U.S. DEPARTMENT OF ENERGY

Revolution Now

The Future Arrives for Four Clean Energy Technologies

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Gaining Force

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

This report focuses on four technology revolutions that are here today. In the last five years they have achieved dramatic reductions in cost[1] and this has been accompanied by a surge in consumer, industrial and commercial deployment. Although these four technologies still represent a small percentage of their total market (e.g. electricity, cars and lighting), they are growing rapidly.

The four key technologies this report focuses on are:

- Onshore wind power
- Polysilicon photovoltaic modules
- LED lighting
- Electric vehicles

In recent years, it has become increasingly clear that well-designed federal and state incentives and investments in research and development have the potential to stimulate significant energy transformations. For instance, from 1980-2002 the U.S. federal government's production incentives for shale gas and support for new drilling technologies laid the foundation for that industry's dramatic rise.[2] Today, time-limited tax credits for wind, solar and electric vehicles and targeted support for research and development are supporting the expansion of these burgeoning markets.

This analysis explains both the magnitude of and mechanisms behind these nascent revolutions – exploring the intersection between declining costs and surging demand. These industries are providing real world solutions for reducing emissions of harmful carbon pollution and slowing the effects of climate change. Each of the sectors examined has also become a major opportunity for America's clean energy economy.

The trends in each sector show 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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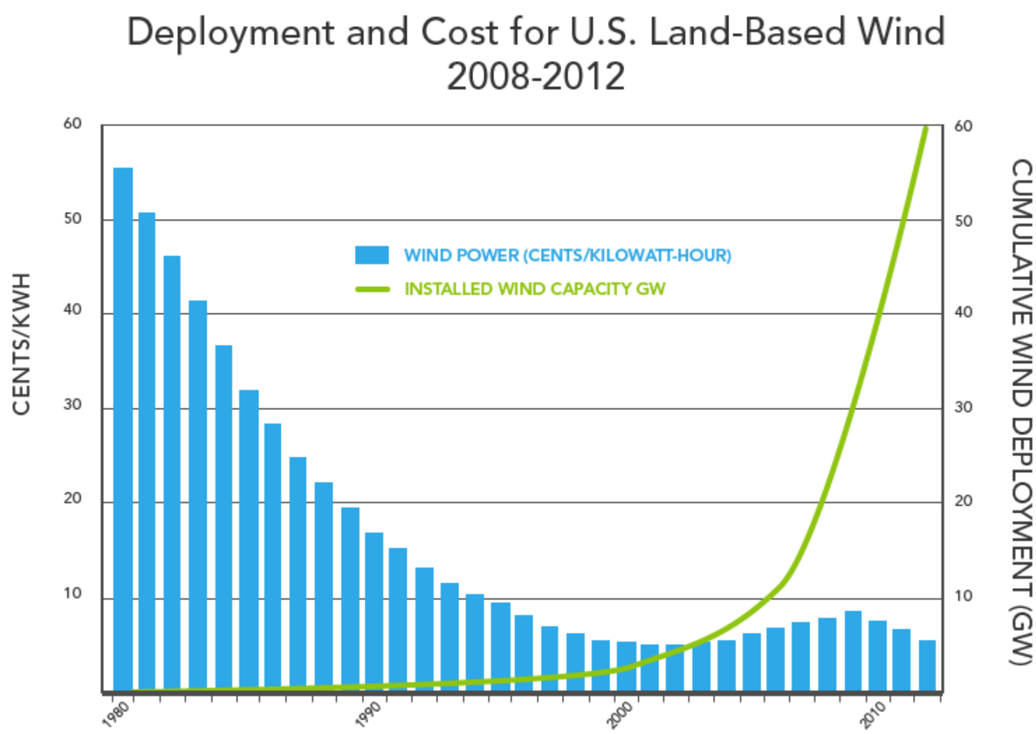
[1] Levelized cost is often cited as a convenient summary measure of the overall competiveness of different generating technologies. It represents the per-kilowatt hour cost (in real dollars) of building and operating a generating plant over an assumed financial life and duty cycle. Key inputs to calculating levelized costs include overnight 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 2013* for a deeper discussion regarding these issues: http://www.eia.gov/forecasts/aeo/electricity_generation.cfm

[2] Moniz, E. et al; *The Future of Natural Gas: an interdisciplinary MIT Study*, MIT, June, 2011.

Land-Based Wind Power



Wind deployments on a steep upward climb[3]

Today, deployed wind power in the United States has the equivalent generation capacity of about 60 large nuclear reactors.[4] 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.

This success has been decades in the making – with both government and private-sector R&D dollars propelling its progress. From a technology standpoint three elements have been key to wind power's success. The first is increasing size: 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 1999 the average amount of electricity generated by a single turbine has increased by about 260%. The second is the scale of production. As with many industries, increases in scale tend to drive down costs. Finally, wind farm

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[3]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. Bloomberg New Energy Finance power plant database (1980-1994) and American Wind Energy Association wind industry database (1994-2012).

[4] This number refers to "nameplate capacity" which represents the peak generation capacity of a wind turbine, solar panel, etc. In practice, electricity generation from renewable resources is variable – which means that they do not always produce at nameplate capacity. See the Energy Information Administration's Annual Energy Outlook 2013 for a deeper discussion regarding these issues: http://www.eia.gov/forecasts/aeo/electricity_generation.cfm

operators have become much more sophisticated in understanding and adapting to dynamic wind patterns. This has helped drive up the "capacity factor" – or the percentage of time that turbines are actually producing electricity. The federal Production Tax Credit – which pays an additional 2.3¢ a kilowatt hour for the electricity produced by wind turbines over the first 10 years of operation – has also been critically important to incentivizing deployment of wind energy.

Skyrocketing demand, downward trending prices

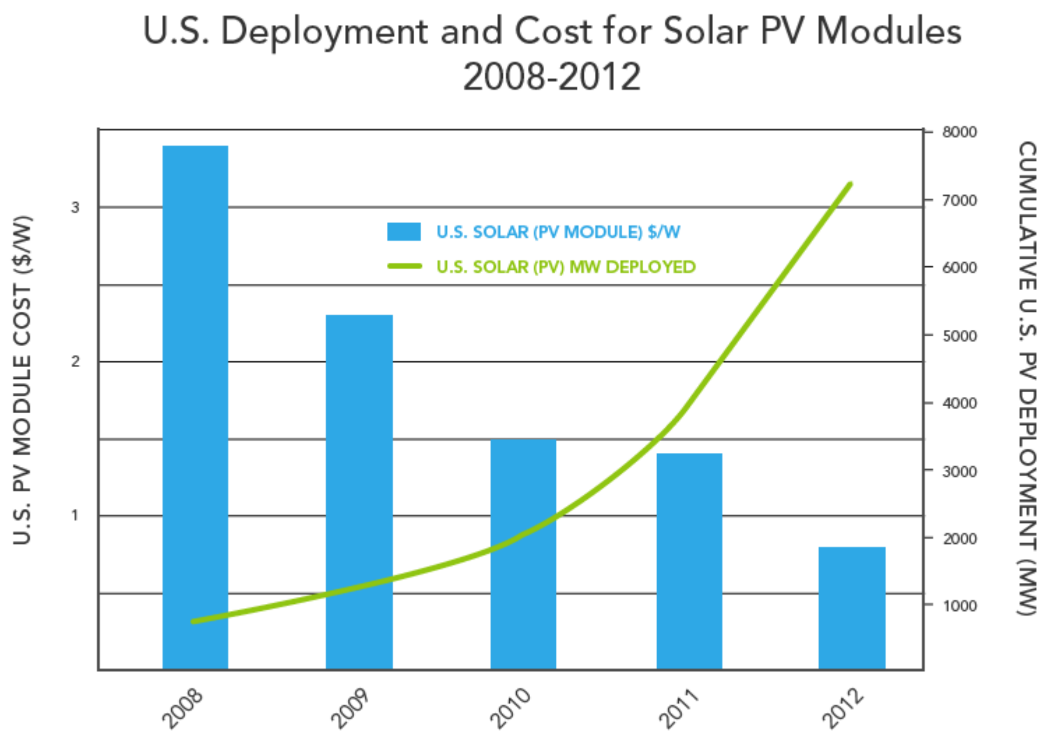
Since the beginning of 2008, wind power capacity has more than tripled in the U.S. This has happened despite a jump in wind turbine costs from 2001 to 2009. But that rise in turbine prices is, in some senses, misleading. The cost to install the same sized turbine, in an area with the same level of wind resource has gone down. However, as more of the prime real estate for building wind farms – windy terrain near power lines and big cities – is populated by wind turbines, developers have moved to areas that are farther away from population centers and power lines, or have lower wind quality. To compensate for lower wind speeds, many turbines are manufactured with bigger blades – to catch more wind. These bigger blades are more expensive, and this increase in costs was accentuated by the steep climb in commodity prices (e.g. steel and oil) from 2004-2008. But as commodity prices have receded, the average cost of new wind power has also started to recede, and deployment of wind turbines has skyrocketed. In 2012, the U.S. deployed almost twice as much wind as it did in 2011. In fact, wind accounted for 43% of new electrical generation capacity in the U.S. – more than any other source.

The future of wind

Wind continues to be one of America's best choices for low-cost, zero carbon, zero pollution renewable energy. The combined potential of land-based and off-shore wind is about 140 quads – 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 to build new power transmission lines from some of the windiest parts of the country, to the most densely populated in order to maintain aggressive growth in the sector. This also includes building "marine" wind farms offshore – where steady ocean breezes harbor 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.[5]

[5] U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy. *2012 Wind Technologies Report*; U.S. Department of Energy, 2012. 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 PV



A generational 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 in space. But today we are in the midst of a generational shift to solar energy. Falling costs for solar power mean that the infinite power of the sun is increasingly within reach for the average American homeowner or business. This shift has come about because of a dramatic retreat in the price of solar PV modules – a trend that has accelerated over the past 5 years. Today, solar PV is rapidly approaching cost parity with traditional electrical generation from gas, coal and oil in many parts of the world, including parts of the U.S.

99% cheaper

In 2012, rooftop solar panels cost about 1% of what they did 35 years ago, [6] and since 2008, total U.S. solar PV deployment has jumped by about 10 times – from about 735 megawatts to over 7200 megawatts.[7] During that same time span the cost for a PV module has declined from $3.40/watt to

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[6] Mints, Paula. *The Global Market for PV Technologies,* Solar PV Market Research, 2012.
[7] Ibid. *Photovoltaic Manufacturer Shipments, Capacity & Competitive Analysis 2011/2012*; Palo Alto, CA, Navigant Consulting Photovoltaic Service Program, 2013.

about $0.80 /watt, and this has catalyzed a rush in solar deployment.[8] While part of this is due to oversupply in the global PV market, a good portion is also due to advances in technology and increased economies of scale.

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. A federal "investment tax credit" equal to 30% the cost of rooftop PV systems has helped this process along. 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 progressively further down the cost curve.

A bright future

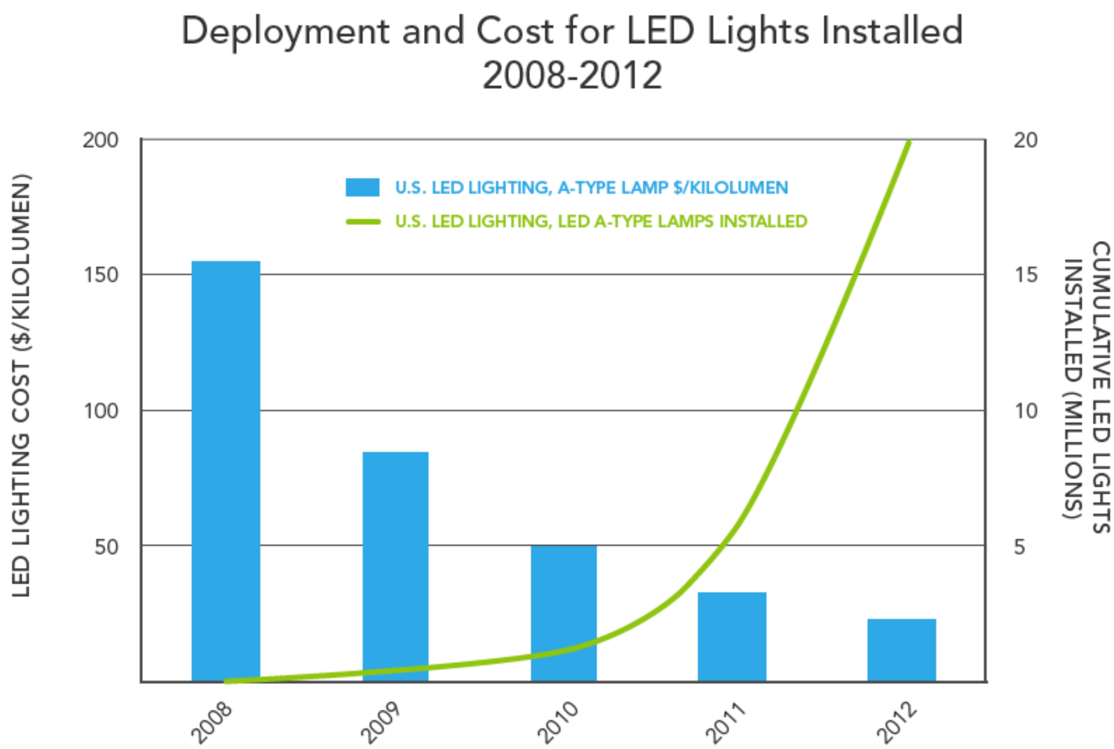
The cost of installing a solar PV system includes not only the price of the actual PV module, but permitting and installation costs as well – what the industry calls "soft costs." As the cost of PV modules has come down some of the best opportunities to bring down the price of solar energy are now reductions in these "soft costs." For example, the soft costs for installing a rooftop solar panel in the U.S. are about five times higher than in Germany ($3.34 per watt in the U.S. vs. $0.62 per watt in Germany).[9] These "soft costs" are lower for utility scale solar and ultimately the competitiveness of residential PV also depends on local electricity prices.

Today, Americans are increasingly turning to the power of the sun, which allows them the security of generating their own, low-cost, electricity. Current trends indicate that solar energy has a very bright future.

[8] 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.

[9] 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



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[10] — 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. Because of this, a standard 60 watt incandescent light bulb can be replaced by a ~9 watt LED light that is 84% more efficient.[11] And although LEDs cost more up front, they also last as much as 25 times longer (1,000 hours vs. 25,000 hours).[12] Because of this, a mother who installs a quality LED fixture when her child is born will not need to change it until that child

[10] Lindgard, RD; Myer, MA; Paget, ML. *Performance of Incandescent A-Type and Decorative Lamps and LED Replacements;* Pacific Northwest Laboratory, November 2008.
[11] 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
[12] For more information see the web site for the U.S. Department of Energy L-Prize http://www.lightingprize.org/about_ssl.stm

goes to college – or even graduates. Over that period, she could save over $140 for every incandescent bulb she swaps for an LED.[13]

For many commercial facilities, the advantages go beyond energy saved. Changing hard to reach light bulbs is a hassle, and even 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 really powerful enough to replace a standard light bulb and even in 2012 would have cost perhaps $50 a piece. At that price, LEDs were destined to remain a distinctly niche product. But today's LEDs are brighter, have better color quality and many cost less than $15. This is making them 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 across the U.S. But by 2013, deployment had grown over 50X to nearly 20 million – almost all of these in applications that would have once utilized energy-intensive incandescent bulbs.

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 on the verge of reaping the rewards of these years of investment. The Energy Department's Office of Energy Efficiency and Renewable Energy projects that 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. As prices continue to decline, LED lighting products will become increasingly competitive and attractive to Americans. This will mean big reductions in carbon pollution, lower energy bills and a more secure energy future for America. [14]

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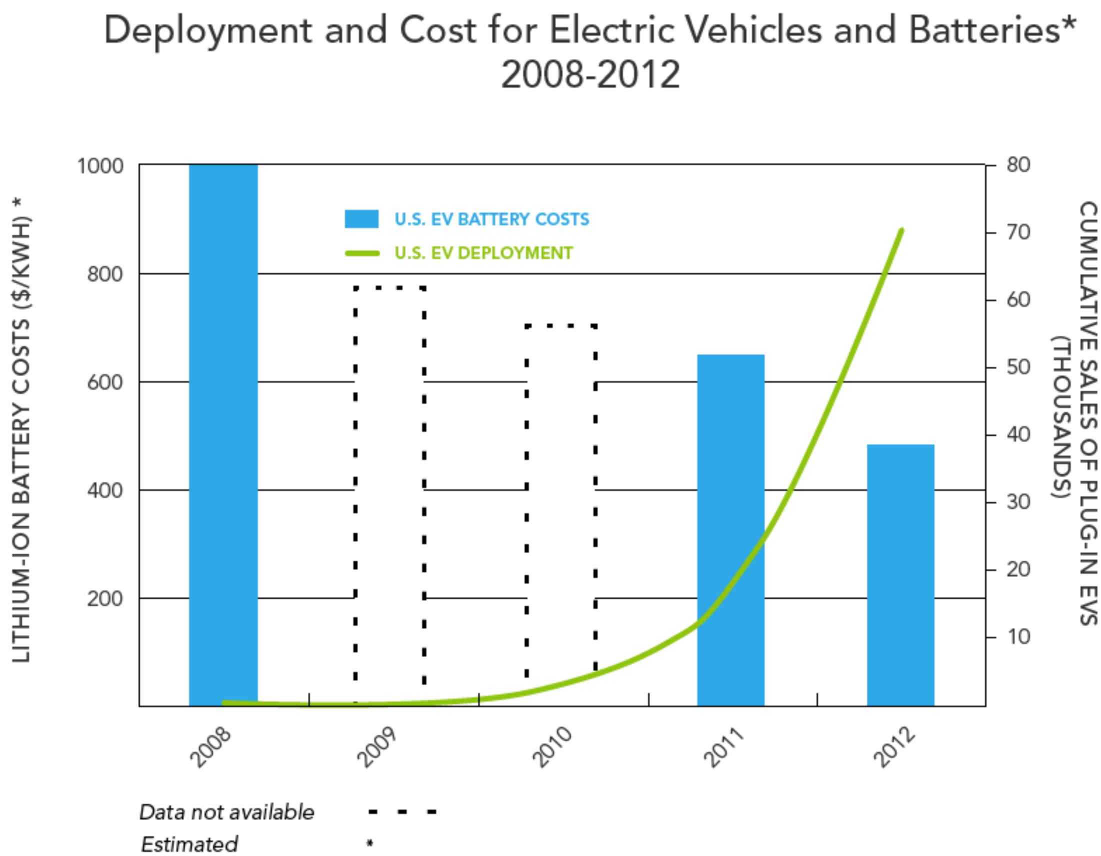
[13]Based on a national electricity cost of 12 cents per kilowatt hour. See http://www.usa.philips.com/c/energy-saving-light-bulbs/23285/cat/en/

[14] 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



Accelerating deployment

Electric cars run on cheap, clean and increasingly green American energy. Over the past five years, the Administration and industry have worked together to bring down the cost of EVs through funding research and development on batteries and promoting consumer adoption of EVs through tax and other incentives. Today, the numbers are clear: more and more drivers are abandoning the gas pump, for the affordability and convenience of in-home electric charging.

A race to the clouds

Before 2010, U.S. EV demand was almost nothing. But in 2012, Americans bought more than 50,000 plug-in electric vehicles. In the first half of 2013, Americans doubled the number of EVs they purchased compared to the same period in 2012.

To maintain this momentum the most critical area for cost reductions is batteries. Energy Department models for EV battery fabrication costs show that the cost of high volume EV batteries has fallen by more than 50% in the past four years. While actual battery production costs are a closely held industry secret, price reductions 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 – or 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. Because of this, we expect costs will continue to decline even further.

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 has topped JD Power's *APEAL Study* on consumer satisfaction for compact sedans. And this spring Consumer Reports said the Tesla Model S was the best car they had ever tested.[15] Fueling these cars is also cheap compared to filling up a gasoline-powered car. The Energy Department calls this cheap electric fuel 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 $1.22. This is in large part because electric motors are about three times as efficient as combustion engines.

But 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.[16] 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 280-mile EV will be equal to a standard vehicle.[17] All around the world, automakers are competing feverishly to design and deploy the electric car of the future. Today America is leading that race and every year, more and more Americans are fueling their cars on cheap, clean, secure, American energy.

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

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

[17] For more information see the Department of Energy's *EV Everywhere Blueprint*, http://www1.eere.energy.gov/vehiclesandfuels/electric_vehicles/10_year_goal.html

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 a mainstream, America will have to invest in building a smarter, more robust electrical grid and an extensive network of EV charging stations.

Those challenges are emblematic of successes in these clean energy markets. Indeed, 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.

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. Already for some of these innovative technologies, that future is here today.