2010 to reduce energy costs at 470 state buildings, with an anticipated annual savings of \$10 million, or 5% to 15% reduction in energy usage.<sup>6</sup>

Driven by continued adoption by commercial and government customers, the global BEMS market is expected to grow from \$1.8 billion in 2012 to \$5.6 billion in 2020.<sup>7</sup> Additionally, as utilities continue to work with increasingly stringent energy efficiency requirements, they are looking more and more toward the deployment of BEMS in buildings to reduce energy demand. Growth in the U.S. market for BEMS over the past two years was 27%, from \$737.2 million in 2011 to an estimated \$935.4 million in 2013.<sup>8</sup>

With buildings accounting for nearly 40% of U.S. energy consumption, BEMS can lead to significant savings for property owners.<sup>9</sup> Up to 30% of the energy used in the 81 billion square feet of commercial buildings in the United States is lost through inefficiencies, creating a large market for BEMS services.<sup>10</sup> For instance, Cooper Realty Investments challenged Johnson Controls to increase the energy efficiency of the Bank of America Plaza building in Columbia, South Carolina. By installing a Johnson Controls Metasys building management system and implementing efficiency technology, the building's energy usage was reduced by 15%, resulting in \$43,000 per year in energy savings.<sup>11</sup>

5. Demand response (DR) is the ability to reduce load in response to price or other signals from the utility, usually to help meet peak demand.
6. <http://investor.enernoc.com/releasedetail.cfm?ReleaseID=457832>
7. <http://www.navigantresearch.com/research/building-energy-management-systems>
8. <http://info.aee.net/advanced-energy-now-2014-market-report>
9. <http://www.eia.gov/tools/faqs/faq.cfm?id=86&t=1>
10. <http://energy.gov/eere/buildings/about-commercial-buildings-integration-program>
11. [http://www.johnsoncontrols.com/content/dam/WWW/jci/be/case\\_studies/Bank\\_of\\_America\\_Case\\_Study.pdf](http://www.johnsoncontrols.com/content/dam/WWW/jci/be/case_studies/Bank_of_America_Case_Study.pdf)

## EFFICIENT BUILDING ENVELOPE



The building envelope consists of all the elements of a building that separate its interior from the exterior environment. This includes external walls, insulation, windows and roofing. Technological advancements in envelope materials have lowered building operating costs. Examples include high-performance insulation, reflective surfaces, air sealing, and efficient windows. The International Energy Agency estimates that heating and cooling loads across the globe can be reduced by as much as 40% simply by using efficient building envelope technologies.<sup>12</sup>

Efficient building materials are used worldwide, with the United States, Canada, and the European Union being the leading markets. In terms of specific technologies, insulation and low-emissivity glass have the highest global market penetration while

reflective cool roofs have established a mature market in North America.<sup>13</sup> Nevertheless, the advanced building envelope market has potential for new technologies, such as integrated advanced roofs that may include PV installations. One major leader in manufacturing efficient building materials is Johns Manville, whose insulation materials are being used in both new construction and retrofit across all sectors, including colleges, warehouses, hotels, residences, and medical centers. Johns Manville cool roofing products for new and existing commercial roofs can reduce solar heat gain and building cooling requirements while enabling seamless integration of solar PV into the roofing system.<sup>14</sup>

The U.S. market for advanced building envelope installations was an estimated \$10.8 billion, with year-over-year growth of 12%.<sup>15</sup> The market opportunity for efficient building materials is even greater, with up to \$3.7 trillion in envelope investments projected between 2015 and 2050.<sup>16</sup> The benefits of efficient building envelope investments can be seen immediately in reduced energy use. 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, insulation, and advanced windows reduce energy consumed for heating. The total yearly savings can add up to nearly 30%. Improvements in building envelope technology could reduce global energy consumption in 2050 by the equivalent of the current total consumption of Texas.<sup>17,18</sup> Residential and commercial buildings in the U.S. account for one-third of the nation's greenhouse gas emissions, leaving ample opportunity for reduction.<sup>19</sup>

12. <http://www.iea.org/newsroomandevents/news/2013/december/pushingtheenvelopeimprovementstobuildingsouterlayerslashenergyuse.html>

13. <http://www.iea.org/publications/freepublications/publication/TechnologyRoadmapEnergyEfficientBuildingEnvelopes.pdf>

14. <http://www.jm.com/en/building-materials/building-insulation/building-insulationcasestudies/>

15. <http://info.aee.net/advanced-energy-now-2014-market-report>

16. Ibid

17. <http://www.eia.gov/electricity/data/browser/>

18. <http://www.iea.org/publications/freepublications/publication/name,45205,en.html>

19. <http://epa.gov/climatechange/ghgemissions/sources/electricity.html>

## EFFICIENT BUILDING INSULATION



One key building material that greatly impacts the efficiency of a building is insulation. Up to 45% of a building's heat can be lost through the roof.<sup>20</sup> The effectiveness of insulation can be determined by its thermal resistance, represented by R-value. The higher the R-value, the greater the insulating power, with R-30 being the recommended minimum value for an uninsulated attic in the U.S.<sup>21</sup> Efficient insulation can be created from a number of different materials including fiber glass, polystyrene, spray foam, rigid foam boards, mineral wool, or recycled paper. Insulation can come in the form of batts, rolls, loose fill, spray in, concrete blocks, or even radiant barriers. The most common locations for insulation in a building are exterior walls, unfinished attic and basement spaces, and floors above exposed spaces (e.g. above garages).

While insulation has been used in some form for decades, the growing focus on energy efficiency has raised awareness opportunities for reducing energy losses related to heating and cooling. Insulation is a well-established means for reducing heating and cooling energy losses, with the commercial and industrial U.S. market totaling around \$10 billion in 2010.<sup>22</sup> Efficient insulation can be added to existing buildings to increase R-value, while efficient insulation that often exceeds state and local building codes is a standard component of new construction.<sup>23</sup> RadioShack built a new headquarters in Fort Worth that focused on meeting LEED standards. RadioShack took the step of installing 1.3 million square feet of Johns Manville Formaldehyde-free™ fiber glass insulation to help meet the standards and maintain high indoor air quality.<sup>24</sup>

Payback time for insulation depends on weather, location, and electricity costs, but the Department of Energy calculates that typical homeowners can see up to 20% savings on heating and cooling bills from sealing leaks and increasing insulation values to R-38.<sup>25</sup> Reducing residential heating and cooling energy use by adding insulation to the home building envelope not only saves money and increases comfort, it also reduces emissions in the utility sector and has a substantial beneficial impact on public health.<sup>26</sup>

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20. [https://www.bpa.gov/Energy/N/energy\\_tips/weatherization/InsulateCeiling.cfm](https://www.bpa.gov/Energy/N/energy_tips/weatherization/InsulateCeiling.cfm)

21. [http://www.energystar.gov/?c=home\\_sealing.hm\\_improvement\\_insulation\\_table](http://www.energystar.gov/?c=home_sealing.hm_improvement_insulation_table)

22. <http://www.insulation.org/articles/article.cfm?ID=PR110401>

23. <http://energy.gov/energysaver/articles/insulation-new-home-construction>

24. [http://www.jm.com/content/dam/jm/global/en/building-insulation/Files/BI%20Toolbox/CaseStudies/JM\\_Insulation\\_CaseStudy\\_RADIOSHACK.pdf](http://www.jm.com/content/dam/jm/global/en/building-insulation/Files/BI%20Toolbox/CaseStudies/JM_Insulation_CaseStudy_RADIOSHACK.pdf)

25. [http://www.energystar.gov/index.cfm?c=home\\_sealing.hm\\_improvement\\_methodology](http://www.energystar.gov/index.cfm?c=home_sealing.hm_improvement_methodology)

26. <http://www.ncbi.nlm.nih.gov/pmc/articles/PMC155901/>

This study is currently being updated to quantify the energy savings, emissions reductions and public health benefits of bringing all under-insulated homes in the US to the 2012 IECC energy code.

## COMBINED HEAT AND POWER (CHP)



Combined Heat and Power (CHP), also called cogeneration, generates both electricity and useful heat from the same fuel source. CHP typically involves dedicated equipment to generate electricity, followed by recovery of exhaust/waste heat for use in industrial processes, space heating, or water heating. Any fuel can be used for CHP, including fossil fuels and renewable fuels. In certain industries, onsite “waste” fuels are used for CHP, such as wood chips, bark and sawdust in forest products, blast furnace gases in steel mills, and various process gas streams in refining and petrochemicals. Because thermal energy (steam, hot water) is more difficult to transport than electricity, CHP systems are typically installed at or near a suitable thermal load. Most U.S. CHP capacity is installed at industrial sites, but it is also fairly common at college campuses, hospitals, military bases, and in district energy plants.<sup>27</sup> Housing complexes and commercial buildings also use CHP. So-called micro-CHP can be used in residences and small commercial buildings for water or space heating or for heating swimming pools.<sup>28</sup> CCHP (combined cooling, heating, and power) is a variation of CHP that uses the waste heat to drive a cooling system (via an absorption chiller) in addition to generating heat and power. CCHP can make sense when heating loads are more seasonal and where there are large cooling requirements, resulting in higher overall utilization of waste heat than would be possible just with CHP.

CHP has been used in some form for over a century. New York City, for example, has operated a district heating system that uses CHP since 1882. Despite its long track record, CHP only makes up about 8% of U.S. generation capacity (about 80 GW), suggesting that there is ample opportunity for greater adoption.<sup>29,30</sup> Hospitals and colleges are good candidates for CHP, as CHP systems can continue to generate power during grid outages. For example, incentivized by ConEdison’s lower rate structure for CHP, New York Presbyterian Hospital installed a 7.5 MW CHP system, reducing the amount of power purchased by 80%. The avoided power purchases and overall fuel savings are expected to reduce greenhouse gas emissions by 67,000 tons each year, not including any emissions from construction.<sup>31</sup>

In the United States, average power plant efficiency is about 34%, i.e., roughly 2/3 of the fuel’s energy content is wasted.<sup>32</sup> Best-in-class power plants have efficiencies of about 50% to 55%. By utilizing waste heat, CHP plants can typically achieve overall fuel efficiencies of 75% to 85%, and sometimes even higher. Overall, CHP reduces annual U.S. energy consumption by 1.8% and avoids CO<sub>2</sub> emission of 248 million metric tons a year. Should the President’s goal of adding 50 GW CHP to U.S. generation capacity by 2020 be met, an additional 100 million metric tons of CO<sub>2</sub> emissions per year could be avoided.<sup>33</sup>

27. District energy is discussed in more detail in the next section.

28. <http://www.aga.org/Kc/ResidentialConstruction/International-Builders-Show/Pages/Cut-Home-Utility-Bills-with-Micro-CHP.aspx>

29. <http://chp.nysed.org/home/index.cfm>

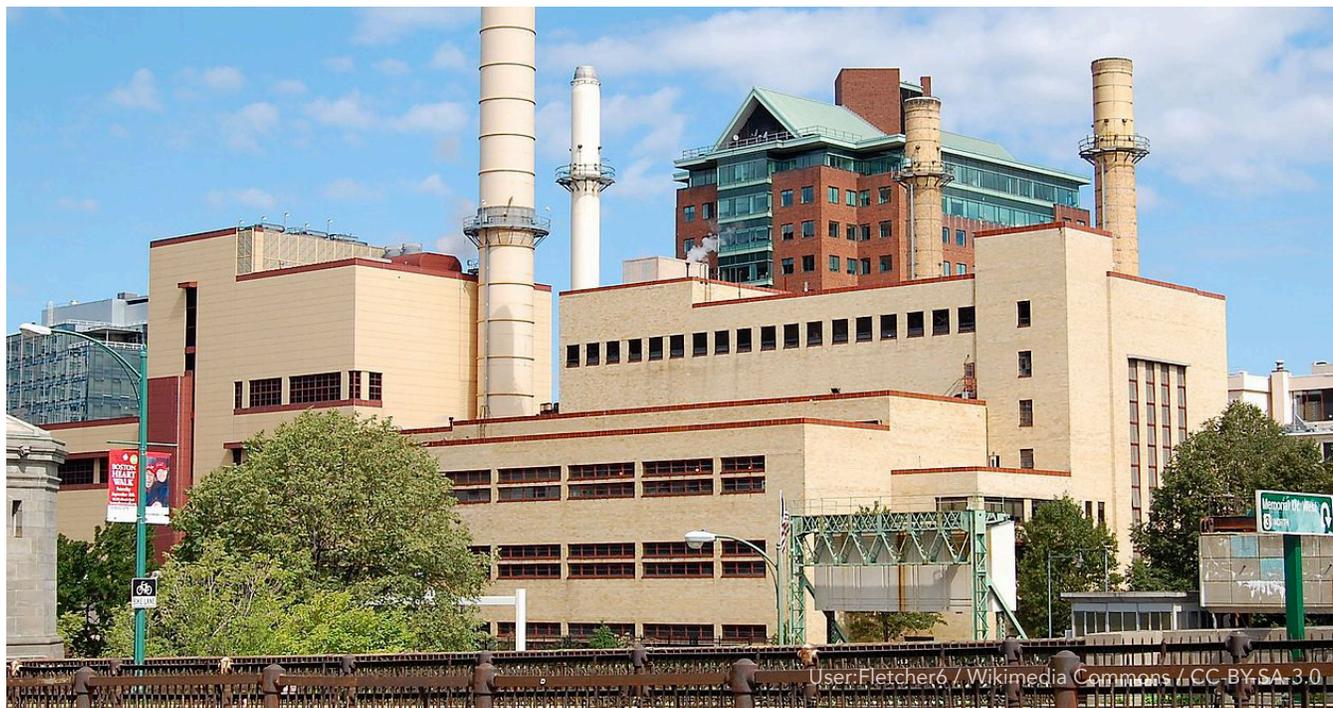
30. [https://www1.eere.energy.gov/manufacturing/distributedenergy/pdfs/chp\\_clean\\_energy\\_solution.pdf](https://www1.eere.energy.gov/manufacturing/distributedenergy/pdfs/chp_clean_energy_solution.pdf)

31. [http://apps1.eere.energy.gov/buildings/publications/pdfs/alliances/hea\\_chp\\_fs.pdf](http://apps1.eere.energy.gov/buildings/publications/pdfs/alliances/hea_chp_fs.pdf)

32. [https://www1.eere.energy.gov/manufacturing/distributedenergy/pdfs/chp\\_clean\\_energy\\_solution.pdf](https://www1.eere.energy.gov/manufacturing/distributedenergy/pdfs/chp_clean_energy_solution.pdf)

33. <http://www.c2es.org/technology/factsheet/CogenerationCHP>

## INDUSTRIAL CHP



Industrial Combined Heat and Power (CHP, also called cogeneration) uses a single fuel, often natural gas, to co-produce electricity and heat for use in industrial operations, usually on-site. Industrial CHP accounts for more than 75 GW out of the approximately 82 GW of installed CHP in the United States, or 7% of the country's total generation capacity.<sup>34</sup> CHP can be applied widely within the industrial sector, but is particularly well suited for industries with significant, steady thermal loads such as refining, chemicals, pharmaceuticals, and forest products.

CHP is a well-developed, mature technology with a long history. The first commercial power plant in the world, Thomas Edison's Pearl Street Station in Manhattan, was a CHP plant.<sup>35</sup> CHP is currently thriving in areas with industrial power needs, including Texas. Despite the state's low electricity rates, Texas is home to 21% of the nation's CHP capacity.

The efficiency of CHP can make it an attractive option for industrial users that have both heat and power demands. In some cases, meeting the thermal loads of a facility can result in excess electricity generation, which can be sold to the grid for additional revenue. Most CHP uses natural gas, resulting in lower emissions than some grid power. Other industries that use CHP include the forest products industry, which uses a large amount of wood waste (e.g., sawdust, bark, spent pulping liquors) which is available at zero cost. Industrial CHP also improves reliability by insulating industries from power supply disruptions. Outages can have especially significant economic impacts on process industries that operate 24/7, where restarting industrial processes is a complex undertaking.

34. <http://info.aee.net/advanced-energy-now-2014-market-report>

35. <http://www.cogeneration.net/ThomasEdisonsCogenPlant.htm>

## DEMAND RESPONSE



Demand Response (DR) is a mechanism that allows utilities to provide customers with information and incentives that encourage customers to reduce energy usage at specific times of the day or year. This gives customers more control over their energy usage and costs, while providing valuable services to grid operators, namely load reduction during peak hours, when electricity is expensive or when grid reliability is compromised. Demand response customers may implement control technology that automatically responds to price or other signals, or customers may respond to a demand response request manually.

The United States leads the global demand response market, with programs mostly set up by regional grid operating entities called Independent System Operators (ISOs). The U.S. demand response market was an estimated \$2 billion in 2013, representing two-thirds of the global market for these services.<sup>36</sup> Most demand response programs today target commercial and industrial customers. For example, EnerNOC, the leading demand response provider, has a contract with an Arizona utility, Salt River Project, to manage a 50 MW network of industrial, commercial and institutional facilities using the company's demand response technology.<sup>37</sup> In the future, there may be opportunities for much wider customer participation on demand response, enabled by the smart grid or other means. Local utility companies or third-party providers may become aggregators of demand response as a service or set up demand response programs at the local level to provide peak demand relief where local constraints exist.

The estimated potential peak load reduction from demand response technology in 2010 was almost 55 GW, a number that continues to grow.<sup>38</sup> In addition, the actual peak load reduction from demand response technology during 2009 was only 15,980 MW or 30% of this potential.<sup>39</sup> Peak load reduction can result in reduced emissions, as peaking plants tend to be less efficient than other plants on the system.<sup>40</sup> Moreover, when electricity demand is high, transmission and distribution equipment tends to be less efficient, resulting in overall greater system losses. Demand response also comes with financial benefits, as it allows customers to be compensated for providing a valuable service to grid operators. By lowering peak demand, demand response moderates energy prices for everyone.<sup>41</sup>

36. <http://info.aee.net/advanced-energy-now-2014-market-report>

37. <http://investor.enernoc.com/releasedetail.cfm?ReleaseID=661778>

38. [http://energy.gov/sites/prod/files/oeprod/DocumentsandMedia/FERC\\_Assessment\\_of\\_Demand\\_Response\\_and\\_Advance\\_Metering.pdf](http://energy.gov/sites/prod/files/oeprod/DocumentsandMedia/FERC_Assessment_of_Demand_Response_and_Advance_Metering.pdf)

39. Ibid

40. Peaking plants are those that run for a small number of hours per year (from a handful up to a few hundred). This can include older, dirtier and less efficient plants that were once used more frequently but have been replaced by other plants for baseload (continuous) duty. It can also include plants built specifically for this purpose like simple cycle gas turbine plants, which are less expensive to build than baseload plants, but also less efficient.

41. <http://www.coned.com/energyefficiency/PDF/DemandResponseProgramsDetails.pdf>

## DISTRICT ENERGY



Just as electricity is distributed over networks of wires to many buildings, it is also possible to distribute heating and cooling via networks of pipes. District energy systems produce steam, hot water, and/or chilled water at central plants and, through a network of insulated pipes (often underground), distribute the steam or water to multiple buildings. District energy plants often include power generation, typically CHP, which further increases overall efficiency.

The U.S. is currently home to over 700 operating district energy networks, spread across all 50 states.<sup>42</sup> These systems primarily serve downtown areas, college and medical campuses, airports and military bases. For example, Veolia Energy operates a district energy system in the Boston-Cambridge area that uses the waste heat of a gas-fired electric power plant to produce steam, reducing 150,000 tons of CO<sub>2</sub> emissions per year through offset generation.<sup>43,44</sup>

By accommodating a variety of fuel types (natural gas, heating oil, geothermal fluids, etc.), district energy systems can reduce cost by switching fuels during periods of price volatility. District energy systems also allow buildings to eliminate the cost of installing, operating and maintaining heating and cooling equipment, reducing upfront capital costs for new buildings as well as reducing maintenance costs while freeing building space for more valuable uses.<sup>45</sup> Since large chillers tend to be more efficient than smaller chillers or air conditioning units, district cooling systems can cut afternoon peak electricity demand, reducing strain on the electricity grid and avoiding peak power costs for building managers. Centralized heating and cooling services create emissions benefits associated with more efficient use of fuel, especially when CHP is part of the plant.<sup>46</sup> Some district energy systems also take advantage of locally produced renewable fuels, which further decrease greenhouse gas emissions.<sup>47</sup>

42. <http://www.districtenergy.org/assets/pdfs/White-Papers/What-IsDistrictEnergyEESI092311.pdf>

43. Ibid.

44. Advanced Energy Economy, Veolia Energy Case Study, <http://info.aee.net/case-studies>

45. <http://www.districtenergy.org/what-is-district-energy/>

46. <http://www.districtenergy.org/what-is-district-energy/>

Some of the efficiency benefits are offset by losses in distribution. Thus, efficient distribution is very important.

47. <http://www.districtenergy.org/assets/pdfs/White-Papers/What-IsDistrictEnergyEESI092311.pdf>

## ENERGY ANALYTICS



Gridco Systems, Distributed Grid Controller (DGC)<sup>™</sup>

Energy analytics for mass-scale building energy efficiency evaluations is a category of software solutions that determine how a building is currently consuming energy and recommend operational and retrofit measures to maximize energy savings. Energy analytics combine different types of data inputs, such as consumption or building asset data, with advanced analytics and modeling techniques to rapidly generate a unique building energy model. Leveraging big data energy analytics via the cloud saves substantial time and costs compared with the traditional manual methods of performing building assessments and audits.

Utilities, program administrators, energy service providers, government, and other building portfolio owners use energy analytics software to identify energy savings opportunities and target buildings with best potential across a portfolio, engage customers with personalized efficiency opportunities that exist in their buildings, streamline on-site energy audits and convert projects faster, and measure savings and evaluate ongoing efficiency opportunities that arise in the future. Con Edison is utilizing Retroficiency’s energy analytics software to drive large-scale building efficiency savings in New York City, as well as to identify candidates with high potential to reduce peak demand to help the utility alleviate constrained areas of the grid.<sup>48</sup>

Energy analytics for buildings can help to identify areas for improvement that may go unseen by a human inspector.<sup>49</sup> The analysis can also help building owners to determine where to make future efficiency investments. Most importantly, the analysis enables building owners to better understand the building’s energy usage, leading to deeper energy savings, lower bills, and increased avoided generation emissions.

48. <http://www.retroficiency.com/about-us/news-item/con-edison-deploys-retroficiency-energy-analytics-to-drive-large-scale-building-efficiency-savings/>

49. [http://www.etcc-ca.com/sites/default/files/reports/ET%2012PGE3341\\_First%20Fuel\\_Final.pdf](http://www.etcc-ca.com/sites/default/files/reports/ET%2012PGE3341_First%20Fuel_Final.pdf)

## ENERGY SERVICE COMPANY (ESCO) SERVICES



Energy Service Companies (ESCOs) are in the business of reducing 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, heating, air conditioning, and motors, as well as energy management and control systems. ESCOs can also provide equipment and services related to onsite power generation such as combined heat and power and rooftop solar power, and may also perform energy procurement. They usually handle all aspects of a project, including design, installation, maintenance, monitoring, and financing.

ESCO services are widely used today, and the industry is growing at a steady pace, with an estimated 2013 revenue of \$630 million in the U.S. and an annual growth rate of 13%.<sup>50</sup> ESCOs mainly serve public and institutional markets, often called MUSH (municipalities, universities, schools, and hospitals). These entities can take a longer-term view and can utilize ESCO financing for large projects. Private sector commercial and industrial facilities only account for about 8% of ESCO industry revenue while 84% of the 2011 ESCO market came from the MUSH market.<sup>51</sup>

ESCOs pioneered the use of a business model called energy savings performance contracting. This financing mechanism has been successful because it eliminates one of the key barriers to energy efficiency deployment – raising capital. With performance contracts, the energy cost savings are used to pay for the capital improvements of the project with the ESCO assuming the risk that the project will save money and energy as expected.<sup>52</sup> For example, Johnson Controls has worked with the public school system in Wyandotte, Michigan, to deliver \$6.9 million in energy cost savings to the district, through the implementation of new windows and HVAC as well as a building energy management system.<sup>53</sup>

50. Advanced Energy Now 2014 Market Report, <http://info.aee.net/advanced-energy-now-2014-market-report>

51. [http://emp.lbl.gov/sites/all/files/lbnl-6300e\\_0.pdf](http://emp.lbl.gov/sites/all/files/lbnl-6300e_0.pdf)

52. <https://www.naesco.org/resources/esco.htm>

53. [http://www.johnsoncontrols.com/content/dam/WWW/jci/be/white\\_papers/GIWhitepaper.pdf](http://www.johnsoncontrols.com/content/dam/WWW/jci/be/white_papers/GIWhitepaper.pdf)

## GROUND-SOURCE AND AIR-SOURCE HEAT PUMPS



A ground-source heat pump is a heating and cooling system that exchanges heat between the earth and the interior of a building. It relies on the fact that ground temperatures tend to be constant throughout the year – this allows it to achieve higher efficiencies than air-source heat pumps, and also makes it suitable for any climate. In the winter, it transfers heat stored in the ground into a building, and in the summer, the system works like an air conditioner, transferring heat out of a building and into the ground. Ground-source heat pumps require vertical wells or horizontal loop fields to be installed to enable the heat transfer to occur. Ground-source heat pumps can also provide domestic hot water from desuperheaters, one of the heat pump's components, and heat water for free in the summer. Air-source heat pumps are more commonly used than ground-source heat pumps, and are another efficient heating and cooling technology that operates on the same principle, but exchanges heat between indoor and outdoor air. Air-source heat pumps have predominately been utilized in warmer climates but advances in technology have recently made them more effective in cold climates.

Both technologies are currently used for cooling, space heating and water heating in residential and small- or medium-sized commercial buildings. For example, a net-zero school building in Irving, Texas, utilized geothermal heat pumps to meet its heating and cooling needs.<sup>54</sup> Each year about 50,000 new geothermal heat pumps are installed across the United States, with over a million ground-source heat pumps currently installed.<sup>55,56</sup> The U.S. market for geothermal heat pumps was estimated at \$115 million in 2013, up 9% from 2012.<sup>57</sup>

Although ground source heat pumps tend to have higher purchase and installation costs than traditional heating and cooling systems, they significantly reduce energy costs, typically 25 to 40%.<sup>58</sup> Ground source heat pumps are particularly beneficial in the summer, as they can reduce peak electricity demand. Depending on available incentives and financing options, a residential or commercial user could recoup the initial cost of investment in two to 10 years.<sup>59</sup>

54. [http://www.bosch-climate.us/files/Lady\\_Bird\\_Johnson\\_Middle\\_School\\_Case\\_Study\\_FHP\\_Geothermal\\_76HCS006\\_Oct4-2013\\_US.pdf](http://www.bosch-climate.us/files/Lady_Bird_Johnson_Middle_School_Case_Study_FHP_Geothermal_76HCS006_Oct4-2013_US.pdf)

55. <http://energy.gov/energysaver/articles/geothermal-heat-pumps>

56. [http://www1.eere.energy.gov/geothermal/pdfs/gshp\\_overview.pdf](http://www1.eere.energy.gov/geothermal/pdfs/gshp_overview.pdf)

57. Navigant Research, Advanced Energy Now 2014 Market Report, <http://info.aee.net/advanced-energy-now-2014-market-report>

58. <http://btrc.ornl.gov/ground-source.shtml>

59. <http://energy.gov/energysaver/articles/choosing-and-installing-geothermal-heat-pumps>

## EFFICIENT HEATING, VENTILATION AND AIR CONDITIONING (HVAC)



HVAC (heating, ventilation, and air conditioning) systems consist of air conditioners, heat pumps, boilers, furnaces, rooftop units, and chillers, as well as associated air handlers, ductwork, and water and steam piping. HVAC systems represent a significant portion of a building's overall energy use. Improvements in efficiency derive from various subsystem technological innovations, such as variable speed drives (which reduce electricity use by electric motors) and increased heat exchanger surface area (which increase overall energy transfer from the fuel to the conditioned space). More advanced HVAC systems also have sensors and controls that communicate with energy management systems and other intelligent controls to further reduce energy usage.

HVAC systems are major capital items and have long service lives (20 to 40 years), which can slow the deployment of high-efficiency alternatives; high-efficiency alternatives are usually considered within normal equipment replacement cycles. Nevertheless, they can result in major energy use reductions, and are in wide use today at the commercial, industrial, and residential levels. For instance, Emory University installed two high-efficiency chillers, which helped to lower energy use for space cooling by nearly 50%. Additionally it reduced energy use by their conventional pump system, which controls temperature in HVAC systems, by 40% by installing high-efficiency and variable-speed pumps.<sup>60</sup>

Heating and cooling is the largest single 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.<sup>61,62</sup> Chillers alone can account for 35-50% of a commercial building's energy use.<sup>63</sup> The International Energy Agency estimated that replacement of inefficient HVAC systems could reduce global CO<sub>2</sub> emissions by as much as 2 gigatons by 2050, representing a 25% reduction in current building emissions.<sup>64,65</sup>

60. <http://www.epa.gov/region9/waste/p2/pdf/EnergyFinalOct12.pdf>

61. <http://energy.gov/public-services/homes/heating-cooling>

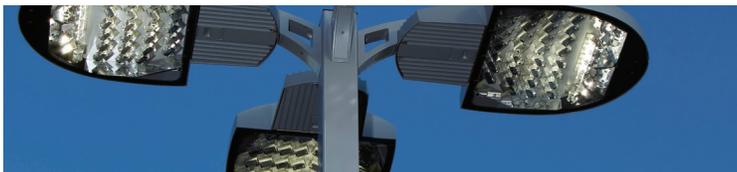
62. <http://www.sba.gov/content/hvac-systems>

63. <http://www.epa.gov/region9/waste/p2/pdf/EnergyFinalOct12.pdf>

64. <http://www.c2es.org/technology/overview/buildings>

65. <https://www.iea.org/publications/freepublications/publication/name,3983,en.html>

## EFFICIENT LIGHTING AND INTELLIGENT LIGHTING CONTROLS



Advanced lighting technology has quickly expanded to include light-emitting diodes (LEDs), energy-saving incandescent bulbs, and compact fluorescent lamps (CFLs). Solid-state lighting, including LEDs, is in the process of transforming the lighting and electronic display markets, offering mercury-free, long-lasting,

extremely efficient, digitally controllable lighting that can be used in residential and commercial settings.<sup>66</sup> Solid-state lighting is five to six times more efficient than incandescent bulbs and up to 1.5 times as efficient as CFLs.<sup>67</sup> Intelligent lighting controls can be used in conjunction with some forms of efficient lighting, particularly LEDs, which can be dimmed or turned on/off without loss of equipment lifespan or performance. Intelligent lighting controls use environmental information (e.g., occupancy, ambient light levels) to automatically adjust light levels and save energy. At each lighting fixture, sensors detect light levels and feed the information to controllers that adjust the lighting based on previously set goals.<sup>68</sup>

About a quarter of all lights in the United States are high-efficiency bulbs, establishing high-efficiency lighting as a mature technology but with plenty of growth potential.<sup>69</sup> One application that has benefited from the new technology is street lighting, where LEDs are rapidly becoming the technology of choice. For example, street lights had accounted for 40% of the electric bill for city of Los Angeles; after replacing 140,000 street lights with LEDs, the city saved over \$5 million in electricity costs annually.<sup>70</sup> While LEDs are still more expensive than traditional lighting, it is anticipated that payback time will be around two years for office and residential sectors by 2016.<sup>71</sup> At the same time, the intelligent lighting controls market is expecting to grow. Navigant Research projects that the global market for lighting controls will grow 14% per year to reach \$4.3 billion in 2020.<sup>72</sup> The largest markets will likely be office and education buildings.

Depending on what is being replaced, high-efficiency lighting typically reduces electricity use by 25% to 80%.<sup>73</sup> Additionally, quality LED lights can last up to 25 times longer than traditional incandescent bulbs.<sup>74</sup> To illustrate the potential of energy efficient lighting, 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 1 million homes for one year. This would result in greenhouse gas reductions equivalent to taking 800,000 cars off the road.<sup>75</sup>

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66. Navigant Research, Advanced Energy Now 2014 Market Report, page 25.

67. <http://info.aee.net/advanced-energy-now-2014-market-report>

68. [https://www1.eere.energy.gov/buildings/ssl/sslbasics\\_ledbasics.html](https://www1.eere.energy.gov/buildings/ssl/sslbasics_ledbasics.html)

69. [http://orf.od.nih.gov/PoliciesAndGuidelines/Documents/Technical%20Bulletins/Intelligent%20Lighting%20Control%20October%202013%20Bulletin\\_508.pdf](http://orf.od.nih.gov/PoliciesAndGuidelines/Documents/Technical%20Bulletins/Intelligent%20Lighting%20Control%20October%202013%20Bulletin_508.pdf)

70. EPA Opportunities to Advance Efficient Lighting for a Cleaner Environment Report

71. <http://www.forbes.com/sites/justingerdes/2013/01/25/los-angeles-saves-millions-with-led-street-light-deployment/>

72. [http://www.mckinsey.com/~media/mckinsey/dotcom/client\\_service/automotive%20and%20assembly/lighting\\_the\\_way\\_perspectives\\_on\\_global\\_lighting\\_market\\_2012.ashx](http://www.mckinsey.com/~media/mckinsey/dotcom/client_service/automotive%20and%20assembly/lighting_the_way_perspectives_on_global_lighting_market_2012.ashx) %20%20%20Residential%20Energy%20Consumption%20Survey%20(RECS)-f3

73. Advanced Energy Now 2014 Market Report

<http://info.aee.net/advanced-energy-now-2014-market-report>

74. <http://www.epa.gov/statelocalclimate/local/topics/residential.html>

75. <http://epa.gov/climatechange/ghgemissions/sources/electricity.html>

## RESIDENTIAL ENERGY EFFICIENCY IMPROVEMENTS



Residential energy efficiency improvements include a number of technologies and building systems that reduce energy use in homes, while still delivering the same or superior service. This includes efficient consumption of energy in appliances and other devices (e.g., lighting, Energy Star TVs, computers and refrigerators), and efficient heating and cooling equipment (e.g., natural gas condensing boilers, heat pump water heaters, and high-efficiency air conditioners). It also includes application of various building materials and systems that reduce energy demand, including efficient windows, wall and attic insulation, air sealing, building controls (e.g., programmable thermostats, use of heating and cooling zones, smart appliances that respond to price and demand signals), wrapping of hot water/steam pipes with insulation, smart power strips that shut off devices to avoid standby losses, and alternatives to air conditioning such as whole-house fans. Some water-saving technologies (e.g., faucet aerators, low-flow showerheads, efficient dishwashers) also reduce energy used for water heating.

Average energy consumption per U.S. home has decreased over time, reducing 21% from 1980 to 2009.<sup>76</sup> Still, there remains a large stock of residential buildings with significant untapped potential for retrofitting with efficient technologies and systems. The implementation of residential sector efficiency varies greatly across the country, driven by the uneven adoption of energy efficient building codes, differences in energy prices, and state policies to promote residential efficiency (typically through utility-sponsored or administered programs). The U.S. market for residential energy efficiency home services was an estimated \$855 million in 2013, up 13% from 2012.<sup>77</sup>

The economic payback for efficiency measures varies considerably. Efficient lighting can have paybacks of as little as one to two years. Other more expensive items, including HVAC systems, wall/attic insulation, and windows typically have longer paybacks but also result in larger total energy savings. In many cases, the choice of what measures to implement, based on achieving a suitable payback, is determined with an energy audit. In states with comprehensive residential efficiency programs, these audits are typically free of charge to the homeowner, and rebates are usually available for qualifying measures to encourage adoption.

Strict building energy codes and appliance standards can save the consumer 30% to 40% compared with normal practices/products. Energy Star products can offer up to 75% energy savings compared to standard products.<sup>78</sup> With commercial and residential electricity consumption making up 35% of U.S. greenhouse gas emissions, full implementation of cost-effective efficiency measures has the potential to reduce these emissions significantly, while also saving money for consumers.<sup>79</sup>

76. [http://www.eia.gov/consumption/residential/reports/2009/consumption-down.cfm?src=%E2%80%B9%20Consumption%20%20%20%20%20Residential%20Energy%20Consumption%20Survey%20\(RECS\)-f3](http://www.eia.gov/consumption/residential/reports/2009/consumption-down.cfm?src=%E2%80%B9%20Consumption%20%20%20%20%20Residential%20Energy%20Consumption%20Survey%20(RECS)-f3)

77. Advanced Energy Now 2014 Market Report, <http://info.aee.net/advanced-energy-now-2014-market-report>

78. <http://www.epa.gov/statelocalclimate/local/topics/residential.html>

79. <http://epa.gov/climatechange/ghgemissions/sources/electricity.html>

## WASTE ENERGY RECOVERY



Waste Energy Recovery (WER) describes any process in which energy that would typically be “thrown away” is captured and put to use (for this reason, WER is sometimes also called recycled energy). In broad terms, there are three types of waste energy sources suitable for recovery and conversion to electricity: waste heat, excess pressure in steam and other industrial process streams 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 useful thermal energy for industrial processes. The amount and type of useful energy produced depends on the nature of the process.

Some specific examples of WER that generate electricity include waste heat recovery (WHR) from industrial processes and boilers, WHR from mainline natural gas pipeline compressor stations (used in organic Rankine cycle plants), 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 produces high pressure steam from heat recovered from petroleum coke calcining kilns. Most of the steam is sold to a neighboring refinery, which displaces natural gas use at the refinery. The rest of the steam is used to produce 4-5 MW of electricity used at the calcining facility.<sup>80</sup>

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. During industrial processes, 20% to 50% of the energy is ultimately lost to waste. WER can improve efficiency of industrial processes by as much as 10% to 50%, depending on the process, while generating electricity that can be used onsite.<sup>81</sup> WER both increases efficiency and displaces the need for purchased fuels and electricity, thus resulting in avoided emissions.

80. [http://www.chpcenterpr.org/wasteheat2power07/WH2P07\\_TOUR.pdf](http://www.chpcenterpr.org/wasteheat2power07/WH2P07_TOUR.pdf)

81. [https://www1.eere.energy.gov/manufacturing/intensiveprocesses/pdfs/waste\\_heat\\_recovery.pdf](https://www1.eere.energy.gov/manufacturing/intensiveprocesses/pdfs/waste_heat_recovery.pdf)

## EFFICIENT WATER HEATERS



Water heating technology spans a range of options, from conventional technologies to renewable systems. Conventional storage water heaters typically run on natural gas or electricity and keep water hot in an insulated tank and ready for use at all times. They have a simple design and are relatively low cost, but they also have standby losses associated with storing hot water for long periods of time. High-efficiency models are available that increase the heat transfer efficiency and reduce the standby losses with more insulation. Tankless (instantaneous) water heaters eliminate standby losses by heating water on demand, creating a continuous supply, though there may be a limit on simultaneous use of hot water devices. Heat pump water heaters are electric water heaters that use heat pump technology to increase efficiency over 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.<sup>82</sup>

Efficient water heaters are being adopted at the commercial and campus levels, but they are most likely to be adopted in homes, where water heating makes up about 15% of an average home's total energy use.<sup>83</sup> Energy Star-rated heaters made up 11% of the gas water heating market and 1% of the electric water heating market in 2011, leaving room for further market penetration.<sup>84</sup> The U.S. market for high efficiency water heaters was an estimated \$1.3 billion in 2013, an increase of 6% over 2012.<sup>85</sup>

Energy-efficient water heaters can use 10% to 50% less energy than standard models; however, actual savings depend on size and location of the heater and water pipes. Residential customers can also take advantage of utility or state programs (covering 37 states) that support the purchase of efficient water heaters, which may include financial incentives. The Department of Energy estimates that 37 million residential water heaters will be replaced between 2010 and 2015. Should those be replaced with high-efficiency solar and heat pump water heaters, it could reduce U.S. total energy consumption by 2%.<sup>86</sup>

82. [http://www.energystar.gov/ia/new\\_homes/features/WaterHtrs\\_062906.pdf](http://www.energystar.gov/ia/new_homes/features/WaterHtrs_062906.pdf)

83. Ibid

84. [https://www.energystar.gov/ia/partners/downloads/U.S.\\_EPA-Ryan\\_and\\_Stephens-Booker.pdf](https://www.energystar.gov/ia/partners/downloads/U.S._EPA-Ryan_and_Stephens-Booker.pdf)

85. Navigant Research, Advanced Energy Now 2014 Market Report, <http://info.aee.net/advanced-energy-now-2014-market-report>

86. [https://www.energystar.gov/ia/partners/prod\\_development/new\\_specs/downloads/water\\_heaters/Water\\_Heater\\_Market\\_Profile\\_2010.pdf?c8db-fc2a](https://www.energystar.gov/ia/partners/prod_development/new_specs/downloads/water_heaters/Water_Heater_Market_Profile_2010.pdf?c8db-fc2a)

## BIOMASS POWER



Solid biomass has been used as fuel in power plants for many decades. The dominant technology is direct combustion in which biomass is burned in a boiler to generate high-pressure steam, which is used to turn a steam turbine-generator set. Other technologies also exist, such as gasification, in which the biomass is first converted to a synthesis gas that can be burned in boilers, reciprocating engines and gas turbines.

Solid biomass resources include logging and agriculture residues, forest products residues such as sawdust, bark and spent pulping liquors, as well as dedicated energy crops, both woody and herbaceous.<sup>1</sup>

In the U.S., biomass represents about 5% of total primary energy consumption, split roughly 50-50 between electricity/heat generation and biofuels production. U.S. biomass electricity generation has remained steady over the past decade at around 5 TWh, about 1% of the nation's electric generation.<sup>2,3</sup> Most biomass power generating capacity is in the forest products industry, where large quantities of biomass residue are readily available onsite at no cost.<sup>4</sup>

A biomass power plant is relatively expensive to build compared with plants utilizing similar technology for other fuels because biomass plants tend to be smaller, but still require large capital expenses. However, when fuel costs are favorable, biomass offers a viable alternative to fossil fuels or electricity purchased from the grid. Biomass is also a form of baseload energy. One of the largest woody biomass plants, located in Nacogdoches County, Texas, produces 100 MW of baseload power and is fueled by materials sourced within a 75-mile radius of the plant.<sup>5</sup> It is also possible to repower older, smaller coal-fired plants with biomass, displacing coal with a renewable fuel. These older plants typically have limited or no modern emissions controls, so repowering leads to significant reductions in emissions of criteria pollutants as well.

Biomass is considered by most authorities to be carbon neutral, provided that it is grown on a sustainable basis. That's because the CO<sub>2</sub> released during combustion is balanced by the carbon dioxide captured by trees and energy crops as they regrow.<sup>6</sup> On that basis, replacing fossil fuels with biomass reduces net greenhouse emissions. In recent years, however, this view has been challenged, with analysis suggesting that biomass may not reduce greenhouse gas emissions much in the short run, given the time it takes for new growth to absorb the carbon dioxide produced by combustion.<sup>7</sup> In 2011, EPA deferred for three years certain permitting rules on biomass power plants so that it could study the science of emissions from bioenergy sources. It is widely acknowledged that with feedstock that regrows quickly or would otherwise decompose and release CO<sub>2</sub> on its own (i.e., forest or lumber and paper mill waste), biomass energy reduces net greenhouse gas emissions relative to fossil fuel alternatives.

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1. <http://www.irena.org/DocumentDownloads/Publications/IRENA-ETSAP%20Tech%20Brief%20E21%20Biomass%20Co-firing.pdf>

2. <http://www.eia.gov/electricity/data/browser>

3. <http://www.eia.gov/electricity/monthly/pdf/epm.pdf>

4. <http://www.eia.gov/todayinenergy/detail.cfm?id=15451>

5. [http://www.southerncompany.com/about-us/our-business/southern-power/pdfs/SP\\_Nacogdoches\\_fact\\_sheet.pdf](http://www.southerncompany.com/about-us/our-business/southern-power/pdfs/SP_Nacogdoches_fact_sheet.pdf)

6. [http://www.nrel.gov/learning/re\\_biomass.html](http://www.nrel.gov/learning/re_biomass.html)

This is the case over a timescale of years to decades, depending on the rate of growth of biomass.

7. [https://www.manomet.org/sites/default/files/publications\\_and\\_tools/Manomet\\_Biomass\\_Report\\_ExecutiveSummary\\_June2010.pdf](https://www.manomet.org/sites/default/files/publications_and_tools/Manomet_Biomass_Report_ExecutiveSummary_June2010.pdf)

8. <http://www.gpo.gov/fdsys/pkg/FR-2011-07-20/pdf/2011-17256.pdf>

## BIOMASS CO-FIRING



Solid biomass (e.g., wood chips or agricultural field residues) may be co-fired with fossil fuels (usually coal) in the same power plant to generate electricity. Co-firing plants are often a result of retrofitting an existing power plant. At low levels of co-firing (up to about 2% biomass), biomass can be simply mixed with coal on the fuel pile, and plant modifications are typically not needed.<sup>9</sup> Higher amounts of biomass in the mix, usually up to about 15%, can be achieved by installing a separate feed system for the biomass. Another option for biomass co-firing is to gasify the biomass and then burn the resulting synthesis gas. This provides greater flexibility on the amount of biomass that can be burned and may have larger environmental benefits; however, it is also more expensive. Co-firing can also be accomplished by means of a dedicated biomass boiler that feeds the steam to the existing steam turbine. New power plants can be designed to burn any ratio of biomass to coal, typically using fluidized bed boilers, which have high fuel flexibility.

Mostly utilized in the United States and Northern Europe, there are about 230 co-firing power facilities in the world, with an estimated total biomass capacity of 1-10 GW (with the variability depending on the actual fraction of biomass in the fuel).<sup>10</sup> Minnesota Power has two co-firing power plants, located in Duluth and Grand Rapids. The Duluth facility generates 50 MW with a 10-90 coal to biomass ratio, while the Grand Rapids plant generates 25 MW with a 15-85 coal to biomass ratio.<sup>11</sup>

Even with separate feed systems, capital costs for retrofits to enable co-firing are low – 10% to 20% of the cost of a new dedicated biomass power plant. Nevertheless, the economic benefit varies greatly because the costs for biomass fuels depend on many factors, and each retrofit is unique.<sup>12</sup> For example, the Tennessee Valley Authority estimates that it will save \$1.5 million per year by incorporating biomass into its Colbert plant.<sup>13</sup> When grown on a sustainable basis, the CO<sub>2</sub> released from biomass combustion is considered by most authorities to be negated by the absorption from regrowth, though that view has been questioned. The International Renewable Energy Agency estimates that the replacement of 1% to 10% of the coal used in the world's power plants with biomass could reduce CO<sub>2</sub> emissions from 45 million to 450 million tons per year by 2035.<sup>14</sup>

9. <http://www.irena.org/DocumentDownloads/Publications/IRENA-ETSAP%20Tech%20Brief%20E21%20Biomass%20Co-firing.pdf>

10. Ibid

11. <http://biomassmagazine.com/articles/5751/biomass-and-coal-a-powerful-combination>

12. <http://www.irena.org/DocumentDownloads/Publications/IRENA-ETSAP%20Tech%20Brief%20E21%20Biomass%20Co-firing.pdf>

13. <http://www.nrel.gov/docs/fy00osti/28009.pdf>

14. <http://www.irena.org/DocumentDownloads/Publications/IRENA-ETSAP%20Tech%20Brief%20E21%20Biomass%20Co-firing.pdf>

## FUEL CELLS



A fuel cell generates electricity by electrochemical reaction, converting the chemical energy in fuel into electricity without combustion. It relies on the same principle as a battery except that the reactants are fuel and air (or pure oxygen), as opposed to the chemicals stored in a battery. Most fuel cells utilize hydrogen as fuel, with water and heat the only byproducts. With natural gas the main source of hydrogen widely available, fuel cell power plants also contain equipment for “extracting” hydrogen from natural gas through a process called steam reforming. Other fuels that have been used with fuel cells include biogas (e.g., from landfills or anaerobic digestion), and for transportation or portable applications, methanol, ethanol, and even gasoline and diesel. Fuel cells are efficient uses of fuel for electricity generation, especially compared to onsite diesel or gas generators, with conversion efficiencies approaching 60%.

Fuel cells markets are small but growing. In 2013, global shipments were about 215 MW, up from 86 MW in 2009.<sup>15</sup> Fuel cells are being used by many different industries, including computing and software, media, construction, food and beverage processing, grocery stores, hotels, warehouse, and distribution.<sup>16</sup> The main application globally has been combined heat and power (CHP), but in the United States, onsite generation reflects the highest use, with revenue for such fuel cell units reaching an estimated \$130 million in 2013.<sup>17</sup> Fuel cells are being used to provide ultra-high reliability power for critical operations such as data centers, as an alternative to other uninterruptible power supply systems. Apple and Microsoft are using fuel cells with renewable fuels to avoid relying on grid power for their corporate data centers. Walmart has installed over 12 MW of Bloom Energy systems across more than 40 projects at their retail stores and distribution centers around the country.<sup>18</sup> An emerging application is grid support, where fuel cells are sited strategically on a utility network. For example, Delmarva Power, Dominion, and NRG Energy are adding fuel cell capacity to deliver reliable power to their grid networks.<sup>19</sup>

Fuel cells are extremely quiet generation sources, which makes them ideal for onsite generation.<sup>20</sup> Fuel cells produce very low levels of criteria pollutants and fewer greenhouse gases than traditional energy sources. EPA estimates that installed fuel cells in the United States reduce CO<sub>2</sub> emissions by 17,000 tons per year.<sup>21</sup> Capital costs for fuel cells remain relatively high, but are expected to fall as the market grows and manufacturing scales up.

15. [http://fuelcelltoday.com/media/1889744/fct\\_review\\_2013.pdf](http://fuelcelltoday.com/media/1889744/fct_review_2013.pdf)

16. <http://www.fuelcells.org/uploads/FC-Business-Case-2012.pdf>

17. <http://info.aee.net/advanced-energy-now-2014-market-report>

18. <http://hondacenter.com/PressRoomDetails.aspx?PressRoomID=151>

19. <http://www.fuelcells.org/pdfs/2013BusinessCaseforFuelCells.pdf>

20. [http://www.fuelcells.org/base.cgim?template=fuel\\_cells\\_and\\_hydrogen](http://www.fuelcells.org/base.cgim?template=fuel_cells_and_hydrogen)

21. <http://www.epa.gov/chp/documents/fuelcells.pdf>

## GAS TURBINES (SIMPLE CYCLE AND COMBINED CYCLE)



Gas turbine technology is mature and in wide use. In its most basic configuration – the simple cycle gas turbine (SCGT) – air is compressed, mixed with fuel (most frequently natural-gas), and the mixture is burned in a combustor. The resulting hot, pressurized gases are expanded through a turbine that drives the compressor and an electric generator. SCGTs have conversion efficiencies of up to about 40%. In a combined cycle gas turbine (CCGT) plant, the hot exhaust gases leaving the turbine pass through a heat recovery steam generator, which produces high-pressure steam that drives a steam turbine connected to a generator, producing more electricity with no additional fuel input. This increases overall electrical efficiency to nearly 60%, making CCGTs the most efficient conventional power plants available.<sup>22</sup>

Gas turbines come in a wide range of sizes and can be used to meet varying needs, from large baseload plants to small distributed and onsite generation installations. The availability of low- priced natural gas in the United States has driven up the utilization rates of existing SCGT and CCGT capacity. U.S. electricity generated from natural gas increased to 27% in 2013, compared to 18% in 2004.<sup>23</sup> The increase in natural gas powered electricity generation played a role in reducing US carbon emissions close to 10% since 2005. More than half of new U.S. generation capacity in 2013 was comprised of natural gas turbine plants with investment and deployment expected to increase in the coming decade.<sup>24</sup>

The capital cost of a CCGT plant is about \$1,000/kW, significantly lower than other baseload options such as coal.<sup>25</sup> When coupled with inexpensive natural gas, CCGT economics compare favorably to other new-build options.<sup>26</sup> SCGTs and CCGTs have rapid startup and ramping capabilities that add flexibility to the grid and can support integration of variable renewable generation. As SCGT and CCGT plants mostly burn natural gas, they emit very low levels of criteria pollutants. Through a combination of higher efficiency and the use of a lower-carbon fuel, CCGT plants emit about half the CO<sub>2</sub> of even the best (i.e., supercritical) modern coal plant.<sup>27,28</sup>

22. <http://www.wartsila.com/en/combined-cycle-plant-for-power-generation>

23. [http://www.eia.gov/electricity/monthly/epm\\_table\\_grapher.cfm?t=epmt\\_1\\_1](http://www.eia.gov/electricity/monthly/epm_table_grapher.cfm?t=epmt_1_1)

24. <http://www.eia.gov/todayinenergy/detail.cfm?id=15751>

25. <https://gcep.stanford.edu/pdfs/symposium2013/NuclearEnergy101.pdf>

26. <http://www.ipgsrl.com/r-d/Coal%20Fired%20Unit%20%20versus%20Natural%20Gas%20Combined%20Cycle.pdf>

27. <http://electrical-engineering-portal.com/an-overview-of-combined-cycle-power-plant>

28. [http://www.energy.ca.gov/sitingcases/huntington\\_beach\\_energy/documents/applicant/AFC/Volume%20%20Appendices/HBEP\\_Appendix%205.1D\\_BACT%20Determination.pdf](http://www.energy.ca.gov/sitingcases/huntington_beach_energy/documents/applicant/AFC/Volume%20%20Appendices/HBEP_Appendix%205.1D_BACT%20Determination.pdf)

## GEOHERMAL POWER



Geothermal power taps into the high-temperature hydrothermal resources of the earth to generate electricity. After drilling into underground reservoirs containing hot water or steam, the power plant brings these fluids to the surface and uses them to drive a turbine connected to a generator to produce electricity.<sup>29</sup> The fluids are then returned to the reservoir. There are three main types of geothermal technologies, corresponding to high, medium and low-temperature resources: dry steam, flash steam and binary. Dry steam plants withdraw steam directly, where it is available, to drive a turbine. Flash steam, the most common geothermal technology in use

today, pumps high-temperature, high-pressure geothermal fluids into a low-pressure tank, which causes the fluids to vaporize (flash); the vapor then drives a turbine. A binary cycle is a closed loop process where low-temperature geothermal fluids are used to heat a second working fluid with a low boiling point (e.g., refrigerants or propane), which drives a turbine. Binary cycle power plants are expected to dominate future markets because low-temperature fluids are easier to access.<sup>30</sup> Another technology that has wide deployment potential but is still in the development stage is enhanced geothermal systems (EGS). EGS works by drilling deep wells into solid rock where there is heat and fracturing the rock to increase surface area. Water is then pumped into the wells to be heated and extracted for use in a binary cycle power plant. Because the natural hydrothermal resources are not needed, EGS can be deployed wherever suitable rock formations can be found.

Geothermal power plants are commonly used for baseload power, especially in the West, Alaska, and Hawaii, where hydrothermal resources are available. With over 3 GW of capacity installed, geothermal energy constitutes 1% of total electricity generated in the United States, and 8% of total non-hydro renewable electricity generation.<sup>31</sup> The state of California generates 6% of its total electricity from geothermal resources.<sup>32</sup> The Geysers, located in the Mayacamas Mountains north of San Francisco, is the world's largest complex of geothermal power plants. The 15 power plants at The Geysers have the capacity to generate 725 MW, enough to power 725,000 homes.<sup>33</sup>

New geothermal plants have relatively high capital costs, as well as ongoing costs for drilling new wells to maintain output over the long term. However, they have zero fuel cost and low operating and maintenance costs. They also operate at very high capacity factors, which make geothermal a good source of baseload power. A power plant built today would sell energy at about \$0.05 per kWh; however, some plants sell power for as low as \$0.03 per kWh. A flash or dry steam geothermal power plant emits only 1% to 4% of the carbon released by a coal plant for the same unit of electricity generated, while binary plants emit nearly zero emissions.<sup>34</sup> In addition to emissions benefits, some plants produce valuable minerals such as zinc, silica, and sulfur.<sup>35</sup>

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29. <http://www1.eere.energy.gov/geothermal/faqs.html>

30. <http://www1.eere.energy.gov/geothermal/powerplants.html>

31. <http://www1.eere.energy.gov/geothermal/faqs.html>

32. Ibid

33. [www.calpine.com/powerplants](http://www.calpine.com/powerplants)

34. Ibid

35. <http://www1.eere.energy.gov/geothermal/faqs.html>

## HYDROELECTRIC POWER



A hydroelectric power plant uses turbines and generators to convert the kinetic energy of moving water into electricity. There are three major types of hydroelectric power plants: impoundment, diversion (run-of-river), and pumped storage facilities. An impoundment facility uses a dam to store river water in a reservoir, which it then releases through a turbine to generate electricity. The height differential (“hydraulic head”) between the reservoir surface and the turbine outlet is what provides the energy for power generation. The Hoover Dam is a classic example. A diversion facility takes advantage of natural elevation changes along a river. Run-of-river plants tend to be smaller than impoundment plants, and low-impact, with diverted streams powering turbines before returning downstream. Niagara Falls

is an exception, with the Moses Niagara Power Plant and the Lewiston Pump Generating Plant together supplying 2.4 GW of hydro capacity.<sup>36</sup> A pumped storage facility pumps water from a lower to an upper reservoir when electricity demand is low and releases the water back into the lower reservoir to generate electricity when demand is high. It is a form of bulk energy storage. In addition to these three major hydro variants, there is a niche application called in-conduit hydropower. Conduit projects use water supply infrastructure such as tunnels, irrigation canals, and pipelines and outfit them with mini turbines and generating equipment.<sup>37</sup>

Hydroelectric power currently constitutes the largest and oldest source of renewable electricity in the United States. It produced 56% of renewable electricity in the United States in 2012, and 7% of the total from all sources.<sup>38</sup> The current generating capacity of hydroelectric power in the United States is nearly 80 GW and there is potential to add an additional 12 GW to existing dams.<sup>39,40</sup>

Greenfield development of new hydropower is relatively expensive and involves a long regulatory approval process. However, these plants have very long useful lives – longer than other types of power plants – and have power costs that are among the lowest available, owing to low operating costs and the ability to recover capital costs over long time periods. Existing hydropower plants are one of the cheapest sources of energy in the United States and are ideal for baseload power. Currently only 3% of the 80,000 dams in the United States produce electricity.<sup>41</sup> While not all are suitable for powering, these dams represent an opportunity to expand hydro at low cost – as low as 1 cent per kWh – with minimal environmental impact. Hydroelectric power plants abated nearly 200 million metric tons of carbon emissions in 2012, the equivalent of 40 million cars.<sup>42</sup>

36. [http://www.infoniagara.com/attractions/hydro\\_power/index.aspx](http://www.infoniagara.com/attractions/hydro_power/index.aspx)

37. <http://www.hydro.org/tech-and-policy/technology/conduit/>

38. <http://www.hydro.org/why-hydro/available/>

39. <http://www.eia.gov/totalenergy/data/annual/showtext.cfm?t=ptb0811a>

40. <http://energy.gov/articles/energy-department-report-finds-major-potential-increase-clean-hydroelectric-power>

41. <http://www.hydro.org/tech-and-policy/developing-hydro/powering-existing-dams/>

42. Ibid

## MARINE POWER



Marine power technologies generate electricity from the kinetic energy contained in moving water, including waves, currents, and tides. Wave power works by harnessing the fluctuations in wave height to generate electricity, for example, with a buoy tethered to the sea floor. As the buoy moves up and down with the waves the relative motion between it and the part that is fixed to the sea floor can be captured to drive a generator. In places with the right undersea topography, daily currents created by ocean tides can be used to drive underwater turbines. Similar technology can be used with the constant flow of water in large-scale ocean currents like the Gulf Stream. In places with large tidal ranges, barrages can be built across estuaries. Water is allowed to flow in with the rising tide and let out via low-head hydro turbines as the tide recedes. Within each category there are many different devices being developed, particularly, for wave energy capture. Proximity to shore, ocean depth, and expected sea conditions are all considerations in the design of marine power technologies.<sup>43</sup>

A zero emission power source, marine power is an emerging technology area, but the potential is great, as the ocean contains vast amounts of energy. The DOE estimates that the United States has the potential to develop about 50 GW of tidal power alone.<sup>44</sup> Capturing just 0.1% of the Gulf Stream's potential would be enough to supply 35% of Florida's electricity needs.<sup>45</sup> At this time, marine projects in the U.S. are principally for demonstration and testing purposes, but there is substantial interest in the technology.<sup>46</sup> As of April 2014, FERC has issued six preliminary permits for 2,200 MW of electricity, while permits are pending for 15 projects totaling nearly 3,900 MW.<sup>47</sup> One of the permitted projects is the Roosevelt Island Tidal Energy project in New York City (expected completion 2015), which will generate 1 MW of electricity.<sup>48</sup>

43. <http://www.c2es.org/technology/factsheet/Hydrokinetic>

44. <http://www1.eere.energy.gov/water/pdfs/1023527.pdf>

45. [http://www.ucsusa.org/clean\\_energy/our-energy-choices/renewable-energy/how-hydrokinetic-energy-works.html](http://www.ucsusa.org/clean_energy/our-energy-choices/renewable-energy/how-hydrokinetic-energy-works.html)

46. Ibid

47. <http://www.ferc.gov/industries/hydropower/gen-info/licensing/hydrokinetics.asp>

48. <http://www.nyseda.ny.gov/Publications/Research-and-Development-Technical-Reports/-/media/Files/Publications/Research/Environmental/marine-hydrokinetic-technologies-background-perspective.pdf>

## UTILITY-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 reactor core to generate steam, which then spins a turbine attached to a generator that produces electricity. Nuclear power, a zero-carbon emission technology, is typically used for generating baseload electricity, as it is a technology that is not easy to start and stop or cycle up and down. Newer technologies (known as Generation III or III+) offer greater reliability and extensive safety features, as well as higher efficiency, with capacity factors above 80%.<sup>54,55</sup>

Nuclear power is a mature technology, with 100 reactors across 65 locations in the United States, totaling 115 GW and producing 19% of the country's electricity.<sup>56,57</sup> As of early 2014, five new reactors are under construction.<sup>58</sup> Nuclear power plants are large facilities that provide substantial amounts of baseload power. Exelon Corporation's Byron Generating Station, located 110 miles west of Chicago, IL, has two reactors capable of producing over 2,000 MW of electricity. In 2013, Byron produced 19.5 million MWh, enough to power more than 2 million homes.<sup>59</sup>

The initial capital investment required for building new utility-scale nuclear projects is significant, typically around \$5,500/kW in the United States.<sup>60</sup> However, once built, the plants have high utilization and low operation and maintenance costs.<sup>61</sup> Nuclear power plants do not produce any emissions or pollutants, including greenhouse gases. Nuclear plants play a major role in reducing CO<sub>2</sub> emissions in the U.S. today; closing one-third of the nation's nuclear plants would cause the country's CO<sub>2</sub> emissions to rise by 8%.<sup>62</sup>

54. [http://www.iea.org/publications/freepublications/publication/nuclear\\_roadmap.pdf](http://www.iea.org/publications/freepublications/publication/nuclear_roadmap.pdf)

55. <http://www.eia.gov/tools/faqs/faq.cfm?id=104&t=3>

56. <http://www.eia.gov/todayinenergy/detail.cfm?id=6310>

57. [http://www.eia.gov/totalenergy/data/monthly/pdf/sec8\\_3.pdf](http://www.eia.gov/totalenergy/data/monthly/pdf/sec8_3.pdf)

58. <http://www.iaea.org/PRIS/WorldStatistics/UnderConstructionReactorsByCountry.aspx>

59. <http://ilcleanenergy.org/site/wp-content/uploads/2014/03/ICEC-Emissions-Study-2014.pdf>

60. <http://www.eia.gov/tools/faqs/faq.cfm?id=104&t=3>

61. <http://www.nei.org/Knowledge-Center/FAQ-About-Nuclear-Energy>

62. [http://content.thirdway.org/publications/794/Third\\_Way\\_Memo\\_-\\_Shutting\\_Down\\_Nuclear.pdf](http://content.thirdway.org/publications/794/Third_Way_Memo_-_Shutting_Down_Nuclear.pdf)

## 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.<sup>49</sup> There are numerous SMR plant designs, though SMRs all rely on the same nuclear fission technology of larger plants. Nuclear fission releases heat in the reactor core to produce steam, which spins a turbine attached to a generator that produces electricity. Unlike utility-scale plants that can take years to construct, SMRs can be assembled offsite and delivered fully constructed. SMRs are smaller, simpler, and can be sited in more places than utility-scale nuclear plants, including submarines, which have been powered by a type of SMR for decades. SMRs generally have their reactors buried in the ground, away from weather hazards. They often use passive cooling systems that are not vulnerable to power outages, increasing the safety of the plant.<sup>50,51</sup>

While no SMRs are operating on the grid in the U.S. or elsewhere as of yet, the DOE believes there will be a substantial domestic and international market once products are developed. DOE is presently working with several companies, including mPower America and NuScale Power, to develop, test, and deploy different types of SMRs.<sup>52</sup> DOE is assisting in design certification, site characterization, licensing, and engineering activities, aiding companies that are targeting SMR commercial operation in the next decade.

A study by Carnegie Mellon University estimates that a 225 MW SMR could have a levelized cost of energy as low as \$65 per MWh once the technology has matured.<sup>53</sup> Given their lower capital costs as well as their safety features, SMRs have the potential to be more appealing to investors than large-scale nuclear projects. Like their utility-scale counterparts, SMRs do not emit any criteria pollutants or greenhouse gases during their operation and can provide a reliable source of baseload power.

49. <http://www.energy.gov/ne/nuclear-reactor-technologies/small-modular-nuclear-reactors>

50. Ibid

51. [http://www.iaea.org/INPRO/6th\\_Dialogue\\_Forum/session-1/3-subki.pdf](http://www.iaea.org/INPRO/6th_Dialogue_Forum/session-1/3-subki.pdf)

52. Ibid

53. [http://www.andrew.cmu.edu/user/ayabdull/Abdulla\\_LCOE.pdf](http://www.andrew.cmu.edu/user/ayabdull/Abdulla_LCOE.pdf)

## RESIDENTIAL AND COMMERCIAL BUILDING SOLAR POWER



Solar photovoltaic (PV) power systems convert sunlight directly into electricity. PV modules (panels) produce direct current, which is converted to grid-compatible alternating current through an inverter. The flat-plate PV modules are commonly mounted on the roofs of residential and commercial buildings. The two main PV materials used in modules are crystalline silicon and thin-films such as cadmium telluride. The former is more commonly used for residential and commercial buildings due to its higher efficiency and associated smaller footprint, which is a desirable characteristic for rooftop applications.

The residential solar market in the United States is booming; nearly 800 MW of residential solar capacity was added in 2013, a 60% increase compared to 2012, along with over 1,100 MW of non-residential (commercial, government, school, and non-profit) solar PV in 2013, a 4% increase.<sup>63</sup> Aside from the improving economics of PV and supportive policies in several states, the growth of residential and commercial solar has been spurred by improvements in sales channels and the availability of third-party financing options, whereby building owners lease the systems or purchase the output under a long-term power purchase agreement (PPA). Whether by a lease or PPA, third-party financing removes a key obstacle – the up-front cost of the system. The industry has also been able to improve its access to capital. For example, SolarCity recently became the first solar company to securitize its distributed solar assets, paving the way for more abundant and lower cost solar project capital.<sup>64</sup>

Distributed solar power reduces emissions through avoided generation and helps to reduce strain on the grid by providing additional local capacity. The installed cost of PV systems continues to decrease due to improvements in technology, economies of scale, and efforts to reduce “soft costs.” In some states, the levelized cost of PV is on par with grid retail prices.<sup>65</sup> In states such as California, New Jersey, and Massachusetts, solar rebates and solar renewable energy credits have made solar competitively priced and sales have taken off. At the end of Q4 2013, residential solar systems cost on average \$4.59 per watt, down 8.7% from 2012, while the price of non-residential PV systems fell over 16% from 2012 to \$4.26 per watt.<sup>66</sup> Over the past two years, about 200,000 U.S. homes and businesses installed rooftop solar systems (about 3 GW of capacity), which is equivalent to 1% of American coal plant generation capacity.<sup>67,68</sup> Numerous studies have shown the extent to which solar energy can effectively reduce carbon emissions. The Western Wind and Solar Integration Study, performed by NREL, evaluated the impacts of operating the Western Interconnect with high penetrations of wind and solar. With the Western Interconnect obtaining 33% of electricity from wind and solar, the study found that CO<sub>2</sub> emissions could be reduced by 29%-34%, or the equivalent of 260-300 billion pounds per year.<sup>69</sup>

63. <http://www.seia.org/research-resources/solar-market-insight-report-2013-year-review>

64. <http://investors.solarcity.com/releasedetail.cfm?ReleaseID=808982>

65. [http://www.rmi.org/electricity\\_grid\\_defection](http://www.rmi.org/electricity_grid_defection)

66. <http://www.seia.org/research-resources/solar-market-insight-report-2013-year-review>

67. <http://www.bloomberg.com/news/2013-12-26/utilities-feeling-rooftop-solar-heat-start-fighting-back.html>

68. [http://www.brattle.com/system/publications/pdfs/000/004/982/original/Coal\\_Plant\\_Retirements\\_and\\_Market\\_Impacts.pdf?1391611874](http://www.brattle.com/system/publications/pdfs/000/004/982/original/Coal_Plant_Retirements_and_Market_Impacts.pdf?1391611874)

69. Western Wind and Solar Integration Study, available at: [http://www.nrel.gov/electricity/transmission/western\\_wind.html](http://www.nrel.gov/electricity/transmission/western_wind.html)

## UTILITY-SCALE SOLAR POWER



There are several technology options for utility-scale solar power systems, although photovoltaic (PV) panels are the most commonly used. Most utility-scale solar farms consist of large arrays of ground-mounted flat-plate PV modules, which convert sunlight directly into electricity via solar cells. The arrays can be fixed-tilt, single-axis tracking, or dual-axis tracking. Tracking adds cost but increases overall energy output. Concentrating photovoltaic (CPV) technology uses lenses to concentrate sunlight onto small PV cells to achieve higher overall conversion efficiencies than flat-plate technology. A minority of utility-scale solar projects use concentrated solar power (CSP) systems, which concentrate sunlight using mirrors or lenses to generate high temperatures that are used to produce high-pressure steam that drives an electricity-generating steam turbine-generator set. Utility-scale PV and CPV plants typically range in size from 1 MW to well over 100 MW, while CSP is generally in the 100s of MW. Peak solar output (midday to late afternoon) also typically coincides with times of peak electric demand, relieving the need for peak generation resources.

PV has driven large expansions in U.S. utility-scale solar power installations over the last decade, such that solar was the second largest source of new electric capacity added in 2013. Nearly 2,900 MW of new utility-scale solar was installed in 2013, a 58% increase from 2012, bringing the cumulative utility-scale capacity in the United States to over 5 GW.<sup>70</sup> These large projects provide significant amounts of power. Once complete, First Solar's 250 MW Agua Caliente Solar Project in Yuma County, Arizona, will be capable of powering the equivalent of about 100,000 homes.<sup>71</sup> Flat-plate PV is utilized most often because the technology can work in both direct and diffuse sunlight. Both CSP and CPV are best suited for sunny areas with low humidity, like the American Southwest.

By the end of 2013, the average cost of utility-scale solar in the U.S. was \$1.96 per watt, down 13.7% from 2012.<sup>72</sup> With no fuel cost and no emissions, solar power both alleviates greenhouse gas emissions and fuel price spikes. Installing 4 GW of CSP in the resource-rich American Southwest could offset 7.6 million tons of carbon emissions.<sup>73</sup>

70. <http://www.seia.org/state-solar-policy/california>

71. <http://www.firstsolar.com/en/about-us/projects/agua-caliente-solar-project>

72. <http://www.seia.org/research-resources/solar-market-insight-report-2013-year-review>

73. <http://www.seia.org/policy/power-plant-development/utility-scale-solar-power>

## ONSHORE WIND POWER



Wind is a free and abundant fuel source. Wind turbines convert the kinetic energy in wind into electricity. Turbines range in size from under 1 kW for off-grid or residential applications, to 8 MW for the largest units in development for offshore applications. For land-based wind farms, turbines typically range from 1.5-3 MW each and the projects typically consist of tens to hundreds of turbines spread over dozens or even thousands of acres for the largest projects.<sup>74</sup> The upwind three-blade design dominates the industry although there are novel designs used for smaller applications. Other major components are the nacelle, which houses the gearbox and generator, and the tower. That represents 4.4% of power-sector CO<sub>2</sub> emissions, and is equivalent to taking over 16.9 million cars off the road.

In the United States, most wind power capacity is in large-scale wind farms, such as RES Americas' 150 MW Hopkins Ridge wind farm serving Washington State utility Puget Sound Energy. Over 900 wind farms are installed across 39 states, with Texas leading the pack in installed capacity and California leading in number of turbines.<sup>75</sup> Distributed wind systems from a few kW to MW-class are being installed by the thousands at homes, farms, businesses, and public facilities across all 50 states. A typical residential 10 kW turbine will save 250 tons of CO<sub>2</sub> and 1.2 tons of air pollutants over its 30-50 year operating life.<sup>76</sup>

The cost of wind power continues to decline. The levelized cost of wind power in 2012 was \$40/MWh, with some PPAs pricing wind contracts as low as \$19.50/MWh, making it competitive with traditional electricity generation sources in some areas of the country.<sup>77,78</sup> With no fuel costs and low operations and maintenance costs, generators can sell this power via fixed-price long-term contracts, or power purchase agreements (PPAs). And as a zero emission source of generation, wind power displaces generation by emitting technologies. The 167 million megawatt-hours of wind energy generated by wind power in the U.S. in 2013 resulted in the avoidance of 95.6 million metric tons of CO<sub>2</sub>. That represents 4.4% of power-sector CO<sub>2</sub> emissions, and is equivalent to taking over 16.9 million cars off the road.<sup>79</sup>

74. The turbines and access to them only occupies about 5% of this land. The rest is available for other uses (e.g., agriculture) or can be left as is (e.g., forest).

75. <http://www.awea.org/AnnualMarketReport.aspx?ItemNumber=6305>

76. <http://bergey.com/wind-school/90-second-expert/helping-the-environment>

77. <http://emp.lbl.gov/sites/all/files/lbnl-6356e.pdf>

78. <http://www.wecc.biz/committees/BOD/TEPPC/SPSG/Lists/Events/Attachments/780/CS%20Renewables%20Forecast%20Dec2013.pdf>

79. <http://www.awea.org/AnnualMarketReport.aspx?ItemNumber=6315>

## OFFSHORE WIND POWER



Offshore wind turbines are located on bodies of water where there is access to stronger wind resources than are typically available on land. These turbines convert the kinetic energy of the wind to electricity with no greenhouse gas emissions. Generally, these turbines are fixed directly to the sea floor, though technologies are being developed to mount turbines on floating platforms, which will enable deployment in deeper water or farther offshore. In general, because of the higher expense of foundations and installation compared to land-based wind turbines, offshore turbines are sized larger (3 MW to 5 MW, with even larger units in development), which enables greater output per turbine.

As of 2012, there were 85 operational offshore wind farms worldwide, located mostly in Europe.<sup>80</sup> While no offshore wind farms have yet been installed in the U.S., 11 projects with a planned capacity of nearly 4,000 MW have reached an advanced stage of development.<sup>81</sup> The long-planned, 130-turbine Cape Wind project in Nantucket Sound is anticipated to provide 75% of the power for the Cape, Martha's Vineyard, and Nantucket.<sup>82</sup> Once in operation, these projects would place the United States as a leader among global offshore wind energy producers.<sup>83</sup>

Offshore wind farms tend to be more expensive to install than land-based projects, but these farms capitalize on frequently stronger and more reliable wind resources and are located closer to large population centers, reducing the need for long-distance transmission. As the offshore wind power industry continues to expand globally, costs are expected to decline just as they have for onshore projects. These offshore wind projects provide a zero emission source of electricity, displacing generation by emitting technologies. According to the state of Massachusetts, 1 MW of offshore wind can power 400 homes and reduce grid powered carbon emissions by 2,600 tons.<sup>84,85</sup>

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80. [http://www1.eere.energy.gov/wind/pdfs/offshore\\_wind\\_market\\_and\\_economic\\_analysis.pdf](http://www1.eere.energy.gov/wind/pdfs/offshore_wind_market_and_economic_analysis.pdf)

81. Ibid

82. <http://www.nytimes.com/2014/01/23/business/energy-environment/us-offshore-wind-farm-made-in-europe.html>

83. [http://www1.eere.energy.gov/wind/pdfs/offshore\\_wind\\_market\\_and\\_economic\\_analysis.pdf](http://www1.eere.energy.gov/wind/pdfs/offshore_wind_market_and_economic_analysis.pdf)

84. <http://www.mass.gov/eea/energy-utilities-clean-tech/renewable-energy/wind/wind-energy-facts.html>

85. [http://www.windpoweringamerica.gov/pdfs/economic\\_development/2009/ma\\_wind\\_benefits\\_factsheet.pdf](http://www.windpoweringamerica.gov/pdfs/economic_development/2009/ma_wind_benefits_factsheet.pdf)

## WASTE-TO-ENERGY



Waste-to-energy (WTE) is the process of generating electricity and/or heat by combusting municipal solid waste (MSW). The MSW is burned to create steam, which then spins a turbine attached to an electric generator. There is a small amount of ash (5-15% of the volume of the processed trash) left over as a byproduct that is sent to a landfill. Although mass-burn combustion is the most widely deployed type of WTE technology, there are other technologies that are being commercialized, including gasification and anaerobic digestion.<sup>86</sup> WTE plants can also include the recovery of non-combustible recyclable materials, either before or after combustion.

There are 86 WTE facilities in the United States.<sup>87</sup> Located across 25 states, primarily in the Northeast, these facilities have a generating capacity of over 2 GW and process more than 28 million tons of municipal trash per year.<sup>88</sup> Non-utility companies, typically subsidiaries of waste management companies, often develop, own, and operate WTE facilities. These companies use power purchase agreements (PPAs) to sell electricity to utilities and contract with trash collectors to provide the waste feedstock. 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 municipal waste per day. The 80 MW facility sells enough electricity to Dominion Virginia Power to power 80,000 homes.<sup>89</sup>

Waste-to-energy reduces carbon emissions by offsetting the need for electricity generated from traditional generation sources while providing a reliable source of baseload power. MSW plants emit half as many pounds of CO<sub>2</sub> per MWh as coal plants.<sup>90</sup> MSW facilities recover energy from waste that would otherwise be buried in landfills, thereby reducing the methane emissions that would be released in decomposition.

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86. <http://www.epa.gov/waste/nonhaz/municipal/wte/basic.htm>

Anaerobic digestion first requires separation of the organic fraction of the waste.

87. <http://www.epa.gov/waste/nonhaz/municipal/wte/>

88. <http://www.epa.gov/epawaste/nonhaz/municipal/wte/>

89. <http://www.covanta.com/facilities/facility-by-location/fairfax.aspx>

90. This calculation by EPA excludes the organic waste in MSW combustion. Including organics results in MSW CO<sub>2</sub> emissions being slightly higher than natural gas but lower than coal plants. <http://www.epa.gov/wastes/nonhaz/municipal/wte/airem.htm>

## ANAEROBIC DIGESTION



Anaerobic digestion (AD), is a process by which waste, such as livestock manure, food scraps, and municipal/industrial wastewater, is broken down by microorganisms in the absence of oxygen into a combination of methane and other gases, otherwise known as biogas. Unlike waste-to-energy from municipal solid waste, anaerobic digestion occurs without incineration and relies on natural breakdown of organic matter into biogas. Different digester types can be used, from covered lagoons at animal farms to above ground steel or concrete tanks. The biogas can then be burned to generate electricity on-site. Biogas can also be purified and made into a pipeline-quality substitute for natural gas, including compressed natural gas (CNG) for vehicles.<sup>91</sup> Co-

digestion adds fats, oils, and grease to manure or wastewater to enhance energy production. Landfill gas (LFG) is biogas produced naturally in landfills and captured for electricity generation.

In the U.S., AD is commonly used with agricultural waste or to power wastewater treatment plants.<sup>92</sup> Interest in using food waste for AD is on the rise, especially as states look to reduce the amount of municipal waste going to landfills. There are over 190 anaerobic digesters operating at commercial livestock facilities, generating 244,000 megawatt-hours of electricity annually.<sup>93</sup> Likewise, there are about 1,500 operating at wastewater treatment facilities. AD is often used in conjunction with CHP for efficient electricity and heat generation. The heat can be used on site by farms and wastewater treatment facilities for hot water, drying biosolids, and for heating digesters. Farms regularly utilize AD, including at Royal Farms No. 1 in Tulare, California. Biogas is generated using slurried hog manure, generating electricity and heat energy for use on the farm.<sup>94</sup>

AD facilities use waste that would otherwise create methane, a more powerful greenhouse gas than CO<sub>2</sub>, when it decomposes in landfills. Many farmers who deploy such facilities are able to reduce manure odors while meeting their electricity and heating demands, avoiding the need to purchase electricity or fuels. In 2009 AD systems reduced over 1.1 million metric tons of CO<sub>2</sub> equivalent by direct emissions reduction or avoided emissions.<sup>95</sup> Municipalities that employ co-digestion biogas facilities also benefit by reducing the amount of clogging fats, oils, and grease in their waste streams, and by utilizing the residual biosolids as fertilizer. Water quality can also be improved, with disease-causing bacteria being removed from groundwater.<sup>96</sup>

91. <http://www.epa.gov/agstar/anaerobic/index.html>

92. <http://www.energy.ca.gov/biomass/anaerobic.html>

93. [http://www.americanbiogasCouncil.org/biogas\\_questions.asp](http://www.americanbiogasCouncil.org/biogas_questions.asp)

94. <http://www.energy.ca.gov/biomass/anaerobic.html>

95. [http://www.epa.gov/agstar/documents/digester\\_status\\_report2010.pdf](http://www.epa.gov/agstar/documents/digester_status_report2010.pdf)

96. Ibid

## ADVANCED METERING INFRASTRUCTURE (AMI)



A smart meter is an electrical device that records consumption of electricity in time intervals of an hour or less, typically 15 minutes. The meter communicates this information, along with data on power outages and quality, to utilities for monitoring and billing purposes, typically over a secure communication network. It is also possible to enable two-way communication with smart meters, allowing utilities to relay detailed energy usage information back to the customer, enabling more proactive end-user energy management.<sup>1</sup> Smart meters are the central component of Advanced Metering Infrastructure (AMI), the broader infrastructure that allows the utility to communicate with smart meters, enabling new products and services as part of the “smart grid.”

The market for AMI in the United States was over \$2.2 billion in 2012.<sup>2</sup> Smart meter deployment by utilities has become commonplace, with an estimated 46 million smart meters installed in the U.S. by mid-2013, covering about 40% of households.<sup>3</sup> As an example, CenterPoint Energy Houston Electric, LLC, completed the installation of more than 2.2 million Itron smart meters as part of its smart grid initiative. In 2012, Itron reported that CenterPoint is now electronically reading meters at a 99.5% accuracy rate.<sup>4</sup>

As one of the foundational components of the smart grid, AMI sets the stage for other grid management technologies to connect and improve the grid, making it more flexible and reliable. First, utilities are beginning to use the data provided by smart meters to improve the efficiency and reliability of the electric system. The use of smart meters results in operational cost savings for utilities; a utility with a service territory of 1 million households is estimated to have operational savings of \$77 million to \$208 million, consumer-driven savings of \$100 million to \$150 million and a net benefit of \$21 million to \$64 million over a 20 year period.<sup>5</sup> Second, customers can use smart meter data to make informed decisions on energy usage, provided they are given the tools necessary for acting on the data.<sup>6</sup> This can lead to lower overall energy usage and also reduced usage during peak demand, when power plant emissions tend to be higher, thus reducing carbon emissions.

1. <http://www.cpuc.ca.gov/PUC/energy/Demand+Response/ami.htm>
2. <http://info.aee.net/advanced-energy-now-2014-market-report>
3. [http://www.edisonfoundation.net/iee/Documents/IEE\\_SmartMeterUpdate\\_0813.pdf](http://www.edisonfoundation.net/iee/Documents/IEE_SmartMeterUpdate_0813.pdf)
4. <https://www.itron.com/na/newsAndEvents/Pages/CenterPoint-Energy-Completes-Itron-Smart-Met>
5. [http://www.edisonfoundation.net/iei/Documents/IEE\\_BenefitsofSmartMeters\\_Final.pdf](http://www.edisonfoundation.net/iei/Documents/IEE_BenefitsofSmartMeters_Final.pdf)
6. [https://www.smartgrid.gov/sites/default/files/doc/files/AMI\\_OM\\_report\\_final\\_12-13-2012%5B1%5D.pdf](https://www.smartgrid.gov/sites/default/files/doc/files/AMI_OM_report_final_12-13-2012%5B1%5D.pdf)

## DISTRIBUTION AUTOMATION AND NETWORK EFFICIENCY



In recent years, many transmission networks have been upgraded with new sensors and automated control equipment, which allow for more efficient centralized control. Distribution networks, however, are further behind in deploying these systems, which could improve system operations. Distribution automation technology includes a combination of line sensors, new control equipment, and intelligent software that constantly optimizes distribution system operations for reliability and efficiency. Substation automation systems collect data about consumption and load and transmit the data to grid operators in real time. The data is used to improve operational efficiency and to help manage the grid during abnormal events, such as outages. Substation automation systems improve response time to problems from hours to minutes or even seconds.

Utilities are installing distribution automation equipment in order to meet rising requirements for reliability and resilience against extreme weather. Utilities in North America spent over \$1.5 billion in distribution and substation automation in 2013, out of an \$8 billion global market.<sup>7</sup> Utilities use these automation technologies to reduce operation and maintenance costs, prevent outages, and have crews respond to outages more quickly and effectively. The granular data delivered by these systems on customer power usage also allows for better load forecasting and more efficient use of generation resources.

Distribution automation helps optimize voltage conservation and reactive power, integrate more distributed generation, and increase energy efficiency throughout the system without needing action on the part of customers, all of which helps to reduce emissions. Still, the primary benefit of distribution automation is a more flexible grid system that can anticipate and head off outages and other problems. A Department of Energy survey found that distribution automation resulted in better reliability for utilities.<sup>8</sup> A grid that incorporates distribution automation is more efficient, flexible, and reliable, and it allows the distribution process to be managed by utilities more proactively.

7. <http://info.aee.net/advanced-energy-now-2014-market-report>

8. <https://www.smartgrid.gov/sites/default/files/doc/files/Distribution%20Reliability%20Report%20-%20Final.pdf>

## ELECTRIC VEHICLES



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 rechargeable batteries. PEVs include battery electric vehicles (BEVs) such as the Nissan Leaf and Tesla Model S, which need to be recharged through external power sources, and plug-in hybrid 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 100 to 250 miles, while PHEVs have electric-only ranges of about 20-40 miles, after which they operate on gasoline like regular hybrid vehicles.

Although sales of PEVs are relatively small, the market is growing quickly. Sales were just under 100,000 units in 2013 in the U.S., or about 0.7% of total vehicle sales, up from approximately 52,000 in 2012.<sup>9</sup> The market has seen tremendous growth, with U.S. revenues jumping from \$700 million to \$3.6 billion between 2011 and 2013.<sup>10</sup> With market penetration at its early stages, the upfront costs of PEVs are higher than traditional vehicles. However, electric drivetrains are much more efficient than gasoline or diesel drivetrains, achieving gasoline-equivalent fuel economy in excess of 100 MPG, creating operational savings, and as battery costs decline and manufacturing scales up, vehicle costs are expected to fall. U.S. Corporate Average Fuel Economy standards (CAFE) for new vehicles, which are set to double to about 41 MPG by 2021, are providing impetus for auto manufacturers to produce PEVs that are successful in the marketplace.<sup>11</sup>

PEVs are beneficial in both reducing emissions and providing grid energy storage. PEVs reduce transportation-related greenhouse gas emissions, even when considering power plant emissions associated with vehicle charging. This benefit varies depending on the power generation mix, but even in regions with relatively high electricity-related emissions there is a net benefit. Assuming 7.6 million EVs are deployed on U.S. roads by 2020 (of the 254 million cars on the road today), up to 5% of annual U.S. emissions could be reduced.<sup>12,13,14</sup> Overnight charging of PEVs can also help increase utilization of off-peak, low-carbon generation (such as nuclear, which benefits from continuous operation, and wind, which often produces strongly at night). With 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. As the size of the PEV fleet grows, the ability to aggregate and manage vehicles in a coordinated fashion has the potential to create a large source of energy storage. Using PEV batteries as storage for grid support is currently in deployment in a number of pilot projects around the country, including by the U.S. Army and NREL at Fort Carson and by the University of Maryland in partnership with NRG and BMW.<sup>15</sup>

9. <http://electricdrive.org/index.php?ht=d/sp/i/20952/pid/20952>

10. <http://info.aee.net/advanced-energy-now-2014-market-report>

11. <http://www.nhtsa.gov/fuel-economy>

12. [http://www.iea.org/publications/globalevoutlook\\_2013.pdf](http://www.iea.org/publications/globalevoutlook_2013.pdf)

13. [http://www.rita.dot.gov/bts/sites/rita.dot.gov/bts/files/publications/national\\_transportation\\_statistics/html/table\\_01\\_11.html](http://www.rita.dot.gov/bts/sites/rita.dot.gov/bts/files/publications/national_transportation_statistics/html/table_01_11.html)

14. <http://www.epa.gov/climatechange/science/indicators/ghg/us-ghg-emissions.html>

15. [http://www.nytimes.com/2013/04/26/business/energy-environment/electric-vehicles-begin-to-earn-money-from-the-grid.html?\\_r=0](http://www.nytimes.com/2013/04/26/business/energy-environment/electric-vehicles-begin-to-earn-money-from-the-grid.html?_r=0)

## ENERGY STORAGE



Several technologies can be used to store energy on the electricity transmission and distribution grid, including pumped storage hydro (PSH), compressed air energy storage (CAES), electrochemical batteries, flywheel systems and thermal energy storage systems. Electricity is then generated during peak hours by releasing the water through a hydro turbine. CAES stores energy by using an electric motor

to drive an air compressor that fills a storage facility (typically an underground cavern) with compressed air. Electricity is generated when the compressed air is released to drive an expander. Electrochemical batteries store electricity as chemical energy and are used in a wide variety of applications from vehicles to flashlights. Lithium ion and other chemistries, including “liquid metal” technology, are being developed for use in the electricity grid and are currently used commercially on a limited basis.<sup>16</sup> Flow batteries are variants of traditional batteries except that the chemicals are stored in tanks separate from the electrochemical cells where the reaction takes place, which extends the duration of storage. Flywheel systems store kinetic energy by spinning up a rotor to very high speeds and then by releasing the energy on an as-needed basis.

With storage playing a crucial role in modernizing the grid and incorporating renewable generation, the industry is rapidly expanding, with new innovations entering the space that is currently occupied by older systems. Pumped storage accounts for 95% of America’s 25 GW of existing energy storage, with most of the capacity constructed in the 1970s.<sup>17,18</sup> The remaining 5% is spread across battery technologies, with CAES in limited use. The Bath County Hydro Pumped Storage Facility in Virginia is the largest pumped storage facility in the world; it has a 3 GW capacity and serves six states and Washington, D.C.<sup>19,20</sup> The energy storage market is expanding quickly, with a number of utilities, including Pacific Gas and Electric, Southern California Edison, and Long Island Power Authority, having released RFPs for storage options.

Energy storage systems can provide benefits to grid operations on three basic timescales: Daily, hourly/sub-hourly, and seconds-minutes. Each storage technology has strengths and weaknesses relative to these timescales. Daily applications include providing firm capacity reserves and system-wide peak shaving when demand is high. On the timescale of tens of minutes to a few hours, energy storage can help with load leveling (smoothing) and peak shaving, for example, to help smooth and firm the output of variable renewable generation. Over timeframes of seconds to minutes, energy storage can help with frequency regulation, voltage support and reactive power. Batteries may be particularly good at these short duration applications because they use power electronics and can respond quickly to changing grid conditions. In addition to these operational benefits, energy storage can help defer or avoid traditional investments in generation (peaking plants), transmission and distribution. And although energy storage itself can be a net consumer of energy, it enables air emission reductions that are expected to outweigh this energy use. The emissions reductions benefits fall into three main categories: increasing grid flexibility to allow for higher penetration of variable renewable generation; offsetting emissions from older, dirtier plants for meeting peak demand; and improving grid efficiency by relieving constraints when demand is high, since this is when transmission and distribution equipment losses are highest.<sup>21</sup>

16. <http://www.greentechmedia.com/articles/read/Ambri-Wins-35M-in-Venture-Funding-For-Liquid-Metal-Battery-Grid-Storage>

17. <http://www.nrel.gov/docs/fy13osti/58655.pdf>

18. <http://energy.gov/sites/prod/files/2013/12/f5/Grid%20Energy%20Storage%20December%202013.pdf>

19. <http://www.energystorageexchange.org/projects/4.pdf>

20. <https://www.dom.com/about/stations/hydro/bath-county-pumped-storage-station.jsp>

21. <http://www.energy.gov/sites/prod/files/2013/12/f5/Grid%20Energy%20Storage%20December%202013.pdf>

## HIGH TEMPERATURE SUPERCONDUCTING (HTS) TRANSMISSION



Superconductivity is a property of some materials whereby electrical resistance, which normally decreases gradually with decreasing temperature, suddenly drops to zero below a critical temperature. Advances in materials have created high-temperature superconductors (HTS), whose relatively “warm” critical temperatures of  $-315^{\circ}$  to  $-230^{\circ}\text{F}$  allow for the use of less expensive and easier to handle refrigerants such as liquid nitrogen. HTS transmission passes electricity through a cable that is insulated with high-pressure liquid nitrogen pumped by refrigeration equipment. The insulation allows HTS transmission to carry 10 times the power of a standard cable of similar thickness with almost no power losses. These lines can connect directly to the existing AC transmission network to add highly efficient transmission capacity that can relieve congestion without the need for high voltages.

Commercial applications of HTS for transmission are beginning to unfold. Several utilities have begun to use HTS transmission for projects in urban areas that do not have space for large transmission towers or extra transformer equipment. For example, the Long Island Power Authority (LIPA), using technology from American Superconductor and Nexans, 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.<sup>23</sup>

The ability of HTS to relieve transmission bottlenecks allows for more efficient operation of the transmission network as well as allowing for more efficient generator dispatch, which can help lower emissions and reduce transmission energy losses. In addition, HTS transmission avoids most of the siting challenges that affect traditional transmission projects. Because HTS lines do not emit or receive interference, placing transmission lines in close proximity to each other does not hinder their operation or subject nearby objects to electromagnetic fields. This allows for the use of much narrower rights-of-way, and for HTS cables to be packed tightly underground, reducing land requirements and enabling the siting of lines where it would otherwise be difficult or impossible.

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22. 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.

23. <http://tdworld.com/overhead-transmission/lipa-energizes-worlds-first-transmission-voltage-superconductor>

## HIGH-VOLTAGE DIRECT CURRENT TRANSMISSION



There are two types of currents that can be used when transmitting electricity: Alternating Current (AC) and Direct Current (DC). The electric grid developed around AC power because it was easier to manipulate and transport efficiently given technological limitations with DC transformers that persisted until the 1980s. Technological advancements have now made high-voltage DC (HVDC) lines a viable option for efficiently transporting power over long distances. With HVDC, converters draw AC power from the grid and convert it to DC power. The DC power flows in one direction over the transmission line, and then goes through a second conversion at the other terminus back into AC power, where it is injected into the grid. The use of converters at either end allows HVDC lines to transfer power between two interconnects without disrupting either system.

HVDC has been used for decades in underwater and underground transmission projects where AC use is limited, but its use in aboveground transmission is increasing, primarily for moving large amounts of remote wind and hydro power to distant load centers. Between 2011 and 2012, revenues in the HVDC industry doubled from \$950 million to \$1.9 billion.<sup>24</sup> For example, Clean Line Energy is currently building several HVDC lines to transport wind power from the wind-rich Midwest to distant population centers. Four planned lines will connect enough renewable energy to avoid 15 million tons of CO<sub>2</sub> each year.<sup>25</sup>

The increased 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. For example, an 800 kV HVDC power line over 1,000 miles loses less than half the power of a comparable 765 kV AC transmission line. The lower line losses and the need for fewer substations to correct for power quality along the transmission line combine to generate cost savings over long distances. As such, HVDC's cost advantages rise with distance such that it is more likely to be competitive when the length is greater than 250 miles.<sup>26</sup>

24. <http://info.aee.net/advanced-energy-now-2014-market-report>

25. <http://www.cleanlineenergy.com/projects>

26. <http://www.wecc.biz/committees/BOD/TEPPC/020209/Lists/Agendas/1/WECC%20planning%20-%20HVDC%20Bahrman.pdf>

## MICROGRIDS



A microgrid is a network of connected electricity generation assets, controls, and loads that can operate separately from a utility grid and/or easily connect to or disconnect from a utility grid. Microgrids come in three basic types: remote, customer-owned, and utility distribution. Remote microgrids provide power to communities far from utility networks. Customer-owned microgrids typically refer to microgrids in use at large facilities owned by a single customer, such as military bases and college campuses. Utility distribution microgrids refer to portions of the grid within the utility system that are configured to act as microgrids. In all cases, microgrids can generate, distribute, and regulate the

flow of electricity to consumers at a local level. Remote and customer-owned microgrids are well-established applications, but utility distribution microgrids are just now emerging as intelligent grid technologies are deployed and more distributed generation (DG) is installed. Utility distribution microgrids rely on software and other technological advances to synchronize and operate in parallel to the larger grid but 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 capacity and another 1,100 MW in planning, according to Navigant Research.<sup>27</sup> Most of these installations are customer-owned microgrids, such as the one used at the U.S. Food and Drug Administration research facility in White Oak, Maryland. This microgrid allowed the facility to maintain operations off-grid for two and a half days during Hurricane Sandy.<sup>28</sup>

Interest in microgrids is driven primarily by their benefits for resiliency and reliability. During blackouts or extreme weather situations such as hurricanes, microgrids can generate and continue to deliver electricity to connected loads with no reliance on the utility grid. Microgrids can be particularly attractive to secure buildings and campuses, such as military bases, that require additional backup in addition to the utility grid. Many customer-owned microgrids are also combined heat and power systems, and as such provide year-round emissions benefits by virtue of their high overall efficiency.

27. <http://www.iaee.org/documents/2013EnergyForum4qtr.pdf>

28. <http://www.technologyreview.com/view/507106/microgrids-keep-power-flowing-through-sandy-outages/>

## SMART GRID DATA MANAGEMENT AND ANALYTICS



Silver Spring Networks

Smart grid communications networks include software and hardware that enable the collection of data from and communication between smart grid technologies, including advanced metering infrastructure (AMI). Smart grid software and hardware technologies allow utilities to collect vast amounts of real-time data. Smart grid data management and analytics solutions help them organize, analyze, and act on that data. These solutions are complex software platforms that use algorithms to scan all of the incoming data and point toward actionable conclusions for utilities, energy service companies, and energy consumers. These programs also help to forecast demand and better identify and monitor outages.

Utilities, energy service companies, and energy consumers across the country are turning to grid communications networks to help them better balance the grid, monitor energy usage, and integrate renewables and distributed generation. An example of this type of software is Gridco's Grid Management and Analytics Platform, which allows for remote control and data collection and analytics of the grid.<sup>29</sup> As more advanced software services emerge in this field, the industry is expected to see significant growth and greater adoption. Global smart grid analytics annual spending is expected to grow from \$0.7 billion in 2012 to \$3.8 billion by 2020.<sup>30</sup>

With more data and analysis providing deeper insight into grid operations, utilities can more precisely manage the grid and get a better sense of where energy efficiency measures and other energy management options may be the most valuable. Smart grid data management and analytics technologies enable utilities to better run their energy efficiency programs, integrate more variable renewable resources, and decrease the need for electricity generated by high-emitting peaking power plants.

29. <http://gridcosystems.com/products/gmap/>

30. <http://www.greentechmedia.com/research/report/the-soft-grid-2013>

## VOLTAGE AND VOLT-AMPERE REACTIVE OPTIMIZATION



Voltage-VAR Optimization (VVO) is a smart grid-enabled utility application. VVO controls the flow of power in the distribution system to increase efficiency and reliability, reduce distribution losses, and accommodate new power flows, such as those originating from distributed generation. VVO provides more precise voltage control, reducing the amount of power required. Historically, utilities have had to use estimates to ensure that end-use customers would have the proper level of voltage after distribution losses. Such an approach requires higher than optimal voltage levels to keep voltage from dropping below minimum thresholds by the time it reaches customers. By using dynamic control, VVO allows distribution lines to have lower overall voltage without impacting service quality.

Increased market penetration of VVO is expected as optimization accuracy increases and more applications verify the investment benefits.<sup>31,32</sup> For example, the Snohomish County Public Utility District invested nearly \$5 million in a Conservation Voltage Reduction system (an application of VVO), which resulted in better voltage quality and energy savings of nearly 54,000 MWh per year.<sup>33</sup> North American shipments of VVO control systems are estimated to increase from 50,000 units in 2013 to over 100,000 units by 2018.

VVO provides more control over the grid, creating a more intelligent, efficient, and stable electricity distribution system. An impact analysis done by the National Electric Manufacturers Association said that VVO is able to reduce distribution line losses by 2% to 5%, and a DOE study of VVO concluded that the technology could reduce distribution line losses by more than 5%.<sup>34,35</sup> The efficiency achieved by VVO results in avoided generation emissions while the addition of VVO technology helps to improve overall grid performance.

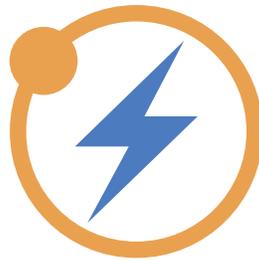
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33. <http://www.nema.org/Policy/Energy/Smartgrid/Documents/VoltVAR-Optimization-Improves%20Grid-Efficiency.pdf>

34. <http://www.nema.org/Policy/Energy/Smartgrid/Documents/VoltVAR-Optimization-Improves%20Grid-Efficiency.pdf>

35. <https://www.smartgrid.gov/sites/default/files/doc/files/VVO%20Report%20-%20Final.pdf>



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