U.S. DEPARTMENT OF ENERGY

Revolution Now

The Future Arrives for Four Clean Energy Technologies – 2014 Update

October 2014

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Gaining Force

For decades, America has anticipated the transformational impact of clean energy technologies. But even as costs fell and technologies matured, a clean energy revolution always seemed just out of reach. Critics often said a clean energy future would "always be five years away."

In 2013, the DOE released a report called Revolution Now highlighting four transformational technologies that are here today: onshore wind power, polysilicon photovoltaic (PV) modules, light-emitting diodes (LEDs), and electric vehicles (EVs). That study showed how dramatic reductions in cost[1] are driving a surge in consumer, industrial, and commercial adoption for these clean energy technologies. This report provides an update and finds that cost reductions and deployment have continued to advance in the past year.

These technologies are changing the nature of our energy system. Solar and wind power are attracting new participants to the energy sector, including household names like Google, Apple and MetLife. LED lighting has emerged as a powerful market competitor to traditional, inefficient incandescent bulbs and EVs are remaking the global automotive economy.

Today, clean energy technologies are providing real-world solutions for reducing emissions of the harmful carbon pollution that causes climate change. Clean energy manufacturing and installation has also become a major opportunity for American workers in the 21st century. In 2014, market data assembled by the U.S. Department of Energy shows that the historic shift to a cleaner, more domestic and more secure energy future is not some far-away goal. We are living it, and it is gaining force.

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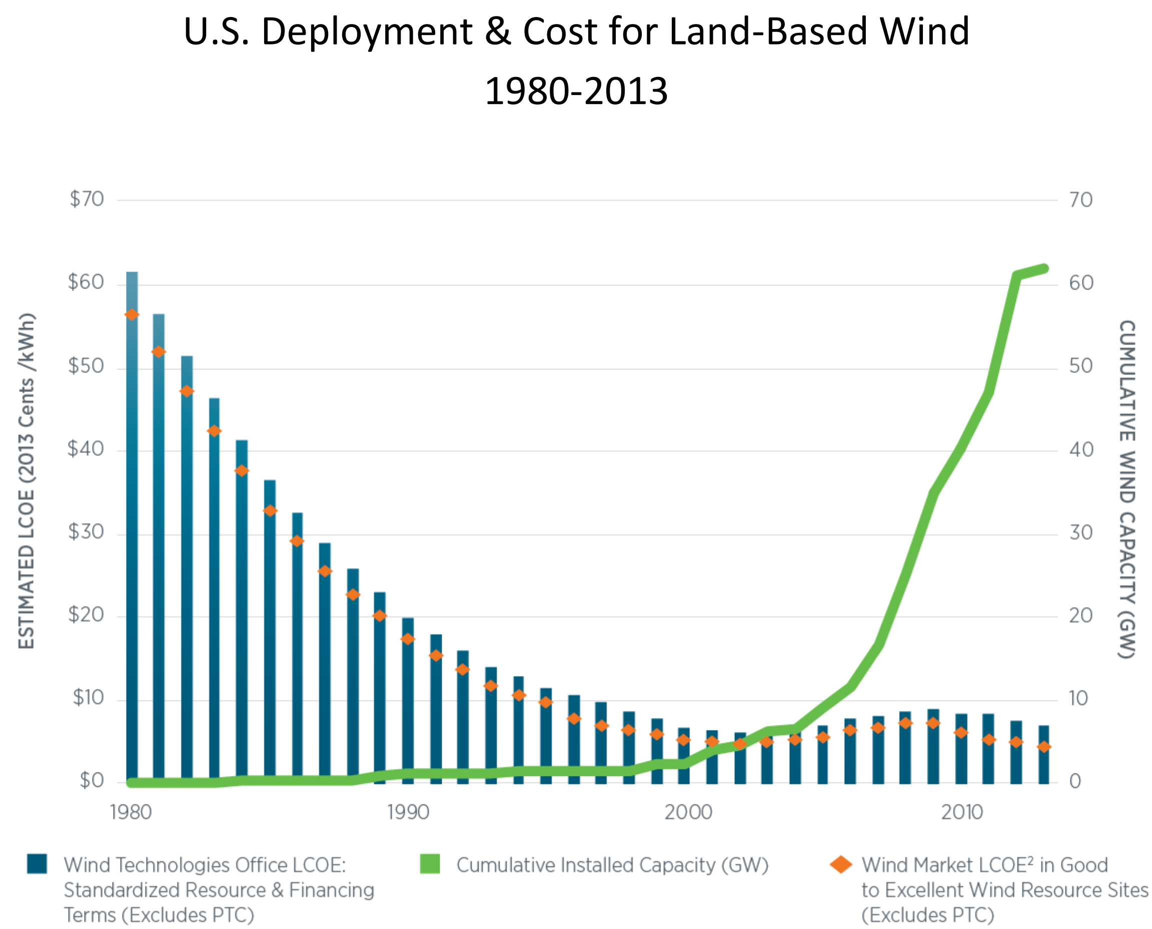
[1]The levelized cost of energy (LCOE) is used as a convenient summary measure of the overall competiveness of different generating technologies. It represents the cost (in real dollars) per kilowatt hour of building and operating a generating plant over an assumed financial life and duty cycle. Key inputs to calculating levelized costs include capital costs, fuel costs, fixed and variable operations and maintenance (O&M) costs, financing costs, and an assumed utilization rate for each plant type. As with any projection, there is uncertainty about all of these factors and their values can vary regionally and across time as technologies evolve and fuel prices change. See the Energy Information Administration's *Annual Energy Outlook 2014* for a deeper discussion regarding these issues: http://www.eia.gov/forecasts/aeo/electricity_generation.cfm

Land-Based Wind Power



Wind deployments on a steep upward climb[2]

Today, deployed wind power in the United States has the equivalent generation capacity of about 60 large nuclear reactors.[3] Wind is the first non-hydro renewable energy source to begin to approach the same scale as conventional energy forms like coal, gas and nuclear.

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[2] Bolinger, Mark; Wiser, Ryan. *MEMORANDUM - Documentation of a Historical LCOE Curve for Wind in Good to Excellent Wind Resource Sites*; Lawrence Berkeley National Laboratory, June 11, 2012. UPDATED February 10th, 2014. Bloomberg New Energy Finance power plant database (1980-1994) and American Wind Energy Association wind industry database (1994-2013).

[3] This number refers to "nameplate capacity" which represents the peak generation capacity of an electric generator (wind turbine, solar panel, nuclear plant, etc.) While no electric generator generates up to its capacity 100% of the year – even generators with very high capacity factors, like nuclear energy, top out at an average capacity factor of around 90% – variable generation resources tend to produce at a lower capacity factor than nuclear generators (average for onshore wind turbines in the US from 2006-2013 was 32%). For more information on capacity factors, see the Energy Information Administration's Annual Energy Outlook 2014: http://www.eia.gov/forecasts/aeo/electricity_generation.cfm

This success has been decades in the making – with both government and private-sector R&D dollars propelling its progress. Wind turbines have gotten progressively larger in terms of generation capacity over the past 30 years and this has helped to drive down costs. In fact, since the 1998-1999 period, the average electric generating capacity of a single turbine has increased by about 162%.[4] Today's wind turbines are taller and have longer blades, which allow them to operate in lower wind conditions and to access stronger, more consistent winds. In the U.S., the average hub height of a new wind turbine in 2013 was 45% taller than in 1998-1999 and the average rotor diameter was 103% greater – which translates to a 310% increase in the blades' swept area.[5] The emergence of larger, more cost-effective turbines was enabled by industry efforts in technology advancement, as well as by considerable investments by DOE, which worked with partners in industry and national laboratories to execute critical R&D in turbine design and performance.

It is also worth noting that, as with many industries, increases in scale of production have helped to drive down the cost of wind energy. Efficiencies and cost-savings through scale-up have been further enabled by the federal Production Tax Credit (PTC), which, for wind turbines under construction before December 31, 2013, pays an additional 2.3¢ per kilowatt hour for the electricity produced over the first 10 years of operation. The PTC has been critically important to incentivizing deployment of wind energy.

Skyrocketing demand, downward trending prices

Since the beginning of 2008, wind power capacity has more than tripled in the U.S. This success has led to new challenges for wind developers. For instance, it has become more difficult to find windy terrain near large power lines on which to build new wind farms. But at the same time, there have been dramatic improvements in technology and operations.[6]

Such improvements have kept wind prices on a long-term downward trend. Leading up to 2009, there was a rise in the price of power purchase agreements (PPAs) for new wind farms – it ticked up to about $70/MWh. However, in 2013 the national average levelized price of new wind PPAs fell to a record low of around $25/MWh.[7] From 2009-2013 wind represented approximately 30% of new electrical generation in the U.S.[8]

The future of wind

Wind continues to be one of America's best choices for low-cost, zero carbon, zero pollution renewable energy, and in an increasing number of markets may be the cheapest source of new energy available. The combined potential of land-based and off-shore wind is about 49,700 TWh[9]– or about 10 times U.S. electricity consumption today. And wind is 100% renewable, so it won't ever run out. The industry is working both to build new power transmission lines from some of the windiest parts of the country to

[4] U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy. *2013 Wind Technologies Report*; U.S. Department of Energy, 2014.

[5] Ibid

[6] Ibid

[7] Ibid

[8] U.S. Federal Energy Regulatory Commission (FERC) Office of Energy Projects Energy Infrastructure Updates

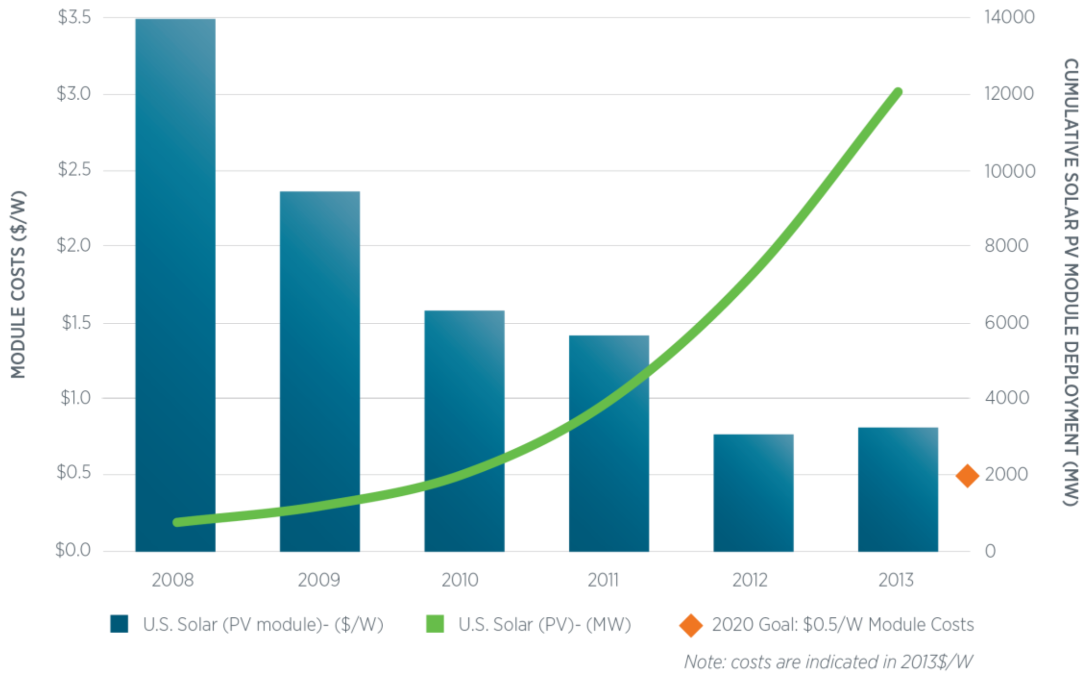
[9] U.S. Renewable Energy Technical Potentials: A GIS-Based Analysis Anthony Lopez, Billy Roberts, Donna Heimiller, Nate Blair, and Gian Porro http://www.nrel.gov/docs/fy12osti/51946.pdf

more densely populated areas and to improve turbines for less windy areas in order to maintain aggressive growth in the sector. This also includes building "marine" wind farms offshore – where steady, strong ocean breezes contain vast wind power potential. With continued technology improvements and policy support, the Department of Energy estimates that as much as 20% of projected U.S. electricity demand could be met by wind power by 2030.[10]

[10] U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy. *20% Wind Energy by 2030: Increasing Wind Energy's Contribution to U.S. Electricity Supply*, July 2008

Solar Photovoltaic Power

U.S. Deployment and Cost for Solar PV Modules
2008-2013



A dramatic shift

Although the energy potential of the sun is, for practical purposes, limitless, the cost of converting that energy into usable electricity has traditionally kept solar PV out of reach for all but a few niche applications – such as powering cell phone towers in remote terrain, warning beacons on offshore oil rigs, and on satellites and spacecraft. But today we are in the midst of a dramatic shift to solar energy. The dramatic decline in the price of solar PV modules means that the infinite power of the sun is increasingly within reach for the average American homeowner or business. Today, solar PV is rapidly approaching cost parity with traditional electrical generation from natural gas and coal in many parts of the world, including parts of the U.S.

99% cheaper

By 2014, rooftop solar panels cost about 1% of what they did 35 years ago, [11] and solar PV installations were about 15 times what they were in 2008.[12] Between 2008 and 2014 the cost for a PV module declined from $3.40/watt to about $0.79/watt.[13]While in 2012, price declines were partially driven by

[11] Mints, Paula. "Photovoltaic Manufacturer Shipments: Capacity, Price & Revenues 2013/2014." SPV Market Research. April, 2014

[12] SEIA and GTM Research. (2014). "U.S. Solar Market Insight Report: 2013 Year-In-Review." March 2014.

[13]Mints, Paula. "Photovoltaic Manufacturer Shipments: Capacity, Price & Revenues 2013/2014." SPV Market Research. April, 2014. (2014) Bloomberg New Energy Finance. Solar Spot Price Index. Accessed July 7, 2014.

oversupply and many manufacturers had razor thin – or negative – margins, in 2014 the glut is mostly past and still prices remain low due to reductions in manufacturing costs.

This is part of a broader trend. Historically, a doubling in industry capacity for solar PV manufacturing has correlated with about a 20% decline in PV prices. As more and more solar panels are built and deployed, costs have fallen. The federal Investment Tax Credit, equal to 30% the cost of rooftop PV systems, has helped this process along, as has DOE's $3.7 billion investment in solar photovoltaic R&D from 1975 to 2008, which has resulted in a net economic benefit of $15 billion.[14] Indeed, federal government investment in R&D for solar PV accelerated solar industry progress by an estimated 12 years.[15] Local incentives for PV deployment in the U.S. – as well as the E.U., Japan, China and other countries – have also helped to push solar manufacturing down the cost curve.

Falling costs have led to a surge in residential, commercial and utility-scale (>100MW) deployments. The DOE's Loan Programs Office kick-started the utility-scale solar industry by financing the first five utility-scale solar PV projects in the U.S with more than 1500 megawatts (MW) of capacity. Today utility-scale solar is being financed by the private sector: as of summer 2014, there were 17 privately financed utility-scale solar PV projects, representing more than 3800 MW of capacity, either built or under construction.

A bright future

The cost of installing a solar PV system includes not only the price of the PV module, but permitting and installation costs as well – what the industry calls "soft costs." As the cost of PV modules has come down, some of the best opportunities to bring down the price of solar energy are now reductions in these "soft costs." In 2012, the soft costs for installing a rooftop solar panel in the U.S. were about five times higher than in Germany ($3.34 per watt in the U.S. vs. $0.62 per watt in Germany)[16], indicating huge potential to reduce these costs in the U.S.

New technologies, government policies and business models are supporting the solar industry's rise. As a result, Americans are increasingly turning to the power of the sun, which allows them the security of generating their own, low-cost, electricity.

Represents average Chinese multi-crystalline module for first 6 months of 2014. Inflation adjustment: "Consumer Price Index - All Urban Consumers" from the Bureau of Labor Statistics. Note: beyond module costs, PV system costs generally include other hardware costs such as inverters, racking, and wiring, as well as process and business soft costs including customer acquisition, permitting, inspection and interconnection, financing and contracting, supply chain, and margin.

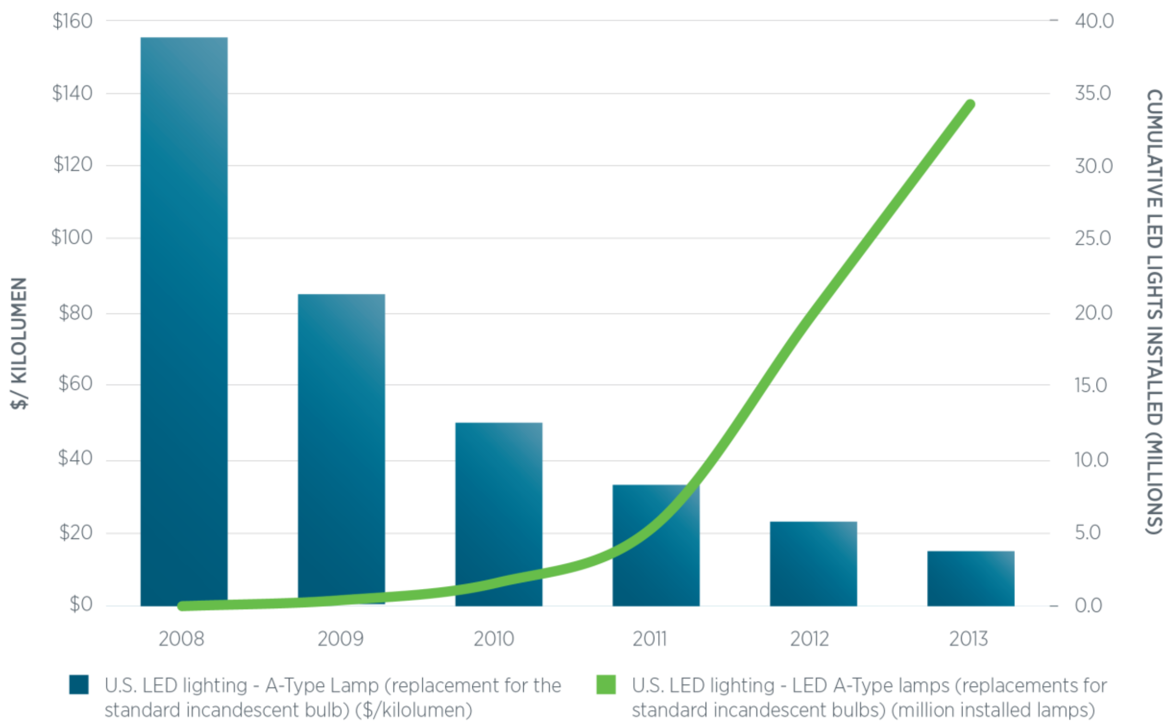
[14] "Retrospective Benefit-Cost Evaluation of DOE Investment in Photovoltaic Energy Systems." DOE, August 2010. http://www1.eere.energy.gov/analysis/pdfs/solar_pv.pdf. In 2008 dollars.

[15] Ibid.

[16] Seel, J.; Barbose, G.; Wiser, R. (2012). *Why Are Residential PV Prices in Germany So Much Lower Than in the United States?;* Berkeley, CA, Lawrence Berkeley National Laboratory, September 2012.

LED Lighting

U.S. Deployment and Cost for A-Type LED Lights
2008-2013



Plenty of light, but not much heat

The argument for Light Emitting Diode (LED) lighting is easy to make: they provide plenty of light, but not much heat. An incandescent light bulb generates light exactly the same way Edison's bulb did 100 years ago: it heats a tungsten filament until it gets blazing hot—in excess of 400°F[17] — and that process produces light. However, about 90% of the energy used by an incandescent bulb is actually transformed into heat rather than visible light – which is why you can burn your fingers when changing a light bulb. In terms of energy use, the light we enjoy from incandescent bulbs is really a byproduct.

LED lighting flips this equation on its head. A standard 60 watt incandescent light bulb can be replaced by a ~9 watt LED light that is 84% more efficient while emitting the same amount of light.[18] And although LEDs cost more up front, they also last as much as 25 times longer (1,000 hours vs. 25,000

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[17] Lindgard, RD; Myer, MA; Paget, ML. *Performance of Incandescent A-Type and Decorative Lamps and LED Replacements;* Pacific Northwest Laboratory, November 2008.
[18] For one example, see the Cree Day Light 60-Watt Replacement, http://www.cree.com/lighting/landing-page/~/media/Files/Cree/Lighting/Lamps/Bulb/CreeBulbDataSheet.pdf

hours).[19] Because of this, a mother who installs a quality LED fixture when her child is born may not need to change it until that child goes to college – or even graduates. Over that period, she could save over $160 for every incandescent bulb she swaps for an LED.[20]

For many commercial facilities, the advantages go beyond energy saved. Changing hard-to-reach light bulbs is a hassle, and can even be dangerous. LED lighting solves this problem in a sleek, elegant, efficient package.

More choice, lower cost

Over the past five years, price reductions in LED bulbs have transformed the economics of the industry. Until recently, installing LED lighting didn't seem like such a bright idea for normal home lighting. They were not generally powerful enough to replace a standard light bulb and even in 2012 cost as much as $50 apiece. At that price, LEDs seemed destined to remain a distinctly niche product. But today's LEDs are brighter, have better color quality, improved dimming capabilities, and can be purchased for less than $10 at the local hardware store. This is making LEDs an increasingly popular choice for Americans who want to reduce their lighting bills or simply don't want to deal with changing bulbs so often.

In 2009, fewer than 400,000 LED lights were deployed as replacements for standard household light bulbs across the U.S. But by the end of 2013, deployment had grown nearly 90 times to 34 million – almost all of these in applications that would have once utilized energy-intensive incandescent bulbs. By 2013 LEDs accounted for about 5% of lighting sales and 1% of total lighting installed nationally. This represents a significant foothold in the U.S. lighting market, but also an enormous opportunity for growth.

A solid investment

For more than a decade, the Energy Department has funded research and development of LED lighting. During the American Recovery and Reinvestment Act, the Department of Energy also made significant investments in manufacturing to help bring down the price of LEDs.

Today, America is beginning to reap the rewards of these years of investment. According to DOE projections, by 2030, LED lighting will save Americans over $30 billion a year in electricity costs and cut America's energy consumption for lighting in half. LEDs are a bright spot in America's effort to reduce carbon pollution, lower energy bills and provide a more secure energy future for America. [21]

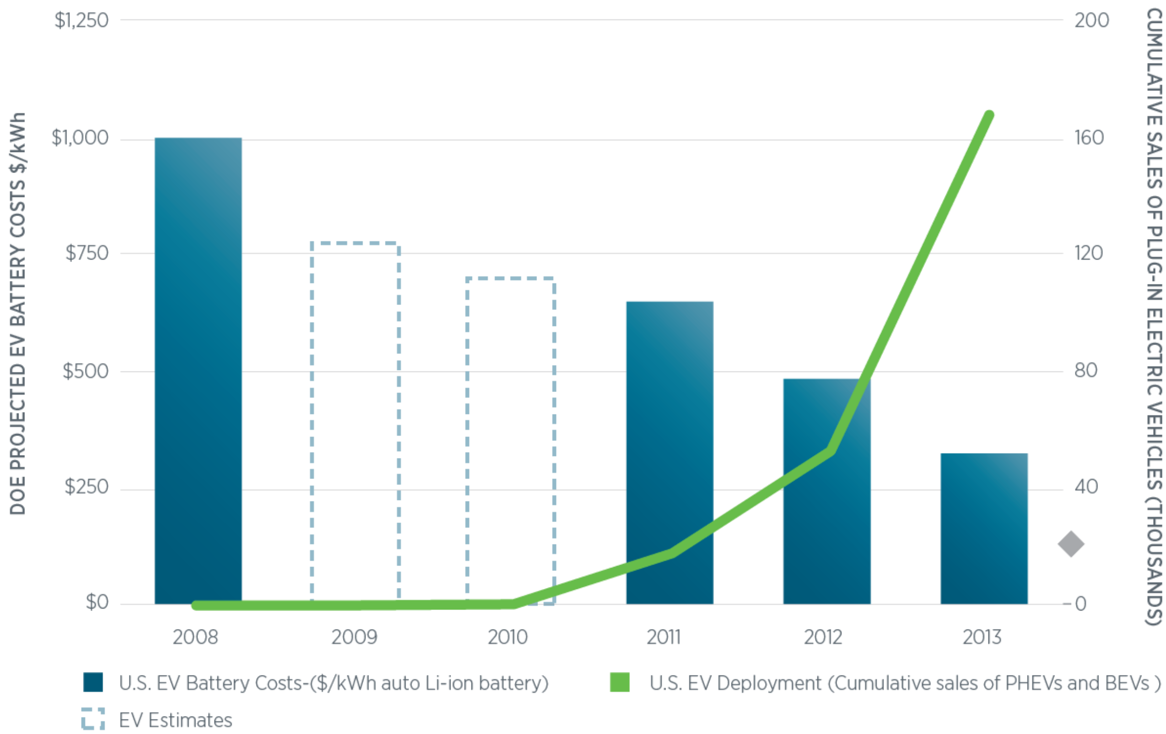
[19] For more information see the web site for the U.S. Department of Energy L-Prize http://www.lightingprize.org/about_ssl.stm

[20]Based on usage of 2 hours per day and a national electricity cost of 12.84 cents per kilowatt hour and a purchase price of $10 for LED lamp and $0.50 for incandescent

[21] U.S. Department of Energy, Energy Efficiency and Renewable Energy. *Energy Savings Potential of Solid-State Lighting in General Illumination Applications.* U.S. Department of Energy Solid-State Lighting Program, January 2012. Available at: http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/ssl2012_energysavings_factsheet.pdf

Electric Vehicles

U.S. Deployment and Cost for Electric Vehicles and Batteries
2008-2013



Accelerating deployment

In 2013, Americans bought nearly 100,000 plug-in electric vehicles (EVs) – nearly double the number purchased in 2012 – and in the first half of 2014, EV sales continued to expand at a rate of about 30% year-on-year. This success is the direct outgrowth of combined federal, state and industry efforts to bring down the cost of EVs through research and development of better batteries, promote consumer adoption through tax and other incentives, and support public and private investments in a new American manufacturing economy.

A race to the clouds

Before 2010, U.S. EV demand was almost nothing. But today EVs are helping America achieve its energy and climate goals and positioning its manufacturing economy to remain globally competitive in the 21st century.

To maintain this momentum the most critical area for cost reductions is batteries. DOE models for EV battery fabrication costs show that the cost of high volume EV batteries has fallen by an astounding 68%

since 2008.[22] While actual battery production costs are closely held by industry, prices in commercial EVs also appear to be on a steady downward glide. These cost reductions can be attributed to a number of factors. So-called "process improvements" – which increase the efficiency of manufacturing by eliminating wasted materials, capital and time – are one key element. So is higher production volume – which helps amortize capital costs for expensive facilities, assembly lines and robots used to build batteries. Finally, automakers are integrating new materials into EV batteries that both reduce cost and increase energy-density –the amount of energy that can be stored in a battery. Today, batteries are receiving an enormous amount of attention from universities, research labs, industry, and government because of their critical role in enabling EVs and other clean energy technologies, which should continue to drive down costs and improve performance.

Road to the future

In many senses, EVs are already competitive with traditional cars. For instance, for three years in a row the Chevy Volt topped JD Power's *APEAL Study* on consumer satisfaction for compact sedans. In 2013, Consumer Reports said the Tesla Model S was the best car they had ever tested and Tesla is now exporting American cars to markets around the world.[23] Compared to gasoline, fueling EVs is also cheap. The Energy Department calls this an "eGallon," and today an eGallon –the amount of electricity it takes to drive an EV the same distance a standard car can travel on one gallon of unleaded gasoline – costs only about $1.27.[24] This is in large part because electric motors are about three times as efficient as combustion engines.

Further progress on reducing the cost of EV batteries will make these benefits available to a larger audience. Some private sector analysts have said that there is a relatively clear technology path to $200/kWh for battery storage by 2020, down from about $1,000 kWh.[25] The Department is working with industry, academia and our own labs toward an even more aggressive goal of $125/kwh by 2022. At that point, ownership costs for a 240-mile EV will be equal to a standard vehicle.[26]

Improved charging infrastructure will also be critical to maintaining momentum. There are now over 18,000 EV charging stations in the U.S., but lack of street charging in America's cities remains a challenge to urban deployment, especially when many residents lack off-street parking at home. Workplace charging, new EV-friendly municipal codes for public and private parking facilities and an expanding network of so-called "fast chargers" – which can charge an EV much quicker than standard chargers – can all help create a more EV-friendly environment and drive continued success.

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[22] Modeled costs are validated through applied research, and represent calculated high-volume commercial production costs, rather than market price.

[23] *The Tesla Model S is our top-scoring car,* Consumer Reports, May, 2013

[24] U.S. average, accessed September 29, 2014, http://energy.gov/maps/egallon.

[25] Hensley, Russell; Newmanm, John; Rogers, Matt. *Battery Technology Charges Ahead;* McKinsey Quarterly, July 2012.

[26] Cost estimates reflect production of batteries at scale and with mature manufacturing processes. For more information see the Department of Energy's *EV Everywhere Blueprint*, http://www1.eere.energy.gov/vehiclesandfuels/electric_vehicles/10_year_goal.html

International automakers are competing aggressively to design and deploy the electric car of the future. But today America has the largest EV market in the world, as more and more Americans are abandoning the gas pump and fueling their cars on this cheap, clean, secure, American energy.

Conclusion

As these and other clean energy industries continue to expand, so will the challenges and opportunities associated with transforming America' energy sector. Already utilities are beginning to wonder how they will support their current business models in the face of increased energy efficiency and cheap rooftop solar power. As EVs move beyond the market for "first adopters" and become mainstream, America will have to invest in building a more extensive network of EV charging stations.

Despite these challenges, electric vehicles, solar PV, wind power and LED lighting are all on track to transform our economy for the better. They will clean up the air in our cities, reduce America's vulnerability to unstable international oil markets and help build an economy that is more competitive and more efficient, all while reducing carbon pollution.

The Energy Department's goal is to encourage these trends by providing performance targets, support for R&D, consumer education, and targeted deployment assistance. With continued progress in critical renewable and energy efficient technologies like these, we can look forward to a future of clean, green, American-made energy. For some of these innovative technologies, that future is here today.