ENERGY AND ENERGY POLICY

A COST BENEFIT ANALYSIS OF ELECTRIC AND HYBRID ELECTRIC VEHICLES

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ABSTRACT

As the inevitable exhaustion of fossil fuel resources looms nearer, mankind has begun the necessary task of converting its energy economy from a chemical to an electrical base. One of the most significant components of the new electrical energy economy is the electric vehicle. Investors, corporations, and governments have turned to the electric vehicle as a means towards reducing greenhouse gas emissions and reliance on fossil fuel resources. Thoroughly assessing the mechanical advantages of the electric vehicle compared to the internal combustion engine vehicle, disproving the feasibility of the closest renewable competitor (hydrogen fuel cell vehicles), discussing methods to mitigate the current shortcomings of electric vehicles, followed by conducting a cost-benefit analysis considering the micro- and macroeconomic effects of an electric vehicle economy will demonstrate that the battery electric vehicle is the most feasible, efficient, and sustainable successor to the traditional internal combustion engine vehicle.

KEYWORDS: batteries, charging infrastructure, cost efficiency, electric vehicles, energy, energy efficiency, fuel cost, greenhouse gas emissions, hydrogen fuel cells, macroeconomic benefit, Tesla
INTRODUCTION

Electric vehicles (EVs) refer to vehicles that use electric motors for propulsion, with electrical energy stored in rechargeable battery packs. Due to the use of electrical energy and lack of combustion products, these vehicles have negligible emissions compared to their gasoline-powered counterparts, and thus are considered better for the environment. To better understand the advantages of electric vehicles, we will provide a basic outline of their inner workings. The key components of an electric car are the electric motor, the motor’s controller and the rechargeable battery packs. These components are connected such that the controller uses the power stored in the batteries and delivers it to the motor while a potentiometer attached to the accelerator pedal delivers signals to the controller to indicate how much power should be delivered.

The motor used can be either an AC or DC motor. A DC motor usually runs on a voltage between 96 to 192 volts and most of these DC motors that are used in electric cars are obtained from forklift industrial vehicles. An AC motor is a three-phase motor that makes use of 240 volts AC and has a 300-volt battery pack attached. DC motors usually have a 20,000 to 30,000 watt range and a controller will be in the range of 40,000 to 60,000 watts. DC motors are usually cheaper and have the option of going into overdrive in short bursts whereby the motor will permit 100,000 watts and supply up to five times the regular horsepower. This enables quick bursts of acceleration in short periods of time, but can also generate significant amounts of heat that could potentially damage the motor. Compared to DC motors, AC motors utilize regenerative braking, an energy recovery mechanism which
slows down the vehicle by acting as a generator and converting its kinetic energy into electrical energy which can then be transferred to the rechargeable battery pack.

The battery is the only physical component in an EV that sets it back in comparison to a gas vehicle, and is thus an important factor in determining the viability of an EV. The lead-acid battery and the lithium-ion battery are the two main batteries used in EVs today. The lead-acid battery is heavy, slow to charge and has a very short life span (approximately 3-4 years). Furthermore, it has a very limited capacity of only about 12-15 kilowatt-hours of electricity, thus requiring frequent recharging and providing low driving range. The Tesla Model S makes use of a Lithium-Iron Phosphate (LiFePO4) battery because it has a longer lifespan (over 6 years) in addition to a higher power retention rate. It is also approximately 60% lighter than a lead-acid battery. These advantages also lead to Li-ion battery technology being significantly more expensive. However, given that cars such as Tesla have plans to mass produce their vehicles, we can expect high production rates of these batteries and thus lower costs in the near future as more and more electric cars switch to this alternative.

Given this high level overview of EVs, the rest of this paper will focus on evaluating the viability of EVs in terms of environmental and economic factors. We will first assess the mechanical advantages of EVs over ICE vehicles and then evaluate the feasibility of hydrogen fuel cell vehicles. We will then discuss methods to mitigate the current shortcomings of electric vehicles, followed by a cost-benefit analysis considering the micro- and macroeconomic effects of an electric vehicle economy.
REASONS FOR ELECTRIC VEHICLES

The past decade has seen the emergence of electric vehicles with large automakers such as Nissan venturing into the electric vehicle arena, while newer companies such as Tesla have made large strides in electric vehicle technology. With the emergence of these cars, the future of ICE vehicles is thrown into question. Proponents of EVs claim that their use brings about environmental, financial and operational benefits.

Battery-powered EVs offer significant environmental advantages over conventional gasoline or diesel-powered cars. Electric operation reduces tailpipe emissions and allows the use of cleaner, renewable and more environmentally friendly energy sources. With EVs, the only exhaust emissions come from power plants that generate the electricity used to charge the vehicles’ batteries. The amount of greenhouse gas reduction depends on the how the electricity is generated. Coal-fired plants produce the most greenhouse gases, but even in regions where most electricity is produced by coal, electric cars can still reduce greenhouse gases by more than 25% compared to conventional vehicles. These “upstream” emissions are an important part of the equation when comparing the overall emissions, or “well-to-wheels,” calculation of EVs (Holdway 2010) . A study by the Union of Concerned Scientists has found that regardless of where an EV is plugged in, the emissions produced by an EV are less than the emissions of an average compact conventional vehicle. When charged by nuclear power or renewable energy sources such as hydroelectric, wind, or solar power, EVs cut
greenhouse gas emissions even more dramatically. Over time, EVs will become even more environmentally friendly as additional renewable energy from other technologies is added to the power grid (Anair 2012).

The financial benefits of EVs are summarized in a McKinsey report, which states that scale effects and manufacturing productivity improvements, representing about one-third of the potential price reductions through 2025, could mostly be captured by 2015. Savings would come largely from improving manufacturing processes, standardizing equipment, and spreading fixed costs over higher unit volumes. New plants could therefore be significantly more productive than those in operation before 2010-11. Additionally, reductions in materials and components prices, representing about 25% of the overall savings opportunity, could mostly be captured by 2020. Component suppliers could reduce their costs dramatically by increasing manufacturing productivity and moving operations to locations where costs are optimal. Furthermore, technical advances in cathodes, anodes, and electrolytes could increase the capacity of batteries by 80% to 110% by 2020–25. These efforts represent 40% to 45% of the identified price reductions (McKinsey 2012).

EVs also exhibit savings for consumers in terms of driving expenses. According to a study done by the Union of Concerned Scientists, the average national price of electricity has remained fairly static over the last decade, whereas the global oil market has caused the average price of gasoline to rise, drop, spike, dip, and rise again over the same time period. Hence, driving on electricity will help safeguard customers from future spikes in the average price of gasoline (Union of Concerned Scientists 2013). The
following graph shows a comparison of the cost to drive 27 miles between an average compact gasoline vehicle and a Nissan Leaf.

![Gasoline vs. Electric: Cost to drive 27 Miles](image)

Comparison assumes a 27 mpg gasoline vehicle (average compact fuel efficiency) and an electric vehicle efficiency of 0.34 kWh/mile (Nissan Leaf). Sources: EIA 2013a; EIA 2013b; EIA 2013c.

Proponents of EVs also cite the advantages EVs have over ICEs in terms of maintenance and driving performance. Despite being an advanced technology, EVs are remarkably simple to maintain. An EV has one moving part, the motor, whereas an ICE vehicle has hundreds of moving parts. Fewer moving parts in the EV means it requires less periodic maintenance and is more reliable. ICE vehicles require a wide range of maintenance, from frequent oil changes, filter replacements, periodic tune ups, and exhaust system repairs, to less frequent component replacement (US Dept of Energy 2005). Brake pads in EVs require periodic maintenance, but not nearly as often as conventional vehicles since EVs do not use brakes as much due to regenerative braking (Zhang Chuanwei 2004). Although quantifying maintenance costs is difficult since
newer EVs have not been on the roads as long as conventional vehicles, a study conducted at the Institute for Automotive Research (IFA) at the Nürtingen–Geislingen University found that EV maintenance can cost 35% less than that of a conventional vehicle (Diez 2014).

In terms of driving performance, EVs have shown to have much better acceleration than ICEs. An electric engine generates instant torque (or turning force) whereas an internal combustion motor has a curve of torque that increases in tandem with engine revolutions per minute (rpm). Although some electric vehicles have very small motors, 15 kW (20 hp) or less and therefore have modest acceleration, many electric cars have large motors and brisk acceleration. In addition, the relatively constant torque of an electric motor, even at very low speeds tends to increase the acceleration performance of an electric vehicle relative to that of the same rated motor power internal combustion engine. The following graph compares the acceleration of a Nissan Leaf with that of an average compact conventional vehicle (Murray 2010).
Figure 1.2

The graph shows that the Nissan Leaf has a much quicker initial acceleration than the ICE vehicle. Although the ICE vehicle has a higher acceleration at certain points, the Nissan Leaf exhibits a much smoother acceleration pattern.
REASONS FOR INTERNAL COMBUSTION ENGINE VEHICLES

Although electric vehicles have shown a lot of promise, it will be some time before they are fully adopted. Additionally, the transition to alternative means of transportation will still require use of internal combustion engines. It is no coincidence that internal combustion engines have been so successful and widely adopted. There are a few reasons for the success of the internal combustion engine. One of the most important reasons is that ICEs use efficient fuels like gasoline and diesel. Another reason for their importance and utility is that because ICEs are so prevalent there’s a higher incentive to research and improve the efficiency of these engines. Additionally, there is already a sound infrastructure built specifically for the needs of ICE users. Also, while ICEs may still produce considerable amounts of emissions, the technology to reduce emissions is improving. Thus it is reasonable to assume that internal combustion engines will play a pivotal role in the transition to alternative fuel sources. ICEs will be needed because other technologies have not yet caught up to the economies-of-scale, power or reliability of ICEs.

Diesel and gasoline are excellent fuel sources because they can safely, for the most part, be transported in liquid state over a large range of temperatures. This also allows them to be used in most environments, which adds to their versatility. Additionally, these fuels have a lot of energy relative to their volume hence they are able to power engines effectively. Refueling is also very easy and takes but a few minutes. This contrasts with the high charging times of EVs. High charging times coupled with shorter ranges create a severe constriction that most consumers are not willing to accept.
Additionally, options to charge are not as widely available as refueling stations are prevalent. There is an already sound infrastructure to support ICEs. EV support infrastructure will most likely increase as the technology is adopted more widely but in the meantime ICEs meet the needs of most.

Even though ICEs do produce emissions, there is plenty of room to increase efficiency so less fuel is used and also so less emission are emitted. The importance of ICEs lies in their application in hybrid vehicles. This seems more feasible than a direct adoption of EVs, which will not be possible until there is improvement in the efficiency of charging and storing electricity. Already there have been many improvements to the internal combustion engine since it’s invention. One of these is direct fuel injection, which involves fuel being pumped directly into the cylinder of the internal combustion engine. This allows for a higher compression ratio during cycles which also increases fuel efficiency. (National Research Council, 2013) Additionally as the technology for engines improves, engines can be reduced in size to achieve similar power while increasing efficiency since less weight is pulled. The use of direct fuel injection along with turbochargers has been a popular move by automakers since it increases fuel economy and offers similar or even better performance. More expensive technologies like variable lift systems are also available but there is room for improvement to increase stability for smaller engines so these can be implemented at a more cost effective level. Most of these improvements lie in using computers to electronically control the mechanisms in place of camshafts, which will allow for greater control.
Newer technologies, in addition to improving older systems, are also being developed like homogenous-charge compression ignition which combines some features of the diesel and gas engine. At low levels, it operates like a diesel engine using pressure and heat compression for combustion. However, fuel is already injected before the compression stroke of the ICE. At higher operating levels, a spark plug provides combustion much like a gasoline engine. As the technology to control switching between levels improves, this type of ignition could significantly help increase efficiency and conserve fuel. There is also the possibility of improving current flex-fuel engines by increasing their ability to effectively use the higher octane of corn-based ethanol. A similar system to the HCCI that allows an engine to run on gasoline at lower levels and flex fuel at higher operating levels is one way that efficiency could increased.

In addition to engines, the structural materials, weight-reduction techniques and aerodynamics of traditional cars can also be improved. There are prohibitive cost factors in implementing some of these technologies because they are still expensive. An example of this is the use of carbon fiber to reduce weight. However, carbon fiber that is strong enough to be used in automobiles is significantly more expensive than current alternatives. Additionally, efficiency improvements for accessories, such as air conditioning and other electronics, are other areas which automakers are currently researching for improvements. The coupling of improvements in mechanical and structural hold much promise for increasing efficiency in internal combustion engines. This will further add to the utility and lifespan of ICE’s.
### Exhibit 2. Conventional Technologies Have Significant Emissions-Reduction Potential

<table>
<thead>
<tr>
<th>Levers</th>
<th>Aerodynamics</th>
<th>Vehicle mass</th>
<th>ICE technology</th>
<th>Transmissions</th>
<th>Power management</th>
</tr>
</thead>
<tbody>
<tr>
<td>Optimized design and frontal area</td>
<td><img src="drag_coefficient.png" alt="Image" /></td>
<td><img src="mass.png" alt="Image" /></td>
<td><img src="ICE.png" alt="Image" /></td>
<td><img src="transmissions.png" alt="Image" /></td>
<td><img src="power_management.png" alt="Image" /></td>
</tr>
<tr>
<td>Lightweight materials</td>
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<tr>
<td>New manufacturing technologies</td>
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<td>Content optimization</td>
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<td>Downsizing</td>
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<tr>
<td>Vaporization and combustion optimization</td>
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<tr>
<td>Reductions in energy losses due to pumping, friction, and heat</td>
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<tr>
<td>Weight reduction</td>
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<tr>
<td>Improved control of automatic transmissions</td>
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<td>Continuously variable transmissions</td>
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<td>Dual clutch</td>
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<tr>
<td>Switching from mechanical to electronic accessories</td>
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<tr>
<td>Optimization of accessories' electricity consumption</td>
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| Impact on CO₂ emissions | 1% reduction per ~0.01 reduction in the drag coefficient | 3%–4% reduction per 10% mass reduction | 1%–20% reduction per technology | 1%–7% reduction per technology | 1%–2% reduction per technology |

<table>
<thead>
<tr>
<th>Approximate maximum potential CO₂ reduction by 2030</th>
<th>5%</th>
<th>5%–6%</th>
<th>40%</th>
<th>5%–10%</th>
<th>3%–5%</th>
</tr>
</thead>
</table>

| Approximate cost to consumer per car² | $100 (20 per percentage point of CO₂ reduction) | $500 (100 per percentage point of CO₂ reduction) | $2,000–$2,500 (500–600 per percentage point of CO₂ reduction) | $100–$200 (20–40 per percentage point of CO₂ reduction) | $150–$250 (50 per percentage point of CO₂ reduction) |

Sources: Expert interviews; BCG analysis.

²For diesel, the potential reduction is 10 to 35 percent.

³Vehicle price increase before VAT.

⁴The cost for an average weight reduction of 250 pounds.

⁵New materials show the potential for weight reductions of up to 37 percent at a cost of $2,100, or approximately $100 per percentage point of CO₂ reduction.

⁶The average for gasoline and diesel; individual technologies vary from $20 to more than $100 per percentage point of CO₂ reduction.

⁷Replacement of a five-speed automatic gearbox with a dual-clutch transmission in a compact car.

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**Figure 2.1**
HYDROGEN AS AN ALTERNATIVE TO ELECTRICITY:

Thus far, we have focused on ICE vehicles as a benchmark to establish the relative advantages of electric vehicles. The reasoning for this is simple: electric vehicles are the only renewable energy vehicles that are close competitors to ICE vehicles. We will support this claim by demonstrating that the next closest renewable competitor, hydrogen vehicles, are not a feasible solution to the problem of creating efficient renewable energy vehicles.

In the vehicle space, calling hydrogen renewable may in fact be a misnomer. Currently, nearly 95% of hydrogen is produced from natural gas, composed mostly of methane (Hoffmann 2002). The hydrogen is produced from this methane using a distributed natural gas steam reforming process which does not provide a significant reduction in wells-to-wheels greenhouse gas emissions (compared to ICE or electric vehicles). In his 2014 study, Cox finds that one kilogram of hydrogen produced in the most efficient commercial route emits a minimum of 14.34kg CO2e versus 11.13kg CO2e for a U.S. gallon of gasoline (of which 13.2Kg is actual CO2 gas in the case of hydrogen) (Cox 2014). There also exist difficulties in transporting bulk quantities of hydrogen (namely converting into liquid form before transport), which lower the feasibility of on-site hydrogen production by preventing the efficiencies of economies of scale. On top of the current production and transportation limitations of hydrogen, hydrogen vehicles lack the long term potential for growth that electric and ICE vehicles have. As such, we have identified three main barriers for hydrogen vehicles, which are production inefficiencies, transportation and storage costs, and a foreseeable lack of future growth avenues.
Production inefficiencies arise from inherent properties of hydrogen. Since molecular hydrogen is not available on earth in convenient natural reservoirs, the manufacture of hydrogen requires the consumption of a hydrogen carrier (either a fossil fuel, in most cases, or water). In the case of water, hydrogen is produced using electrolysis which uses electrical or thermal energy from a primary source, which ironically will be fossil fuels in most cases. As for producing hydrogen from fossil fuels, manufacturers use the process of steam reforming. Figure 1 shows a schematic representation of steam the steam reforming process.

Steam Reforming Schematic

Steam and hydrocarbon enter the reactor as feedstock, and hydrogen and carbon dioxide are generated as outputs. The process is facilitated through the following chemical reactions:
The first reaction, where methane reacts with water to create carbon monoxide and hydrogen, is endothermic and so requires a temperature of 850°C for optimal conversion. Again, this heat is usually supplied by fossil fuels, as current best processes of water electrolysis have an efficiency of 50% to 80%, so that 1kg of hydrogen (which has a specific energy of 143 MJ/kg, about 40 kWh/kg) requires 50 to 79 kWh of electricity. At 0.08 $/kWh, that's $4.00/kg of hydrogen, which is 3 to 10 times the price of hydrogen from current steam reformation of natural gas (EERE 2002). The price differential is a result of the fact that steam reformation utilizes a direct conversion from fossil fuels to hydrogen, while electrolysis burns an energy source to create electricity for the hydrogen electrolysis process.

Although we have established that steam reformation is the most efficient process of producing hydrogen, it is more appropriate to compare electrolysis, the renewable production method of hydrogen production, with renewable forms of grid-produced electricity. We believe this is justified due to the fact that about 5% of current hydrogen production is renewable, while 13% of electricity in 2013 was produced from renewable sources (Bossel
In his 2006 study, Bossel compares the energy needs of renewable hydrogen cells with renewable electricity. Figure 2 shows his comparison of production strategies.

**Renewable Hydrogen vs Renewable Electricity**

Three strategies (two hydrogen and one electric) are outlined. In the leftmost strategy, Hydrogen is produced by electrolysis, compressed to 20 Mpa and distributed by road to filling stations, stored at 10 MPa, then compressed to 40 MPa for rapid transfer to vehicles at 35 Mpa. Only 23% of the original renewable energy is reaches a vehicle's wheels. In the middle strategy, hydrogen is produced by electrolysis, liquefied, and distributed by road to filling stations. Again, the energy retention here is only 20%. Compare these two strategies with the electric strategy. Renewable electricity is transmitted through the grid, which is charged into batteries, and powers vehicles with regenerative braking, transferring 69% of the original energy to wheel motion. Although further study in electricity storage, converters, drive systems, and electricity transfer will create a more accurate picture, it is readily
apparent that hydrogen, an artificial carrier, is much less efficient than electricity, which serves as renewable hydrogen's own energy source.

Aside from the inherent inefficiencies of hydrogen production, certain properties of hydrogen prevent ease of storage and transport, preventing economies of scale. Firstly, hydrogen has a low viscosity of $0.083\text{g/cm-s} \times 10^{-5}$ at 1 atm and 20°C. It is very difficult to prevent leaks from developing in hydrogen pipework; pipework pressure-tested for nitrogen will often leak significantly when handling hydrogen loads. In a high-pressure storage system, hydrogen is estimated to leak 3 times faster than natural gas and 5 times faster than propane (Pritchard and Rattigan, 2010). Combining hydrogen's propensity to leak with its very low ignition energy causes an explosion hazard. Because hydrogen readily forms an explosive mixture with air, the energy necessary to initiate an explosion of a 2:1 hydrogen/oxygen mixture is only about 0.02 mJ, less than one tenth of the energy required to initiate explosions with other fuels such as methane, LPG, or petrol. In terms of transport, hydrogen is most easily transported in its liquid form. As we have discussed earlier, liquefaction will consume about a third of the original hydrogen's energy. Further, the complications of rapid phase transitions, boil-off, and condensation must be mitigated during transport. Due to these challenges, producers and regulators are reluctant to build hydrogen pipelines – which would require extensive materials and integrity testing – and have yet to start supplying hydrogen refuelling stations through bulk road tanker transport – which would necessitate thorough risk mitigation of transport through populated or urban areas.
ELECTRIC RANGE PROBLEMS

Most electric vehicles have a maximum range of only 100 miles, which means that the point of no return is only 50 miles. There are some exceptions including Tesla Motors vehicles. The longer range is only accomplished through higher capacity batteries and thus a higher initial price. The problem with this is that batteries are expensive, which is why Tesla electric vehicles are nearly four times the price of other electric vehicles (Massias, 2011). Therefore, a solution could be as simple as making batteries cheaper and more efficient. There is another problem, which is that the batteries cannot take up too much space or be too heavy. A heavy battery is inefficient because it takes more electric power to move. A battery cannot take up too much space, because then it would be cumbersome and expensive to build bulky electric vehicles. Therefore, batteries need to become lighter, cheaper and more efficient. Another issue is charging times for electric vehicles. Extending the range of electric vehicles by increasing the size of batteries could lead to even longer charging times.

The range would not be an issue if there was massive infrastructure built around electric vehicles. However, this infrastructure could be unwieldy and hard to use. although Tesla is planning to build charging stations. Pumping gas takes little to no time, whereas charging an electric vehicle takes at least 30 minutes with a Tesla supercharger and significantly longer with other charging methods. The other inventive solution might be switching stations. One could drive one’s electric vehicle into the station, take a fully charged battery and then leave the depleted battery to charge. However, there are a number of logistical problems with switching stations. First, switching heavy batteries requires machinery and expertise. The Nissan Leaf’s battery, which is quite standard, weighs around
A Tesla vehicle’s battery weighs much more and can make up the entire floor of the car (Fisher, 2013). A trained individual may also be required to operate machinery to switch the battery, which would add to costs. Second, the switching stations would have to monitor the batteries being switched, since batteries are expensive and can be damaged or no longer charge fully. One could simply go to a switching station with a used up battery that has been worn out or simply broken and switch it. Then, the switching station would lose money. To prevent such scenarios, one would need a trained individual or some kind of testing device that tests the batteries. That would be expensive and time consuming. It is a foreseeable problem switching stations would have to overcome, for them to truly be fast and efficient. Therefore, at this time switching stations as well as charging stations do not seem viable. Charging stations take too long and switching stations would probably be very costly and/or take too long. Hence, electric vehicle range is very important, since electric vehicles do not have an infrastructure built around them.

The problems with electric vehicle range are numerous and there is no easy fix. One solution currently is to just have larger batteries, as Tesla does. The problem is that leads to very expensive cars. Therefore, if a consumer wants an electric vehicle with a larger than 100 mile range, they will have to buy a more expensive luxury vehicle. However, emerging battery technology does hold promise. If batteries can become cheaper, lighter and more efficient, electric vehicle ranges can be extended further than 100 miles quite easily. If the batteries become lighter, the car will weigh less and use less electricity to power. If the batteries become cheaper, they can reduce the cost of electric vehicles dramatically, allowing
for larger batteries and, thus, greater range. A cheaper electric vehicle means the range can be extended for fractions of the cost previously. Batteries are indeed becoming better, and research is being done, so it does seem viable. More efficient batteries can make electric vehicles much more popular.
## Electric Vehicle Comparison

<table>
<thead>
<tr>
<th>Electric vehicle</th>
<th>Battery</th>
<th>Range advertised</th>
<th>Range in real world</th>
<th>Charge times</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>BMW Mini E</strong></td>
<td>35kWh, air cooled; 18650 cells; NMC 355V, 96s53p</td>
<td>250km, 156 miles</td>
<td>153km, 98 miles; 112km, 70 miles below freezing</td>
<td>26h at 115VAC; 4.5h at 230V, 32A</td>
</tr>
<tr>
<td><strong>Chevy Volt</strong></td>
<td>16kWh, liquid cooled Li-manganese, 181kg (400lb)</td>
<td>64km, 40 miles</td>
<td>45km, 28 miles; 140hp electric &amp; 1.4 liter IC engine</td>
<td>10h at 115VAC; 4h at 230VAC</td>
</tr>
<tr>
<td><strong>Toyota plug-in Prius</strong></td>
<td>3 Li-ion packs, one for hybrid; two for EV, 42 temp sensors</td>
<td>20km, 13 miles</td>
<td>N/A; 80hp electric &amp; 98hp IC engine</td>
<td>3h at 115VAC; 1.5h min 230VAC</td>
</tr>
<tr>
<td><strong>Mitsubishi iMiEV</strong></td>
<td>16kWh; 88 cells, 4-cell modules; Li-ion; 109Wh/kg; 330V</td>
<td>128km, 80 miles</td>
<td>88km, 55 miles; highway speed, mountain pass</td>
<td>13h at 115VAC; 7h at 230VAC</td>
</tr>
<tr>
<td><strong>Nissan LEAF</strong></td>
<td>24kWh; Li-manganese, 192 cells; 80Wh/kg, air cooled; 272kg (600lb)</td>
<td>160km, 100 miles</td>
<td>100km, 62 miles at highway speed with heater on</td>
<td>8h at 230VAC; 30 min high ampere</td>
</tr>
<tr>
<td><strong>Tesla Roadster</strong></td>
<td>58kWh, 6,831 Li-cobalt computer cells; liquid cooled</td>
<td>352km, 220 miles</td>
<td>224km, 140 miles; 172km, 108 miles driven sports car</td>
<td>3.5h at 230VAC high ampere</td>
</tr>
<tr>
<td><strong>Think City</strong></td>
<td>24.5kW, Li-ion or sodium-based</td>
<td>160km, 100 miles</td>
<td>N/A. Sodium-type has few problems</td>
<td>8h at 115VAC</td>
</tr>
<tr>
<td><strong>Smart Fortwo ED</strong></td>
<td>16.5kWh; cylindrical Li-ion (computer cells), made by Tesla Motors</td>
<td>138km, 85 miles</td>
<td>Less than predicted</td>
<td>8h at 115VAC 3.5H at 230VAC</td>
</tr>
</tbody>
</table>

Table 4.1
There is new battery technology, in the form of an air aluminum battery that is not rechargeable. The air aluminum battery has the capability of making a subcompact electric vehicle have a range of over 1,000 miles (Mearian, 2014). The battery just uses air, water and aluminum. The only issue is that the battery is not rechargeable, but an innovative design allows for replacement of aluminum cartridges, which makes the battery reusable.

The battery will work in conjunction with a common Lithium ion battery found in electric vehicles. This will allow the electric vehicle to be driven short distances without using up the aluminum battery cartridges. The air aluminum battery will kick in effectively as a range extender. This can ease people’s range anxiety that is currently associated with electric vehicles.

Aluminum-air batteries do wear out under normal use. The aluminum through use turns into aluminum hydroxide. Worn out aluminum-air batteries can be recycled to create new batteries (Cobb, 2014). This opens the door for feasible electric vehicle infrastructure to be built around these batteries. Switching stations can be a real possibility in which people take their used air aluminum batteries and switch them for new ones (Cobb, 2014). Also, water needs to be added to the battery every couple hundred miles of use, though readily available tap water can be used.

The only problem with this technology is it is not on the market yet. It has not been incorporated into current electric vehicle models. The companies claim that travel distances,
purchase prices and life-cycle costs of their aluminum-air battery system are comparable to that of petrol powered vehicles (MacKenzie, 2014).

**Air Aluminum Battery Schematic**

![Air Aluminum Battery Schematic](image)

**Figure 4.1** Unlike lithium-ion batteries, the aluminum air technology relies on a chemical reaction between aluminum, water and oxygen to create electricity (Cobb, 2014).
Figure 4.2 The Phinergy-Alcoa team has resolved the lifespan limiting CO2 issue by developing air electrodes with a silver-based catalyst that allows oxygen into the cell while blocking CO2 molecules (Cobb, 2014).
Air Aluminum Battery Cartridge

Figure 4.3 What an aluminum cartridge would look like
Water Refill

![Water Refill Image]

**Figure 4.4** Stops for water every couple hundred miles would be needed when using the air aluminum battery (Cobb, 2014).

Lithium Ion batteries are also going to become cheaper. Tesla is constructing the Gigafactory, a lithium ion battery factory, which would reduce the cost of Lithium ion batteries by a minimum of 30% due to economies of scale (Evans, 2014). On September 3, 2014, Reno, Nevada was selected as the final location of the Gigafactory with $1.25 billion incentive grants from the State of Nevada in the form of tax breaks and perks. Therefore,
Lithium ion batteries will become cheaper, and these savings can be passed on to consumers. This will allow the feasibility of extending electric vehicle ranges by simply making larger batteries.
COST BENEFIT ANALYSIS

The most effective way to quantify and analyze the overall benefits of electric vehicles is through a simple cost-benefit analysis. Therefore, we have looked into a quantitative analysis of both micro factors associated with electric vehicles as well as more difficult to quantify macro factors involved with these electric vehicles. In the former section, we will break down two different scenarios. The first is when electric and hybrid electric vehicles are compared in sensitivity tables to lower cost ICE vehicles. We felt this was the best approach given that electric vehicles are inherently higher cost yet could produce long term savings. The next scenario is against similarly priced luxury sedans versus electric vehicles. Finally, we look into a review of the literature on the effects of oil and our own estimation of health related effects of electric vehicles. An emphasis here is that our analysis is not comprehensive given the scope of potential externalities related to these vehicles and the length of our project time.
COST EFFICIENCY ANALYSIS OF LOW COST ICE VERSUS ALTERNATIVE OF ICE VERSUS ALTERNATIVE ENERGY VEHICLES

Assumptions:

1) Average of gas costs = $4.00 (U.S. Department of Transportation)

2) Miles driven per year = 12,000 miles (U.S. Department of Transportation)

3) Interest rate = 6% (Ng, Michelle, 2011)

4) Electricity cost = 2.2 cents (Ng, Michelle, 2011)

5) Consumers have no preference toward being “environmentally friendly”.

Electric and Hybrid vehicles have long been seen to be the solution to the problems created by fossil fuels. With the ability to reduce carbon emissions and reduce negative externalities, these vehicles can cut the dependence on foreign oil sources. However, the U.S. economies reluctance to accept the widespread production is puzzling. Thus, this section will analyze the cost efficiency of alternative energy vehicles. This analysis was done by comparing hybrid-electric and electric cars to an average ICE sedan. More specifically, this research was done through a lens of an average American consumer using the Chevrolet Volt, Toyota Prius and Honda Civic as the electric, hybrid and ICE respectively.
Cost Efficiency of ICE to Hybrid and Electric Cars

Fuel Price Efficiency

<table>
<thead>
<tr>
<th></th>
<th>Honda Civic LX</th>
<th>Toyota Prius</th>
<th>GM Volt</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial Cost ($)</td>
<td>18,490</td>
<td>22,000</td>
<td>40,000</td>
</tr>
<tr>
<td>MPG</td>
<td>32</td>
<td>50</td>
<td>N/A</td>
</tr>
<tr>
<td>Fuel Cost/mile (cents/mile)</td>
<td>400/32 = 12.50</td>
<td>400/50 = 8.00</td>
<td>2.2</td>
</tr>
</tbody>
</table>

Table 5.1

Statistics on the Chevrolet Volt, Toyota Prius and Honda Civic were gathered to answer the main question of is it actually worth it to drive? The table above shows initial cost of each vehicle and the cost per mile of the car. Now since the initial cost is higher on some of the vehicles, the fundamental question is whether the savings per mile compensates for the higher price tag and how long that would take.

There a couple of assumptions made in order to build a model that compares the costs of the different vehicles. The first is the average 6% interest rate an American can borrow to finance a car. Second is the average miles driven which was calculated by assuming 40 miles per working day with 20 working days. Adding in 200 miles on the weekend’s sums to 1,000 miles per month. Compared to the Honda the Hybrid saves 4.5 cents and $45 dollars per month (U.S. Department of Transportation).

Now using the information we have above, a basic model and sensitivity table will be created in order to compare the time to break-even on the different cars. This paper’s model
will be based off the present value of an annuity, which is derived from discounting future cash flows.

**Derivation of Formula:**

The future value of an annuity is the future value of a series of cash flows. The formula for the future value of an annuity, or cash flows, can be written as

\[ FVA = P + P(1 + r) + \ldots + P(1 + r)^{n-1} \]

When the payments are all the same, this can be considered a geometric series with \(1+r\) as the common ratio.

Using the geometric series formula, the future value of an annuity formula becomes

\[ FVA = P \left[ \frac{1 - (1 + r)^n}{1 - (1 + r)} \right] \]

The denominator then becomes \(-r\). The negative \(r\) in the denominator can be remedied by multiplying the entire formula by \(-1/1\), which is the same as multiplying by 1. This will return the formula shown below.

**Present Value equation 1**

\[ PVA = PMT \times \left[ \frac{(1+r)^T - 1}{r(1+r)^T} \right] \quad (Equation 1) \]

**Figure 5.1**

Originally:

PVA = Present Value of Annuity

PMT = Payment per period
R = interest rate (per month)

T = number of periods

However, this will be slightly adjusted so that PMT = Fuel cost savings per month and PVA = the initial price difference between the cars.

Thus, the equation becomes:

$$\Delta P = \text{FuelSavings per month} \times \left[ \frac{(1+r)^T-1}{r(1+r)^T} \right] \quad (\text{Model})$$

Note: Interest rates are assumed to be .5% per month from an average 6% per year.

Now, we can construct a sensitivity table based on varying interest rates and gas price assumptions. This table will show how long (in our case T) it will take to break-even when purchasing a hybrid car over an ICE.
Hybrid Break Even

Based on the table above it would take about 7.98 years for an average American to break even when purchasing a hybrid over a traditional ICE vehicle. These are based off the $4.00 per gallon gas assumption and all other assumptions stated before. “N/A” essentially means the consumers will not break-even because of interest rate compounding.

Similarly, another sensitivity table was made for the breakeven time between purchasing a electric vehicle to ICE.
Electric Break Even

As shown in the table, the most abundant output is N/A. Combining the results from both sensitivity tables we can see which vehicles are the most cost effective. First ICE then hybrid followed by electric.

The fact that the majority of the table is N/A inherently implies why consumers are not shifting toward electric vehicles. The use of electric cars at this point seems to be economically inefficient. It would take almost 40 years to breakeven on a hybrid car based on a 6% interest rate and $4.00 per gallon assumption. This opportunity cost of 40 years is a strong factor that contributes to the low demand for electric vehicles at this point.
Juxtaposing the Volt, Civic and Prius, the data and model demonstrate that alternative energy cars in the short and long term are cost inefficient. Even though the Volt and Prius are much more fuel-efficient, the initial cost prevents consumers from purchasing an alternative energy vehicle.

However, there are many factors that will promote the usage of electric vehicles. These factors, among others, include economies of scale on the automobile industry, declining charging costs and subsidies or taxes. These will be discussed more in detail.

Case Study - Tesla Model S vs. Nissan Leaf

With codename “white-star” during its research, Tesla Model S was introduced in June 2012, after a much-anticipated arrival. The Tesla S is a top of the line luxury sedan that is fully electric and it received a 5.0 NHTSA safety rating. The Model S actually has two different options, the 60kWh and 85 kWh batteries. Another similar more affordable car is the Nissan Leaf (U.S. Department of Energy). The leaf has a 24kWh battery but has smaller dimensions in comparison. However, beside the battery size there are a couple of features that are most critical to an electrical vehicle: performance, environmental impact, and charging.

The performance of the model S is unparalleled at this point in the electric vehicle market. In terms of miles per charge it has the highest in the market. With the 85kWh battery fully charged the Tesla model S could go 265 miles, although this varies with weather conditions and speed of the car. Another important statistic to bring to light is Miles per Gallon of Gasoline Equivalent (MPGe) where 1 gallon of gasoline = 33.7kWh. The Model S
with the 85kWh battery gets 89 MPGe. In addition to this, the annual fuel cost is roughly only $700 based on 12,000 annual miles and electricity cost $.12/kWh(U.S. Department of Transportation 2014). The only real downside to the Tesla’s performance is the initial cost of $69,900. Combined with low production, this initial cost is preventing most consumers from buying the Tesla S(US Dept of Energy 2014).

The Nissan Leaf lags slightly in performance in terms of horsepower and acceleration but it makes up for its weaknesses in fuel savings. The Leaf has 114 MPGe and the fueling costs only about $550 a year (using the same assumptions as the Tesla). However, the Leaf can only travel 84 miles on a full charge so this limits the consumer in a variety of ways(Nissan 2014).

From a purely economical and consumer perspective is it even worth buying the Tesla Model S? Assuming the consumer does not prefer clean energy, lets quickly analyze the costs. The national average for the cost of fuel is $3.90 with the comparable large sedan getting about 22mpg. Also assuming 12,000 miles driven per year, the total fuel cost for a comparable sedan is $2,659. Assuming the same for the Model S with electricity costing $.12 kWh, the total cost for fuel is $524. Thus, the average savings per year is $2,135. Consequently, the more a consumer drives the more he or she will save during the year and vice versa. However, the average luxury sedan costs roughly $50,000, which is almost $30,000 cheaper than the Tesla S. Thus, with the current technology it would take 15 years to start saving money(Tesla 2014)
COST BENEFIT ANALYSIS OF THE TESLA S VS HIGH PRICE LUXURY SEDANS

We conducted a cost-benefit analysis with separate assumptions from our main analysis looking to quantify the potential cost savings by using the Tesla S over the next 8 years versus high price luxury sedans which appear to be the main group where there could be cost savings. As shown in the previous section, there do not appear to be cost savings in the short term versus most other types of vehicles. This is an especially relevant analysis given that this could be the main group of people who would switch over to the newer Tesla model which is currently the most efficient car in its cost class and could likely be the future projecting forward of electric vehicles. Therefore, this is why we used it as a model. The following assumptions were made:

1) The price of 93 octane oil, annual mileage and interest rates will be the same as in the assumptions in the comparison of an EV and ICE vehicle above.

2) Comparison Car MPG is 21.5 MPG (Combined) for Competitors: BMW 7 Series = 21, Lexus 460 = 20, Mercedes S Class = 22, Audi A8 = 23. Tesla performance characteristics are closer to these models or to performance models than to the mid-range luxury vehicles. (Kelley Blue Book 2014)

3) Tesla's MPGe per EPA is 96 mpg (Tesla 2014)

4) Annual Gas Price Rate increase is 1.70 %. Set at current inflation. (CPI 2013)
5) Tesla Model S MSRP: $69,900 (Edmunds 2014)

6) Length of Ownership – 8 years (Polk 2014)

7) 200 minutes saved via Gas Station times savings based on an estimate of 40 trips to the station per year in a normal car

8) $50/hour, for the leisure time of an individual able to afford a Tesla

As per other reports, the present value equation is shown below:

\[ PV = \frac{C_1}{(1 + r)^n} \]

Based on these assumptions and the use of present value calculations over 8 years we were able to add up the total present value added over this time for regular cars and hybrids.

**Calculations:**

**Price Point Calculation:**

The competitors list in Table 7.1 was assimilated and the average MSRP was used to help calculate the Tesla price premium:

<table>
<thead>
<tr>
<th>MSRP</th>
</tr>
</thead>
<tbody>
<tr>
<td>$47,800</td>
</tr>
<tr>
<td>$73,600</td>
</tr>
<tr>
<td>$82,500</td>
</tr>
<tr>
<td>$51,900</td>
</tr>
<tr>
<td>$92,350</td>
</tr>
<tr>
<td>$78,100</td>
</tr>
<tr>
<td>$71,990</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>---------------</td>
</tr>
<tr>
<td>Jaguar XJ</td>
</tr>
<tr>
<td><strong>Average MSRP</strong></td>
</tr>
</tbody>
</table>

**Table 7.1**

As mentioned in assumption 5, the average MSRP was found to be $69,900. Hence the price premium here is $71,430 - $69,900 = $1,530 which will be used later in the cost effectiveness section.

**Discount Factor Calculation:**

The initial discount factor of 1 was taken and multiplied by (1+.06). 6% was used as it is the risk free discount rate cited above. This discounting was taken into account for 8 years.

**Gas Price Calculation:**

Starting with the initial gas price of $4.00 there was a 1.7% increase multiplied by this $4.00 for each of the subsequent years.

**Gas Cost Calculation:**

Each year we multiplied the 12,000 yearly miles by the gas price for the year based on the increasing gas price value. This was then divided by the comparison car mpg value of 21.5 mpg to get the overall cost of gasoline for the year for the luxury sedans.
PV of Gas Regular Car Calculation:
For each year, the gas cost was divided by the discount factor given the discounting for each year to take into account present value. This was then added for the next row, the total PV of gas, regular car.

Fuel Costs Hybrid Calculation:
In this calculation, we took the total number of miles travelled to be the same as a normal car, so 12,000 a year. We then multiplied this by the gas price for each year but divided it now by the 96 mpg we assumed for hybrid vehicles as they are more efficient than the other vehicles. This helped to find the overall fuel costs for the hybrid vehicles.

Value of Time Calculations:
Here we used a baselines assumption of 50 dollars per hour for the opportunity cost of time. From there we assumed 40 trips to the gas station a year with 5 minutes each time we spent refueling. This meant that there would be 200 minutes spent refueling each year. However, the difference between the electric vehicle and the luxury sedan is that the electric vehicle was assumed to only have 20% of the total refuel needs of the luxury sedan thus making the time savings 160 minutes. To make the estimation simpler, we assumed we were comparing this to the case of a Tesla home charged vehicle which would have an in garage charger and not take extra time to charge otherwise. Therefore, we multiplied the 50 dollars per hour by
the 160 minutes spent. This was then divided by 60 minutes per hour and divided by the
discounting factor for each year.

### Present Value Determination Data

<table>
<thead>
<tr>
<th>Discount Factor</th>
<th>1.0</th>
<th>1.1</th>
<th>1.1</th>
<th>1.2</th>
<th>1.3</th>
<th>1.3</th>
<th>1.4</th>
<th>1.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year</td>
<td>1.0</td>
<td>2.0</td>
<td>3.0</td>
<td>4.0</td>
<td>5.0</td>
<td>6.0</td>
<td>7.0</td>
<td>8.0</td>
</tr>
<tr>
<td>Gas Price</td>
<td>4.0</td>
<td>4.1</td>
<td>4.1</td>
<td>4.2</td>
<td>4.3</td>
<td>4.4</td>
<td>4.4</td>
<td>4.5</td>
</tr>
<tr>
<td>Gas Cost</td>
<td>2232.6</td>
<td>2270.5</td>
<td>2309.1</td>
<td>2348.4</td>
<td>2388.3</td>
<td>2428.9</td>
<td>2470.2</td>
<td>2512.2</td>
</tr>
<tr>
<td>PV of Gas Cost</td>
<td>2232.6</td>
<td>2142.0</td>
<td>2055.1</td>
<td>1971.7</td>
<td>1891.7</td>
<td>1815.0</td>
<td>1741.4</td>
<td>1670.7</td>
</tr>
<tr>
<td>Total PV of Gas, Reg Car</td>
<td>15520.3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fuel Cost, Hybrid</td>
<td>500.0</td>
<td>508.5</td>
<td>517.1</td>
<td>525.9</td>
<td>534.9</td>
<td>544.0</td>
<td>553.2</td>
<td>562.6</td>
</tr>
<tr>
<td>PV of Fuel Cost, Hybrid</td>
<td>500.0</td>
<td>497.7</td>
<td>460.3</td>
<td>441.6</td>
<td>423.7</td>
<td>406.5</td>
<td>390.0</td>
<td>374.2</td>
</tr>
<tr>
<td>Total PV of Fuel, Hybrid</td>
<td>3475.9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Value of Time Savings</td>
<td>133.3</td>
<td>125.8</td>
<td>118.7</td>
<td>111.9</td>
<td>105.6</td>
<td>99.6</td>
<td>94.0</td>
<td>88.7</td>
</tr>
<tr>
<td>Total PV of Time Savings</td>
<td>877.7</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 7.2
Savings based on Present Value Calculations:

<table>
<thead>
<tr>
<th></th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tesla Price Premium</td>
<td>-$1530</td>
</tr>
<tr>
<td>Total PV of Gas Savings</td>
<td>$12044.3638</td>
</tr>
<tr>
<td>Total PV of Time Savings</td>
<td>$877.6508586</td>
</tr>
<tr>
<td>Total Savings</td>
<td>$14452.01466</td>
</tr>
</tbody>
</table>

Table 7.3

As seen in table 7.3 above, when adding the price premium to the total PV of gas savings which is simply the difference in the PV of gas costs between the hybrid and the luxury sedan as well as the PV of the time savings between both of them we find that the total savings amounts to $14,000 dollars over 8 years.

The Tesla Model S outperforms every competitor from a performance standpoint, and is also significantly larger than most mid to high-priced luxury sedans. Most comparison vehicles are therefore drawn from the upper end of luxury sedans, with the BMW 5 and Mercedes E class also included for balance. Given that this calculation can be swayed either way based on which vehicles are included, and given that the discount calculated is relatively small, it makes sense to use 0 for economic calculation purposes. It is shown overall that the savings over multiple years is over 14,000 dollars which suggests a long term savings in using electric vehicles.
Uncertainties: There are a myriad of uncertainties that are included in these models. However, the biggest factor is oil price. With OPEC making a decision not to cut supply recently oil prices have been dropping dramatically. Oil has dropped from around $100/barrel to $68.51/barrel which leads to a more cost efficient model for the ICE vehicles. However, oil prices are highly volatile and this leads to unpredictability which cannot be captured in our cost-benefit model.

Another huge concern is quantifying the cost of carbon in the environment. Scientists have spent years trying to quantify the externalities and costs associated with greenhouse gas emissions and particularly CO$_2$. Moreover, it is difficult to quantify the cost of global warming because costs are realized over long periods of time and it is difficult to isolate the factors. Factors would include: health costs and environmental costs.

Another limiting factor of this model is energy sustainability. Electric vehicles are increasingly being generated using natural gas owing to the explosion of shale gas in the U.S. Natural gas is only expected to grow in availability and as a source of power generation. This will lead to the independence from foreign importers for natural gas.

Many of the factors listed above are not accounted for in the cost benefit analysis. The oil price, cost of carbon and energy sustainability are factors that are difficult to quantify. However, the cost of pollutants is estimated in the next section because we believed that it is a huge negative externality that could not be ignored.
QUANTIFYING THE UNQUANTIFIABLE

REVIEW OF LITERATURE - OIL IMPORTATION

Baseline Estimations:

Figure 6.1 below uses data from the 2001 National Household Travel Survey to estimate the percentage of U.S. light-vehicles unlikely to switch to electric cars with switchable, 100-mile batteries. We will use two scenarios, one with oil prices being high over $5/gallon, and the other being baseline or around $4/gallon. In the high price case, around 10% of US light vehicles will be exchanged in addition to the roughly 20% already in line to be exchanged in the baseline case. This equals around 30% of these vehicles being switched by 2030. It adapts the methodology used by McKinsey (2009) to estimate the addressable market size for alternative powertrain vehicles and was presented in a paper by Thomas Becker from the University of California, Berkeley (2009).
Market Size

<table>
<thead>
<tr>
<th>Oil Price Scenario</th>
<th>Types of Vehicles Excluded</th>
<th>Percentage of Excluded U.S. Light-Vehicles</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SUVs and trucks used by construction and agricultural workers</td>
<td>5%</td>
</tr>
<tr>
<td>High Prices</td>
<td>Vehicles with more than 20% of trips with five or more occupants</td>
<td>3%</td>
</tr>
<tr>
<td></td>
<td>SUVs owned by high-income households with two or more children</td>
<td>1%</td>
</tr>
<tr>
<td></td>
<td><strong>Total</strong></td>
<td>10%</td>
</tr>
<tr>
<td>Baseline</td>
<td>Single-vehicle households with at least one monthly trip of over 80 miles</td>
<td>5%</td>
</tr>
<tr>
<td></td>
<td>Vehicles in a multiple-vehicle household with at least one monthly trip of over 80 miles</td>
<td>16%</td>
</tr>
<tr>
<td></td>
<td><strong>Total (including those excluded in High Price Scenario)</strong></td>
<td><strong>30%</strong></td>
</tr>
</tbody>
</table>

Figure 6.1

The assumptions of both a high price and baseline scenario was integrated into the graph below to show the expected numbers of gasoline, electric, and hybrid cars from 2010 to 2030 by Becker.
The above figure shows the changing composition of the U.S. vehicle fleet from 2010 to 2030. As you can see, integrating all our assumptions the vehicle fleet changes from majority of gasoline cars to majority electric cars.

**Oil Importation Effect:**

One of the largest externalities that can be seen is the trade balance changes due to the US decrease in the economy’s consumption of petroleum. In 2008, the US spent nearly $600 billion dollars on oil, which was over 65% imported (McKinsey 2009). Furthermore, 70% of the petroleum and 40% of the oil is used for light-vehicle transport (McKinsey 2009). Each
of the electric vehicle deployment scenarios will lead to significantly lower consumption of oil as well as a lower trade deficit.

Oil Importation

![Graph showing oil importation and U.S. domestic production over time.]

Figure 6.3

Data: Energy Information Agency

The economic downturns from foreign oil supply interruptions will lead to suboptimal monetary policy to control oil-induced price inflation, and imposes a high
military cost to secure foreign oil supplies. This is where the deployment of electric vehicles comes in as they will significantly reduce the transportation sector’s reliance on petroleum based fuels which will thereby diminish the problems associated with oil dependency in the United States. An estimate shown below of the trade balance singles out petroleum imports as a trade good impacted directly by the deployment of electric vehicles. This assumption is indeed valid as our domestic electricity is generated largely from domestic sources. However, this also requires assumptions concerning the auto industry into the future. The table created by Becker below can be seen to have integrated these assumptions for both the High Price and Baseline price scenarios described. It compares the expected annual U.S. Oil Imports with the CAFE Standards for ICE vehicles as a comparison.

**Projected Oil Imports**

![Projected Oil Imports Graph](image)

*Figure 6.4 Source: Becker 2009*
QUANTIFYING POLLUTANTS

Given the negative health related externalities of emissions they must be taken into account. Such pollutants include but are not limited to sulfur dioxide, nitrous dioxide, particulate matter, and volatile organic compounds as well as heavy metals, oils, and grease which are all runoff pollutants. With this information, we have compiled information on the three scenarios mentioned for the macroeconomic analysis based on the health care costs associated with each type of pollutant from the U.S. Department of Transportation.

The health care cost savings are calculated by multiplying the number of vehicle miles traveled (VMT) by the fleet of electric vehicles in each year by the health cost of each pollutant used by the Department of Transportation (2014). The net present value calculation uses a 5% discount rate to discount the health care costs for each year through 2030 back to 2014. The non-carbon power generation scenario (renewables plus nuclear and hydroelectric) has 100% of the power for electric vehicles sourced from zero polluting sources. The current grid generation mix scenario uses the 2014 electric generation and pollution profile. This setup is analogous to the Becker 2009 paper.

There are two sets of situations shown based on estimates from the Department of Transportation. The first is using the current electric grid to produce electricity for the needs of the 2030 market for electric vehicles established in the Becker paper mentioned earlier. This is compared in both the high price and baseline scenarios. Furthermore, there is the other situation where there is non-carbon generation of electricity thus causing what was
originally a sulfur dioxide negative externality to be become a reduction in sulfur dioxide use.

Calculation:

\[
\frac{VMT \times HC_{pol}}{1.05^n}
\]

<table>
<thead>
<tr>
<th>(thousands of 2014 $)</th>
<th>Pollutant</th>
<th>Baseline Scenario</th>
<th>High Price Scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current Grid Generation Mix</td>
<td>Particulate Matter</td>
<td>$19,775</td>
<td>$32,456</td>
</tr>
<tr>
<td></td>
<td>Nitrous Oxide</td>
<td>$16,767</td>
<td>$27,626</td>
</tr>
<tr>
<td></td>
<td>Sulfur Dioxide</td>
<td>-$48,806</td>
<td>-$79,118</td>
</tr>
<tr>
<td></td>
<td>Volatile Organic Compounds</td>
<td>$18,146</td>
<td>$29,929</td>
</tr>
<tr>
<td>Total</td>
<td>$5,882</td>
<td>$10,894</td>
<td></td>
</tr>
<tr>
<td>Non-Carbon Power Generation</td>
<td>Particulate Matter</td>
<td>$61,067</td>
<td>$100,723</td>
</tr>
<tr>
<td></td>
<td>Nitrous Oxide</td>
<td>$24,892</td>
<td>$41,057</td>
</tr>
<tr>
<td></td>
<td>Sulfur Dioxide</td>
<td>$31,654</td>
<td>$53,886</td>
</tr>
<tr>
<td></td>
<td>Volatile Organic Compounds</td>
<td>$18192</td>
<td>$30,605</td>
</tr>
<tr>
<td>Total</td>
<td>$135,807</td>
<td>$225,673</td>
<td></td>
</tr>
</tbody>
</table>

**Figure 6.5**

As shown in the table, as electric vehicles become more prevalent and become a larger proportion of the U.S. population, the airborne pollution that stems from the operation of motor vehicles declines significantly and the savings are increased. However, we must also take into account the costs associated with the energy required to create this additional electricity. This information was readily available for the year 2014 which we used to prepare present value calculations given a 5% discount rate associated with forecasting the deployment of electric vehicles between 2014 and 2030. The top panel details the cost
savings using present value for the electric vehicles in each of the scenarios assuming a polluting source creating the electricity. Conversely, the bottom shows the additional electricity being produced from non-pollutive sources such as hydroelectric which creates a much broader gap in the value and externality projections in favor of electric vehicles.

To take it a step further, we quantified this cost saving in terms of the VSL measurement, which is the value of a statistical life. The Environmental Protection Agency recently valued a life at $9.1 million dollars, which is the estimate we will use. We will take each of the above scenarios and quantify the lives saved through each (EPA 2011).

<table>
<thead>
<tr>
<th></th>
<th>Baseline</th>
<th>High Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current Grid</td>
<td>.646 lives</td>
<td>1.12 lives</td>
</tr>
<tr>
<td>Non-Pollutant</td>
<td>14.9 lives</td>
<td>24.8 lives</td>
</tr>
</tbody>
</table>

**Figure 6.6**

As seen in the graph above, there is the potential to save multiple lives especially in the non-polluting electricity production case. Therefore, it makes sense to try to quantify it as we have in this case.
CONCLUSION:

As research into electric vehicles progresses, they will become more efficient and cheaper to develop. Until this point is economically feasible, the use of internal combustion engines and hybrids is important as our economy transitions to EV’s. These two types of vehicles are also further being developed along with technology for electric vehicles. The uncertain research and development schedule makes projections into the future somewhat difficult to make and also creates larger variance.

When focusing on the larger scale macro effects of electric vehicle deployment we see that it is provides the greatest benefit in high price scenarios when the trade balance will effectively be able to be offset by these electric vehicles. However, without domestic battery production which was an assumption in the model the deployment of said electric vehicles would offset a reduction of the trade deficit overall which was a simplifying assumption made in Becker’s study.

In quantifying the health benefits of using electric vehicles, we found that the benefits of the deployment of electric vehicles was nearly twenty times larger when using electric vehicles which use non-polluting sources of gathering electricity. This is largely due to the negative health effects from the sulfur dioxide produced from the existing coal power plants which produce electricity. This was also shown in the VSL measurements. Furthermore, this quantifiable difference in health outcomes could provide another possible benefit by allowing for the centralization of purchasing power by electric car drivers into a set of network operators which would ultimately allow for the sourcing for electricity from the wholesale market.
Overall, hybrid electric vehicles appear to be cost efficient both in terms of cost benefit analysis versus both low price vehicles and high price luxury sedans as well as versus the macro effects from pollution that we quantified. However, it appears that without drastic changes in oil prices or the assumptions in our analyses all electric vehicles do not appear to be a cost efficient method yet. The main issues will be as stated electric range problems and the overall creation of an electrical infrastructure to allow for these large scale changes that our assumptions are based off.
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