Shifting Gears: Transcending Conventional Economic Doctrines to Develop Better Electric Vehicle Batteries

BY CLIFTON YIN AND MATTHEW STEPP | OCTOBER 2012

Like all economic policy debates in the United States, energy and climate policy is shaped by competing "economic doctrines." Those who subscribe to the neoclassical economic doctrine see climate change as a relatively straightforward problem caused by failing to charge polluters of greenhouse gases (GHG) for the full costs of their emissions. Once the price is right, the theory holds, the market will respond appropriately (if it hasn't already) and develop the needed solutions. By contrast, those informed by neo-Keynesian perspectives favor a more direct response, such as subsidizing renewable energy or requiring its use. Finally, those supporting the innovation economics doctrine argue that price signals, regulation and subsidies are insufficient to drive clean energy transformation. Instead, innovation policies, such as investments in research and the development and commercialization of next-generation alternatives, are the best solution.

Ultimately, the issue of which doctrine leads to the best policies and policy outcomes cannot be resolved through the rehashing of economic theories and select evidence marshaled by each side. Only logic and actual experience can determine which is the right doctrine and right approach. Luckily, there is a real world case where the fit of each doctrine can be tested: the adoption of electric vehicles (EVs). As this report shows, the past and present development of the EV industry makes it clear that the neoclassical and neo-Keynesian approaches have failed and will continue to fail to drive the development of electric vehicles. According to the EV example, the innovation approach to clean energy policy is the right one. High fuel taxes in places like Europe—10 times higher than the prices proposed by most neoclassical-based advocates in the United States—have not led to any significant deployment of EVs. Nor have large EV vehicle subsidies both at home and abroad. The only answer is a robust R&D strategy to develop much better and cheaper batteries to dramatically lower the cost and increase the performance of EVs.

To do this there are a number of steps policymakers should take:

1. More aggressively fund battery innovation, possibly by diverting funds used for the EV tax credit to instead support key battery innovation programs, like the Advanced Research Projects Agency-Energy's (ARPA-E) Batteries for Electrical Energy Storage in Transportation (BEEST) program.

2. Foster greater collaboration between the Department of Defense (DOD) and the Department of Energy (DOE) on battery development.

3. Support a "BatteryShot Initiative" akin to DOE's SunShot Initiative (SunShot coordinates the national pursuit of cost-competitive solar energy with a specific goal in mind). BatteryShot could coordinate government battery RD&D with the goal of producing a battery with a total system cost of less than $250/kWh and a range of at least 300 miles per charge.[1]

REDUCING LIGHT DUTY VEHICLE SECTOR EMISSIONS: A CASE STUDY IN COMPETING CLIMATE CHANGE-ECONOMIC DOCTRINES

The role of economic doctrines in the public policy process is pervasive, involving far more than economists generating reports and forecasts. Economic doctrines are steeped in philosophies concerning the essential factors of a stable and growing economy. They determine which types of policy interventions, if any, are appropriate to promote economic growth. Economic worldviews as adopted in the political marketplace are like political ideologies. Everyone—not just economists in government agencies, Congressional committees, and think tanks—possesses some basic beliefs informed by economic doctrines. The doctrines guide people's thinking and deliberations and help them make sense of a complex and rapidly changing economy. As noted economist Joseph Schumpeter once wrote with respect to doctrines or ideology, "the majority of economists… are ready enough to admit its presence, but like Marx, they find it only in others and never in themselves. They do not admit that it is an inescapable curse and vitiates economics to its core."[2]

In the report *Economic Doctrines and Approaches to Climate Change Policy*, ITIF analyzed how actors in the climate change policy debate, both in the United States and abroad, rely on different economic doctrines to favor or oppose different policy solutions. Unfortunately, most policy actors ground their thinking about clean energy and climate change policy in either the neoclassical or neo-Keynesian economic doctrines, with the result being limited progress in the fight to reduce GHG. One side wants a carbon tax, the other even deeper subsidies or stricter regulations for existing high-cost, often low-quality clean energy. Given that renewable energy, including hydroelectric and nuclear power, still roughly accounts for only 18 percent of energy consumption in the United States, up from 14 percent in 2000, it is clear that the approaches based on these doctrines have failed in confronting the dramatic challenge of global climate change.[3]

This phenomenon is particularly well-demonstrated by the debate over how to best drive greater adoption of electric vehicles as part of the effort to reduce greenhouse gas emissions from passenger cars and light trucks ("light duty vehicles" or LDVs). As more than 20 percent of U.S. greenhouse gas emissions and roughly 45 percent of the nation's oil consumption can be attributed to the LDV sector, cutting LDV emissions has major implications for both mitigating global climate change and reducing foreign energy imports.[4] However, while there are a number of technology options for reducing LDV oil consumption, all of them possess a combination of significant cost and performance issues holding them back from widespread adoption. The key question is just what exactly is the best policy approach for dramatically reducing GHG emissions and oil consumption from the LDV sector? And the probable answer to that question depends largely on the particular economic doctrine held by any particular policy actor.

The increased adoption of battery electric vehicles is both a particularly promising opportunity for reducing a high level of light duty vehicle-sector emissions and a revealing case study on the ineffectiveness of conventional economic doctrines when it comes to climate and energy policy.

Leading Options for Reducing Light Duty Vehicle Emissions

Greater vehicle energy efficiency, natural gas vehicles, biofuels, hydrogen fuel cell vehicles, and electric vehicles are commonly held up as the leading options for reducing LDV sector emissions. It is clear that substantially reducing GHG emissions from LDVs will ultimately require something other than carbon-based fuels like gasoline or natural gas to power vehicles. There are three plausible alternatives: biofuels, electricity and hydrogen. All have potential. But the increased adoption of battery electric vehicles is both a particularly promising opportunity for reducing a high level of LDV-sector emissions and a revealing case study on the ineffectiveness of conventional economic doctrines when it comes to climate and energy policy.

Greater Vehicle Energy Efficiency

One option to reduce LDV oil consumption is to increase the fuel efficiency of conventional, internal combustion engine (ICE)-propelled cars. Researchers are exploring options for optimizing vehicle design to boost airflow efficiency, improve engine transmission and cooling technology, and reduce vehicle weight through the use of lightweight materials such as carbon fiber. Increased gasoline vehicle efficiency could have a modest impact on carbon emissions. For example, according to the Boston Consulting Group, a 10 percent reduction in a vehicle's mass could result in carbon dioxide emission reductions of as much as 3–4 percent over the course of the vehicle's lifetime.[5]

But while boosting vehicle fuel efficiency is a welcome effort, it is nonetheless a short-term fix. The 2009 United Nations Climate Change Conference in Copenhagen set a goal of reducing global GHG emissions by at least 50 percent below 1990 levels by 2050, but reaching that goal isn't simply a matter of making each unit of economic activity 50 percent "cleaner." GHG emission reductions must also account for economic growth. In the case of the LDV sector, while the number of LDVs on the road globally in 2010 was approximately 750 million, that figure is expected to grow more than 47 percent by 2039, to 1.1 billion.[6] Consequently, according to environmental scientist Roger Pielke, Jr.'s analysis, meeting the 50 percent emissions reduction target would require an annual average de-carbonization rate of 4.4 percent between now and 2050 (assuming 3 percent annual global GDP growth).[7] Of course, it is unlikely that economic growth is going to hold steady over the next several decades—it may very well be higher than predicted. Regardless, given the substantial GHG emission reductions needed, the relatively minor reductions offered by greater vehicle energy efficiency are simply insufficient. As researchers at the Imperial College in the United Kingdom and Aachen University in Germany noted, "incremental improvements to ICE vehicles have an important role to play" in driving greater LDV sustainability, but only in the "short to medium term."[8]

Natural Gas Vehicles

With the significant increase in U.S. natural gas production, some have touted the impact of vehicles running on compressed natural gas in lieu of conventional gasoline. As many as 112,000 natural gas vehicles (NGVs) are on the road today in the United States, with almost 15 million worldwide.[9] Furthermore, greater use of natural gas in transportation is a key component of President Obama's *2012 Blueprint for American-Made Energy*.[10] "Think about an America where more cars and trucks are running on domestic natural gas than on foreign oil," President Obama declared in a speech in early 2012. "Let's get more of these natural gas vehicles on the road."[11]

NGVs could very well make a major impact toward the goal of reduced energy imports. Like greater vehicle energy efficiency, however, natural gas vehicles fundamentally cannot achieve GHG emission reductions at the level needed to mitigate global climate change. There is no doubt that the combustion of natural gas in NGVs is cleaner than the combustion of gasoline in ICE-cars. But NGVs have only 15 to 30 percent lower levels of GHG emissions than ICE-vehicles.[12] And their environmental impact is even less positive when accounting for the full cycle of energy production, transportation, and consumption—so-called "well-to-wheels" analysis—as the production of natural gas can still substantially contribute to climate change. A study by scientists Ken Caldeira and Nathan Myhrvold suggests that when factoring in the lifecycle GHG emissions from building and running the natural gas plants that supply NGVs, switching en masse from coal to natural gas for electricity production "would have zero effect on global temperatures by the year 2100."[13] In addition, as natural gas is produced and piped around the country, there remains significant risk of methane leakage—the Environmental Protection Agency pegs the leak rate at as high as 3 percent. In fact, one study concluded that given estimated leak rates, NGVs are worse for the climate than gasoline vehicles over a 20-year period.[14]

Biofuels

Wider use of fuels derived from organic matter like corn, wood, algae, vegetable oil, agricultural waste, and even garbage is another option for reducing LDV emissions. In the United States, corn ethanol contributes to around 10 percent of the gasoline supply.[15] In Brazil, the world's leading producer of sugarcane ethanol, the head of the state-run oil company predicts that biofuel will take over more than 75 percent of the country's light vehicle fuel market by 2020.[16]

Vehicles using biofuels may produce lower levels of GHG emissions than ICE cars. But on a "well-to-wheels" basis, biofuels can actually generate more GHGs than gasoline.[17] The Union of Concerned Scientists points out that the total carbon footprint of biofuels "includes more than just what comes out of the tailpipe. It also includes emissions from farms, factories, and any land use changes required to grow the necessary source material."[18] In addition, there are concerns about the indirect impacts of increased biofuel production, such as higher fuel prices and higher corn prices in the case of corn-based ethanol. The Department of Energy, Department of Defense, and numerous start-ups and universities are conducting ongoing research into next-generation biofuels based on technologies like algae, but whether these fuels can be adequately scaled-up to supply a large portion of the transportation sector remains to be seen. Finally, as is discussed below in the context of EVs, even if radically new biofuels technologies could work effectively, neoclassical and neo-Keynesian-inspired policy solutions won't result in their large-scale penetration of the vehicle market.

Hydrogen Fuel Cell Vehicles

Hydrogen fuel cell vehicles (HFCVs), another example of an alternative fuel vehicle, use fuel cells in lieu of ICEs. Hydrogen fuel cells convert the chemical energy in hydrogen to electricity, releasing water vapor instead of carbon dioxide in the process. HFCVs must be regularly refueled at hydrogen filling stations. Fortunately, the Honda FCX Clarity, the most well-known commercially available HFCV, can travel 240 miles on a full tank. Use of the vehicles remains very limited, however. Companies like Honda and Mercedes-Benz are only leasing HFCVs, and only to customers in southern California, where a hydrogen filling station infrastructure exists.[19]

HFCV technology is promising, but it lags behind electric vehicles in terms of commercialization and wide scale adoption. Costs remain prohibitively high—producing a single vehicle comes with a price tag of $100,000—and building an HFCV refilling station infrastructure is a slow process.[20] Furthermore, while HFCVs produce only water vapor when on the road, the process of acquiring the hydrogen to power them can require fossil fuels and produce GHGs. "There are emissions from hydrogen production depending primarily on the feedstocks and conversion processes used, and fuel distribution can also add to GHG emissions," the Center for Climate and Energy Solutions notes. "Most hydrogen produced today is obtained from natural gas using a process called Steam Methane Reforming (SMR)."[21] If hydrogen could be produced through clean energy processes, the GHG impact of HFCVs would likely be similar to EVs, assuming the latter consumed entirely clean energy electricity. But like biofuels, neoclassical and neo-Keynesian-inspired policy solutions won't result in HFCVs displacing ICE vehicles in any case.

Electric Vehicles

Finally, electric vehicles are an alternative to conventional gas cars. There are three types of electric vehicles, which are powered at least in part by batteries.

- *Hybrid electric vehicles* (HEVs) have both an ICE and a battery, which is charged by the ICE and regenerative braking. Whereas typical brakes dissipate the energy lost by stopping, electric vehicles can capture some of that energy and direct it to the battery for later use. HEVs have a very limited range in terms of solely battery-driven power; they rely on their ICEs to do most of the work.

- *Plug-in hybrid electric vehicles* (PHEVs) also have both an ICE and a battery. As the name implies, the battery is not only charged by the ICE and regenerative braking, but also by plugging into the electricity grid. PHEVs tend to have a longer all-electric range than HEVs.

- *Battery electric vehicles* (BEVs), or "all-electric" vehicles, are propelled solely via battery and electric motor and thus have no ICE at all. As such, their batteries are charged entirely via electricity from the grid and by regenerative braking.

The Toyota Prius is a popular example of an electric vehicle, with both HEV and PHEV models. In fact, when accounting for all Prius models, it was the world's third best-selling car in the first three months of 2012.[22] GM's Chevy Volt is a PHEV, while examples of BEVs include the Nissan Leaf, Mitsubishi i-MiEV, and Ford Focus Electric.

A Closer Look at Battery Electric Vehicles

Greater vehicle energy efficiency, biofuels, and the different alternative fuel vehicles all have the potential to reduce LDV sector GHG emissions, and therefore merit continued support for technological development. But only electric vehicles offer a plausible path to get to the 84 percent GHG reduction relative to 2010 that is needed to meet the United Nations' 2050 goal, as roughly calculated in the ITIF report, *Ten Myths of Addressing Global Warming and the Green Economy*. Any one of the three EVs could prove to be highly successful. BEVs deserve a particularly close look due to their relatively more advanced market position and perhaps easier path toward technology effectiveness and price competitiveness. In that sense, driving the mass adoption of BEVs is an ideal long-term solution for cutting LDV sector emissions.

Of course, despite having no tailpipe emissions, BEVs still effectively emit carbon dioxide when considering the sources of electricity from the grid acquired through recharging. After all, almost 50 percent of grid electricity in the United States comes from coal. But a 2012 report by the Union of Concerned Scientists found that across the United States, BEVs charged from the grid still produce lower global warming emissions than the average compact, gasoline-powered vehicle with a fuel economy of about 27 miles per gallon.[23] For example, driving a BEV in Juneau, Alaska is the equivalent of driving a car with a fuel economy of 112 miles per gallon. [24]

Furthermore, BEVs that are charged entirely from clean sources have the overall effect of generating close to no GHG emissions. While most U.S. electricity generation comes from coal today, over time the utility-sector will increasingly shift to low-carbon sources if policymakers adopt the innovation approach to electric power generation policy.

WHY ARE SO FEW ELECTRIC VEHICLES ON THE ROAD TODAY?

The 4,400 pound BEV "Electrobat," unveiled by the New York-based Electric Vehicle Company in 1897, was the world's first commercially-produced electric vehicle.[25] The car had a maximum range of 50 to 100 miles before its 1,600 pounds of lead-acid batteries had to be replaced.[26] At the time, cars powered by electricity, gasoline, and steam were in a tight battle for supremacy—each type of automobile had about a third of the burgeoning market at the turn of the century.[27] In fact, of the 4,192 cars produced in the United States in 1900, 28 percent were electric.[28] Steam cars were inexpensive, but took a long time to start and needed to be refilled with water every few miles. Electric cars actually had a "strong early advantage," as *Popular Science* senior editor Seth Fletcher writes in his book, *Bottled Lightning: Superbatteries, Electric Cars, and the New Lithium Economy.* "They were clean, quiet, and civilized. Gas-powered cars were unreliable, complicated, loud, and dirty."[29] In fact, gas car magnate Henry Ford reportedly bought his wife Clara at least two electric cars with 50-mile driving ranges in the early 1900s.[30]

Battery electric vehicles face performance and cost issues that, barring major technological improvements, will significantly limit their competitiveness.

Nevertheless, a notable technological improvement for gas cars came with the invention of the electric starter in 1912.[31] Whereas gas car drivers once had to start ICEs by using a hand crank (which could break arms upon backfiring), the electric starter greatly increased the gas car's convenience of use. Thus, as people began to drive longer distances and the price of gasoline dropped, gas cars steadily supplanted electric and steam cars, and the gas car culture that came to dominate the 20th century took root. Now, any new entrants face an uphill battle due to the entrenched infrastructure and industry of gasoline cars. In addition, BEVs face performance and cost issues that, barring major technological improvements, significantly limit their competitiveness.

Today, BEVs constitute a niche market. In the United States, 10,064 BEVs were sold in 2011—a market share of less than 0.08 percent.[32] Research firm IDTechEX, based on market trends and the progress of ongoing global research, projects that 10 percent of all cars sold worldwide will be BEVs by 2025.[33] Yet this projected market growth falls far short of both the ideal—a global vehicle fleet consisting entirely of BEVs—and what some experts consider the bare necessity. In order to meet the atmospheric carbon dioxide emission stabilization levels set by the Intergovernmental Panel on Climate Change, new vehicle sales for ICE cars would have to drop to 50 percent by 2020 and 40 percent by 2030, with the difference made up by all three kinds of EVs, according to analysis by IBM Global Business Services.[34] But BEVs must overcome numerous obstacles before consumers in developed and developing nations alike can be expected to embrace them en masse.

Limited Range

In contrast to comparable ICE-propelled cars, which can travel more than 300 miles between refueling, BEVs in the market today tend to have a range of less than 100 miles per charge. For example, the Nissan Leaf—by far the most popular BEV of early 2012, with worldwide sales of more than 27,000 units in the first three months of the year[35]—has a range of 73 miles.[36] The 2012 Mitsubishi i-MiEV, a BEV hatchback, travels 62 miles between charges.[37]

A 2010-2011 survey conducted by Deloitte Touche Tohmatsu that interviewed more than 13,000 people in 17 countries in the Americas, Asia, Australia, and Europe, found a large gap between consumer expectations of electric vehicle capabilities and actual capabilities. In regard to vehicle range, while on average 80 percent of the drivers surveyed drove less than 50 miles on a typical day, more than half the respondents in all 17 countries would not even consider buying an electric vehicle with a per-charge-range of less than 200 miles. In the United States, 56 percent of respondents pegged 300 miles as the minimum range needed for them to consider buying an electric vehicle.

While Americans drive on average less than 40 miles a day, most BEVs would force drivers to at least think twice about longer-distance travel.[38] "It may be true that the average American drives 40 miles a day, but there are many times when that average American is going to want to drive 120 or 150 miles," notes Scott Doggett, associate editor for the automotive information site Edmunds.com.[39] Lacey Plache, the site's chief economist, concurs, pointing out that "charging a vehicle only at home at night is insufficient for some consumers' driving habits; other consumers are simply plagued by range anxiety and do not want to risk being stranded."[40] The fact is that BEVs' limited range can result in irrational fears on the part of consumers. A 2010 trial in the United Kingdom found that drivers were very cautious when planning trips with BEVs. The longest trip made over the course of the study was only 25 percent of the average vehicle range, even though 93 percent of the trips were made with the vehicle battery charged at least halfway.[41]

While higher performance models with longer ranges exist, higher costs tend to make them unrealistic options for many consumers. In contrast with the Leaf and i-MiEV, for example, the 2011 Tesla Roadster boasts an impressive range of 245 miles per charge. Its price tag tops $100,000.[42]

High Costs

As a luxury vehicle, the Tesla Roadster is not representative of the mass consumer BEV market, but even lower cost BEVs are not yet cost-competitive. According to estimates by researchers at the Belfer Center for Science and International Affairs at Harvard University, a BEV with a range of 100 miles costs $4,819 more over 10 years than a comparable ICE vehicle based on 2010 purchase and operating costs, including battery recharging.[43] This suggests that gasoline cost savings of BEVs over an assumed lifetime of a decade—a primary BEV selling point—will not offset their higher purchase prices.

Furthermore, with the exception of China, India, and Korea, a majority of respondents in every nation surveyed by Deloitte signaled that they would not be willing to pay more for an electric vehicle than a conventional car. Seventy-one percent and 65 percent of survey participants in the United Kingdom and the United States, respectively, expressed this view. And given that incomes in China and India are dramatically lower than U.S. incomes, it is highly unlikely that consumer sentiment there would actually translate into favorable consumer behavior for BEVs. Moreover, even if EVs were price-competitive, most consumers apply very short discount rates to their purchasing decisions and may not be willing to pay more now to save more later—especially when some consumers do not retain their cars beyond three to five years.[44] In fact, analysis by the Energy Information Administration in their *Annual Energy Outlook 2012* found the discounted fuel savings of BEVs, assuming five years of ownership with savings discounted at 7 percent, to be "significantly less than the incremental purchase cost of the vehicles." "Although consumers may value high-cost battery electric vehicles for a variety of reasons," the report concludes, echoing the findings of the Belfer Center, "it is unlikely that they can achieve wide-scale market penetration while their additional purchase costs remain significantly higher than the present value of future fuel savings."[45]

As a result, BEVs continue to rely on financial support, such as government subsidies, to be more cost-competitive with gasoline cars. After all, the researchers at the Belfer Center and the Energy Information Administration did not account for subsidies when comparing the lifetime costs of ICE vehicles and BEVs, which can help make up the difference. Nissan's Global General Manager of Product Strategy, Francois Bancon, acknowledged this reality, stating that the Nissan Leaf depends on government subsidies to be cost-competitive. "[Government support] is the key," Bancon observed to journalists in June 2012. "This technology is expensive, the car is expensive. Where we sell the best is where the governments offer their support."[46] But even with large subsidies—the federal government offers a $7,500 tax credit for purchasing BEVs—the cars remain a niche market.

Slow Recharge Time

A key characteristic of gasoline vehicles is ease of use. Drivers can pull into a gas station (located ubiquitously) and leave in less than five minutes with a full tank of gas. By comparison, charging BEVs while on the road can involve long-wait times, assuming one can even find a charging station outside the home. Existing BEV charging technology falls under three categories:

- *Level 1* involves plugging a BEV into a 120-volt common electrical outlet, found in all homes. All electric vehicles come with a standard charging cable to perform Level 1 charging.
- *Level 2* uses a 240-volt circuit that requires a special wall- or pedestal-mounted outlet that can be hard-wired to a garage or charging station.
- *Level 3,* or "quick" or "fast" charging, is done by plugging into a large installation with a 480-volt connection.[47]

While Level 1 charging is available for all BEV vehicles, it can take up to 20 hours to fully recharge a vehicle. Level 2, meanwhile, charges in around 8 hours, making it ideal for overnight charging. But even under that scenario, BEV owners are inconvenienced if they need to drive on a moment's notice. Furthermore, the cost—including installation—of a Level 2 home charging station can be up to $2,000.[48] And apartment dwellers may be unable to install home charging stations. Level 3 charging can almost fully replenish a BEV's battery in half an hour, but the high-voltage process can shorten its lifespan due to its low density.[49] Also, with a price tag of at least $20,000, with another $20,000 typically needed for installation, Level 3 charging stations are primarily options for private operators, not the public at large.[50] New technology could reduce charging times, but this technology will need to be developed.

Again, the technological limitations of BEVs have led to consumer disconnect. Only 13 percent of respondents to a 2011 IBM survey of U.S. consumers expressed a willingness to pay more than $1,000 for a home charging station.[51] Furthermore, a majority of respondents in every nation surveyed by Deloitte—with the exception of India—

considered two hours or less to be the longest acceptable time to fully recharge an electric vehicle. People in Japan have particularly high expectations regarding charge time, with 64 percent of participants considering one hour or less to be the longest acceptable time.[52] Of course, even the speedy—by BEV standards—Level 3 charging process falls short relative to the only standard that matters in the effort to transform vehicle transportation: the gas refueling process for ICE cars, which can be done in less than five minutes.

The Solution: Better Batteries

The common source of performance and cost issues of battery electric vehicles is its foundational technology: its battery.

The common source of performance and cost issues of BEVs is its foundational technology: its battery. There is a broad consensus that bringing down BEV costs and improving their performance requires fundamentally new battery technology. Case in point: Reuters reported in September 2012 that Toyota "scrapped plans for widespread sales of a new all-electric minicar, saying it had misread the market and the ability of still-emerging battery technology to meet consumer demands." As Toyota Vice Chairman Takeshi Uchiyamada acutely observed, "The current capabilities of electric vehicles do not meet society's needs, whether it may be the distance the cars can run, or the costs, or how it takes a long time to charge."[53] Seth Fletcher notes that improving batteries is a challenge electric vehicles have faced for generations. "If you were out in the country and you ran out of charge [with an electric car], you were stuck," he observed in an interview with National Public Radio on electric vehicles in the early 20th century. "If you were driving a gas car, you could stop and get a tin of gasoline from the general store and fill up in a matter of minutes. That [recharging] problem has actually plagued the electric car ever since. If you want to take electricity on the road with you, you have to have a way to store it…we've always needed better batteries."[54]

A 2012 report by scholars at the University of Oxford reached the same conclusion: "Rapid consumer adoption is contingent on increasing [electric] vehicle performance and lowering the cost, which depends on advancements in battery technology."[55] Indeed, electric vehicle batteries can constitute up to half of vehicle production costs—up to $16,000, according to a Deloitte analysis.[56] In a 2012 forum on green technology, Ford CEO Alan Mulally lamented the fact that a battery for the company's all-electric Focus costs around $12,000 to $15,000, while a gasoline-powered Focus sells for $22,000 in its entirety. "So, you can see why the economics are what they are," he noted.[57] Dr. Winfried Wilcke, an advanced battery researcher at IBM, made an unfortunate contrast by roughly estimating the price of new ICEs to range from $3,000-$5,000.[58] With a weight of 600 to 700 pounds or so, current batteries also reduce electric vehicle fuel economy.[59] Innovating cheaper batteries and improving battery energy density and efficiency can therefore simultaneously have a major impact on BEV range, cost, and charge time.

Whereas lithium-ion batteries cost roughly $600/kWh today, experts have concluded that a ceiling cost of $300/kWh—with major corresponding improvements in performance—is necessary for BEVs to be able to compete with gas cars.[60] A 2012 McKinsey study, for example, indicates that BEVs will be cost-competitive with gas cars at a battery cost of approximately $275/kWh, assuming gas prices in the United States remain at or above $3.50 a gallon.[61] A more detailed analysis conducted by the Energy Information Administration (EIA) analyzes the impact of significant battery technology breakthroughs on the cost of BEVs in the year 2035. Specifically, the EIA case study assumes both improved battery energy density such that BEVs could go 200 miles on a single charge, and a 70 percent reduction in the cost of batteries in 2009. Since EV batteries were at the $1000/kWh level that year, a 70 percent reduction would amount to a cost of $300/kWh.[62] As can be seen below in Figure 1, EIA ultimately found that given those breakthroughs, the cost of BEVs with 100-mile and 200-mile ranges could be expected to drop $3,600 and $13,300, or 13 percent and 30 percent, respectively, by 2035, in comparison to a reference case that assumes only incremental technological improvements from 2010 onward.[63]

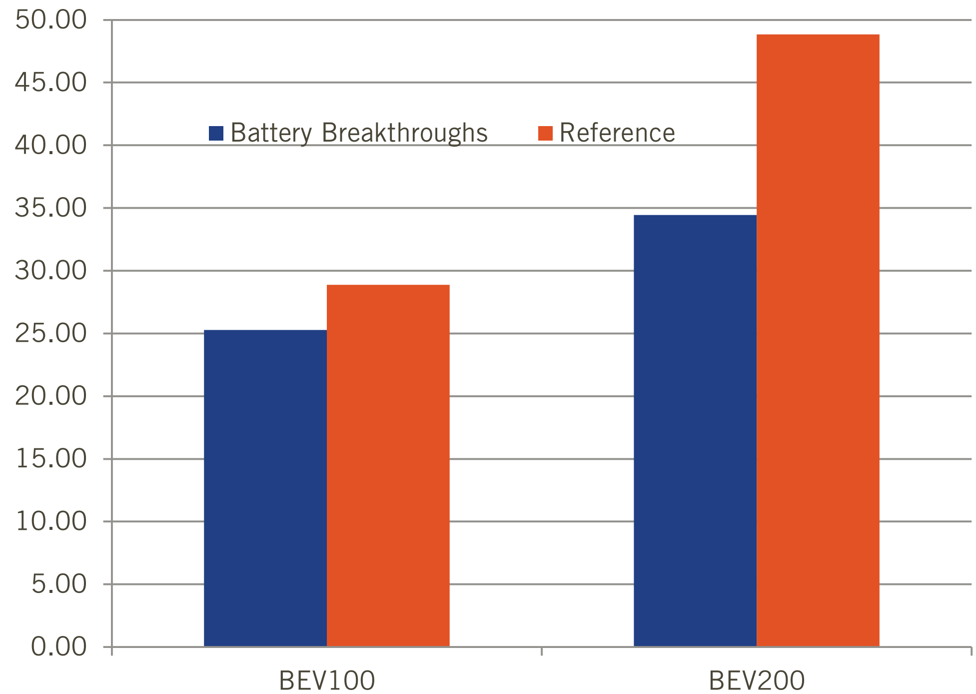

Figure 1: Total Price for Passenger Cars in 2035 (thousands, 2010 USD) Source: Energy Information Administration

Battery Technology Overview

Today, there is a wide variety of batteries used in EVs, utilizing materials that include nickel and iron—commonly used in PHEVs—and lead-acid. Lithium-based batteries, however, are increasingly seen as having the most potential for use in next-generation BEVs. "Lithium-ion batteries," a group of Oxford University researchers noted in a May 2012 report, "have become the preferred choice owing to high efficiency and long life...[but] scaling up the technology remains problematic because of high cost."[64]

The leading problem with lithium-based batteries is energy density; the batteries need to be further developed to enable longer driving distances between recharging while keeping weight and costs down. According to *Scientific American,* the lithium-ion batteries popularly used in today's BEVs "rely on a metal oxide or metal phosphate (typically cobalt, manganese or iron-based materials) cathode as a positive electrode, a carbon-based anode as a negative electrode and an electrolyte to conduct lithium ions from one electrode to the other."[65] As such, researchers have focused on utilizing different materials in battery components to increase the battery's overall energy density. By incorporating a mix of silicon, carbon, and carbon fibers into its anode, for example, Envia Systems has been able to produce a lithium-ion battery prototype that could enable a BEV that can go 100 miles today before recharging to go 300 miles instead.[66] Furthermore, the Envia battery theoretically costs around $400/kWh, in comparison to the close to $600/kWh cost associated with today's conventional lithium-ion batteries.

There has also been work to innovate lithium battery variations. IBM, for example, launched a Battery 500 Project to develop a lithium-air battery that can power a BEV for 500 miles on a single charge. Lithium-air batteries differ from lithium-ion batteries in that they use oxygen rather than a metal oxide or metal phosphate to drive a chemical reaction.[67] Meanwhile, another battery manufacturer, PolyPlus, has worked not only on a lithium-air battery and a conventional lithium-ion battery, but also on a lithium-water battery. That battery draws upon the oxygen in water to create a controlled chemical reaction while completely submerged in water, thus making it ideal for underwater robotics and marine sensing.[68]

The advancement of batteries and the battery electric vehicle industry has been hampered by a rigid focus on conventional policy options offered by the neoclassical and neo-Keynesian economic doctrines, none of which effectively drive innovation.

Nevertheless, it remains to be seen what other kinds of advanced battery breakthroughs will emerge to make BEVs more cost- and performance-competitive. Although lithium-based batteries are the focus of much attention, some scientists are actually working to improve on the nickel-iron battery designed by Thomas Edison over a century ago and apply it to BEVs.[69] The key question is what the government can do to best spur and accelerate innovation across a variety of battery designs and thus increase the chances of game-changing technology breakthroughs. In this regard it is necessary to evaluate the three major groups of EV policies (as informed by economic doctrines): carbon taxes, EV subsidies and regulatory requirements, and R&D funding.

EVALUATING CONVENTIONAL ELECTRIC VEHICLE POLICIES

As drastically reducing LDV carbon emissions ultimately requires better and cheaper BEV batteries, driving battery innovation should be the primary focus of policymakers. Unfortunately, the advancement of batteries and the BEV industry has been hampered by a rigid focus on conventional policy options offered by the neoclassical and neo-Keynesian economic doctrines, none of which effectively drive innovation. Instead, such policies only push innovation indirectly, if at all, while focusing on increasing vehicle adoption.

Neo-Keynesian Economics on Electric Vehicles: Subsidization

The dominant BEV policy today is subsidizing consumer purchasing of existing BEVs, which is a product of neo-Keynesian thinking. The core principle of the neo-Keynesian economic doctrine is that demand drives economic growth (and innovation). According to neo-Keynesians, if companies think consumer demand is increasing, they will have an incentive to invest more, including in better technology. Moreover, because neo-Keynesians don't focus on allocation efficiency (the market condition whereby resources are allocated in a way that maximizes the net benefit), they have no qualms about using policy to pick particular technologies or products—in this case, subsidizing BEVs. As a result, they focus on subsidies to favored technologies, as well as regulatory requirements (such as significant increases to the required fleet vehicle mileage per gallon average, or mandates to have a certain share of zero-emissions vehicles on the road, like those in California), as a way for government to spur demand for BEVs and ensure a level playing field between BEVs and conventional gas cars.

By artificially lowering the price of BEVs through subsidies or by spurring sales through mandates, neo-Keynesians hope to boost the development and adoption of the vehicles, which, they believe, will increase economies of scale and lower BEV prices. This theoretically creates a reinforcing feedback loop that drives BEV prices down over time and results in more private sector investment in BEV technology. The United States, for example, offers a tax credit of $7,500 for BEVs, and in 2012, the Obama Administration proposed increasing the credit to $10,000 and making it available at the point of sale instead of as a credit taken at tax filing—all part of the president's stated goal to put 1 million electric vehicles on the road by 2015.[70] Similarly, the United Kingdom offers grants of £2,000–£5,000($3,110–$7,777 USD) for consumers to purchase BEVs and PHEVs.[71]

In the United States, there is an array of other subsidies at the state and even local level. California appropriated more than $26 million for fiscal years 2009-2012 for rebates of up to $2,500 for the purchase of "clean vehicles," which includes BEVs and PHEVs.[72] In fact, select California residents could theoretically purchase Nissan Leafs in 2011 at a cost of $14,780, down from the $32,780 list price of a base model. In addition to taking advantage of the $10,000 in combined federal and state subsidies, residents of eight counties in the San Joaquin Valley Air Pollution Control District could apply for an additional $3,000 rebate for the purchase of a zero-emissions vehicle. Finally, with Sony Pictures Entertainment offering employees a $5,000 allowance for the purchase of an electric vehicle, Californians working at that company and living in the San Joaquin Valley would have been able to shave $18,000 off the price of a new Nissan Leaf in 2011.[73] Additional perks for BEV owners in the state include reduced charging rates and free parking throughout various California localities, as well as permission to drive in high-occupancy vehicle lanes with only one driver up to the year 2015.[74]

However, countries are hard-pressed to simply subsidize their way to BEV mass deployment because of the challenge of maintaining subsidies in times of budget austerity, as evidenced by the substantial curbing of solar subsidies in Germany, Italy, and Spain in 2011 and 2012, and the inability of lower income nations to afford BEV subsidies to begin with.[75] Unfortunately, when subsidies inevitably expire, BEVs will likely not be cost-competitive with conventional cars and the BEV industry will be put in a position to lobby for more subsidies just to stay afloat.

In fact, a September 2012 report by the nonpartisan Congressional Budget Office (CBO) concludes that the $7,500 U.S. tax credit for BEVs is unlikely to make them affordable relative to conventional gas cars. Specifically, the CBO summary of the report notes that PHEVs and BEVs require a tax credit of more than $12,000 at the very least "to have roughly the same lifetime costs as a comparable conventional or traditional hybrid vehicle…Consequently the credits will result in little or no reduction in the total gasoline use and greenhouse gas emissions of the nation's vehicle fleet over the next several years."[76]

Another helpful illustration of how even robust government subsidization efforts can fall short in driving greater BEV adoption, never mind innovation, can be found in the Portuguese EV market. Katie Hinds describes the situation in detail at *Transportation Nation*:

> Sergio Monteiro, Portugal's Secretary of State for Public Works, Transport and Communications, said his country is laying the groundwork for EVs—but so far his fellow citizens aren't buying. "We have more than 1,300 charging points," he said, adding that Portugal is also financially incentivizing the purchase of EVs. "The average cost (of an electric car) is around [$45,000 USD] in Portugal, and we have a reduction of [more than $6,200 USD] subsidized by the state." But, said Monteiro, "We only managed to sell 200 vehicles [in 2011]." And 60 of those went to government administrators…"It was like the field of dreams," he said. "You have the infrastructure, then services would come. That was not the case." He added that it was "living proof that infrastructure can only do so much—you need to break a number of barriers." And chief among them is cost. Even with a [more than $6,200 USD] euro reduction, Monteiro said, EVs are too expensive for the average Portuguese citizen navigating austerity measures.[77]

As a matter of fact, in addition to the direct purchase subsidies and more than 1,300 charging stations in 25 cities, Portugal also offers income tax relief of up to 30 percent for electric vehicle buyers.[78]

Similarly, Germany exempts BEVs and PHEVs from annual circulation taxes for being on the road in the first five years after their purchase.[79] In fact, the German government was so optimistic about vehicle subsidization policies spurring purchases that they announced a goal in 2009 of getting a million BEVs and PHEVs on the road by 2020. However, with only 2,044 such cars licensed in the country in 2011, German car industry experts are increasingly pessimistic about the prospects of meeting the 2020 goal. "Electromobility in Germany is about to die," the director of the Automotive Research Center at Duisburg-Essen University, Ferdinand Dudenhöffer, told DPA news agency in June 2012. "As things look today, we may reach a tenth of that goal, if we're lucky."[80] As German broadcaster Deutsche Welle related, "German WWF activist Viviane Raddatz [has] accused German carmakers of relying too much on government subsidies, rather than focusing on more intelligent technical solutions." "The undertone of the domestic auto industry," Deutsche Welle quotes Raddatz as saying, "is 'we haven't received enough funding, so small wonder we haven't made much progress.'"[81] If countries like Germany and Portugal are any indication, vehicle subsidization measures favored by neo-Keynesians alone are not enough to overcome the BEV technological limitations that discourage their wider adoption. Indeed, the experience of nations that have subsidized EVs make the infamous Ford Edsel look like a best seller.

Neoclassical Economics on Electric Vehicles: "Let the Market Work" and Carbon Taxes

In contrast with the neo-Keynesian economic doctrine, the neoclassical economics doctrine holds that supply normally meets demand and as such, the economy can be viewed as simply a large market of goods and services that is generally in equilibrium and often best left alone. Economic growth is seen primarily as a result of the efficient allocation of resources. Furthermore, there are conservative and liberal strains of neoclassical thought. "In general," ITIF's *Economic Doctrines and Approaches to Climate Change Policy* notes,

> Conservative neoclassicalists view markets as less prone to failures, a compelling case for limited government intervention. Liberal neoclassicalists, however, consider market failures to be more common, but still generally limited…liberal neoclassicalists are more likely to be willing to support intervention in the pursuit of greater economic equity and fairness, a market consequence that conservative neoclassicalists generally do not seek to correct through government action.[82]

In the context of electric vehicle policy, more conservative neoclassicalists are thus inclined to support a lack of government intervention to "let the market work," whereas more moderate and liberal neoclassicalists favor correcting for market failure by imposing a carbon tax.

Carbon Taxes

More moderate and liberal neoclassicalists favor carbon taxes to control for the negative externalities associated with GHG emissions. The thinking goes that since burning gasoline emits GHG emissions (a negative externality), markets will best allocate economic activity (e.g. driving, pollution, etc.) if each activity pays its full cost. In this case the full cost of burning gasoline is achieved by imposing a tax on the gasoline based on the amount of carbon it emits and on the basis of a model of the costs imposed by the carbon. This would also have the effect, in their doctrinal view, of reducing emissions of GHGs. Because those who hold the neoclassical economics doctrine believe that markets should allocate all economic resources, they are loathe to advocate for BEVs in particular, as that would be "picking winners"—something only the market is qualified to do. Rather, they say that a carbon tax will spur a range of market solutions likely to include more efficient ICEs, less driving, and perhaps some increase in BEV adoption.

One intended result of carbon tax is thus to make BEVs more competitive with ICEs by increasing gasoline car operating costs, theoretically spurring more adoption and deployment of BEVs, and also, over time, driving BEV costs down. Former Vice Chairman of General Motors Bob Lutz, for example, has advocated increasing U.S. gas prices (a de facto carbon tax) for that purpose. "If he were 'emperor,'" *Autoweek* reported, "the only office he says he's qualified for based on his foreign birth, Lutz says he would raise the price of fuel price by 25 cents a gallon per year, which would convince people to buy [electric] cars."[83] In fact, the aforementioned Deloitte survey suggests that gas prices reaching four dollars a gallon is a tipping point for 53 percent of Americans that would make them more likely to consider buying an electric vehicle.

And yet the average price of a gallon of gas in the United States has hovered around four dollars since early 2011, all the way through the first half of 2012, with no major corresponding uptick in electric vehicle sales.[84] In fact, sales of the Nissan Leaf dropped 69 percent in June 2012 from a year earlier.[85] Even with higher gasoline costs, the cost of BEVs is still prohibitively high for consumers in comparison to conventional cars, subsidies included. "Compared to a [gasoline-powered] Nissan Versa, a Leaf owner would have to hold on to the Leaf for seven years in order to recoup the price difference through fuel-cost savings even if gas prices rise to $4 per gallon," economist Lacey Plache observes. "Compared to a Chevy Cruze, a Volt owner would need 12 years. But according to a recent Edmunds.com analysis, consumers tend to own their vehicles for just five to six years, on average."[86]

Of course, Europe exists as a natural experiment in evaluating the effect of a carbon tax. The price of a gallon of gas in Western Europe has been almost double that of the United States throughout the first half of 2012—around eight dollars per gallon in Belgium, France, Germany, the Netherlands, and closer to nine dollars in the case of Italy.[87] Furthermore, 17 of the 27 European Union countries employed a carbon-related tax on gasoline cars as of 2011 above and beyond the high gas prices.[88] For example, in Germany, Portugal, and Spain, among other countries, the amount of a car's registration tax is based at least in part on its carbon emissions. In Finland, the registration tax on a new car can run as high as 50 percent of its cost depending on its carbon dioxide rate.[89] Thus, in comparison with an average U.S. gas price of four dollars per gallon, European nations have the equivalent of gas taxes of approximately four dollars to five dollars a gallon, or 16 to 20 times what GM's Lutz has proposed. As the burning of a gallon of gasoline results in close to 20 pounds of carbon dioxide and there are 2,000 pounds in a ton, a gas tax of five dollars a gallon amounts to a carbon tax of $500 a ton.[90] That figure is substantially higher than the minimum $10 per ton of carbon that would have resulted from the 2009 Waxman-Markey GHG emission trading scheme. Indeed, a carbon tax of such magnitude can be considered politically impossible in the United States, given current circumstances.[91]

Despite these massive European taxes on ICE vehicles—especially in comparison to the United States—and corresponding subsidies for electric vehicles, BEV sales in Europe have remained sluggish to say the least. Since early 2011, Nissan has sold 11,000 BEV Leafs in the United States, but only 3,000 in Europe.[92] As a late 2011 report by Resources for the Future scholars Thomas Klier and Joshuan Linn, *Fuel Prices and New Vehicle Fuel Economy in Europe*, notes, "little empirical evidence supports (a) an effect of fuel taxes on carbon dioxide (CO_2) emissions…or (b) an effect of recently proposed fuel tax reforms on the new vehicle market."[93] BEVs' performance levels simply cannot compete with gas alternatives and higher carbon taxes can do little to change that. As ITIF wrote in *Ten Myths of Addressing Global Warming and the Green Economy*, while the approach of European countries has "induce[d] Europeans to drive smaller cars and drive less than Americans, it has not induced them to switch to electric cars…Price signals only lead to behavior change when there is a viable substitute."[94] Europe's experience is evidence that, like the subsidies favored by neo-Keynesians, carbon and gas pricing is an insufficient impetus for the technological innovation that can lead to market-ready, zero-carbon substitutes to gas cars.

Unfortunately, assuming policies implemented under the conventional economic doctrines, such as subsidization and carbon taxes, were actually effective at driving mass deployment of BEVs, the desired level of innovation would not necessarily arise. "Even if you had 50 or 60 million electric vehicles on the road," notes Sven Beiker, executive director of the Center for Automotive Research at Stanford University, "it still wouldn't bring about the

revolution in battery technology that all of us hope for."[95] Ultimately, technology push—and not market pull—can best help ensure the development of better electric vehicle batteries. To be sure, increasing electric vehicles sales through direct price subsidization or by artificially increasing the cost of gas alternatives through carbon taxes may encourage incremental technology improvements. Greater production can be expected to result in incrementally better and cheaper versions of existing batteries. This result would be fine if incremental innovations were the only technology barriers holding BEVs back from mass adoption, but unfortunately, that is not the case. Dramatically improved batteries, both in terms of cost and performance, are needed, along with subsidies to primarily benefit existing, underperforming technology. That means policies that support the entire cycle of innovation, from research and development through technology commercialization.
The fact is, innovation is a complex process and price alone will not induce all types of innovation in similar ways. Economist Vernon Ruttan of the University of Minnesota showed that price was certainly a factor in what he called "induced innovation." However, he was largely referring to incremental innovation and engineering advances that are industry led, shorter term, and therefore, more responsive to price and market signals.[96] Induced innovation will be very important to energy technologies like solar photovoltaic that have been around for years and that focus on incremental advances to drive down price. By contrast, the pursuit of next-generation clean energy innovation—as in the case of electric vehicle batteries—will require radical or breakthrough technologies, often coined "pipeline innovation," which is long term in nature and less price sensitive at the R&D stages. To complicate the process further, existing innovation systems (rules, regulations, culture, and the like), as well as information asymmetries, uncertainty, risk, technology-path dependency, chicken-or-egg externalities, and a host of other "failures," affect the actions of innovators and entrepreneurs in the market. Specifically, entrepreneurs in the research and development phase encounter great uncertainty in market conditions. Couple this with the fact that pipeline innovation requires pushing a breakthrough idea through the valley of death—the phase in the development of technologies between research and commercial introduction in the marketplace—to translate it into a usable, market-worthy option.

"Let the Market Work"

More conservative-leaning neoclassicalists argue that there is no need for government involvement in the vehicles market, including a technology-neutral tax. On the contrary, government policies like BEV subsidization are certainly a foolhardy distortion of the market, but so too are carbon taxes that don't target a particular technology. In the United States, the $7,500 federal tax credit for BEV purchases has been a particular target of conservative neoclassicalists' ire. In fact, Congressman Mike Kelly (R-PA) introduced legislation in early 2012 to repeal the credit. "If there is a green energy revolution in America, it won't be led by bureaucrats in Washington," he declared in a *USA Today* editorial. "It will be market-driven."[97]

According to this conservative neoclassical economic doctrine, the higher BEV prices that would result from market deregulation through the ending of subsidies would incentivize producers to develop cheaper and more effective products. And if they don't, that is what the market dictated. As Todd Thurman of the Heritage Foundation opines in circular logic, "If the electric car is viable the government would not need to offer rebates to buy the cars."[98] Moreover, some, but not all, conservative neoclassicalists are skeptical of government support for advanced battery R&D. For example, in response to an August 2012 Department of Energy announcement that it was distributing $43 million to 19 new research projects aimed at improving energy storage technology, *Daily Caller* associate editor Paul Conner noted that "Conservatives argue that such innovation should be driven by supply and demand in the private sector so that taxpayer funds are not risked."[99]

ACHIEVING THE MASS ADOPTION OF BATTERY ELECTRIC VEHICLES THROUGH AN INNOVATION STRATEGY

A larger and more coherent government effort with innovation as the focus can help lead to the battery technology breakthroughs that will ultimately make battery electric vehicles both cost- and performance-competitive with their gasoline counterparts.

Policymakers and advocates need to stop looking to the neoclassical and neo-Keynesian economic doctrines as the North Star guide to climate policy and look instead to an emerging doctrine of "innovation economics." Policies generated by the conventional doctrines—technology-specific subsidies and regulations, "technology neutral" carbon pricing, and the "let the market work" approach—will not make BEVs competitive with gas cars because they do not address the core technology problems of BEVs.

Whereas innovation is "manna from heaven" and a derivative factor under the neoclassical and neo-Keynesian economic doctrines (firms automatically do it if they have the demand for it from customers), the innovation economic doctrine recognizes that innovation is a complex process, central to driving economic growth, that markets acting alone will often not optimize. Thus, innovation economics, unlike the other economic doctrines, does not treat knowledge and technology as something that happens outside economic activity. Instead, innovation economics makes an explicit effort to understand and model how innovation occurs, seeing such advances as a result of intentional activities by economic actors, including government. The doctrine of "innovation economics" reformulates the traditional model of economic growth and recognizes knowledge, technology, entrepreneurship, and innovation as primary factors for economic growth rather than as independent forces that are largely irrelevant in the prevailing doctrinal approaches to economic growth.[100] Such policy is particularly apt in energy, in which complex institutional systems shape the process of innovation, and where the notion of a "market" as a unifying principle is too limiting. Consequently, innovation economics focuses on facilitating innovative actions and supports complex innovation systems with a variety of policy tools in order to move the economy in a strategic direction.

How to Spur and Accelerate Battery Innovation

The federal government has already made substantial efforts to support advanced battery development to increase performance and lower costs. In fact, the U.S. Department of Energy (DOE) explicitly recognized the need for better batteries, noting that "the lack of affordable, highly-functional batteries has been a particularly high barrier to the widespread adoption of electric vehicles."[101] However, a larger and more coherent government effort with innovation as the focus can help lead to the battery technology breakthroughs that will ultimately make BEVs both cost- and performance-competitive with their gasoline counterparts.

Renewed Investment in RD&D

A variety of federal entities are supporting battery innovation. The Advanced Research Projects Agency-Energy (ARPA-E), the federal government's oft-praised energy innovation leader, has a program focused specifically on the development of better electric vehicle batteries: Batteries for Electrical Energy Storage in Transportation (BEEST). Since 2010, BEEST has invested around $36 million in 10 projects across the country, covering a wide variety of advanced battery research areas that includes lithium-air and ultracapacitors. One project, an effort by researchers at Stanford University to commercialize a decidedly unconventional "all-electron battery" for electric vehicles, leveraged $1.5 million in ARPA-E support to attract an additional $25 million in private funding.[102] Another agency awardee, the previously mentioned PolyPlus, is moving to bring their innovative lithium-water batteries to market within two years.[103]

Meanwhile, the Vehicle Technologies Program within the Energy Efficiency and Renewable Energy Program (EERE) at the DOE has funded the U.S. Advanced Battery Consortium (USABC), a public-private partnership between National Labs, DOE, Ford, General Motors, and Chrysler.[104] The consortium invests in battery R&D projects through a 50/50 cost share between the DOE and the company contracting the R&D. A123, an advanced battery manufacturer, for example, received crucial support from USABC that led to a breakthrough lithium-ion battery technology that does not require a cooling or heating system and could therefore result in a lighter, longer-lasting battery pack.[105] Ted Miller, a member of USABC's management committee from the Ford Motor Company, points to government support for the consortium as a government best practice: "The reason the USABC model has been so effective is that the contributors have the technical and business expertise to develop appropriate goals, to evaluate advanced technologies, and they have a vested interest in successful results."[106]

The National Labs have also been active on the advanced battery development front. At the Argonne National Laboratory in Illinois, for example, researchers have been testing new materials for lithium battery cathodes and are beginning to license patents to different battery makers. In fact, Envia Systems, the California company that announced the development of a high-density, lithium-ion battery in early 2012, based its work on technology licensed by Argonne.[107] In addition, scientists from multiple national labs—Argonne, Lawrence Livermore, Pacific Northwest, and Oakridge—have been involved in research for IBM's Battery 500 Project. In fact, scientists conducted essential experiments on electrolytes at Argonne and not IBM's own Almaden research center, as might be expected.[108]

Given their accomplishments so far and their significant promise if successful, federal agencies like ARPA-E, the National Labs, and the EERE Vehicle Technologies Program deserve more funding to make good on the variety of projects that they are already supporting, and to identify new ones altogether. As policymakers look to more aggressively fund battery innovation, they should divert some funds used for the EV tax credit to instead support these key battery innovation programs.

Align DOD's Battery Programs with Those of DOE

Of course, the Department of Energy is not alone in advanced battery innovation—the Department of Defense (DOD), too, has multiple programs dedicated to battery innovation. Much focus has been directed at developing lightweight, portable batteries for dismounted troops, and because this work has revolved around lithium-based batteries, it is very applicable to advanced EV battery research.[109] That being said, DOD also has researchers working solely on EV batteries. For instance, the U.S. Army Tank Automotive Research, Development and Engineering Center (TARDEC) seeks to make efficient lithium-ion batteries for the Army's future multipurpose ground vehicle, the Joint Light Tactical Vehicle. TARDEC demonstrated a prototype vehicle in 2011, though more work remains before it can be produced cost-effectively at scale.[110]

DOD and DOE signed a memorandum of understanding (MOU) in the summer of 2010 that laid out the groundwork for cooperation on the development of an array of clean energy technologies, including advanced batteries.[111] As Assistant Secretary of Defense Sharon Burke noted in early 2012, however, "projects started under the MOU to date focus on improved energy efficiency, supply, and storage for dismounted troops, contingency bases, and platforms," with no mention of batteries.[112] Firming up this collaboration, with a renewed focus on battery technology, would be a simple way to ensure that both departments' efforts are productive and aligned. One way of doing this would be for Congress to officially legislate the collaboration between DOD and DOE so additional funds could be appropriated for their efforts. Another possibility is for DOD to align some of its cost and energy density goals with the goals of DOE's battery innovation programs, which would immediately leverage DOD's large research and procurement budgets toward developing similar breakthrough batteries.

Create a Battery Shot Initiative

Finally, as part of a government-wide effort to better coordinate battery innovation between DOD and DOE, between agencies within each department, and between the public and private sector, policymakers should create a "BatteryShot Initiative" akin to DOE's SunShot Initiative. SunShot coordinates the national pursuit of cost-competitive solar energy with a specific goal in mind, driving down the cost of solar electricity to about $0.06 per kilowatt-hour.[113] In that vein, BatteryShot could coordinate government battery RD&D efforts and establish a clear metric for success, such as ARPA-E's goal of producing a battery with a total system cost of less than $250/kWh and a range of at least 300 miles per charge.[114] The new Initiative could be even more ambitious: USABC management committee member Ted Miller, for example, pegs achieving a battery cost of $100-150 kWh—assuming stable fuel and electricity costs—as the point where BEVs can truly compete with gas cars.[115]

The idea of greater intergovernmental coordination is not new. An August 2012 study by the Government Accountability Office (GAO) identified 39 initiatives across six government agencies dealing with battery and energy storage R&D and analyzed the extent to which there was overlap or duplication of efforts. Of course, the initiatives cover a variety of technologies, including power for weapons systems, personal electronics, and military installations, and batteries for not only electric vehicles, but naval and space craft as well. But the GAO report did find that six programs at the DOE alone, and five at DOD, that deal with advancing electric vehicle battery technology and came to the conclusion that greater coordination is desirable. "While we did not find clear instances of duplicative initiatives, it is possible that there are duplicative activities among the initiatives that could be consolidated or resolved through enhanced coordination across agencies and at the initiative level."[116] Furthermore, DOE's *2011 Quadrennial Technology Review* noted that "the Department collaborates with other federal agencies to leverage expertise, advance research, development, demonstration, and deployment programs, reduce redundancy in energy research programs, and leverage government purchasing power to facilitate commercialization and initial deployment." The *Review* goes on to ask, "How can DOE best coordinate activities between and among these types of organizations?" [117] That is the key policy question going forward. The fact is that a BatteryShot Initiative is a relatively simple, but potentially effective, strategy for spurring battery innovation. By setting clear, aggressive goals for technology improvement, BatteryShot would not only better focus government innovation efforts, but also create a more competitive environment among the various federal entities working on breakthrough batteries.

CONCLUSION

U.S. Energy Secretary Steven Chu has been bullish about the prospects of national battery technology breakthroughs. "The advanced battery competition is a race the United States can and should win," he noted at a speech at the Detroit Economic Club in January 2012.[118] In fact, while batteries for a typical EV car cost around $16,000 today, DOE projects that through innovation, costs could be lowered to $10,000 by 2015 while also improving performance.[119]

BEVs face a potentially promising future. During a competition in late 2011, researchers from the University of Applied Sciences in Offenburg, Germany, ran a BEV with a lithium-ion battery around a track for over 36 hours on a single charge. The car ultimately drove 1013.77 miles and set a new world record in the process. Of course, the car is completely unsuited to mass adoption—it is a completely no-frills single-seater that traveled at an average of 28 miles per hour—but it is a promising hint of what greater battery innovation can accomplish.[120] Indeed, robust battery innovation holds the promise that all BEVs will one day boast a similar range, at low cost and high speed, to displace GHG-emitting, ICE-powered cars as the vehicle of choice for consumers around the world. But realizing this promise requires throwing aside ineffective policy choices based on faulty economic doctrines and implementing innovation policies that help break through the core technology barriers impeding the widespread market deployment of BEVs.

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