Topic:
The Incentives, Criteria, and Problems Associated with Investment in New Energy and Battery Technology.

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<tr>
<td>CNG</td>
<td>Compressed Natural Gas</td>
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<tr>
<td>BEV</td>
<td>Battery Electric Vehicle</td>
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<td>BRT</td>
<td>Bus Rapid Transit</td>
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<td>EV</td>
<td>Electric Vehicle</td>
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<td>FCV</td>
<td>Fuel-Cell Vehicle</td>
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<td>FISU</td>
<td>International University Sports Federation</td>
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<td>FTA</td>
<td>U.S. Federal Transit Administration</td>
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<td>GDP</td>
<td>Gross Domestic Product</td>
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<td>GHG</td>
<td>Greenhouse Gas</td>
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<tr>
<td>ICE</td>
<td>Internal Combustion Engine</td>
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<td>LEV</td>
<td>Low Emission Vehicle</td>
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<td>LIB</td>
<td>Lithium-Ion Battery</td>
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<tr>
<td>LPG</td>
<td>Liquefied Petroleum Gas</td>
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<tr>
<td>LRT</td>
<td>Light Rail Transit</td>
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<tr>
<td>NEV</td>
<td>New Engine Vehicle</td>
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<tr>
<td>PSC</td>
<td>Perovskite Solar Cell</td>
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<td>RFTA</td>
<td>Roaring Fork Transit Authority</td>
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Abstract

Our project was concerned with determining the criteria for incentives and barriers to investment for new energy technology, especially in regards to new battery technology, and with a particular focus on transportation and grid storage applications. We approached this inquiry from the scientific, governmental, and industrial perspectives. Doing so we considered the broader range of factors that contribute to progress in these mentioned areas. The research conducted to write this paper has shown that each perspective brings with it its own unique criteria for innovation and investment in these technologies. Overall it can be said that across the greater spectrum there are issues of high costs, low storage capacities, and governmental approaches that lack the ambition necessary to perpetuate a complete adoption of new energy and battery technologies in the short-term.

1 Introduction

Rapid advances in materials science research, in regards to both improvements to existing designs such as the lithium-ion battery and the application of novel base materials such as perovskite, have created new opportunities and challenges in the field of energy science, and bring into focus questions about potential improvements and scalability. Additionally, technological advancement in any field can be greatly influenced by certain government policies. Developed countries with higher GDPs typically impact new energy technology markets the most, using their national or local policies for economic progression, national security purposes such as energy independence, or for environmental protection. While the focus in renewable energy development has usually been on developed countries such as the United States and Germany due to their scientific and research capabilities, developing countries, especially China and India, have taken an active role in becoming leaders in this space. The initiatives that they set forth in the past couple of years have allowed for the rapid
expansion of renewable energy observed in Asia. While they are acutely aware of the necessity for renewable energies, their policies are designed to encourage domestic economic development in conjunction with environmental awareness. To assess the scientific and governmental impact on new energy and battery technology on investment, we investigated the transportation and energy grid storage industries. Economic and environmental concerns have led to a rise in diversity in the automobile sector especially when it comes to vehicle engines and fuels. Investment in public transportation is primarily focused on alternative fuel and new energy technology. Governments are looking to public transportation as a platform to lower greenhouse gas emissions and oil dependence. As public transportation moves toward hybrid and electric vehicles, improvement in battery technology will become all the more important. The dominant type of grid storage is lithium-ion battery technology, which not only replaces gas plants in meeting peak demand, but also smoothes renewable energy sources such as solar and wind. With Tesla producing lithium-ion batteries in its Gigafactory with net zero emissions and at the lowest costs possible, companies are trying to expand lithium-ion battery storage to all possible grid applications.

2 Basic Design of a Battery
A battery is a device consisting of multiple electrochemical cells that convert stored chemical energy into electrical energy, then to be finally converted into useful mechanical work (Linden 2002). Chemical energy is the potential stored in the bonds of chemical compounds that is released upon chemical reaction and the breaking of those bonds (Encyclopædia Britannica Online 2015). Electrical energy is produced by the movement of charges – specifically negatively charged electrons – through a circuit (Grant & Phillips 2008). This movement of electrons is created by the potential difference between the two given points, flowing from the point of high potential to the point of low potential. Finally, mechanical energy is expended to perform work, such the movement of a piston or the spinning of a wheel (Wilczek 2008).
A battery operates when placed into an external circuit, allowing the electrolyte components of the battery to operate as ions and proceed to chemically react at their separate terminals. The movement of charges in these chemical reactions creates the electrical energy that flows out of the battery as electrical energy, soon to be converted into useful work. Each electrochemical cell in a battery contains two terminals: the cathode (positive) and the anode (negative). The cathode must have a higher electrical potential relative to the cathode to allow for the movement of electrons that produces the current that can power external devices (Linden 2002). The battery is composed of multiple cells, usually identical, and each containing their own cathode and anode and separated by permeable layers. The total voltage of the battery is equal to the sum of the voltages of all of its constituent cells, as they are linked in series. The typical design of a battery cell consists of the following components:

· The anode

· The cathode

· Electrolytes, which serve as catalyst to increase battery conductivity by promoting the movement of ions (Borkowska, Syzdek, Zalewska & Wieczorek 2011)

· A polar medium, such as water to facilitate movement of ions

· A porous separator between the anode and the cathode to prevent a short-circuit (Linden 2002)

Each battery design must consider how it manipulates and applies these components to achieve ideal impact.

With current technology, no single type of battery cell has been applied to all applications. This is because those who have engineered batteries have had to balance the two primary operative considerations of a battery – energy density and power density – when designing a battery for a particular purpose (Hammock, Ryan & Ziech 2012). Batteries with high energy density can
store large amounts of energy and release it reliably over long period of time. Batteries with a high power density can release large amounts of energy quickly, which is often necessary for the ignition of an engine. In current battery designs, there is often a trade-off between these two considerations. A small device such as a mobile phone can be started with a relatively low burst of energy, so its battery is designed to prioritizing energy density so the device can be sustained, rather than power density. A typical car battery, on the other hand, has a high power density to effectively start a car but lacks the energy density to run one, and thus the car is run by gasoline or hybrid means.

The batteries of the modern era and the trends that have motivated their evolution – cost, renewability, impact upon the environment, among others – have seen a transition towards the rechargeable battery becoming increasingly ubiquitous in everyday appliances, from mobile phones to laptops to cars. For this reason, though there are many types of batteries, in this paper we will be focusing on rechargeable batteries such as automotive batteries. As the name would indicate, a rechargeable battery is one that can be returned to its initial state following its discharge, thus becoming reusable. When a voltage is applied to the battery that is greater than the battery’s voltage, a current will flow through to the battery in the reverse direction from when the battery supplies current, and the battery will charge. Within in this category, we nonetheless see a large diversity of battery designs, materials, and applications.

Take for example, the lead-acid battery. Though rechargeable and featured within in automobiles, the lead-acid battery serves a particular purpose: namely, to start a car; it is not responsible for supplying the fuel to keep a car in motion and was not designed to do so. Lead-acid batteries are composed of cells of lead (Pb) and lead dioxide (PbO₂) plates submerged into an electrolyte solution of 38% sulfuric acid and 62% water (Linden 2002). When the engine is ignited, a chemical reaction results in the release of electrons from the PbO₂ cathode, transmitting a current that can be used to power an external device. This is referred to as the
‘discharge’ of the battery. During the discharge, the acid in the electrolyte solution reacts with the Pb metal plates, forming lead sulfate (PbSO₄). Upon being recharged, the chemical reaction is reversed and the PbSO₄ reforms into PbO₂ and Pb while the sulfate is returned to the electrolyte solution. Thus the battery is returned to its initial phase and may be discharged once more.

**Figure 1: Charging of the Lead-Acid Battery** (A Guide to Lead Acid Batteries 2015)

However, the lead-acid battery found in an automobile has certain properties that make it ineffective as an engine, and thus only relegated to its role in ignition. One of these is found in the reaction described above, specifically the formation of PbSO₄. When the lead-acid battery discharges, more and more PbSO₄ accumulates on the metal plates, which can inhibit further
reaction as the surface area of the reaction is covered in PbSO₄. It is for this reason that the automotive lead-acid battery should not be discharged completely the way a mobile phone battery can be, lest the reverse reaction to charge the battery become difficult or impossible as there no longer a surface area for the reaction (Hammock, Ryan & Ziech 2012). Thus lead-acid batteries are not often discharged above 50% of its capacity.

A method of accounting for this is to build deep cycle batteries – lead-acid batteries designed to be discharged on a regular basis. The design of a deep cycle battery differs from that of a standard SLI battery in three ways (Linden 2002):

- Thicker electrodes to increase the energy density
- Larger spacing between the electrodes to prevent the buildup of solid residue
- Room beneath the battery for this residue debris to accumulate

There is, however, a trade-off for this more effectively dischargeable battery, as it is larger, heavier, and provides lower current than a typical car battery, all concerns when designing an automotive battery. It is for these reasons that the deep cycle battery has not emerged as serious option for powering automobiles, though it has been sparingly implemented to power some recreational vehicles.

Through this lead-acid battery example, we observe a number of the issues that must be considered if rechargeable batteries are to be a viable option for powering commercial automobiles and storing electrical energy in grid storage application. Additionally, we must consider other issues that are relevant to the viability of any new battery technology, such as the safety of the battery. The 1978 recall of the Ford Pinto due to problems involving its exploding fuel tank stands as a reminder when considering the impact that personal safety can have upon the design of an automotive component. Cracks and disintegrations within a battery can cause short-circuits and explosions if the applied materials are not accounted for from a containment
perspective. The lead-acid battery is the most toxic variety of widely used battery, containing the highly toxic metal lead and corrosive sulfuric acid solution (Household Waste 2000). This has been one of the motivations in transitioning away from lead-acid batteries and towards newer and cleaner alternatives such as lithium-ion batteries.

The impact of automobiles on the environment has become an increasingly visible issue in the past few decades, as we must consider both the impact that a car engine has upon the environment, as well as the disposability of its parts. Additionally, the costs and sources of conventional fuel sources such as petroleum has lead to the rise of hybrid electric vehicles, which consist of an engine powered in tandem by a conventional combustion engine along with an electrical component.

Hybrid-electric cars have come to make efficient use of the combination of conventional and electrical engines. The “idle-off” feature powers down the vehicle’s conventional engine when the car is stopped, allowing the electrical engine to take over. An improved fuel economy is observed, as current hybrids use both an internal combustion engine and an ultracapacitor driven electric drive system (Hybrids Under the Hood: Drivetrains 2010). The “power-assist” provided by the electrical component of the hybrid engine allows for the downsizing of the internal combustion engine, as the electrical component can compensate for the needed power. Regenerative brakes convert the vehicle’s kinetic energy into electrical energy to charge the battery, as opposed to letting this kinetic energy dissipate as heat as most conventional brakes do (Hybrids Under the Hood: Drivetrains 2010). All of these successes make use of the improved rechargeable batteries, such as nickel-metal cadmium and lithium-ion batteries, and further innovation in the field of hybrid-electric vehicles rests heavily on the improvement of its electrical component.

2.1 State of the Rechargeable Battery
We look now to new batteries that may potentially provide the means of powering a car or other
similarly power-intensive applications. As mentioned before, one of the key elements for the innovation of battery technology is the ability to increase the energy density of the reactions. A conversation with Dr. Khalil Amine, a lead scientist at Argonne National Laboratory whose research group pioneered the technology found in the hybrid-electric Chevrolet Volt, identified the discovery and refinement of higher energy density chemistry within the battery as the necessary step for the creation of more widely applicable rechargeable batteries. As of 2014, the lithium-ion battery in the Chevrolet Volt only has a battery capacity of 16.5 kWh, translating into only 38 miles of travel on average through its electrical means between charges (2013 Chevy Volt Gets 38 Mile Electric Range, Higher 98 MPGe rating 2012). Much research has been directed towards improving the energy density rechargeable batteries.

The most commonly used rechargeable battery in the world as of 2015 is the lithium-ion battery (LIB) (Leiva 2013). Found in a wide range of applications, from mobile devices to the Tesla Model S, the LIB has seen a significant role in the transition from conventional batteries such as lead-acid to rechargeable batteries. Variance in new LIB technology and design stems largely from the new materials that have been incorporated into the device. Considerable research has been conducted into illuminating the most efficient materials for anodes, cathodes, and additives to improve the capabilities of LIBs. The increasing demand for batteries in various applications has led research to focus on improving energy density, durability, output power, and cost of lithium ion battery solution. A number of materials have been researched as potential components of LIBs – such as nickel-cobalt-aluminum, nickel-manganese-cobalt, manganese spinel, titanate, and phosphate – each affording different levels of cost, performance, lifespan, power, and safety (Boston Consulting Group 2010).
2.2 Mechanism of Lithium-ion Battery Reaction

Rechargeable lithium batteries operate distinctly from non-rechargeable through their use of intercalated lithium compounds rather than pure metallic lithium. Intercalated compounds can be reversibly included or inserted into other compounds with layered structure. This reversible condition of the battery coincides with its rechargability, as the entry of Li ions into the partner substance induces the charging of the battery.

The electrochemistry of the reaction proceeds as follows: positive Li ions travel between electrodes, moving from the positive lithium-transition metal electrode to the negative (often graphite) electrode during charging. The reverse occurs when the battery is discharged. When the external power source applies an over-voltage, electrons flow through a closed external circuit to produce useful work while this is occurring and power the external appliance (Lithium Ion Technical Handbook 2003). Over the course of this process, the partner transition metal is oxidized during charge, and then subsequently reduced during discharge. However, some
transition metals, such as cobalt can only be oxidized to certain degree before the reaction becomes irreversible, limiting the depth of discharge available and thus significantly hampering the storage capacity of the battery (Lithium Ion Technical Handbook 2003).

As of 2011, the graphite electrode discovered by Rachid Yazami is the most commonly used electrode in commercial lithium ion batteries (Yazami & Touzain 1983). In the past two decades, lithium-ion batteries (LIBs) have come to dominate the portable electronics market, appearing in devices such as cell phones, music players, and tablets. However, when considered as a potential power source for KWh level load applications such as powering automobiles and storing the energy captured from renewable sources such as photovoltaic cells and wind turbines, current LIB technology is greatly limited by storage capacity issues. These issues stem largely from the electrode materials incorporated into these batteries, which create noticeable limitations. The standard LIB found in mobile devices makes use of the graphite anode, exploiting the naturally large conductivity of the carbon material. However, graphite has a relatively low theoretical capacity (372mAh/g), affording the battery a smaller energy density and an inability to store large amounts of electrical energy (Ma, Cao, & Hu 2014).

The intercalation reaction that allows for the rechargeability of the LIB produces its own unique set of issues, such as the expansion of the solid electrolyte phase and the volatile increases in volume during this intercalation. For this reason, one of the prevailing views is that progress in the LIB field will be achieved by moving away from the classical intercalation reaction and towards more novel interactions between the lithium ion and the electrode. One such direction is the alloying reaction. In traditional chemistry and metallurgy, an alloy is created when two or more metals are combined into a mixed substance whose characteristics are determined by the nature of the new inter-metallic bands that have been formed. Similarly, the alloying reaction proposed for LIBs involves the reversible alloying of lithium with a partner substance such as lithium or germanium, followed by the subsequent dissociation during discharge (Kim, Son,
Recent research has explored the various ways in which lithium can alloy with other metals and metalloids, such as tin, phosphorus, germanium, lead, and antimony. Tin in particular can alloy with lithium to yield a wide of alloys such as $\text{Li}_2\text{Sn}_5$, $\text{LiSn}$, $\text{Li}_7\text{Sn}_3$, $\text{Li}_5\text{Sn}_2$, $\text{Li}_{13}\text{Sn}_5$, and $\text{Li}_{22}\text{Sn}_5$ (Park, Kim, Kim & Sohn 2010). With such a wide range of possible combination, we choose to focus on silicon, as it has provoked the most substantive discussion on the issues of intercalation as well as the potential for the incorporation of nanotechnology into the battery design.

![Figure 3: Charge and Discharge Mechanism of the LIB](ICs Simplify Backup Power in Energy Harvesting Products 2015)

### 2.3 The Silicon Anode

Silicon (Si) has recently appeared as one of the more attractive options for anode materials for LIBs due to its physical characteristics (gravimetric capacity 4200 mAh/g; volumetric capacity 2400 mAh/cm$^3$) as well its relative abundance, cheapness, and environmentally benign properties (Ma, Cao, & Hu 2014). Yet the substantive issue with Silicon remains its rapidly fading capacity (stemming from its less conductive metalloid nature), which significantly
impedes its application in anode materials. A less conductive material will produce a weaker current as provide a less substantial source of power.

The mechanism of electrochemical lithiation of Si is a critical to the improvement of anode performance in LIBs. Lithiation coincides with the charge phase, while delithithion coincides with the discharge of the battery. The intercalation reaction of Li ions into Si powder produces an equilibrium Li-Si binary region between the first charge and discharge phases. In the binary region, the initially crystalline Si becomes an amorphous Li$_x$Si during the first lithiation (Dunn, Kamath & Tarascon 2011). This amorphous phase will proceed to recrystallize into Li$_{15}$Si$_4$ during this first lithiation phase. The binary region reappears through the first delithiation (discharge) phase, ultimately reproducing amorphous Si, though some residual crystalline Li$_{15}$Si$_4$ will remain (Park, Kim, Kim & Sohn 2010). In subsequent cycles of lithiation and delithiation, the binary phase disappears as residual crystalline Li$_{15}$Si$_4$ accumulates and the reversible capacity of the system fades rather quickly. Thus, the poor cycling performance of current silicon electrons is observed.

Exploration of this failure mechanism in further detail points to two main causes for the rapid loss in capacity in Si anodes:

1. Si anodes have relatively volatile volumes during the cycle of reactions, changing by about 400% (Chan, Peng, Liu, MacIlwrath, Zhang, Huggins, Cui 2008). This large change in volume increases the internal resistance and the loss of contact area between the Si and the conductive materials, resulting in the poor transport of electrons.

2. The solid electrolyte interphase (SEI) formed during the battery discharge due to electrolyte decomposition on the surface of anode at the low potential. During delithiation, the SEI layer that has formed upon on surface the Si breaks down into fragmented pieces as the silicon shrinks, re-exposing the Si surface to electrolyte and creating a new SEI layer (Wu, Chan, Choi, Ryu, Yao, McDowell, Lee, Jackson, Yang,
Hu & Cui 2012). The SEI is an electronic insulator, so as the SEI accumulates on the surface of the Si, eventually the electrostatic interaction on at the surface of the Si is terminated. Thus, the substantive increase of the SEI over charge-discharge cycles impedes the necessary electrochemical reactions for the battery to transmit energy to an external device.

It becomes evident, then, that for the Si anode LIB to become a viable option for the automotive and grid industries, new research and technological advancements must address these two issues. One potential solution to the issues articulated above may be through the application of nanomaterials science to the design of the Si anode. A number of recent research initiatives have demonstrated that reducing the size of anode material to nanoscale allows for the material to withstand significant lithiation and delithiation strains with the problematic fractures that plague Si in its powder and produce the increases in internal resistance and the losses in contact area (Wu, Chan, Choi, Ryu, Yao, McDowell, Lee, Jackson, Yang, Hu & Cui 2012; Liu, Wu, McDowell, Yao, Wang & Cui 2012). This is due to the reduced dimensions of nanomaterials, which allow for far higher intercalation and deintercalation rates, as well as the reduced impact of the charge-discharge volume change when the Si particles are downsized to nanoscale. Li et al. describe the substantive impact that nano-Si anodes have on capacity retention as compared to Si powder (Li, Huang, Chen, Wu & Liang 1999), while Kim et al. demonstrated that differently sized Si nanoparticles afford distinct battery performances, allowing for further research into the idealized parameters of more novel nanoparticles (Kim, Seo, Park & Cho 2010).

There are a number of ways nanoparticles for Si anodes can be produced, and each method produces distinct forms of these nanoparticles each with their unique upsides and downsides. One-dimensional nanowire and nanotubes are one such variant that provide a superior cyclic stability derived from the limited diameter and the large volume change it can accommodate
(Chan, Peng, Liu, MacIlwrath, Zhang, Huggins, Cui 2008). Two-dimensional Si thin film also demonstrates improved cycle stability and rate capabilities, minimizing variations in volume during the charge-discharge cycle (Ohara, Suzuki, Sekine & Takamura 2004). These thin films become display improved performance as they become thinner, which is problematic as thinner sheets run significantly higher synthesis costs. Most recently, three-dimensional macroporous structure materials have emerged as a prospective route to more efficient Si anode LIBs. The walls of these structures are on the order of nanometers to tens of nanometers, shortening ionic pathways. These macropores also allow for the less hindered infiltration of electrolyte and liquid-phase Li ion diffusion, reducing the concentration polarization and increasing the rate and capacity of the battery cell. Finally, macroporosity may accommodate volume change during the charge-discharge cycle without disrupting the structural integrity of the electrode (Esmanski & Ozin 2009). Novel methods of producing these three-dimensional macroporous material structures are currently being pioneered, such as the simplistic synthesis proposed by Bang et al. (Bang, lee, Kim, Cho & Park 2012).

Despite the improved capacity retention of nano-Si anodes as compared with bulk Si, there remains issue of electrical conductivity. As a semiconductor, Si has an intrinsically low electrical conductivity, resulting in a slower transportation of electrons through the battery circuit. New research has delved into the concept of incorporating conductive materials into the nano-Si anode. Lui et. al and other groups have demonstrated that increasing the conducting additive content can improve performance of the electrodes, experimenting primarily with the additive impact of Mg$_2$Si, CaSi$_2$, NiSi, FeSi, CoSi$_2$, and FeSi$_2$ (Lui, Guo, Young, Shieh, Wu, Yang & Wu 2005; Wang, Sun, Bradhurst, Zhong, Dou & Liu 2000). These central metal components act as a buffering and conductive matrix for the formation of amorphous Li$_x$Si throughout cycling. Si-C composites, especially graphene, have also been researched, and have gone on to show high reversible capacities and cycling stabilities due largely to the softness of C and the relatively small volume change during Li insertion, all in addition to the superior

There also remains the issue of SEI accumulation in Si anodes, which new research into the creation of hollow and yolk-shell structures of Si composites has aimed to solve. These novel shell structures are coated with conductive materials, and provide distinct advantages for nano-Si anodes functioning as an electron highway so that all particles are electrochemically active, as well as retaining an internal void space for reversible silicon expansion (Liu, Lu, Zhao, McDowell, Lee, Zhao & Cui 2014). Additionally, Chen et al. have written on a simple approach to fabricate the mono-disperse (single-sized) hollow porous Si variety of nanoparticles via magnesiothermic reduction and Ag coating of nano-Si particles (Chen, Mei, Ji, Lu, Xie, Lu & Lee 2012). These mono-dispersed particles went on to demonstrate a high reversible capacity of 3762 mAh/g, a capacity retention of 93% after 99 cycles, and a high rate performance of over 2000 mAh/g at a current density of 4000 mA/g.

Another source of innovation in nano-Si battery technology, as well as battery technology as a whole, may come from improvement of binder technology. The electrodes in LIBs may be bound together by conductive material, known as binder, which can greatly improve their storage capacity and conductive capabilities. Researchers at Lawrence Berkeley National Laboratory have recently engineered new polymer binder known as PVP for Si anodes in rechargeable LIBs, which demonstrated an increased storage capacity of over 30% (Bourzac 2011). When used in tandem with a lithium sulfide cathode and nano-Si cathode, the PVP bound LIB was found to have a 94% retention of its original storage capacity following 100 charge-discharge cycles (Seh, Zhang, Li, Zheng, Yao & Cui 2013).

In summary, Silicon anodes provide clear innovative opportunities for LIBs, both in terms of their performance and the economics of production. A number of issues continue to hinder the applicability of Si-based materials, even at the nanoscale, such as a low conductivity and lower energy density stemming from the nanoscale nature of the particle. Current researches have
found promising routes to solving these issues, with work focusing on:

1. Synthesis of nano-sized structures to improve the density of electrode materials, as well as the fabrication of thicker electrodes to increase the energy density of the battery reactions.

2. The application of surface coating to avoid side reactions, accumulation of SEI, and to promote a more conductive electrochemical environment.

3. Utilization of cheaper and more advanced production methods, such as 3D printing, to optimize the structures of the electrodes (Lopes, MacDonald & Wicker 2012)

2.4 Perovskite - A Study in Scalability

Perovskite is a mineral composed of calcium titanate – chemical formula CaTiO₃ – with a cubic crystalline structure that has come to define a class of compounds with the structure \( A^{2+}B^{4+}X_2^− \). (Wenk & Bulakh 2004). While diversified, these compounds share noteworthy characteristics that make them of interest to battery engineers, such as potential superconductivity. (Kulkarni, Ciacchi, Giddey & Munnings 2012). One of these perovskites in particular – methylammonium lead triiodide (CH₃NH₃PbI₃) – has a high charge carrier mobility and lifetime, allowing light-generated electrons to move develop into a current rather than have their energy dissipate as heat within the cell (Hodes 2013). These characteristics have made it an attractive research material for photovoltaic solar cells, which in recent years have become an attractive option for charging the LIBs in electric vehicles, as it remains to be seen how long it will take for governments to construct cross-country networks of charging stations (Xu, Chen & Dai). Xu et al. combined perovskite solar cells (PSCs) with LIBs and demonstrated that PSCs-LIB units possess a much high power-conversion efficiency (15.67%) and storage efficiency (7.80%) than silicon-based solar cells (Xu, Chen & Dai). Beyond the efficiency statistics, perovskites have piqued research interests due the benefits they provide in the greater context of the research-to-market assembly line.
This observation keys us into what may be the most significant ramification of perovskite innovation. That is, the scalability factor of substances with research potential. Seth Darling, a researcher at Argonne National Laboratory researching perovskite’s solar energy capabilities, explained to our group the importance of considering scalability when determining the criteria for incentivizing research in the field of energy innovation. Though the energy and power densities are the most important metrics for determining the intrinsic efficiency of a battery, the wider context demands we examine size, weight, potential for improvement, cost of materials,
and as the example of perovskite goes on to demonstrate, ease of production. Though current perovskite cells have a lower efficiency than silicon-based cells (25%) (Green 2009), perovskites have an exceptionally low production cost as compared with silicon-based cells, making perovskite an increasingly attractive commercial option for use in energy technology (Wang 2014). Traditional silicon cells require an expensive, multi-step process conducted at temperatures above 1000°C in a high vacuum, whereas perovskite-based materials are often produced in traditional wet lab settings via easily scalable solvent or vapor deposition techniques using relatively abundant source materials (Is Perovskite the Future of Solar Cells 2013).

Additionally, solar cell efficiencies of devices incorporating perovskite have increased from 3.8% in 2009 to 20.1% in 2015 (Collavini, Volker & Deglado 2015), suggesting perovskite to be one of the fastest advancing solar technologies to date. Beyond even silicon in solar cell efficiencies are multi-junction cells which while they are suggested to have a limiting efficiency of 86.8% under highly concentrated sunlight are significantly more expensive (Green 2003). The materials also have the advantage of being transparent, lightweight, and flexible, the most substantial issue being that they degrade quickly in moist environments (Sivaram, Stranks & Snaith 2015). As the substance develops further towards commercial usage, we have seen emerging solution to this issue, such as the encapsulation process suggested by Ramos et al. (Ramos, Cortes, Aguirre, Castano & Ahmad 2014). As the conversation with Dr. Darling illuminated, the scientific community expects perovskite to be applied to niche and lower energy applications within the next decade, with larger scale applications along rooftops and in newer electric automobiles along the way.

From exploring the perovskite situation, we can gather many of the variables necessary for determining the criteria for incentivizing research in new energy technology in general: namely, material cost, scalability, and potential for innovation. While the content of research into energy
science may be promising with many newly available materials and high energy density chemistries, we must understand the greater context through which the research operates, as well as how the science can potentially evolve based its commercial impact and the governmental research initiatives that may incentivize it.

3 The role of Developed Countries’ Energy Policy in new battery technology

All of the progress and new technological advances within the new energy technology field operates within the realm of government. Policies and legislature provide a foundation for innovators to create and develop. The technologies that are most extensively researched are usually projects either financed directly by the government or incentivized by the government through subsidies, tax exemptions, or strict laws to mandate usage of new energy sources. While each country has different philosophies and motives, developed countries have relatively larger potentials for ensuring renewable energy and new energy technology research becomes a priority within their domains. The incentive programs enacted by each country to encourage energy innovation weights certain criteria higher than others depending on the individual country. Economic progression, security concerns (energy independence), and environmental protection make up the key motivations for developed countries’ energy initiatives, and these can be seen in the enacted policies. Developed countries by definition have more advanced economies and, in many cases, more active governments. Especially in the 21st century, developed countries’ governments have been leading the movement to develop cleaner and more efficient ways to harvest and use energy.

To be as unambiguous as possible, this paper will define developed countries based on the International Monetary Fund’s (IMF) classifications. The three main criteria that are used to classify the world into advanced economies (developed countries), emerging markets, and developing economies are the per capita income level, export diversification, and integration into the global financial system (Frequently asked questions, n.d.). Using IMF’s thresholds for
these determiners, 36 countries are considered to have advanced economies (World economic outlook, 2014). These include the United States, many European countries, and others such as Japan, Canada, and Israel. As case studies for examples of developed countries’ governmental impact on emerging energy technologies, we will look specifically at the United States and several European countries. These three countries represent a good sample of developed countries that can provide useful examples of how policy influences the business aspect of energy technologies.

3.1 Origin of U.S. Energy Policy

The United States more formally began to prioritize developing their domestic power sector during the 1970s. There were a variety of factors that catalyzed this new political focus. One reason for the change was security. Oil crises of the 1970s were alarming to politicians. They realized that dependence on foreign energy made the country vulnerable to crises and conflicts with their suppliers, such as the Persian Gulf War in the early 1990s (Norberg-Bohm 2000). There were also environmental concerns that began to cause worry around this time as well. Urban smog and acid rain created concerns about climate change and how different energy policies might be able to minimize damage to the environment (ibid.). Also at this time, what is sometimes referred to as the era of diminishing electricity prices was coming to an end. Before the 1970s electricity costs continued to decrease, making it easier to maintain the increase of scale of energy production. However, security and environmental concerns both contributed to this stabilizing of the cost of electricity in the United States (ibid.).

In 1977, the U.S. Department of Energy (DOE) was formed in an effort to consolidate all of the energy research and development as the budget continued to increase (Norberg-Bohm 2000). The formation of the DOE serves a more formal marker for the United States government’s interaction and influence with the energy industry. While there was political consciousness regarding energy policy before this department was formed, the DOE represents a commitment
to increase energy security and protect the environment at the most efficient price for the
government, the industry, and the American people. Throughout the 1970s and onwards the U.S.
government passed a series of bills into law such as the Public Utilities Regulatory Act of 1978,
the Natural Gas Policy Act and the Power Plant and Industrial Fuel Use Act of 1978, the Clean
Air Act of 1971 (along with its 1991 amendments), and the Energy Policy Act of 1992 to name
a few (Norberg-Bohm 2000). While all of these acts were applied to different industries of
energy production, they all shared the common objective to secure the U.S. energy industry. To
do this, the government has to enact policies that incentivize private energy suppliers to produce
energy in a cleaner way. The two main methods of doing this has become to either pass a law
making certain processes illegal, or to supply tax breaks or subsidies to reward energy
manufacturers that are making an effort to protect the environment. Ever since these types of
restrictions and functions have been enacted starting in the late ‘70s, it has not only controlled
certain dangerous processes within energy production, but it has created large potential for new
clean emerging technology in the energy industry.

3.2 Government Incentives for Hybrid Vehicle Technologies

One of these emerging technologies that found traction due to U.S. legislative actions is the
hybrid-electric vehicle (HEV). These HEVs combine a gasoline engine with an electric motor,
which is powered by a storage battery charged via regenerative braking (Diamond 2009). They
provide a more efficient way to travel by recapturing certain energy that would otherwise be
lost in a normal vehicle. Now while HEVs are great for the environment and for the consumer’s
fuel expenditure in the long run, they face certain barriers to adoption that have been present
since their creation. Obstacles in the HEV market include lack of knowledge by potential
adopters, low consumer risk tolerance, and high initial production costs (ibid.). HEVs are more
expensive than equivalent gasoline only vehicles, but it has been shown that the savings on fuel
cost due to the efficiency of the HEV engine over time will actually return a net saving in the
long run. Still, the initial cost difference is a deterrent to consumer demand. The United States Congress as well as several state governments have attempted to offset these barriers through the creation of other consumer incentives. The U.S. Federal Government began implementing these new incentives with a provision that provided a $2000 tax deduction for all qualifying hybrids until 2005. Policy then transitioned to a different procedure in 2006, when the Energy Policy Act of 2005 replaced the old tax deduction with a tax-based credit based on an individual model’s emission profile and fuel efficiency compared to equivalent gasoline vehicles (ibid.). This type of incentive improves upon its predecessor by differentiating more efficient models from older hybrids. This incentivizes innovation by encouraging car companies to not simply output hybrid cars, but to strive to output the best possible hybrid car. These tax credits would range from several hundred to several thousand dollars, phasing out gradually after the manufacturer sells a total of 60,000 hybrid and other low emission vehicles (ibid.). On top of the federal government administered these types of tax credits, many other states offered additional incentives for HEVs as well.

States would vary on the quality and quantity of their incentives, as some states made it a point of emphasis to be environmentally conscious more than others. Colorado was the state with the highest effective incentive structure as of 2008. Tax credits range from $2500 to $6500 depending on the model. Several states including California, Florida, Virginia, New Jersey, New York, and Utah all allow hybrid drivers to ride in the high occupancy vehicle (HOV) lanes on certain highways within their state (Diamond 2009). Washington state has tax exemptions for not only hybrids, but for electric vehicles as well. The sale, labor, or services related to batteries for electric vehicles may not be taxed under any circumstances (Exemptions n.d.). All of these incentives seem like great steps in the right direction, but many question their actual utility.

David Diamond published a paper in the March 2009 issue of the journal Energy Policy asking the question, “what is the true impact of government incentives policies designed to promote the
adoption of hybrid-electric vehicles?” Diamond utilized a large array of literature dating back to 2001 in an effort to compile reliable findings regarding the efficiency of government involvement in the hybrid market. These studies provided a foundation on which his paper could grow, with many interesting and relevant data-backed answers to large, extensive questions. For example, a 2003 examination of the first generation Honda Civic Hybrid and Toyota Prius was among the first to distinctively conclude that lifestyle costs for hybrid vehicles would exceed costs for equivalent non-hybrid vehicles at past and current gas prices (Canes 2003). Canes found that the most important consumer incentive was the enticing lower total ownership cost for hybrids compared to equivalent gasoline models based on vehicle price, fuel cost and maintenance expenses, present even if pollution costs and fuel prices well above recent records are included in the analysis (Diamond 2009). This evaluation of two of the first mass-produced hybrid cars was very influential in improving the public image of the hybrid vehicle. A later total ownership cost analysis of hybrid models in 2006 went a step deeper, including standard $3-4 gas prices and newly initiated federal tax credits into its evaluation. The conclusion was that the five-year total ownership costs for all hybrid models were more expensive than non-hybrid counterparts except for the Toyota Prius and Honda Civic Hybrid, which had slight lifetime cost savings of $406 and $317 respectively (The Dollars and Sense of Hybrids 2006).

Much of David Diamond’s 2009 paper was actually partially based on case studies that he conducted the previous year on individual states, specifically Virginia, in which he intensely studied the impact of local government incentives created for hybrid vehicles. By examining hybrid market share for each individual county in Virginia, Diamond concluded that high occupancy vehicle lane incentives, income, and environmentalism were all significant predictors of market share, but the HOV lane effect was highly variable depending on local conditions (Diamond 2009). Virginia as well as other states’ incentives, average income, and social preferences are all significant factors in the explanation of a state’s market share.
Diamond also noted that sales tax waivers on hybrid vehicles tended to be more significant than income tax credits, and that certain states such as Virginia’s HOV incentive appeared to have significantly impacted its corresponding market share (ibid.). So while consumer demand for the hybrid vehicle can be generally complicated, it’s helpful for future studies such as Diamond’s to have reports that break down the data and relay the most significant factors of the demand’s origins.

Not only consumer studies aided the research that would go into Diamond’s paper however. When Americans purchase and drive hybrid cars, they of course use less gasoline. This impacts the U.S. government positively in two ways. First, cleaner emissions help promote a healthier environment, which has been a focus for federal governments around the world over the last several years. Second, the smaller the domestic demand for gas is, the less dependence the U.S. has on foreign oil. Diamond referenced certain literature that measured these aforementioned consequences to the growth of the hybrid vehicle market. Turrentine et al. in 2006 found that the reduction in GHG (Green House Gas) emissions and oil consumption due to hybrids is largely a function of hybrid market share and also the efficiency of the hybrid fleet compared to the larger non-hybrid fleet. However, the study also estimated that at 1.2% of the national automobile market, hybrids could reduce US oil consumption and GHG emissions by 0.4% compared to baseline scenario with conventional gasoline vehicles (Diamond 2009).

Compiling these various supplementary resources from the past decade enabled Diamond to establish confident conclusions on the current hybrid market in the United States (as of 2009). As stated before, the goal of the federal and state governments incentivizing the hybrid vehicle industry is to increase domestic economic security and to protect the environment from destructive emissions of non-hybrid vehicles. To achieve this, the U.S. government can measure success by how efficient their initiatives, via tax relief or utility fixtures such as HOV lanes, are at encouraging the American consumer to purchase hybrid vehicles. Of course, several factors such as monetary incentives, gas prices, and vehicle miles traveled all have a direct impact on
total ownership of a hybrid. However, Diamond’s tests and regressions suggest that consumers react to each of these factors to varying degrees (Diamond 2009). While a detailed benefit-cost or lifecycle cost analysis might not suggest a big difference in total expenditure between some hybrid vehicles compared to other non-hybrid vehicles, it’s not unusual to find that many American consumers buy hybrids simply based on general notions of perceived savings or vehicle image. Consumers who tend to act this way tend to typically come from households with higher incomes. This is reflected in Diamond’s studies. There seems to be a positive relationship between income and hybrid adoption, at least for the Ford Escape and the Toyota Prius. From an equity standpoint, this relationship also suggests that financial incentives from the government may disproportionately benefit higher income consumers who are more likely to purchase hybrids in the first place. American consumers with lower incomes are less able to afford the more expensive up-front cost for a hybrid and therefore more likely to discount future fuel cost savings from a hybrid purchase. If this is the case, and the monetary incentives of owning a hybrid are considered weak or negligible by the entire group of consumers whose income is below a certain level, then this could result in incentive payments effectively creating a subsidy for the highest income consumers without significantly affecting their purchase decisions. Or as Diamond puts it, “current monetary incentives for hybrids may be regarding those who need the incentive the least for a purchase they were likely to have made anyway” (Diamond 2009). Some may ask how can these incentives be improved to avoid this dilemma while still encouraging Americans to own hybrid vehicles. We touch on possible solutions to this problem and others concerning the U.S. government’s hybrid vehicle incentive program in the discussion section of this paper.

More recently, the U.S. Department of Energy has released initiatives as well to improve the cost and functional efficiency of hybrid and electric cars. A significant amount of government time and money has gone into researching new methods of improvement. The U.S. DOE has requested $359,000 in their 2015 budget release just for “Vehicle Technologies” alone,
highlighting some of their “aggressive vehicle technology goals” that include battery energy storage, improvements in lightweight materials performance, more efficient combustion engine technologies, and alternative fuel vehicle community partner projects (Department of Energy Congressional Budget Request 2015). Through federal funding, these projects are able to work to improve the batteries needed to power hybrid electric (HEV) and plug-in electric (PEV) cars. The department’s website points to battery technology as a key to improving vehicles' economic, social, and environmental sustainability. Transitioning to a light-duty fleet of HEVs and PEVs could reduce U.S. foreign oil dependence by 30-60% and greenhouse gas emissions by 30-45%, depending on the exact mix of technologies (Vehicle technologies office, n.d.). As was stated before and reiterated on the Department of Energy’s website, the government’s main incentives for creating more efficient hybrid and electric cars are to improve national security by reducing dependency on foreign fuel sources and protecting the environment by cutting down on harmful emissions from combustion-engine vehicles. The U.S. government has invested a lot of resources into the hybrid and electric vehicle field of emerging technologies, but there are also many other applications of battery and energy storage innovations that we should be focusing on as well.

3.3 Energy Infrastructure

Another sizable aspect of the Department of Energy’s initiative to modernize the United States energy infrastructure is the electric grid storage system. A more advanced system of storing energy will help the nation meet the challenge of handling projected energy needs while maintaining a robust and resilient electricity delivery system. Predictions of future U.S. energy consumption ranging upwards of 5 tera kilowatt-hours annually by 2050 stresses the need for the planning and implementing of grid expansion to meet this growing need (Grid Energy Storage 2013). Economic and commercial viability, resiliency, cyber-security, and impacts to carbon emissions and environmental sustainability are all national areas of interest that will be
challenged and stretched by the growth of energy consumption in the United States. In the past few years, this problem is becoming more and more apparent, and the urgency of energy storage requirements has become a greater, more pressing issue that is expected to continue growing over the next decade at least (ibid.). In the United States, electricity and energy distribution is a private industry, so the government does not control that process. However, the energy providers all over the country are heavily regulated by the U.S. government, mainly due to the possibility of monopolizing the industry and also because grid storage can be considered a form of public work infrastructure. Many new regulations and actions have been taken by the federal and state governments recently in an effort to combat the increasing need for energy problem and also find new ways to expand the grid storage system.

One of the biggest markets for the grid storage expansion is California, and regulators have taken notice. In October 2010, the state government enacted a law requiring the California Public Utilities Commission (CPUC) to establish appropriate 2015 and 2020 energy storage procurement targets for California load serving entities, if cost effective and commercially viable by October 2013. By February 2013, the CPUC determined that the Southern California Edison must procure 50 MW of energy storage capacity by 2021 in the Los Angeles area along with other proposed storage procurement targets and mechanisms totaling 1,325 MW of storage (ibid.). Since these laws were enacted in 2010 however, project developers have planned to create storage above and beyond these regulators’ targets. As of mid-2014, more than 2,000 megawatts of energy storage projects have applied to interconnect with the state’s grid. In other words, project developers have received the market signal of a 1.3-gigawatt mandate and proposed enough storage to provide nearly double that amount over the coming years (St. John 2014). This is a great sign for energy grid storage in the view of the federal and state government. Entrepreneurs and business developers know that there exists such a large demand for energy storage, so the financial incentive for expanding the capabilities of modern grid technology is more than enough motivation for the rate of growth of technology to meet the rate
of growth of energy needs. The breakdown of these 2014 proposals include 1,669 megawatts of standalone battery storage, 44 megawatts of other standalone storage, 255 megawatts of batteries combined with generation projects, and a 90-megawatt project combining solar and batteries (ibid.). Even with these optimistic proposals, the California state government has set a great example for other states to follow simply by creating grid energy thresholds and deadlines in place. In fact, U.S. Congress has introduced two federal bills that establish incentives for storage deployment (Grid Energy Storage 2013).

Even though grid storage issues have only recently become prevalent, California has shown that through enacting certain policies and incentives for private developers to follow, extremely impressive results are possible. In this case, the government’s motive to for these actions is clear. Energy storage can be considered a part of the national infrastructure controlled by private entities, so part of the federal and state governments’ responsibilities is to make sure that all of their citizens have access to available energy. So far, the incentive programs that have been created have shown to be extremely successful, and hopefully innovation in this field will continue to keep pace with the growth of the United States’ energy needs.

3.4 Clean Cities Program

Another topic that will be mentioned in more detail later on in this paper is the impact of battery technology within public transit systems. While this might not seem to be an obvious method for the Department of Energy’s motives to reduce dependency on foreign oil and reduce dangerous emissions, public transit is a major government fixture in the larger cities in the United States. Even though public transportation varies logistically depending on the city or state, there have been federal guidelines on these services ever since the Alternative Motor Fuels Act of 1988 and the Clean Air Act Amendments of 1990. The Energy Policy Act of 1992 (EPAct) required certain vehicle fleets to acquire alternative fuel vehicles and subsequently in 1993, the Department of Energy created the Clean Cities program. The purpose of this initiative
was to provide informational, technical, and financial resources to EPAct-regulated fleets and voluntary adopters of alternative fuels and vehicles (About Clean Cities). This program has evolved over the last few decades to include public transportation in their initiative. Currently, the Clean Cities program consists of nearly 100 local coalitions working to cut petroleum use in communities across the country. They are comprised of businesses, fuel providers, vehicle fleets, state and local government agencies (which control public transportation and the type of vehicles are used for this purpose), and community organizations. Nationally, these groups look to build partnerships with local coalitions of public and private sector transportation stakeholders (ibid.). By incentivizing local governments to implement cleaner public transportation methods, the Department of Energy continues to satisfy its goals of increasing national security and protecting the environment. Locally within these “clean cities”, these networks of stakeholders provide technical assistance to fleets implementing alternative and renewable fuels, idle-reduction measures, fuel economy improvements, and emerging transportation technologies (ibid.). Wherever these coalitions exist, such as large cities like Chicago, New York, San Francisco, Los Angeles, Pittsburgh, and many others, the public transportation in these cities is held to a certain standard. This type of national policy is a great example of how the federal government can catalyze change and improvement at the local level. Because the Department of Energy developed this program to fulfill their goal of energy independence and of environmental protection, and several years later local public works are helping to contribute to the initiative.

### 3.5 Regulations Global Government Initiatives by Country

As one of the wealthiest countries in the developed world, the United States has taken steps to become one of the global leaders in climate change and new energy technology. Implementation of tax and various other incentives through federal and state policies for new, cleaner energy technology have made noticeable differences in the way the United States
consumes energy. While demand for electricity and fuel continue to grow, new innovations such as private and public vehicle battery technology, grid energy storage methods, and a wide array of other technologies have eased this constant increase of consumption. Other developed countries’ governments have instilled similar statutes, and many times for similar reasons as well. New innovations have global impact. For instance, entrepreneurs in California can impact legislature in Germany with their developments. So taking a look at other developed countries’ energy policies, it shouldn’t be surprising to find significant similarities and differences within their government incentives.

Many countries around the world, including the United States, have implemented a “scrapping” program over the past decade, which generally is a government program that provides some sort of reimbursement for trading in older vehicles to promote the purchase of newer, cleaner vehicles. The U.S. dubbed the program “cash for clunkers”, but other countries had similar variations (Sivak 2009). For instance, Canada began the “Retire your Ride” program in 2009, which would allow residents of Canada to trade in a vehicle made before 1995 for a variety of rewards that might include cash or a public transit pass (Retire your Ride n.d.). In France there were a few more restrictions to partake in their scrapping program. The scrapped car had to be over 10 years old and the new car for which one would exchange for had to meet certain CO₂ emission standards, and cleaner cars would provide a bigger subsidy. The French government would also extend this program overseas for foreigners purchasing French manufactured cars as well (Schweinfurth 2009). Spain, Germany, and the U.K. installed programs similar to France, with subtle differences in eligibility such as nine-year-old vehicles compared to ten-year-old ones. Germany and the U.K. also had no emissions restrictions on new cars purchased through the scrapping program like France and Spain (ibid.). In general, these programs were all similar in objectives and in basic practice. These scrapping programs were started during the global economic recession around 2008 or 2009, aiming to provide economic support for the car industry while also providing environmental benefits and promoting the use of hybrid or low
emission vehicles. The differences between the programs country to country can be found in the financial implementation and the effectiveness of these initiatives.

Figure 5 from Schweinfurth’s 2009 paper displays a chart with information for five of the largest car-scrapping schemes by country. The table shows that while there are subtle changes in program details such as eligibility restrictions, reward incentives, or start dates, the most important figures are the cost to the national government and change in new car registration. At this time, the economy all over the world was in poor shape, so it would be very typical to see significant decreases in new car registrations. This means less revenue for the car industry and also older cars with worse emissions are driving longer on the road. Each country spent a certain amount of money on their scrapping program to combat these specific effects of the economic recession. Germany spent by far the most money on their program, 5,000 €, while the U.S. spent 2,000 €, and Spain, France, and the U.K. all spent around 400 €. However, Germany achieved the most success with their scrapping program, witnessing a 26% increase in new car registrations, significantly more than any of the other three countries with available data (Schweinfurth 2009). The data seem to show that the money Germany spent on their program seemed to provide significant aid to their national car industry and their environment as well.

While the main purpose of scrapping programs across the world was for economic relief,
another important factor of these initiatives was to encourage the use of cleaner, newer, innovative technology in their countries’ vehicles. Newer hybrid technology means cleaner emissions, less greenhouse gas, and safer environment. The evidence shows that the average car bought was more efficient than the average car traded in, but that the new cars built were not hybrids or other best-in-class environmental performers. The U.S. claimed that the fuel efficiency of the new cars purchased under the program was 58% greater than of the old cars traded in. The average CO₂ emissions of new cars purchased under the scrapping scheme in the U.K. were 132 grams per kilometer (g/km), about 16 g/km less than the average emissions of new cars purchased outside the program. In Germany, small and compact cars were mostly sold under the scheme. Ultimately, the schemes seem to have steered buyers toward smaller, more fuel-efficient vehicles (Schweinfurth 2009). However, a considerable part of energy consumption in a car’s life cycle is incurred during its production, in some cases offsetting the efficiency and emission gains of the new technology. Moreover, the increased purchase of more fuel-efficient cars follows a general trend that is mainly a result of increasing fuel prices (Sivak 2009).

Ultimately, the realm of government involvement within new hybrid or battery technologies is always fluid. Political and economic situations change each day, not simply year to year. Governments have to be willing to adapt and also be able to admit when a program is not working. The objectives of these governments when it comes to these types of market inventions are relatively standard. These types of policies are put in place to improve the economy, ensure national security through certain resources, and protect the environment. Like everything the government does, every citizen is concerned with the efficiency of their spending, because its citizens directly fund the government. When resources go to waste, policy-makers are usually to blame for not fully interpreting the needs of the social, economic, political, or environmental situation into which they are entering. As David Diamond and Arne Schweinfurth have mentioned, there is always room for improvement within government, and
hopefully as our energy needs continue to expand in the upcoming years, policy-makers around the world will be able to satisfy the needs of their citizens.

4 Developing Countries Policies & Initiatives

There has been sustained growth in renewable energy over the past decade driven by continued awareness worldwide that renewables play an indispensable part in shaping the future and managing the rising greenhouse gas CO₂ emissions. This growth has continued even against the backdrop of higher energy demand and a dramatic decrease in oil prices (Krauss 2015) which may lead some to expect a short term focus-shift away from renewables due to their higher relative cost, especially upfront expenses and development time. However, these low oil prices actually led to a decrease or elimination of fossil fuel subsidies in roughly 30 countries (Klevnäs, Stern, Frejova 2015). Furthermore, it appears that despite these challenges, global carbon emissions associated with energy consumption actually remained stable in 2014 while the global economy grew for the first time in four decades (IEA 2015).

While the focus in technological development has usually been on developed countries, such as the United States and Germany due to their scientific and research capabilities, these countries have also long justified slow implementation of renewable energy on the lack of developing countries to follow suit. However, this argument can no longer be made as developing countries are taking more active steps in becoming world leaders in renewable energy and technological innovation. Between now and 2040 it is estimated that developing countries will build three times the renewable capacity as developed countries (New Energy Outlook 2015).

Before going into the initiatives and policies taken by developing governments, we must look at the barriers present in the market. This section will list the major barriers and an explanation of their relevance while solutions will be addressed later in the paper with respect to each country. The main barrier to renewable energy development is the current low energy prices derived from traditional energy sources. For the last several decades, the abundance of fossil fuels has
allowed for energy to be generated and distributed in much the same way as well as in an extremely cheap way. The reason for such cheap energy is due to a usually localized abundance and the fact that the price has just been set at a small arbitrary markup on the cost associated with delivering such energy from the ground to the consumer. Furthermore, the prices do not include the environmental costs associated with them later.

The next barrier is high upfront costs and long payback periods, which becomes very problematic since consumers usually value the cost of consumption and will not discount the future benefit of paying higher prices for renewable energy now. Along similar lines, there exists a principal agent problem in the sense that those making decisions on energy efficiency, at a local level, usually do not benefit, such as building owners or tenants.

Ultimately, renewable energies will need to be our energy source going forward, but the question becomes how fast governments will take steps to combat the growing fossil fuel problem and what obstacles lie in their way to achieving a carbon-neutral world.

4.1 China

Despite impressive economic development over the past couple of decades, China remains a developing country with a low GDP per capita income and therefore faces some additional challenges in its transition to a low carbon economy as renewable energy capacities and income levels vary across different regions. The immense improvements experienced economically over the last 50 years, and as a result advances in the quality of life, have not come without their consequences; China prioritized absolute economic growth and development over sustainable development, leading to enormous pressure on the environment in terms of air, water, and soil pollution. “Scenario analysis shows that if China does not change its economic growth pattern, by the year 2030 its per capita CO₂ emissions will reach 8 tonnes per capita, while more than 80% of petroleum will be imported from foreign countries” (China’s Move to Low Carbon Economy 2009).
Such current trends are not sustainable and actually pose a threat to future economic and social development as well as national security. Millions of people are expected to migrate to urban areas in the next decade, increasing pressure on the use of energy and natural resources (China Human Development Report 2013). China recognized this issue at the 18th Communist Party Congress in November 2012 by incorporating the concept of an Ecological Civilization into the Party’s constitution: “we must foster the idea of ecological civilization and strive to build a beautiful China by following the path of sustainable development” (Yuwen 2012). This is a direct call to action by the Chinese government illustrates the dire need for environmental protection and renewable energy sources to secure future economic development and energy security.

Since the incorporation of energy importance into the Chinese constitution, China has made enormous strides and taken the lead globally in renewable energy generation, already generating 25.3% of total global renewable power capacity in 2014 (Figure 6).

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<tr>
<th>TECHNOLOGY</th>
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<th>BRICS</th>
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<td>2.3</td>
<td>0.2</td>
</tr>
<tr>
<td>Wind power</td>
<td>370</td>
<td>129</td>
<td>144</td>
</tr>
<tr>
<td>Total renewable power capacity (including hydropower)</td>
<td>1,712</td>
<td>380</td>
<td>668</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Country</th>
<th>GW</th>
</tr>
</thead>
<tbody>
<tr>
<td>China</td>
<td>443</td>
</tr>
<tr>
<td>United States</td>
<td>185</td>
</tr>
<tr>
<td>Germany</td>
<td>92</td>
</tr>
<tr>
<td>Italy</td>
<td>50</td>
</tr>
<tr>
<td>Spain</td>
<td>49</td>
</tr>
<tr>
<td>Japan</td>
<td>54</td>
</tr>
<tr>
<td>India</td>
<td>76</td>
</tr>
</tbody>
</table>

Figure 6: Renewable Electric Power Global Capacity (Top Regions / Countries, 2014)

Last year, 2014, China invested over $83 billion in renewables representing roughly 33% of all
global renewable investment. While the investment of developed countries peaked in 2011, developing countries are continuing to invest more and are closing the gap rapidly (Figure 7).

Such investments continue to increase and look poised to allow developing countries to eclipse developed countries in renewable energy. This suggests that efforts to decrease and stabilize CO₂ emissions are being taken seriously and may be closely linked to China’s ever expanding emphasis on renewable energy. Since the Renewable Energy Act passed in 2005 China has focused on the extensive development of the sector; funding has increased 915% from $8.2 billion to $83.3 billion while the U.S. increased funding only 230%, from $11.6 billion to $38.3 billion (Figure 8).
Such vast investments have allowed the leveraged cost of electricity (LOCE) in Asia, particularly China and India, for renewable energies to be the lowest in the world, even approaching or surpassing the levels of fossil fuels (Figure 9). After additional government incentives and policies, this makes the generation of electricity from renewables in Asia almost more economical than from fossil fuels.

![Figure 9: The Levelized Cost of Electricity from Utility-Scale Renewable Technologies (IRENA Renewable Cost Database)](image)

Referring back to Figure 1, we can see that China has a big interest in hydro and wind power which currently contribute 64.6% and 26.5% of national renewable energy, respectively. Hydropower is China’s second-largest energy source after coal and the country’s installed hydropower capacity is set to rise to 350 gigawatts (GW) by 2020, up from 280 today. The country is already home to half the world’s 80,000 dams, more than the United States, Brazil, and Canada combined.
In terms of wind power, China has exceptional wind resources due to its large land mass and long coastline, and it is estimated that there is 2,380 GW of exploitable capacity on land and 200 GW on the sea (Figure 10). Taking this theoretical capability one step further, “researchers from Harvard University and Beijing’s Tsinghua University suggest that the Chinese wind power industry has hardly begun to tap its potential. According to their meteorological and financial modeling…there is enough strong wind in China to profitably satisfy all of the country’s electricity demand until at least 2030” (Fairley 2009).

Figure 10: China’s Potential Wind Power (Fairley 2009)

While solar energy is still quite comparatively small, China’s stake in the global solar market is unmistakable at 16%. However, while the capacity to produce 28 GW may be there, transmission infrastructure has not kept up. For example, solar farms in sunny western regions are unable to transmit their power to high demand locations in the south and east due to a lack of infrastructure.

In order to encourage further development of these renewable energies, particularly the three most promising ones, China allows for the importation of technologies which it itself does not
have the capabilities currently to produce effectively. This will allow for faster technological advancement since it is able to take the best parts from around world. To enhance development domestically, it put in place several incentives to encourage further development and make renewable energies more feasible and competitive with conventional energy. 2 of the major support schemes put in place concern the Corporate Income Tax (CIT) and Value Added Tax (VAT).

Since all business, even those in the renewable energy sector, look to make a profit down the road, there have to be incentives in place to justify the huge upfront business expenses required for renewable energies. Therefore, China has put in place a reduced CIT rate of 15% which will be available to advanced and new technology businesses to encourage innovation in solar, wind, biomaterial, and geothermal energy. Furthermore, a 3-year exemption from the CIT is followed by a 50% reduced CIT for another 3 years for environmental protection and energy or water conservation projects. To offset some initial costs, a 10% credit of the amount invested in such projects is available to applied against the CIT, with any left over credit carried forward for up to 5 years. Additionally, only 90% of the revenue generated by these companies will be taken into account for CIT calculations. Lastly, China will give a 150% deduction for Research and Development costs incurred for CIT computation. Overall, this presents significant tax break for companies dedicated to either renewable energy or technological innovation behind the renewables. Such tax breaks may make it possible for businesses to justify the high initial costs, especially as costs for such products decrease significantly.

On the consumer side, the VAT exemptions are in place to encourage smarter consumption and push people towards renewables. A 50% refund will apply on the sale of wind power as well as self-produced PV power, with the second especially encouraging consumers to install solar cells in their homes. A 100% refund of VAT is paid on the sale of biodiesel oil generated from animal fat and vegetable oil, and VAT paid on the sale of goods made from recyclables is
refundable. Furthermore, electric vehicles and vessels owners are able to take advantage of a 50% Vehicle and Vessel Tax, and until the end of 2017 all new energy vehicles purchased will be exempt from the Vehicle Purchase Tax. Since the transportation sector is responsible for a large percentage of emissions generated, such incentives should push people to buy energy-efficient or neutral vehicles while at the same time installing solar panels at home.

Beyond these support schemes, there are operating subsidies such as feed-in tariffs, financial funds and allowances, and financial subsidies. Feed-in tariffs will allow renewable energy companies to offer energy at a market competitive rate, thereby driving up demand for more renewable energy and, as costs for renewables fall, decrease demand for fossil fuels. Financial funds will be available to facilitate the development of renewable energy relating to a variety of activities, which include: scientific and technical research, renewable energy projects in rural areas, construction of stand-alone electricity generation systems in remote areas and island, construction of information systems, and localization of renewables manufacturing facilities. This will allow for financial support in the early stages of development and implantation especially when profits are not yet realized. Lastly, direct financial subsidies will support energy conservation projects as well as promotion of the development and utilization of renewable energy.

All of these policies have been put in place in order to make renewable energies more feasible in today’s world so that they can start to make an impact as soon as possible. Even though this may pose a serious investment from the government, the long-term benefits will outweigh these upfront costs. If that were not enough though, besides the environmental incentives to invest in renewable energy, there are also long-term economic benefits such as enormous job growth both in China and globally (Figure 11).
Figure 11: Breakdown of Estimated Jobs Resulting from Renewable Energies (IRENA)

4.2 India

Although both are developing countries, India presents a slightly different case than China which can mainly be attributed to their different economic standings. While China has become an economic superpower, India at roughly $2 trillion GDP is only 1/5 the size of the Chinese economy (Report for Selected Countries and Subjects). This presents an interesting issue, because India still wants to grow its economy rapidly much like China did for the past couple decades; however in order to achieve such growth it is not practical to stifle fossil fuel output since that is currently still the most abundant, cheapest, and easiest way to produce and therefore promote economic development. Currently, India is the second-largest consumer of oil in the Asia-Pacific region behind China. As this oil consumption continues to rise, with production staying relatively flat, it will leave India highly dependent on imports to meet the consumption needs.
However, even though India has this vision of a rising economic power, it is also very aware of the issues that climate change is presenting to the country. Additionally, new generation of electricity is vital to India’s future as it attempts to connect 400 million people currently without electricity to the grid. It intends to ensure that every household will have electricity by 2022 and to demonstrate this commitment, the government set aggressive targets for increasing renewables in the total energy production, as currently they contribute only about 12.3% of the total energy capacity. Universal access to energy is central pillar to achieving future sustained economic, so as part of its Union Budget 2015-2016, India’s 2022 goal is to have installed 60 GW of wind power and 100 GW of solar, which is more than six times the current installed capacities (Key Features of Budget 2015-2016).

Solar power has an enormous potential in India due to its roughly 300 sunny days per year which would result in a theoretical yearly yield which would exceeds the possible energy output of all fossil fuel energy reserves in India (Solar). India has realized this and implemented a National Solar Mission in 2010 with the goal of establishing India as a global leader in solar energy. The main focus will be on the development and deployment of large-scale rooftop projects, since that will be the most effective area use. Besides these national programs, there are also solar initiatives on the state level, particularly to ensure citizens access to electricity. This could be achieved through off-grid solar stations in remote areas where grid infrastructure would be cost-prohibitive.

In order to accomplish these goals India has opened itself up to the world as well as put in place domestic policies to encourage the development, deployment, and utilization of these renewable energies; it will mainly allow Foreign Direct Investment (FDI) and an income tax holiday. The FDI allows for up to 100% of foreign investment in the renewable sector with no prior approval needed. This is meant to increase the rate at which projects can be built and financed by eliminating some of the red tape usually associated with clean energy projects. To further strengthen the infrastructure sector, there can also be external commercial borrowings for
project use in special purpose vehicles in the infrastructure sector. The income tax holiday applies to renewable energy plants generating power before April 2017 and will allow for 10 years of tax free operation. This encourages companies to start the development of plants and grid systems since it will diminish the running costs later on, thereby making it a better business model.

Looking at operating subsidies, the Indian government will offer fed-in tariffs in terms of Generation Based Incentives (GBI) and accelerated depreciation. The GBI is meant to make the price of renewable energy more competitive with fossil fuels, such as making wind power projects eligible for an incentive of INR 0.50 per unit of power for a time period between four and ten years. This should also encourage foreign investors by making sure that their renewable power projects will be able to compete in the long-run. Accelerated depreciation laws will allow renewable companies to provide accelerated depreciation at 80%. This is significant because accelerated depreciation provides a way of deferring CITs by the reducing taxable income in current years, in exchange for increased taxable income in future years. These tax savings will allow business to purchase new assets now instead of later on thereby encouraging increased current development of renewables.

These incentives and subsidies have been put in place to speed up the process of renewable energy in India. Furthermore, since the country itself still wants to focus on modernizing these policies allow for a vast amount of foreign investments, which means it does not draw any money or resources from India while providing them with technologies.

5 Automobile Sector

In the last decade many studies have shifted to addressing the problem of the occurring climate change, and the decreasing amount of fossil fuels. These bring with them changes in the ecosystem and have effects on products and markets all over the world (Chandramowli & Felder 2014; Tang et al. 2014). In parts of this paper the changes in vehicle propulsion
technology, energy technology as well as alternative fuels shall be addressed.

It is broadly known, that car usage leads to a broad range of air emission that directly contribute to smog formation and climate change (Frenken et al. 2004). Apart from the regulatory stimulus there are also many other factors that can have an influence on the technological responses of a company (Oltra & Saint Jean 2009a). Factors could be technological opportunities, demand conditions, knowledge bases as well as surrounding conditions (Oltra & Saint Jean 2009a). As early as the 1970s car manufacturers have been active in R&D programs trying to reduce car emissions (Frenken et al. 2004). In more recent history those manufacturers were looking for a substitute for the internal combustion engine (ICE) (Pinkse et al. 2014). The solution they found were the low-emission vehicles (LEVs) which can be further divided into electric vehicles (EVs), hybrid electric vehicles (HEVs), fuel cell vehicles (FCVs), plug-in electric vehicles (PEVs) (combination of battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs)) and compressed natural gas vehicles (CNGVs) (Frenken et al. 2004; Pinkse et al. 2014; National Research Council 2013). The trade-off between the development of the dominant design (ICE) and the investigation of alternative LEVs shape the innovation activities of the automotive industry (Oltra & Saint Jean 2009a). In the beginning regulations were predominantly focusing on the EVs (Oltra & Saint Jean 2009b). Due to the underperforming battery technology of EVs compared to the mainstream technology other technologies (HEVs, FCV) started to be supported by the automotive industry (Oltra & Saint Jean 2009b). The R&D efforts not only focused on new engine technologies but also on different types of fuels. Even though governments are largely subsidizing LEVs, a big shift from the conventional ICE to new technologies cannot be observed (Pinkse et al. 2014). Nevertheless it remains very difficult to make LEVs attractive to mainstream customers, as it does not only require product innovation of the vehicle but also of connected technologies (Pinkse et al. 2014).
5.1 Transition to Low-Emission-Vehicles

Before going into different arguments of the research done concerning this topic a short overview of the alternative LEVs, which are technically capable of competing in the future with ICE vehicles, will be provided. Triggered by the California Air Resources Board (CARB) mandate of the LEV program in the 1990s, automobile companies were strongly stimulated to pay more attention and invest money in the development of more efficient, environmentally friendly and clean vehicles (Frenken et al. 2004). The term clean involves also investing in newer cleaner energy resources. Evolving from these investments were three major options for future car systems, which are most likely to be among the successors of the ICE technology (Frenken et al. 2004). Those five options were the EVs, HEVs, FCVs, PEVs and CNGVs, which will be discussed in detail. For more than a century now the automobile market has been dominated by ICE technology, which was constructed and designed by Otto, Daimler and Benz in the 1880s (Dijk & Yarime 2010). Compared to the first engine the technology has improved greatly over the last decades for instance in horsepower, weight and fuel efficiency. In the time between 1990 and 2003 the fuel consumption of the fleet of German automotive manufactures decreased by 25% (Dijk & Yarime 2010). The improvement of the ICE especially in the way of fuel efficiency was made possible trough the application of two new engine components, which were the variable valve system and the direct injection (Dijk & Yarime 2010). Other factors that should be named are the common rail technology, particle filters, new material that lightens the vehicle as well as the stop and go technology (Oltra & Saint Jean 2009b). Since the ICE technology is a very mature technology it is unclear if the technology will be capable to meet the future emission and environmental standards (Oltra & Saint Jean 2009b). BEVs, FCVs and CNGVs can operate only on their specific fuel, which will be addressed later in this section (National Research Council 2013). In comparison ICEVs, HEVs and PHEVs can use fuels produced in different ways using petroleum, biomass, natural gas or coal (National Research Council 2013).
5.1.1 Internal Combustion Engine (ICE)

Before going into more detail of the alternatives to an internal combustion engine (ICE) it is necessary to understand, why the automobile sector has been so heavily reliant on this technology for more then a century now. The main reasons for this dominance over the alternative engines has been the high power output, low cost, the ability to operate for long distances in a wide range of temperatures and environmental conditions, readily available fuel as well as the fuel infrastructure (available gas stations) (National Research Council 2013). ICEs can run on many different fuels, but in the end, gasoline and diesel remained the fuels of choice. This can be easily explained, both types of fuel have the following beneficial features: low cost and high energy density as well as allowing hundreds of miles of driving before refueling (National Research Council 2013). As a result to ongoing technological progress world reserves for crude oil have been expanded. This is not the only reason why, the feedstock of choice for gasoline and diesel has remained crude oil, but also due to the fact, that the production has kept up with the world wide demand (National Research Council 2013). Nevertheless it is very important to keep in mind, that petroleum use is the largest source of greenhouse gas emissions (GHG) in the United States of America (National Research Council 2013). This factor, enhanced by governmental incentives as well as state laws, is mainly the reason why more and more automobile companies worldwide are investing in R&D to find other low emission engines as well as cleaner fuels. Further it is very important to notice from an economical point of view, that light-duty vehicles account for the single largest share of U.S. petroleum demand (National Research Council 2013). This means, that the U.S. as well as other big automobile reliant countries, which have no own or not enough own natural reserves of crude oil, are depend on other players in the market and their market price for crude oil (petroleum). Nevertheless, even though there are many push factors in motion that are suppose to lead to a transition in this sector from using ICE to using new engine technologies, customers still chose to buy ICE vehicles. This is only due to the benefit of having a functional well
developed infrastructure and due to the fact that right now all alternative vehicle options are more expensive than the conventional ICE vehicle.

### 5.1.2 Electric Vehicles (EVs)

Beginning in the mid 1990s electronic engines emerged as an alternative technology to the dominant design of the ICE. At first there were only the pure EVs from which later than the HEVs evolved (Dijk & Yarime 2010). Frenken et al. (2004) give a very fitting definition of an EV: “An EV can be defined as a vehicle that is propelled by an electric engine that is powered by a battery.”

They are thus also referred to as battery electric vehicles (BEV), which will be discussed later. More than 90% of the transport sector worldwide, is powered by fuels derived from oil (van Vliet et al. 2011). However, as already mentioned in the section above, the consumption of diesel and petroleum is considered very problematic due to doubts about security of oil supplies, cost of oil, GHG emission and emission of air pollutants and volatile organic compounds (van Vliet et al. 2011). It all started around the time of the California ZEV requirements. Around that period car manufactures showed an increasing interest in the innovation as well as the marketing of their EVs (Dijk & Yarime 2010). The obvious advantages of this new engine technology compared to the ICEVs is that they do not emit any tailpipe emissions, have less moving parts, which means less need for maintenance, and they are silent (Oltra & Saint Jean 2009b). Nevertheless EVs may cause emission of GHGs and other air pollutants depending on the mix of electricity sources used (van Vliet et al. 2011). What that means is, that electricity can be produced in different ways using different types of sources, which will have different GHG emission. Those sources can be coal plants as well as renewable energy. This will lead to the fact, that at the moment EVs can be fueled with electricity from renewable energy sources if possible. Doing so the emission would drastically decrease. If the demand for electricity reaches a certain point at which it can not only be sourced from renewable energy other sources like a
coal plant need to be used. This will lead to an increase in GHG emission per vehicle. Due to this fact investments in R&D and technology are undertaken to ensure new clean energy sources. The projections of the past show, that an EV increases the electricity consumption of a household in an developed country by 50% (van Vliet et al. 2011). Imagining the introduction of a large number of EVs presents new challenges and problems. These challenges are improving the electricity distribution grid, taking care of legal and privacy issues regarding coordinated smart charging systems and building an infrastructure for charging (van Vliet et al. 2011). A perfect example out of recent history is the company TESLA. They introduced their EV in different models as well as their own charging network. This example will be explained in more detail later in the paper.

However it became obvious in the early 2000s that EVs would be unsuccessful in the product market (Dijk & Yarime 2010). But what where the reason why this technology was so unsuccessful until now, even though electricity costs a third of diesel or petroleum?

The obvious disadvantages of the EVs were the short life of their batteries with limited storage capacity, recharging time of approximately 6 to 8 hours, higher price compared to the ICEVs and the travel distance of EVs (Dijk & Yarime 2010; Oltra & Saint Jean 2009b; Frenken et al. 2004). It can therefore be said, that EVs were only limited to niche markets for example dedicated to specific uses as airport shuttles, delivery vehicles or captive fleets (Oltra & Saint Jean 2009b).

5.1.3 Hybrid electric vehicles (HEVs)

Over the last ten years HEVs have experienced a significant rate of growth. As of the year 2010 1,5 million hybrid-electric engines were sold worldwide (Dijk & Yarime 2010). This number has increased even further in recent history. So what are HEVs? HEVs can be defined as vehicles that are propelled by an internal combustion engine as well as an electric engine (Frenken et al. 2004). At the moment HEVs are the most viable powertrain alternative due to
their hybrid configuration that as mentioned above include a relatively small IC engine and an electric engine (Oltra & Saint Jean 2009b). In the late 1990s the first automotive companies launched HEVs (Dijk & Yarime 2010). It was around that time that Toyota presented their first Prius to the Japanese market. Toyota faced the same price problems as most of their competitors did with the EVs. To solve this they initially paid a premium of 10% on each of their Priuses to push down the initial price (Dijk & Yarime 2010). As a result Toyota was able to sell more than 15,000 HEVs annually in the first years and achieved to sell more then 100,000 by 2008 (Dijk & Yarime 2010). One of the main reasons why this technology moved forward so quickly was the possibility to fuel the cars with conventional as well as alternative fuels. Furthermore the parallel engine system compared to a serial system can deliver more power, as both engines can be used simultaneously (Oltra & Saint Jean 2009b). This technology has the ability to compete with the ICE in terms of range and speed and all of that with a total efficiency that can be twice as high as the ICE (Oltra & Saint Jean 2009b; Frenken et al. 2004). Recently innovation made it possible to make HEVs even more efficient then before by harnessing the kinetic energy that is generated when the car uses the brake (Frenken et al. 2004). In recent literature concerning this topic the hybrid technology is seen as a transition technology between the ICE and the FCV. Since HEVs have shown such commercial success it is possible that instead of being developed side-by-side with the FCVs they could in fact be seen as a competitive threat to the development of FCVs (Oltra & Saint Jean 2009b). Nevertheless the economic factor of the extra cost for an HEV remains. Currently due to the extra cost for the battery, electronic controls and the electronic motor HEVs cost about $4,000 to $5,000 more than their equivalent ICEV (National Research Council 2013).

5.1.4 Plug-in electric vehicles (PEVs)

As of right now there are three distinctly different configurations in the automobile sector in production, which utilize battery power for propulsion (National Research Council 2013).
Those three different types are HEVs, which were discussed in a previous part of this paper, PHEVs and BEVs. The PHEV is a hybrid vehicle, which can be recharged from the grid. It can further be seen as a BEV supplemented by an ICE based drive (Jorgensen 2008). The first mass-produced PHEV introduced into the U.S. market was the Chevrolet Volt and the first BEV was the Nissan Leaf (National Research Council 2013). Due to the harmful GHG emission government adopts many solutions to solve this issue, such as introducing PEVs in the automotive sector as well as new renewable energy resources (solar, wind) as clean energy (Dai et al. 2013). Overall it can be said, that PHEVs are conceptually quite similar to the already discussed HEVs. The batteries used in PHEVs have a volume of 4-20 kilowatt-hours (kWh) of stored energy that can be recharged from the grid (National Research Council 2013). A fully charged battery allows those vehicles to travel from 10 to 40 miles on electricity before an engine is needed. This will lead to the conclusion that those drivers who do not exceed this range and always charge their vehicle before using it again will use little to no gasoline at all. To make these technologies attractive to customers the range and the recharging time need to be adjusted. For example the battery of a BEV or PHEV needs to have a volume of 78 kWh to achieve a range of 300 miles (National Research Council 2013). Taking this volume into account an considering the cost of $450/kWh the current battery pack cost for an 78 kWh battery sums up to be $35,000 (National Research Council 2013). The government as well as the industry are aware of this problem. So global R&D activity for Li-ion battery technology, which will be the battery of choice, is funded at a level of numerous billion dollars annually (National Research Council 2013). What the latest research on this topic has shown, is that there will be just a few affordable BEVs with the ability to greatly exceed the 100 miles range for the next years to come. The other mentioned problem of these PEVs will be the recharging time. Unless there is a technological breakthrough allowing batteries to be recharged in 10 minutes or less especially BEVs will be limited to local travel in urban or suburban areas only (National Research Council 2013). At the moment a technique called battery swapping is tested. What
this means is, that a vehicle with a nearly empty battery pack would drive into a battery station where a large automated machine would extract the battery and replace it with a freshly loaded one. If this technology would be largely available it would solve the range as well as the recharging problem. Nevertheless this technique would face the following problems:

- Battery packs need to be standardized;
- Swapping station need to keep a large expensive inventory of different types and sizes of battery packs;
- Grid peaking problems through recharging the battery pack right after arrival;
- Customer objection of old batteries, because they don’t know how far they will be able to drive on them (battery deterioration over time);
- Seasonal peaks in long-distance travel are likely to intensify inventory problems (National Research Council 2013).

### 5.1.5 Fuel cell vehicles (FCVs)

FCVs are vehicles that are driven by an electric engine, which is exclusively powered by a fuel cell (Oltra & Saint Jean 2009b; Frenken et al. 2004). This fuel cell converts for example hydrogen or any other energy carrier into electricity (Frenken et al. 2004). When the chosen fuel is hydrogen, the engine generates no pollutants (Oltra & Saint Jean 2009b). FCVs show similar advantages as a typical EV and more. FCVs have the ability to generate breaking energy, a very low noise rate, zero-tailpipe emissions, high energy efficiency, diversity of energy sources and rapid refueling (Frenken et al. 2004; Oltra & Saint Jean 2009b; National Research Council 2013). As well as EVs the FCVs face major problems. First of all the fueling of the FCVs is a major concern, because the use of hydrogen as fuel necessitates large changes in the current fueling infrastructure (Frenken et al. 2004). Additionally FCVs have yet to demonstrate a on-road durability for 15-years of service life (National Research Council 2013). Furthermore, as
hydrogen is stored in the form of gas a novel storage technology is needed (Frenken et al. 2004). It is therefore also possible to avoid these problems by using different types of fuels like gasoline or methanol (Frenken et al. 2004; Oltra & Saint Jean 2009b).

The economic viability of FCVs is also questionable since they are the most expensive option of all the three major LEVs discussed in this paper (Oltra & Saint Jean 2009b). All of these mentioned factors show, that even though this technology is the most promising one it is not even close to being compatible with ICEVs. At the moment there needs to be more research in this area and further infrastructural changes. Until then FCVs only result in prototypes for just limited range, which then can be used for urban transit buses or airport vehicles (Oltra & Saint Jean 2009b).

5.1.6 Compressed natural gas vehicles (CNGVs)

The last type of vehicle this paper will focus on, are the CNGVs. The main reasons CNGVs are important for this topic are reduced fuel cost, displacement of petroleum with a domestic produced fuel and reduced tailpipe GHG emissions (National Research Council 2013). Lately the focus on CNGVs has drastically increased in the academic literature as well as in the automobile sector. A key driver of this increased interest in CNGVs comes mainly from the fact, that there is a high likelihood, that natural gas prices will remain significantly below gasoline prices and that the technique of “fracking” can be used to secure this resource inside the home country (National Research Council 2013). There are nevertheless problems with this technology as well. Mainly the fuel storage needs to be addressed. The gas storage tank is rather large and rather heavy. In numbers this means, that the cheapest solid steel cylinders weigh 4 to 5 times as much as a gasoline tank that can hold the same amount of fuel (National Research Council 2013). There are advanced cylinders that weigh about half as much as the steel cylinders but will automatically cost more. Other than the problem with the fuel tank CNGVs do not require any significant re-engineering compared to the ICE vehicles. Other then that the
already existing infrastructure for natural gas can be used. There will be a need for improvements to this infrastructure in the case more natural gas cars are being sold, which will lead to an increase of the demand for natural gas. At the moment nevertheless CNGVs are still considerably more expensive than their gasoline-powered counterparts (National Research Council 2013). Considering these higher costs it will take about 10 years to recover the higher purchase prices for a CNGV, but these higher prices can come down in the case of more CNGVs being sold (National Research Council 2013).

5.1.7 Case Study: Tesla

When considering the technologies presented it can be concluded that no real disruptive and systemic technology managed to gain access to the mass market. The only success story, the Toyota Prius is not a classical disruptive and systemic innovation, as the hybrid technology does not require for a new infrastructure to be developed and also does not fully replace the ICE technology (Hardman et al. 2015). We therefore want to extend the findings though a case study of a company in the EV sector, which had a more successful market entry. The work of Hardman et al. (2015) shall be at the basis of this work and extended with additional literature. Another reasons that we have chosen to look in more detail at the EV technology is that literature has mentioned that FCV technology is far from a market introduction as costs are very high and infrastructure issues have not yet been solved, in fact many studies have shown that demand for this technology may decline (Nykvist & Nilsson 2014; McKinsey & Company 2011). Further it is also interesting to see the development in the energy market due to the market entry strategy of Tesla Motors. If a market entry is however realized in this sector a high end-encroachment strategy as described by Hardman et al. (2015) may be a plausible strategy if successful for EVs. Since Tesla Motors vehicles share more similarities with the FCVs than others, they have been chosen to be compared to FCVs by Hardman et al. (2015). To be more specific the authors take a closer look at what can be learned from the successful market entry
strategy of Tesla Motors and what can possibly be the market entry strategy for future FCVs (Hardman et al. 2015).

5.1.7.1 Introduction to Tesla

Tesla Motors is a well-known global enterprise that produces, markets and designs electric powered vehicles, as well as lithium-ion battery packs and vehicle powertrain components (Mangram 2012). What makes Tesla Motors special is that unlike other EV companies they have chosen a different market entry strategy, which is driven by a higher price but at the same time technical excellence (Hardman et al. 2015). To achieve this goal Tesla Motors has invested large amounts in research and development. Doing so they have secured 203 patents and further 280 patents pending in the end of 2013 (Tesla Motors 2014b). According to the CEO of Tesla Motors Elon Musk Tesla is pursuing a three-stage market entry strategy (Hardman et al. 2015). This three-stage market entry process was formulated as the following:

1. Develop a high price low volume vehicle which was done in the form of the Tesla Roadster in 2008;
2. Develop a mid volume, mid price vehicle which was introduced in 2012 in form of the Tesla Model S and Model X that will follow in late 2015 early 2016;
3. Develop a low price and high volume vehicle that be introduced to the market in 2016-2017 and will be called Tesla Model 3 (Hardman et al. 2015).

It can be said that companies in the mobile phone business have done the same Apple Inc. is as good example. What Tesla Motors are trying to accomplish is to introduce a high price product in the first stage of the market entry process and then incorporate the resources and knowledge into a low price product. (Hardman et al. 2015).

5.1.7.2 Situation analysis of the EV market

First of all there is to say, that the term EV covers different sorts of technologies. These vehicles
include plug-in hybrids (e.g. the Chevrolet Volt), battery electric vehicles (e.g. Tesla Roadster) and gas electric hybrids (e.g. pre 2004 Toyota Prius) (Mangram 2012). All were explained in detail in the sections above. To say something about the sales prospect is highly speculative, because the market is highly reliant upon various market drivers (Mangram 2012). These mentioned market drivers are identified as infrastructure development (smart grid developments as well as density of recharging stations), public policy, energy economics (fuel prices) and technological developments (vehicles performance and advances in the battery technology) (Mangram 2012). The market for EVs has been growing significantly over the last years. For Tesla this means growing competition from other EV entrants and further indirect competition from existing and emerging plug-in hybrid car manufacturers and from other substitutable technologies like gasoline hybrid vehicles or the ICEVs (Mangram 2012). Recently BMW entered the market of BEVs by introducing their new i3 and i8 model. The i8 is a direct competitor to the Tesla Roadster, because it is a high price sports car that settles in the same market. Remembering the three-stage model of Tesla the BMW i3 is mainly designed for the third and last stage. This stage is not yet occupied by any Tesla product. Nevertheless Tesla Motors has the competitive advantage in the superior battery electric vehicle (BEV) technology, the first mover market position, the unique component product lines and the brand recognition (Mangram 2012).

5.1.7.3 Supercharger network

Next to the EVs Tesla Motors produces, they are also highly invested in the charging infrastructure for their vehicles, which is available to the Model S as of now and is expected to be available to all future Tesla vehicles (Tesla Motors 2015b). This technology is essentially free for the owners of a Tesla Model S as the costs are already included in the purchase price of the vehicle. (Hardman et al. 2015; Tesla Motors 2014)

Their so-called supercharger network allows charging of up to 135 kW per hour. This is
significantly more than what other car manufacturers offer (Reinecke 2014). This allows for a charging speed of 170 miles of range per hour, which is 17 times the amount, a regular public charging station can supply (Dai et al. 2013; GGEMO 2013). It also is an open system that can generally be used by any other EV however no-other car manufacturer supports this technology up to this point (The Economist 2014; Reinecke 2014). Currently Tesla has 380 Supercharger stations open in North America, Asia and Europe (Tesla Motors 2015b). In April of 2014 there were only 90 Supercharger stations, this means an increas of over 400% (Tesla Motors 2014). As these numbers show Tesla Motors is highly investing in the infrastructure. This will lead to a higher supply for EVs. Which will further lead to an increase in the energy needed. As of now the energy used by the supercharger network stems from the grid. As of now the demand is not exceeding the supply. If this case should happen so called dirty energy sources like coal are used. In the meantime Tesla Motors is working on a project to only use clean energy sources for their supercharger network. Close to Sacramento a supercharger station is built that exclusively operates on solar energy. As Tesla Motors is investing most of their revenues into R&D especially in the energy supply as well as their supercharging network it is possible, that the idea of all supercharger networks beeing supplied by clean energy can be achieved in the next 5 years.

5.1.7.4 Outlook

To be able to determine how successful Tesla Motors market entry strategy is, it is not sufficient to look at the financial figures but also look at future developments of the company. We therefore will provide a short outlook at threats and opportunities that can be foreseen from this point.

Tesla is largely investing in infrastructure to reduce the costs of their vehicles and partnered up with Panasonic to build what they call a “Gigafactory”. This 4-5 billion dollar factory is supposed to achieve a cost reduction of up to 30% and deliver sufficient batteries for 500,000
Mangram (2012) performed a SWOT analysis to further analyze the business model of Tesla. Especially, the threats and opportunities are interesting in this section. The opportunities are seen to be advancements in the development of vehicle battery technology. This expectation is also shared by a study conducted by Hensley et al. (2012) who expect battery prices to dramatically decrease. In addition Tesla and other EV makers have created significant barriers of entry. This is amplified by increasing consumer recognition of the potential saving and other advantages of EVs. A rise in government incentives and that there are many niche markets that have not been touched by EVs present further opportunities for EV makers such as Tesla (Mangram 2012).

Possible threats identified by Mangram (2012) where that new competitors may enter the BEV market this could be especially threatening if large car makers with greater resources and economics of scale entered the market. In addition this would be intensified if these achieved major breakthroughs in battery technology. Furthermore, other substitute technologies such as gas vehicles or others may pose a treat for Tesla. Lastly, the oil price may be problematic for EV sales if for example it drastically decreased demand may decline. Hardman et al. (2015) also stated that treats might come from the National Automotive Dealers Association if they succeed in blocking Tesla’s direct sales and service approach. Moreover the authors also state that first competitors i.e. the BMW i8 have already arrived and may pose a treat to Tesla.

5.2 Transition to Alternative Fuels

Worldwide we recognize, that more than 90% of the transport sector is powered by petroleum-based fuels (van Vliet et al. 2011). As already mentioned above the consumption of diesel as well as petrol is considered problematic due to the GHG emissions, doubts about security of oil supplies and the cost of oil. Due to these problems this section will focus on the transition from petroleum-based fuels to alternative fuels. Before going into more detail, it is necessary to make
clear what the term alternative fuels means and covers. Alternative fuels are transportation fuels like hydrogen, ethanol, electricity, compressed or liquid natural gas as well as gasoline and diesel derived from natural gas, biomass or coal (National Research Council 2013). On the other hand petroleum-based fuels are fuels that are derived from crude oil or unconventional oils. Many different alternative fuel pathways have been proposed in literature over the last decade. This section of the paper will mainly focus on the biofuels, electricity and hydrogen as alternative fuel options.

5.2.1 Biofuels

The term biofuel is used to describe any liquid fuel produced from a biomass source (National Research Council 2013). In the United States only corn-grain ethanol and biodiesel as of now are produced in commercially relevant quantities (National Research Council 2013). Even though biofuels can be derived from a variety of different feedstocks. As of now ethanol and biodiesel have been of interest, because it is well known how to process them from commercially available agricultural products. This is a clear cost advantage and since corn and soybeans are largely found in the United States. Further it makes the United States dependent on other countries or other markets. However there is a problem with both the ethanol as well as the biodiesel. Neither one can be fully used by car engines as of know. This means that both need to be blended into the fuel in various proportions. As of 2011 ethanol supplied around 10 percent of the volume of the U.S. gasoline demand and biodiesel, which was produced via transesterification of various vegetable oils or animal fats, supplied less then one percent of the U.S. transportation fuel demand (National Research Council 2013). Even though biofuels are widely available in the U.S. they still require government subsidies or mandates to really compete economically with petroleum-based fuels. Due to these fact the focus on cellulosic biofuels has switched away from ethanol to a biofuel that is a drop-in fuel (National Research Council 2013). Research has found, that the amount of biofuels that can be produced and used
are not limited by the availability of biomass but rather by the availability of capital to built the relatively expensive biorefineries. The primary barrier to this alternative fuel is the economic factor. At the moment the production of biofuels is more expensive than the production of petroleum-based fuels. Further can pure ethanol not be used in conventional ICEs, because of the cold start problems (National Research Council 2013). From a perspective of energy produced biofuels can compete with petroleum-based fuels. But as mentioned above it is not possible to use pure ethanol. So it will always be dependent on petroleum-based fuels.

5.2.2 Electricity

As of right now electricity is widely available, comparatively inexpensive and plentiful throughout the United States. The average retail price in the U.S. for electricity is round about $0.10/kWh (National Research Council 2013). Nevertheless there are significant variations from state to state. These variations have to do with the time of use, various incentives and taxes and the local generation mix (National Research Council 2013). From research studies it is known, that electricity is mainly produced by hydropower, which is the cheapest type of electricity. Hydropower is followed by natural gas, coal and nuclear sources. The study by the National Research Council (2013) shows, that gas turbines are good suited to be used as backup power for renewable energy generation source like solar and wind, because they offer the feature of being ramp up relatively quickly. Due to this fact, the shares of the electricity generation from natural gas tends to increase correlative as renewable energy increases (National Research Council 2013). Electricity is nevertheless not always the cleanest when it comes down to GHG emissions. It is relatively GHG emission friendly when the electricity is produced by renewable energy sources. The so called upstream emissions can be found in producing natural gas, mining coal, building solar panels and wind turbines and power plants and need to be added to the combustion emission of electricity generation (National Research Council 2013). One of the major problems with electricity as a fuel source is the effect it has on
the power grid. Imagine the owners of EVs charging their cars during peak load periods. This would ultimately lead to problems with the electricity supply from the grid. This will lead to higher GHG emissions due to the fact, that when peak loads are high the oldest and most likely the dirtiest sources of power will be forced into service. There are different ways to approach this problem. Approach number one will be changing the customer behavior. This means, that customers are suppose to load their vehicles in off-peak times. This will help to keep GHG emissions low and use renewable energy sources. This behavior can be influenced by giving customers the incentives to use off-peak times to charge their EVs. These incentives could be lower electricity cost during off-peak times and significantly higher prices during peak times. The second approach could be to invest into the grid supply volume. This could be done, by investing more in the energy sources for the electricity. These sources should then be renewable energy sources to keep GHG emissions as low as possible. This would nevertheless increase electricity cost and would hurt the economics of electricity as an alternative fuel. Another problem of electricity as an alternative fuel is the charging infrastructure. The current cost for charging station per vehicle is ranging between $800 to $4,200 (National Research Council 2013). So it can be said, that for electricity to be effective in reducing net GHG emissions as an alternative fuel, the entire United States electric power system need to shift largely to electricity production from sources that emit low GHG emission like renewables, natural gas or nuclear (National Research Council 2013).

5.2.3 Hydrogen

Europe, Japan and the United States have been investing for the last 10 years serious amounts of effort and money into the development of FCEVs and the needed production and delivery technologies to supply hydrogen (National Research Council 2013). The majority of hydrogen in the United States is made from natural gas with other sources including coal and water electrolysis. The benefits of hydrogen as an alternative fuel for the automobile sector is clear the
emission factor. If hydrogen is used as a fuel in the FCEVs the only emission of the vehicle is water (National Research Council 2013). Most of the major players in the gas industry store, produce and distribute hydrogen in either a cryogenic liquid or a gas form. The current hydrogen production (10 million tons per year) in the U.S. would be enough to fuel about 45 million cars (National Research Council 2013). The problem hydrogen as an alternative fuel is facing as already explained for the other alternative fuels is the infrastructure. As of right now most of the hydrogen is transported and used in large amounts. To be useful for the automobile market the hydrogen infrastructure would need to focus on wide distribution of small amounts if distributed through retail outlets, comparable to what can be seen for gasoline today (National Research Council 2013). As sources for hydrogen several primary feedstock and technology choices are possible to use. These include coal gasification, large-scale wind and solar electrolysis, natural gas reforming and biomass gasification (National Research Council 2013). From the mentioned choices natural gas reforming is the major used process to generate hydrogen. The reason is easily explained and lied in the economical point of being the choice with the lowest costs. From a standpoint of clean energy the option of using large centralized electrolysis with wind or solar power would be the preferred choice. This process is nevertheless still in an early phase and research is trying to lower the cost. Since this fuel is suppose to be the future countries all over the world increasing their efforts to make the technology (FCEVs) as well as the fuel widely available. In the year 2010 Japan for example announced a plan that they will have by the year 2025 1000 hydrogen stations and 2 million FCEVs (National Research Council 2013).

6 Public Transportation

In this section we will discuss public transportation in relation to new energy technology investments. The study of public transportation illustrates specifically how the government can help promote innovative battery technology. We will then look to the future of batteries within
the industry, which is becoming all the more relevant as the use of hybrid and electrical buses increases.

6.1 Why public transportation?

We chose to focus on government transportation specifically, for it is one of the largest platforms for energy technological advancement within a government owned sector. For example, in the United States public transportation is a multi-billion dollar industry, yet fuel efficiency has yet to change in public buses for the last thirty years (Li, Kahn, & Nickelsburg 2015). In addition the need for transportation continues as the world population rises and urban communities grow. With the heavy focus on private automobiles as the primary mode of transportation, streets are becoming highly congested leading to individuals’ time wasted in traffic as well as large fuel emission rates (Li, Kahn, & Nickelsburg 2015). Public transportation is a great source in cutting roadway congestion and lowering emission rates at a time when governments are looking to enact greener policies.

6.2 Modes of Public Transportation

Public transportation is extremely broad in its span; it moves travelers across land and water. Looking at land alone, we find multiple transportation systems in existence. The major land transportation systems include buses, railways, tramways, streetcars, Light Rail Transit (LRT) systems, and metro systems (Vuchic 2013). In this report, the focus will be on Bus Transit Systems, for buses are “the most widely used transit technology” with almost every city containing a bus transportation system (Vuchic 2013). This will allow us to narrow our investigation down to the incentives, criteria, and problems relevant to the most-widely used transportation system within the world. Moreover, it is arguable that the insights found in bus transit will carry over to other public transportation areas.
6.3 Diesel Fuel Today

Traditionally, bus engines operate on diesel fuel. Issues arose with the use of petroleum-based fuels for transportation, for they have historically been expensive as well as increase dependence on oil exporting countries. As a result, research began to find a lasting, cheaper, and healthier solution. From this, new technology developed, which I will discuss further in the next section. Today we are still looking for a reliable alternative to replace diesel-reliant public transportation systems, including promising alternatives utilizing battery technology. Currently, oil and diesel are at unprecedented low prices due to oversupply (Puko 2015). The market has not cleared due to suppliers competing for market share and in result, refusing to curb production (Puko 2015). With demand much below supply, oil and diesel prices have dipped with U.S. diesel prices down to $2.445 per gallon and gas down to $2.09 per gallon (U.S. Energy Information Administration 2015). But uncertainty remains on the future of the oil industry, so governments would be smart to continue their interest in new energy technologies.

6.4 Major Advancements Today

Today the primary energy innovations in public transportation concern electric vehicles, hydrogen fuel cells, and hybrid vehicles (The National Academies 2015). Of these technologies, both hybrid and electric vehicles entail battery use. Hybrid buses usually operate using either lead-acid or nickel-metal hydride batteries (Ranganathan 2006). Other popular technologies include compressed natural gas (CNG) buses and solar powered buses. The science behind batteries used to power hybrids and electric buses is explained in Section 2 of this paper. In addition, the use of these technologies in the private automobile sector is explained in Section 5 of this paper. Next, investment in alternative fuel and new energy technologies is discussed. In particular, we will analyze the procurement of CNG, hybrid, and electric buses.

6.5 Case Studies

To illuminate the differences between countries public transportation systems and how this
affects the incentives for innovation in public transportation, we will present two separate cases comparing the United States’ and China’s public bus systems. From these case studies, we will see how different countries are looking to innovate in the future.

In the United States and China, buses account for the largest portion of public transportation. Buses gross the most revenue of all public transportation systems in the United States, accounting for 38.4% of revenue from public transportation in 2011 (American Public Transportation Association 2013). In addition, public buses account for 38 percent of all passenger miles in the United States public transportation system (Li, Kahn, & Nickelsburg 2015). In China, the number of public buses in operation has increased significantly in the last thirty years with the country now containing over 500,000 city buses (China Market Research Reports 2015). Beyond their wide-use, buses are a great source to study due to their low acquisition costs compared to other major transportation networks such as railway systems, which require complex infrastructure in addition to the purchase of vehicles.

6.5.1 Public Transportation within the United States

First, we will look into investment in new energy buses within the United States. Public transportation systems within the United States are generally administered by local public transportation agencies, which are limited to purchasing vehicles from a small number of manufactures (Li, Kahn, & Nickelsburg 2015). There are a total of 800 transit agencies accounting for the 65,000 buses (Xu et al. 2015). Currently, agencies are slowly starting to purchase new energy buses. As of 2012, there are 9253 compressed natural gas (CNG) buses, 3974 hybrid-diesel buses, 174 hybrid-gasoline buses, and 52 battery-electric buses. (Xu et al. 2015). Electric buses and hybrid buses are slowly gaining popularity within the United States, yet the number of CNG buses significantly outnumbers electric and hybrid buses. Electric and hybrid buses are more fuel efficient and less harmful to the environment making them a better long-term investment (Li, Kahn, & Nickelsburg 2015). The research in the last decade has
shown, that CNG buses are only a temporary solution to the diesel fuel dependence with electric vehicles and hybrids being the future of public transportation. However, the United States seems to be largely stuck within the CNG buses stage of advancement due to government policy regulations. This policy regulation includes the “Buy America” mandate enacted in 1933, which places limitations on agencies when they procure buses, (Li, Kahn, & Nickelsburg 2015). The mandate requires government agencies to buy buses manufactured within the United States. Without being able to acquire technology internationally, this places a limit on the advancement of public transportation technology as well as leads to domestic companies charging higher prices due to reduced competition. For example, “buses in Tokyo and Seoul are half the price of U.S. buses and buses produced in China are even cheaper,” (Li, Kahn, & Nickelsburg 2015). Therefore, the local transportation agencies often buy inefficient, expensive products as opposed to purchasing advanced bus technology being developed in China, Japan, and South Korea. Only 1.49 percent of the buses purchased by the US transportation agencies from 1997 to 2011 were from foreign companies (Li, Kahn, & Nickelsburg 2015). This is due to a specific clause in the Buy America Mandate, which requires that final assembly take place within the United States and a minimum of 60 percent of the cost of manufacturing occurs within in the United States (Li, Kahn, & Nickelsburg 2015). Therefore, the bus manufacturing industry comes down to a few large companies. A little less than 50 percent of the bus manufacturing is in the hands of only two American companies, Gillig Corporation and New Flyer of America (Li, Kahn, & Nickelsburg 2015). Overall, the Buy America mandate has many of the same hindrances to innovation as tariffs. On top of the incentive to buy domestically, transportation agencies are encouraged to rebuy from the same companies to ease and centralize replacement parts and maintenance processes (Li, Kahn, & Nickelsburg 2015). This effectively locks agencies into buying from the same few companies. Therefore, a transportation agencies options for investing in new energy technology is dependent upon the vehicle technology offered by their supplier if the agency wishes to not alter the maintenance process.
The federal government controls transportation agencies by making them adhere to its policies in order to receive funding. Transportation agencies receive funding from both the Urbanized Area Formula Program and the transit capital investment program. The first assigns funding based on formulas that vary by a city’s size. If the population is below 200,000 people then the formula is based on population and population density. If the city is larger than 200,000 people then the formula is based on bus miles, passenger miles, and population. The transit capital investment program funds one-time projects such as the replacement of older buses (Li, Kahn, & Nickelsburg 2015). To receive funding from these programs, transportation agencies must follow the Buy America mandate.

Additionally, local transportation agencies are subject to the requirements of the Clean Air Act (Li, Kahn, & Nickelsburg 2015). These standards have lead some to switch from diesel buses to CNG buses and hybrid buses. A prime example is Los Angeles, which replaced all of its diesel buses with CNG buses in 2011 (Weikel 2011). Los Angeles wanted to reduce greenhouse gas emissions and improve air pollution. After the switch, the Los Angeles County Metropolitan Transportation Authority had 2,221 CNG buses, one electric bus, and six gas-electric hybrid buses (Weikel 2011). The conversion was estimated to yield 80 percent less carcinogenic particulates in the atmosphere and 300,000 less pounds of greenhouse gases a year (Weikel 2011). The downside to acquiring the CNG buses was the high price of the vehicles, yet the lower fuel costs softened the high acquisition cost. This investment shows the popularity of CNG buses compared to electric and hybrid buses within the United States. Although the reason for only purchasing a few electric and hybrid buses was not given, presumably it was the high cost of battery technologies compared to CNG buses.

Analysis of the United States transportation system shows the local transportation agency’s decision on what energy technology to invest in is affected by several factors. Agencies look to the price of energy technology, the cost of fuel, and resulting emission levels (Li, Kahn, &
Nickelsburg 2015). For a standard 40-foot bus, the upfront cost for a diesel bus is about $300,000, $330,000 for a CNG bus, and $450,000-$550,000 for a hybrid bus (Li, Kahn, & Nickelsburg 2015). In terms of fuel efficiency, hybrid buses are the most efficient, diesel the second, and CNG the worst (Li, Kahn, & Nickelsburg 2015). An important additional cost of CNG buses is the requirement of a re-fueling and maintenance station that is not necessary for traditional buses. The main draws to CNG buses are the reduced cost of fuel and lower greenhouse gas emissions, although the buses are less fuel-efficient than diesel buses. Hybrid buses have the lowest impact on the environment compared to CNG and diesel buses, but the gap between alternative energy fuels and diesel is decreasing (Li, Kahn, & Nickelsburg 2015). It is also of note that increased federal funding leads to increased investment in hybrid buses, for the extra capital allows agencies to cover the 50 percent higher initial cost (Li, Kahn, & Nickelsburg 2015).

Another example of CNG popularity is its inclusion in the Colorado state program. The RFTA (Roaring Fork Transit Authority) is Colorado’s second-largest public transportation system (Mitchell 2015). In 2014, RFTA served a total of 4.9 million people in Colorado’s Western slope (Mitchell 2015). In 1998 the area was suffering from congestion due to vacationers driving to the ski slopes from their hotel rooms. RFTA originally planned to build a light rail system to counteract the problem, yet after research, it was determined the project would not receive adequate government funding based on the population density (Mitchell 2015). In 2003, RFTA decided to build a BRT (Bus Rapid Transit) system since it was a cheaper alternative to a rail system. The BRT project development started in 2009. The planning process was particularly complex because of the area’s severe weather conditions. The buses would face below zero temperatures and altitudes of 8000 feet (Mitchell 2015). Only about 18 months before the BRT was to go into operation, it was decided that CNG buses would be used for the BRT system. At the time diesel fuel prices were at historic highs causing issues for the RFTA in meeting its cost targets (Mitchell 2015). The RFTA decided to acquire CNG 22 buses, which
would save RFTA $128,000 a year and $1.54 million over the lifetime of the buses (Mitchell 2015). Beyond fuel costs, other factors favoring CNG buses were “its availability as a domestic fuel source, increasing natural gas supply, lower price volatility, and fuel diversity,” (Mitchell 2015). The major hesitation in choosing CNG buses for the BRT system was the RFTA’s history with CNG buses. In 1991, the RFTA acquired one diesel bus and had it converted to run on natural gas. The bus was not able to work in the high altitudes, and therefore, it had to be converted back to a diesel engine before being put into operation (Mitchell 2015). The loss on this investment made the RFTA concerned that the CNG technology would again fail in the high altitudes. Therefore, the RFTA sought the advice of Cummins Westport (Mitchell 2015). After discussing the use of modern CNGs in other high altitude locations with Cummins Westport, the RFTA went forward with the decision to use CNG buses. This demonstrates one of the major problems with investment in new energy technologies. By investing in new technology, agencies risk losing out on their investment if the technology proves to be unreliable. Therefore, agencies must not only spend money to invest in new technologies, but also spend time and money to ensure these technologies will work within their specific transportation system. RFTA also asked Cummings Westport to advise them on the quality of natural gas fuel in the area. Poor natural gas quality could lead to declined engine performance in their buses. Cummins Westport found that the natural gas was of good quality, which allowed RFTA to move forward (Mitchell 2015). Rather than put all 22 buses into operation simultaneously, RFTA tested four of the buses in the 2013 Winter X Games (Mitchell 2015). It is unclear if these were used to manage the event’s demand needs or if RFTA wanted to demonstrate its use of alternate energy technology to the public. The buses were purchased from Gillig, one of the two major bus manufactures in the United States. Through testing, the RFTA learned that the buses would need “plug-in engine block heaters” in order to start the low temperatures (Mitchell 2015). Despite the minor problems RFTA faced with the technology, the CNG buses were considered a success. After completing testing at the Winter X games, the 18
other CNG buses were purchased from Gillig. The buses were delivered in July 2013, and the BRT system went into operation on September 2013 (Mitchell 2015).

Before inserting the CNG buses on to the street, RFTA discussed the decision with the public and its Board of Directors. The conversation focused on three major concerns: “cost, technology familiarity, and environmental impact,” (Mitchell 2015). Many were concerned with the increased cost of CNG buses, but the agencies analysis showed that the lifetime savings on fuel price would overcome the initial cost of the buses (Mitchell 2015). In addition, many were concerned about the use of CNG technology based of the 1991 test run, yet after noting the vast improvements in the CNG technology and that CNG buses were becoming popular alternatives to diesel with rising oil prices, this fear was overcome. In fact, to date about “25% of all new transit vehicles purchased in the United States are being equipped with CNG engine technology,” (Mitchell 2015). In terms of environmental impact, the greenhouse gases from CNG buses from well-to-wheels is 20 percent less than diesel fuel buses based off RFTA’s findings (Mitchell 2015).

In addition to accounting for the costs of the new buses, RAFT also had to look into building a CNG fueling station, which it enlisted Trillium CNG to build (Mitchell 2015). The fueling was to be done indoors to provide seamless procedures between traditional and CNG buses (Mitchell 2015). Along with building the fueling station, the RAFT and Trillium had to deal with the local fire marshal to meet all safety codes. This led to modifications in the design. The inclusion of CNG increased the cost of the BRT system by $16.4 million (Mitchell 2015). The BRT system was paid for using three sources: “FTA grants ($9.4M), Qualified Energy Conservation Bonds issued by the State of Colorado ($6.65M), and a $365k grant for the fueling station from the Encana Corporation,” (Mitchell 2015).

The program is viewed as a success. Despite experiencing a few issues with the technology, the buses have been very reliable. In addition, the public has responded very well to the use of
alternative energy technology and especially appreciates how quiet the buses are compared to diesel engines (Mitchell 2015). The RFTA recently decided to buy a CNG motor coach to increase the use of CNG technology within their transportation system.

Now, we will shift the focus to China, where battery focused technology in the form of hybrid and electric buses are at the forefront of investment. As will be demonstrated, this is largely due to China’s policy initiatives to enact greener technologies.

### 6.5.2 Public Transportation within China

China is a growing country within the transportation industry. Much of its growth has been due to “foreign direct investment” starting in the 1990s (Tang 2009). Foreign investment included “alliances and joint ventures between international automobile manufactures and Chinese partners,” (Tang 2009). Due to the benefits of international involvement, China has become one of the primary innovating countries within the automotive industry. International involvement however has led to the foreign dominance of international manufactures within China, but as will be explained through the following cases, China has sought to increase manufacturing domestically through demonstration programs. Demonstration programs are when the government invests in new technology to bring it to the public’s attention, and therefore, stimulates the purchase of this technology within the private sector. We will discuss China’s demonstration programs in Jinan and Shenzhen later on in this section. In the early 2000s China was looking to lower greenhouse emission rates by having major cities invest in public buses that use “liquefied petroleum gas (LPG) or compressed natural gas (CNG),” (Gan 2002). However, today research has focused away from CNG technology and toward new energy buses such as hybrid, electric, and fuel cell technology due to their lower greenhouse emission rates. In 2014, 27,000 new energy buses were sold signaling a 160 percent increase from 2013 (China Bus Industry Report 2015). Of the buses purchased, 47.5 percent were plug-in hybrids with lower prices (China Bus Industry Report 2015). In addition to plug-in hybrid buses, battery
electric buses also showed an increase in popularity due to improved technology and government policies. Battery electric buses accounted for 47 percent of the buses sold (China Bus Industry Report 2015). In 2013, battery electric buses only accounted for 16 percent of buses sold (China Bus Industry Report 2015).

In order to determine the effectiveness of a country’s public procurement system in implementing lasting innovations, we will look at the Energy-saving and New Energy Vehicles (NEV) Demonstration Promotion and Application Program in the cities of Jinan and Shenzhen. The NEV demonstration program lasted from 2009-2012 and sought to install a minimum of 1000 NEVs in 25 cities across China (Li, Georghiou, & Rigby 2015). The technologies classified as NEVs include “hybrid vehicles, plug-in hybrid electric vehicles, battery electric vehicles and fuel cell vehicles,” (Li, Georghiou, & Rigby 2015). The government saw a need for NEVs within China as the population was growing quickly, so battery powered vehicles were highly in demand. China imports most of its engine-related technologies despite being the largest market for automobiles (Li, Georghiou, & Rigby 2015). Therefore, by placing an importance on NEVs, the government could stimulate the growth of a domestic automotive industry. In addition to stimulating the economy, the program would also aid China in its goal to cut greenhouse gas emissions (Li, Georghiou, & Rigby 2015). China made emission reduction one of its top priorities with the government recently agreeing to “cut its greenhouse gas emissions per unit of gross domestic product by 60-65% from 2005 levels under a plan submitted to the United Nations,” (Duggan 2015).

In 2009, at the start of the NEV demonstration program, Jinan was to host the National Games of China. Jinan is the second largest city in the Shandong province with a population of 3,527,566 people (Shandong 2010). The city used the high-traffic event to promote the NEV demonstration program (Li, Georghiou, & Rigby 2015). The demonstration program in Jinan successfully implemented new battery technology in the form of hybrid vehicles, but, as will be
seen, overall the NEV industry was not stimulated.

The public bus system in Jinan is operated by a state-owned company rather than being directly under local government control. Therefore, the Jinan government subsidized the state-owned company with an additional 40 million yuan in 2009 for the procurement of NEVs (Li, Georgiou, & Rigby 2015). The Jinan government mandated that the vehicles selected must be “12-meter-long diesel-electric hybrid models with paralleled batteries, and their exhaust emissions should be less than China’s national Tier IV standard,” (Li, Georgiou, & Rigby 2015). In addition, the central government also provided the company with subsidies to fund the implementation of the program. With these subsidies the transportation operator and government procurement agency put together a tender offering that allowed the company to procure 100 hybrids buses to be used for the games and then later integrated into the city’s transportation routes (Li, Georgiou, & Rigby 2015). Hybrid buses were chosen over electric buses for the project for two main reasons. First, the technology behind the hybrid buses was more advanced, so it was believed the technology would perform more reliably. Second, the buses were a less expensive option. An electric bus would have cost the operator 1.2 million yuan compared to .95 million yuan for a hybrid vehicle once subsidies were applied to the prices (Li, Georgiou, & Rigby 2015). On top of the higher price, electrical vehicles require charging stations to be built around the city. Based on the subsidies provided to the operator, these charging stations would have been too expensive to purchase at a cost of 30 million yuan per station (Li, Georgiou, & Rigby 2015). Therefore, hybrid buses were chosen due to their better affordability and advanced technology. After deciding upon the NEV technology to be implemented, a tendering offer was sent out by which two companies were chosen to supply the buses. A company within the local area would provide 80 percent of the buses, while a company outside the Jinan area would provide the other 20 percent (Li, Georgiou, & Rigby 2015). After interviewing Jinan officials, it was found that the local supplier was favored within the decision process because the provincial government would provide subsidies if the supplier
was chosen from within the province (Li, Georghiou, & Rigby 2015). The provincial government’s hope was that the production of NEVs within the province would stimulate the growth of NEV industry locally (Li, Georghiou, & Rigby 2015). This shows how subsidies affect investment decisions. Companies will act in a way that provides the least cost to them in order to produce the largest return on investment. Once the vehicles were in place, they were quite successful. They maintained the capability to operate as frequently as traditional buses and produced a 26 percent oil savings (Li, Georghiou, & Rigby 2015). This led to the procurement of another 100 buses into the government transportation system in 2010. This is an example of a company making an investment, and due to the proven reliability of the technology, deciding to purchase more of the technology. By testing the technology from this initial investment, the company was able to eliminate the worry of technological malfunction causing this hindrance to investment to disappear.

The NEV demonstration program was largely successful. The program led to the local supplier improving its technology, which allowed the NEVs to be sold at more affordable price. When a second round of buses was procured in 2010, the investment was much cheaper for the operator (Li, Georghiou, & Rigby 2015). By lowering the price of NEVs, the program paved the way for future installments of hybrid buses into both the public and private sector. In addition, the hybrid buses were reported to have slightly improved the efficiency of the transportation system, although no data could be found to support this statement (Li, Georghiou, & Rigby 2015). Also, the public reported becoming more aware of NEV technology, one of the main goals of the project, for the buses were used in four of Jinan’s most popular bus routes (Li, Georghiou, & Rigby 2015). The extent and impact of this public awareness is unclear. The only goal that was not reached was that the NEV industry was barely stimulated, if at all, beyond aiding the development of the local supplier. The local supplier reached a record total of 1500 NEVs sold in 2013, and further, was able to extend its sales beyond regional buyers (Li, Georghiou, & Rigby 2015). In contrast to the local suppliers success, Jinan is one of the slowest growing areas
of the 25 participants in the demonstration program. This is surprising for it was one of the first and largest adopters of the program (Li, Georghiou, & Rigby 2015). One belief is that the economy, since not very established in the NEV industry, was not ready to take on the risk associated with further establishment of this industry due to uncertainty with future government policy. Therefore, the program was successful in Jinan despite its goal of stimulating the NEV industry.

Similarly, a program was implemented in Shenzhen where there was a large investment in battery-powered electric vehicles. The program not only was successful to promoting NEV technology, but also stimulated the local NEV industry. The program was implemented for the 2011 Universiade. Universiade is a major sporting event organized by the International University Sports Federation (FISU) where college athletes from around the world compete against each other in their sport of choice (FISU 2015). The event is second only to the Olympic games (FISU 2015). The use of citywide events when implementing new energy technology into public transportation is a common theme for many Chinese cities. Major events allow the city to focus on its public transportation efficiency in preparation for the event as well as put the technology in front of the largest number of people. Examples of this are the 2008 Olympics in Beijing and the 2012 EXPO in Shanghai (Li, Georghiou, & Rigby 2015).

Shenzhen is a city that is known for its rapid technological development, which many call the “Shenzhen Speed,” (Li, Georghiou, & Rigby 2015). In the last thirty-five years, the city has grown from a small town with a population of 30,000 people to an internationally recognized city (Shenzhen Government Online 2015). In 2011, it had the fourth largest GDP of any Chinese city, and it was listed it as the most innovative city in China by Forbes (Li, Georghiou, & Rigby 2015). The city has a similar government structure to Jinan with “an administrative group led by the vice-mayor with heads of the local Development and Reform Commission (DRC), Bureau of S&T, Bureau of Finance and Commission of Economy and
Informationalization” (Li, Georghiou, & Rigby 2015). However, in contrast to Jinan, the Shenzhen area was much more established in the NEV industry before partaking in the demonstration program. Its major two NEV manufacturers, BYD and Wuzhoulong Motors, were chosen to be the suppliers (Li, Georghiou, & Rigby 2015). BYD was founded in 1995 as a battery manufacturer. Later, it began selling automobiles and added upper-stream electric car manufacturing to its business. In 2009, BYD earned the approval to manufacture coaches, and today, it is a privately owned company that specializes in both information technology and automobiles (Li, Georghiou, & Rigby 2015). BYD controls almost all of the upper-stream suppliers for the NEV industry making it a powerful player in that industry. The company also has offices across the country to gain business regionally in the sales of its battery and electric vehicles (Li, Georghiou, & Rigby 2015). In contrast, Wuzhoulong Motors was founded in 2000 as an energy-saving coach manufacturer. The company stands out due to its superior technology in both the materials with which it manufactures its vehicles as well as its “smart hybrid motor controller, which integrates an energy controlling system, automatic clutch controlling system and information management system,” (Li, Georghiou, & Rigby 2015). Its products save about 25-30 percent more oil than traditional diesel vehicles (Li, Georghiou, & Rigby 2015).

In preparation for the 2011 Universaide procurement, Shenzhen decided to first test the NEV technology in a pilot program. The government provided 50 million yuan for the purchase of 30 hybrid buses and 20 electric cars (Li, Georghiou, & Rigby 2015). BYD and Wuzhoulong Motors were chosen to be suppliers for the pilot because they were local companies known to have quality products. Similar to the Jinan demonstration, the government wanted to choose a supplier that would benefit the city’s local GDP. The 30 buses would be implemented into three bus lines across the city, and the 20 electric vehicles would be given to various government bodies (Li, Georghiou, & Rigby 2015). To complement the 20 electric vehicles, charging stations were also provided. The electric cars ended up being rented as opposed to procured due to a failure to gain permission for the procurement of the electric vehicles. The government
ended up renting “a plug-in hybrid compact sedan” known as a “F3DM” “for 80,000 yuan for two years” (Li, Georghiou, & Rigby 2015). No reason was given about why plug-in hybrid and electrical vehicles were chosen, yet as previously noted, these vehicles are included on the list of vehicles subsidized by the central government, which is likely the reasoning behind their selection.

From the success of the pilot, the government decided to continue its contract with both BYD and Wuzhoulong Motors for the demonstration in 2011. Each supplier offered the government several NEV models to choose from for the demonstration. BYD proposed its F3DM hybrid compact sedan, its E6 pure electric sedan, and its K9 pure electric coach “with a fast charging function and a solar energy panel on top to provide additional electricity,” (Li, Georghiou, & Rigby 2015). The K9 model is particularly impressive due to its ability to be fully charged in an hour and its ability to operate on two-thirds the energy needed for traditional vehicles. Wuzhoulong Motors proposed its FDGFCL10 model, “a ten-seater hydrogen fuel cell van with a maximum speed of 40 km/h, featuring a smart inductive electricity assisted steering system, ‘stepless’ driving system and a permanent magnet synchronous motor,” (Li, Georghiou, & Rigby 2015). The second suggested model was its “FDG6120SDEG, a hybrid coach model equipped with lithium iron phosphate battery featuring an automatic series-parallel hybrid driving system, stepless series-parallel transmission function, automatic mechanical transmission technology and a diesel engine that met the requirement of the Euro-III emission standard,” (Li, Georghiou, & Rigby 2015). Its third option was the “FDG6700EV, a pure electric coach model equipped with an engine produced by Shanghai Dajun, and a lithium iron phosphate battery,” (Li, Georghiou, & Rigby 2015). The government decided to procure 200 K9 electric buses and 300 electric taxis from BYD and 1511 energy-saving and new energy buses from Wuzhoulong Motors. Wuzhoulong Motors ended up creating six new vehicles from the original three models it presented to the government. These six vehicles included “1350 hybrid single-layer buses, 20 hybrid double-layer buses, 53 pure electric buses, 26 pure electric
vans, 60 hydrogen fuel cell sports venue vans and 2 hydrogen fuel cell coaches,” (Li, Georghiou, & Rigby 2015). In particular, the 20 hybrid double-layer buses and the 26 pure electric vans were brand new inventions in China. Therefore, not only does investment in new technology improve that technology, but it also stimulates the invention of new technology to meet investors’ needs. The 2,011 vehicles were implemented into the transportation network preceding Universiade. Due to the decision to procure electric vehicles, the government also had to put in place a plan to set up a charging station system across the city. In order to accomplish this, the city brought in a local company, the Shenzhen Lineng Charging Station Co. Ltd. The company upgraded the 25 stations already in existence and added 34 more stations across the city (Li, Georghiou, & Rigby 2015).

Similar to the Jinan demonstration program, the program resulted in the participating suppliers improving their NEV technology or inventing new products to fit the government’s needs. In addition, the improvements in technology allowed the suppliers to sell the NEVs at a lower cost, and the public reported being more aware of NEV technology (Li, Georghiou, & Rigby 2015). However, in contrast to Jinan, the Shenzhen demonstration had a much larger impact on the local economy. All of the 2011 vehicles became a permanent part of the transportation system. The Universiade procurement was only the start of the demonstration program in Shenzhen; it served as a successful base case for future implementation of NEVs into the public transportation system. By 2012, Shenzhen planned to have 24,000 NEVs implemented into both the private and public economy with “50 charging stations for buses, 2500 charging piles for government vehicles, 200 charging stations and 30,000 charging piles for the public,” (Li, Georghiou, & Rigby 2015). Due to the success of the program, Shenzhen is looking to invest further in new energy industries such as “nuclear, solar, wind and bio-energy technologies and electricity storage technology,” (Li, Georghiou, & Rigby 2015). This again shows how investment in technology leads to further investment and research. The vast success of the program in furthering both the NEV industry and other alternative energy resources in the
region earned Shenzhen the title “2011 Best Participant City in the NEV Demonstration Program,” (Li, Georghiou, & Rigby 2015). Shenzhen’s large investment and success with battery-powered electric buses demonstrates the strong future of battery technology within public transportation. The city is one of the leading hubs for innovation, and therefore, it serves as a test case for the world. It is only time before the success of the technology within Shenzhen spreads across other Chinese cities and ultimately to other countries.

6.6 Case Study Applications

From the case studies examined above, the incentives, criteria, and problems associated with public transportation can be discussed. The major incentives for innovation within public transportation systems seem to be to lower greenhouse emissions. Both China and the United States use this as the reasoning to switch to new energy technology. Often this incentive arises from a larger green policy, which places standards on vehicle emissions. In addition, the United States within the BRT RAFT case actually used high diesel costs as an incentive to innovate. However, this incentive is not applicable today, for diesel prices are at all time lows due to the oversupply within the industry. Therefore, we will assume this no longer holds in the 2015 market.

The criteria for investment in new energy technology are government subsidies that support innovation and major events that put a focus on the improvement of public transportation. Transportation operators are much more likely to buy innovative technology if the government will pay for this acquisition. The major cost of investing in new technology comes from the initial acquisition and supporting technology. Normally after the initial stage, new energy vehicles provide cheaper fuel costs. In addition to government funding, many of the innovation projects correlated with public events that would cause a transportation operator to improve public transportation to prepare for anticipated high demand of its services. In China this was important, for the demonstration program, which means it sought to introduce the product to the
public in order to spark the technologies popularity within the private sector. In the Colorado case, the use of the buses appeared to be more of a need for buses to fulfill demand for the event, yet the coincidence is still noteworthy. Further research would need to be done to see if citywide events correlate with innovation in new energy technology. It seems that large public events act as a catalyst by supplying the need for improvement beyond the many positive benefits of new investment.

The problems that accompany innovation are the high initial expenses, technological malfunctions, and barriers to entry. Sufficient government funding can solve the high initial expenses issue. As noted earlier, investment in hybrid buses increases as federal funding of public transportation increases. In addition, we saw in China that investment in new energy technology allows suppliers to improve their technology, and in turn, reduce its price for future investors. Technology malfunctions are a given with new technology. Agencies should do their research before investing in new technology to make sure they do not experience unforeseen problems. Companies and governments seek to avoid profit loss, so the risk of the technology failing is a major concern and hindrance to investment in new energy technology. The last problem is barriers to entry, for they impede the incentive to innovate as can be seen in the United States. Barriers to entry include the Buy America mandate as well as operators tendency to get locked into a certain supplier to ease maintenance and part replacement for its vehicles. Both of these barriers lower market competition. When a few sellers hold power over the market, they are not pushed to innovate yet enjoy high prices. If these sellers do not innovate, then transportation agencies are limited in their ability to invest in new technology by being “locked” into these few suppliers.

The question still remains where the future of public transportation is heading. We believe China, one of the countries at the head of innovation in vehicles, forecasts the future more accurately than the United States, which has been limited by the Buy America mandate. The
major technologies to date include hybrid buses, electric buses, hydrogen fuel cell buses, and CNG buses. We believe countries will invest primarily in the near future in hybrid buses, for they are cheaper and more reliable currently than electric bus technology. Hybrid buses are more fuel-efficient and have less emissions compared to diesel and CNG, making them better long-term investments. However, we believe electric buses will be the primary mode of innovation once electric bus technology is further improved. For example, Shenzhen made the decision to invest in electric vehicles. It is the most innovative and growing city of all those examined. The city already contained some charging stations to help lower the initial acquisition cost. Once cities are able to make investment in charging stations and the price of electric buses decreases with improvements in technology, we believe electric buses will become quite popular within public transportation. With hybrid and electric buses being the way of the future, the research behind automotive batteries will become ever more important. The longer electric buses can last without recharging and the faster this recharging can take place, the more feasible this technology becomes to integrate into existing transportation systems. Therefore, future research should be focused on improving battery technology to allow widespread implementation of electric buses. Such a movement would solve a large portion of the world’s greenhouse emissions issue and decrease reliance on oil-exporting countries.

7 Grid Storage

The energy grid is the system by which energy produced at plants gets transferred to homes, businesses, etc. According to the energy department, it is “a complex network of power plants and transformers connected by more than 450,000 miles of high-voltage transmission lines” (Pierce 2014). The basic process, explained in the graphic below, is that energy generated in the power plants is adjusted for voltage and then transmitted via lines from substation to substation, then adjusted for voltage again before entering areas of usage. (Pierce 2014) While this system is an amazing feat of engineering, the process is very precarious. With all of the steps needed to
bring power to areas of use, the potential for technical issues in the system or weather related outages is high.

Figure 12: Energy Grid and Flow of Electricity (Pierce 2014)

7.1 U.S. Energy Grid

In the United States, there are three separate grid systems: the Eastern Interconnection, the Western Interconnection, and the Texas Interconnection. (Pierce 2014) Their geographic locations and voltages are given by the figure below. Providers may range from “a not-for-profit municipal entity; an electric cooperative owned by its members; a private, for-profit company owned by stockholders (often called an investor-owned utility); or a power marketer” to “Some federally-owned authorities—including the Bonneville Power Administration and the Tennessee Valley Authority” (Pierce 2014). All of these providers buy, sell, and distribute power (either they provide from their own power plants or buy from “other utilities, power marketers, independent power producers”).
Because of the U.S. electric grid’s age, the Energy Department has to continually invest in keeping the grid reliable. Through The American Recovery and Reinvestment Act of 2009 (Recovery Act), it has spent nearly $4.5 billion to modernize the grid (Pierce 2014). In modernizing the grid, the Energy Department looks to tackle two issues: reliability and resiliency. Reliability means “fewer and shorter power interruptions”, while resiliency means “better prepared to recover from adverse events like severe weather” (Pierce 2014). The figure below shows the estimated economic costs of weather-related power outages (the number one cause of power outages in the U.S.), which range between $18 and $33 billion every year. These costs come in the form of “lost output and wages, spoiled inventory, delayed production and damage to grid infrastructure” (Pierce 2014). Furthermore, as climate change intensifies, weather experts predict an increase in the frequency and intensity of extreme weather events, and, therefore, an increase in the number of outages (Pierce 2014).
7.2 Energy Grid Solution: Storage and Localization

One of the solutions to a better grid system is to have energy storage in localized grids. According to the Department of Energy, energy storage “can address issues with the timing, transmission, and dispatch of electricity, while also regulating the quality and reliability of the power generated by traditional and variable sources of power” (U.S. DOE 2013). Instead of having every piece of the grid solely dependent on an extensive network that is prone to damage at every step, localized pieces of the grid would have their own power supply during an outage. These sometimes-autonomous pieces of the grid are called “microgrid” (Pierce 2014). The technologies that allow a microgrid to function separately from the existing network include small local plants and alternative energy sources such as solar and wind. Most local areas cannot sustain an entire power plant, and therefore they depend on other sources of energy.

In most of these scenarios, storage of energy is imperative. When damage occurs to the entire network, stored energy could be released to cover the local grid for a time. In the case of small local plants or alternative energy sources, these usually do not produce a steady enough amount of energy to cover the microgrid without storage. For example, solar energy is only generated during daylight hours, and therefore needs to be stored in order to provide energy at night. In contrast, wind is usually only abundant during the night, and needs to be stored to even the
distribution of power into the day (U.S. DOE 2013). A power plant small enough to be located close to homes also would not be able to generate enough power to run homes during peak usage. Therefore, energy storage is essential to increasing the reliability and resilience of the grid, as well as to make the process more environmentally friendly.

### 7.3 Storage Technology Variations

There are a multitude of energy storage technologies currently in use. Examples are pumped hydro, compressed air energy storage (CAES), flywheels, superconducting magnetic energy storage (SMES), and batteries (U.S. DOE 2013). The figure below charts what stage of development each technology is currently in. Certain characteristics of each technology make it better or worse suited for different applications. A storage system that is flexible in performance is extremely lucrative, since it can adapt to varied grid requirements and services (Kanellos 2014).

![Figure 3 - Maturity of electricity storage technologies](image)

**Figure 15: Maturity of Electricity Storage Technologies (U.S. DOE 2013)**

CAES systems use energy to push air into underground caverns, pressurizing the air in order to unleash it to create energy when needed. Pumped hydro essentially uses excess energy to push
water to a high elevation reservoir and release it through a hydroelectric turbine when electricity
generation is needed. Both technologies shelter microgrids against technical glitches elsewhere,
and also allow full utilization of renewable energy. While CAES and hydro are “large, mature,
and commercial utility-scale technology”, (U.S. DOE 2013) have strict geographic
requirements, making them unfeasible in many sites. Electrochemical batteries, on the other
hand, are smaller in terms of both their capabilities and their site requirements. Batteries are
used in lower power areas and have shorter discharge times, up to 6 hours (U.S. DOE 2013).
Best of all, they do not need any geographic specifications.

7.3.1 Battery Technology

Within battery technology, there are several different chemistries currently in use in the U.S., as
can be seen in the chart below.

<table>
<thead>
<tr>
<th>Battery Type</th>
<th>Number of 1MW+ Deployments</th>
<th>Largest Installation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lithium Ion</td>
<td>15</td>
<td>40</td>
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<tr>
<td>Sodium Sulfur</td>
<td>11</td>
<td>4*</td>
</tr>
<tr>
<td>Lead Acid</td>
<td>9</td>
<td>36</td>
</tr>
</tbody>
</table>

*There are two 4MW deployments

Figure 16: Number and Size of Battery Installations by Chemistry (U.S. DOE 2013)

While centralized applications exist in various sizes, widespread deployment is hindered
by shortcomings in “energy density, power performance, lifetime, charging capabilities, safety,
and system cost” (U.S. DOE 2013). Lithium ion, the leading battery technology in electric
vehicles, is also the most common chemistry for storage batteries. However, this technology is
suited for discharges under two hours, making it a good source when uninterrupted power is
necessary, whereas sodium sulfur (NaS) batteries can handle discharges up to eight hours, even
if they are behind in energy and power (U.S. DOE 2013). There are other battery chemistries
available, along with developing technologies such as SMES, electrochemical capacitors, thermochemical energy storage, etc. Their properties are listed in the table below (U.S. DOE 2013).

<table>
<thead>
<tr>
<th>Table 3 - Technology Types Source: Advancing Energy Storage</th>
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<tbody>
<tr>
<td><strong>Technology</strong></td>
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<td>-----------------</td>
</tr>
<tr>
<td>CAES</td>
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<td>Pumped Hydro</td>
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<tr>
<td>Advanced Lead-Acid</td>
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<tr>
<td>NaS</td>
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<tr>
<td>Li-ion</td>
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<tr>
<td>Flow Batteries</td>
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<td></td>
</tr>
<tr>
<td>SMES</td>
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<tr>
<td></td>
</tr>
<tr>
<td>Electrochemical Capacitors</td>
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<tr>
<td></td>
</tr>
<tr>
<td>Thermochemical Energy Storage</td>
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</tbody>
</table>

Figure 17: Applications and Challenges of Various Storage Technology (U.S. DOE 2013)
While each type of storage has its strategic benefits and obstacles, li-ion battery storage specifically is at the forefront of grid storage and worth further investments for several reasons. First, the environmental impact of batteries is smaller than that of building reservoirs for hydroelectric storage or caverns for CAES. Second, batteries are quicker and easier to deploy when necessary. Also, battery storage’s cost structure is such that adjustments can be made to purchase only how much storage is needed at a cost effective level for individual parts of the grid system, whereas with Hydro and CAES, large upfront costs are necessary. Li-ion batteries are already widely used in other applications such as electric vehicles, so their previously high production costs are declining due to economies of scale. Tesla’s new Gigafactory mass produces millions of li-ion batteries to shaving costs off individual units.

7.4 Multiple Grid Applications

Due to li-ion batteries’ short high energy density, charge/discharge efficiency, and short period of discharge times (under 2 hours) it is extremely well suited for grid applications of power quality and frequency regulation. Frequency regulation is essentially smoothing “momentary differences caused by fluctuations in generation and loads” (U.S. DOE 2013). The graph below shows that frequency regulation is necessary to smooth out the demand line; energy storage units that are “ready to increase or decrease power as needed are used for regulation and their output is increased when there is a momentary shortfall of generation to provide up regulation. Conversely, regulation resources’ output is reduced to provide down regulation when there is a momentary excess of generation.” (U.S. DOE 2013) So, the distinct characteristics of battery storage make it a perfect fit for this job.
Figure 18: Smoothing Effect of Frequency Regulation (U.S. DOE 2013)

7.5 Economic Feasibility and Incentives

With regards to this functionality, Li-ion batteries have already proved to be economically feasible. In one example from a 2014 conference on electric vehicle batteries, PG&E, a producer of these battery systems, reported that via a 2-megawatt storage system of Li-ion batteries, it was able to provide frequency regulation for 6 hours a day, 11 a.m. to 5 p.m (Kanellos 2014). The system also tracked its own revenues and costs, and showed that it generated net revenue of $318 in September 2014 as a result of the frequency regulation (Kanellos 2014). Apart from the obviously beneficial financial impacts, the system also produces the positive externality of having smoothed renewable energy sources, at no cost, which paves the way for expanding renewable energy in the grid. Critics are skeptical of solar energy because of this added smoothing cost that usually comes from natural gas generators, but with this technology that is no longer a concern (Kanellos 2014).

There are three main fears with Li-ion batteries: cost, safety, and lifespan (Kanellos 2014). As for the first complaint, it’s already been shown that Li-ion batteries are cost efficient in regards
to frequency regulation, and also help renewable energy sources become cost efficient. In terms of safety, certain chemistries in the Li-ion family are prone to thermal sensitivity, but the phosphate family of chemistries is devoid of that problem. As for lifespan, Bud Collins, CEO of NEC Energy Solutions, claimed that Li-ion batteries can be designed and supported to last 20,000 cycles, or about 20 years (Kanellos 2014).

There are also three things that the market demands from energy storage that Li-ion batteries can provide: at least four hours of service, economic viability (especially in areas where government policy does not subsidize storage/renewables), and versatility (Kanellos 2014). With regards to being able to provide at least four hours of service per day, the earlier example of a 2-megawatt Li-ion battery system was running at least six hours per day. As for economic viability, exploration of the breakeven point of Li-ion battery systems will come in the next section, but the previous example of the 2-megawatt Li-ion battery system has actually generated revenue when used in frequency regulation (in this case, for renewables). As for the last demand, the chart below shows that Li-ion batteries are among the most versatile types of grid storage in terms of number of successful applications. It is only doubtful in three of the applications (Kanellos 2014).
Dominance of Lithium-ion batteries and Case Study

As of October 29th, 2015, Li-ion batteries account for 70% of the grid storage market by power, and 39% by energy (Frankel 2015). Power is essentially the capacity of the storage; in this case, it is how much electricity (usually in Megawatts) can be stored at one time. Energy is the total amount of flow through the system in a given time frame, so it increases as time goes on, and is basically a measure of usage of that storage (Frankel 2015). They are also the fastest growing technology, with a compounded annual growth rate (CAGR) since 2011 of 48% in power capacity and 62% in energy capacity, whereas the grid storage market as a whole has shown CAGR of 33% and 20% for power and energy, respectively (Frankel 2015). The chart below shows global deployments of grid storage by technology. Most of that growth is happening in developed countries, lead by Japan and the U.S. While Japan leads the market in energy capacity deployed, the U.S. leads in proposals, with 350 projects and 776 Megawatts deployed or underway (Frankel 2015). However, AES Energy Storage is looking past these major players...
and into grid storage opportunities in Ireland, the Netherlands, Dominican Republic, and Philippines, which are extremely young markets (Frankel 2015).

![Figure 20: Grid Storage Deployments by Technology (Frankel 2015)](image)

7.6.1 Environmental Impact and Case Study: Tesla

In the U.S., Tesla is one of the leading manufacturers of Li-ion batteries, and they do so with the smallest footprint possible. Tesla’s Gigafactory, set to begin producing Li-ion cells in 2017, is powered by renewable energy sources, and hopes to have net zero energy usage (Tesla Gigafactory 2014). From being produced with the lowest possible environmental damage, to making renewable energy usage at the grid smooth and cost efficient, Li-ion batteries are an extremely environmentally friendly option. The benefits of storage is that they essentially afford “flexibility without burning fuel”, that is they can use unreliable sources of energy without having to burn more fuel at peak times to keep up with demand (St. John 2014). Tesla also chose Li-ion because it does not expect a better technology alternative in the next 10 years, so by producing the batteries on a massive scale, they are simply making them less expensive. Because of Li-ion’s widespread use as the battery chemistry of choice in so many applications outside grid storage (consumer electronics and electric vehicles (St. John 2014)), it makes the
use of them in grid storage much more economically viable than a less common technology.

To look at a deeper field study, we can look to AES Energy Storage, which is betting on Li-ion batteries as “the technology to go to for the next seven to ten years” (St. John 2014) (just like Tesla). As of late 2014, most of the company’s 200 megawatts of Li-ion grid storage projects focused on the short-duration applications such as frequency regulation, but the company claims that almost half of its roughly 1,000 megawatts of upcoming projects are “long-duration” ones—meaning they are “capable of providing energy for two to four hours” (St. John 2014).

7.6.2 Cost-Benefit Analysis

In terms of a cost-benefit analysis, CEO of AES, Chris Shelton compared the costs of a two-hour battery to the costs of a gas-fired power plant (what usually generates the needed electricity at the grid’s peak energy and ramping demand time). He claims that their two-hour unit costs less than $1,000 per kilowatt, making it less expensive than the traditional gas alternative. It also makes Li-ion less expensive than sodium sulfur (NaS) and flow batteries, both of which have similar application abilities to Li-ion (St. John 2014).

However, what Chris Shelton was referring to was a strict estimate of variable cost (dollar-per-kilowatt cost). To understand the total costs, the battery’s lifespan and discharge capacity over that lifespan has to be taken into consideration. These factors are influenced by not only how the batteries are constructed, but also by how they are used, so estimates of this total cost (an energy estimate of per-kilowatt-hour) vary immensely (St. John 2014). AES did not provide any estimates of that, but claimed that they only offer the per-kilowatt cost since that is how the rest of the market (i.e. gas power plants) looks at cost (St. John 2014). Only time will tell if these total costs of Li-ion batteries make them economically sustainable for grid storage applications.

There are macro factors that will affect the breakeven point between traditional gas power plants and Li-ion batteries (Gas, li-ion market), but many companies are going full speed ahead with this technology for both short and long term applications. The price of gas is the main
factor in the variable costs of gas-fired power plants (St. John 2014). Therefore, depending on
the price of gas, Li-ion battery storage may be more or less expensive than gas plants. In the last
year and a half, gas prices have fallen dramatically (by more than half), making Li-ion relatively
more expensive. However, before this drop in prices, many companies banked on Li-ion for
long-duration projects along with AES (St. John 2014). For example, “A123 Energy Solutions,
the grid-scale arm of lithium-ion battery manufacturer A123… has launched a long-duration
storage system that it has deployed in Spain and Japan”. A123 was an American company
acquired by China’s Wanxiang Group, and sold to Japan’s NEC for $100 million (St. John
2014).

7.7 Future Opportunities

The largest future opportunity seems to be in long-duration storage – storage that can provide
hours of capacity – rather than short applications such as frequency regulation (which is Li–
ion’s primary application). According to Mid-Atlantic grid operator PJM, “the global market for
replacing gas-fired peaker plants is some twenty to forty times larger” than the market for
frequency regulation (St. John 2014). As can be seen by Tesla’s Gigafactory, more demand
means more production, which means economies of scale, which means lower costs of batteries.

As we have seen, grid storage is essential in supporting the energy grid by storing energy at low
demand times, for use at peak demand times in accordance with the goal of increased reliability
and resilience, at a small environmental footprint. The dominant type of grid storage is lithium-
ion battery technology, which not only replaces gas plants in meeting peak demand, but also
smooths renewable energy sources such as solar and wind. With Tesla producing lithium-ion
batteries in its Gigafactory with net zero emissions and at the lowest costs possible, companies
are trying to expand lithium-ion battery storage to all possible grid applications. While the
variable costs of lithium-ion storage are lower than gas plants, the breakeven point is
questionable when considering long-term total costs, especially when considering dropping gas
prices.

8 Discussion

Scientific innovations in the realm of energy and battery technologies have shown much promise, especially as the approach has come to factor in scalability and the cost of materials in parallel with the actual physical capabilities of new battery materials and designs. The example of perovskite research demonstrates the way that a solution-based approach (beginning with a hypothesis a la the scientific method) looks for a solution to the problems rather than exploring the science for its own sake. The high costs and difficulty with creating a cross-country charging network for electric cars was a catalyst for inspiring on-the-go rechargeable batteries in cars, and it was the meticulous process of producing silicon panels for charging these batteries that further inspired this recent and promising push towards perovskite. Approaching research with a greater contextual balance, considering cost of materials, ease of production, and potential for improvement may be the key to more impactful new energy technology in a nearer future. Similar words can be said for silicon, whose natural abundance and attribute have made it an increasingly viable option, as research continues to illuminate new improvements for its incorporation into battery design - whether that is via nano materials or alloys. We believe that research in the realm of energy and battery technology should continue this solution-based approach, as it has already shown much promise in innovating novel materials such as perovskite that have suddenly become viable options for renewable energy materials in recent years.

Many of the government incentive programs covered led to important questions about battery technology and the role of government. From David Diamond’s evaluation of the real influence of government incentive programs on hybrid market share, he looks into how monetary incentives, gas prices, and vehicle miles traveled have a direct impact on total ownership cost of a hybrid vehicle. Looking further into Diamond’s results, we find that the weak relationship
between monetary values and state market share also has significant policy implications. This is a curious conclusion. It could be the case that hybrid car dealers factor state incentives into their pricing structure and charge consumers more for these vehicles. As a result, the government is technically subsidizing car dealers who sell hybrid cars, instead of subsidizing the consumers and encouraging the purchasing of hybrid vehicles. Also based on the trends found within individual states in Diamond’s paper, it seemed that up-front sales tax waivers were significantly more effective than delayed rebates or tax credits in encouraging hybrid purchase. With these results in mind, government agencies such as the U.S. Department of Energy might want to allocate the majority of their resources to up-front tax waivers, as it seems to be a more efficient use of their funds.

Globally, there seem to be other more efficient policy alternatives that would be more effective in protecting the environment and improving the economy than the ones currently in place. According to economist Arne Schweinfurth, policy-makers have instruments at their disposal that create fewer unintended side effects than do direct subsidies and can create considerable long-term effects. Another tendency within bureaucracy is the postponement of necessary long-term structural adjustments. Short-term subsidy designs do not address long-term problems. Certain structural adjustments such as driving down costs and overcapacity or decreasing fleet emissions should be done through sustainable sector policies focusing on the long term. To be most efficient, policy-makers must follow clear rules regarding market intervention through subsidies for certain technologies. The process of market intervention should at the very least involve an assessment of the impacts and side effects of the subsidy, the main objectives, clear targets or beneficiaries of the intervention, monitoring and adjustment mechanisms, as well as complimentary policies and an exit policy to successfully and efficiently phase out the program. Many government programs do not go through the necessary steps to ensure the success of their initiative, and resources are wasted because of easily avoided inefficiencies.

Focusing the topic on the automobile sector showed major gaps in the academic research. This
gap became more and more obvious the more the research focused on Tesla Motors as an example. Many automobile companies are investing significant amounts of money in their R&D department to research new engines for their cars. This is reasonable on the first look. But the engine can be perfect and still won’t work in a market. It is rather necessary to also invest in infrastructure as well as in the new energy sources available. Many papers are not really focusing on this topic. Further they totally forget to also include some research on the fuels used by automobiles. If Tesla is taken into account it shows that it is possible to build a car using alternative fuels and produce low GHG emissions. Even though they are no major player in the market. Further they even built their own supercharger network. This will secure the supply for their cars. They are not only focusing their efforts to the U.S. but rather to Europe and Japan as well. This should be a perfect example of how other companies and the government should do it. Only if the infrastructure of new alternative fuels is secured, new alternative low emission vehicles will be bought. If the demand for LEVs rises the demand for energy and thereby new energy sources will automatically rise as well. With a rising demand for energy investments in this specific sector will be preformed. This will secure on the long run a cleaner and saver energy support. It would have been nice if research had focused more on this chain rather than only on the engines. I expect to see due to Tesla Motors a growing supercharger network not only by Tesla Motors but by all major players in the market. Due to this development more academic papers will focus on this topic and will further try to solve the still open questions. Speaking about this chain behind the low emission vehicles many people in the economy as well as researchers forget about the source of energy and how this source highly influences the amount of GHG emission. Sure a car that runs on electricity or hydrogen has no real GHG emission. So people believe that they are actually clean. But what most of them are forgetting is to calculate the source of energy into the equation of GHG emission. So what this means is the factor, that energy can be produced clean by renewable energy sources or dirty by for example coal. People need to be aware of what type of fuel they use and from what type of source this
fuel stems. As explained in the section about the alternative fuels and the low emission vehicles is that if for example the grid is reaching its peak, dirty sources are being used to supply all the demand of the grid. The government as well as the automobile industry need to raise the awareness in the customer to use off peak hours to charge their vehicle from the grid. Only on this way it can be secured, that clean energy sources are being used. Further it is necessary for the EVs to be successful to make these sources available and more transparent. So customers can actually see where there energy stems from. This topic nevertheless is not being addressed in most of the research. Even though it is significant for a understanding of the incentives as well as problems of investing in new energy technology.

The incentives, criteria, and problems government agencies and state-owned companies face when investing in new energy technology for public transportation is often shaped by policy and funding. A major example is the Buy America mandate within the United States. This mandate has almost eliminated international technology from being implemented into the country’s bus system. This has caused technological innovation to lag behind other countries. This leads to the question of why the United States has chosen to not invest further in research and development to catch up to other countries. We can only assume that the United States sees its domestic focus as more important than being at the forefront of innovation. They are willing to invest in CNG technology instead of the expensive, but promising, future of hybrid and electric buses. Therefore, it seems that the United States will act as a laggard and adopt new technology only once other countries prove hybrid and electric buses to be worthwhile investments. Further research should be done to assess the costs and benefits of either being at the forefront of innovation or avoiding the risk of investment in new bus technologies. In contrast to the United States, China promotes domestic production when installing innovation, but is willing to import technology to meet initiatives and further technological progress. China’s open borders have allowed it to become more advanced than the United States in terms environmental and economic efficiency of public bus transportation. Therefore, if the United
States attempts to put a greater focus on innovation, it should look to break down the barriers it has placed within the public transportation industry in order to allow it to catch up with China. This will allow the US to take a step toward reaching its global warming initiatives by embracing superior battery electric bus technology. In addition, further research should be done to assess how the United States’ focus on its domestic market and affordable technology will impact its success in the climate change race. Will such a gap in the U.S.’s technological advancements cause it to fall behind on its global warming initiatives? This is particularly pressing as countries are currently meeting to address this issue. These are questions that should be addressed to understand how the United States’ investment strategy is impacting the growth of its economy and its success in adapting to world’s shifting focus toward fighting climate change.

On top of analyzing the investment approach of the United States within public transportation, further work should be done to assess countries’ capacities to set up the infrastructure necessary for electric bus systems. These systems are very expensive, but electric transportation technology would cut out countries’ major source of greenhouse gas emissions - transportation. However, as noted earlier, the production and storage of electricity for hybrid and electrical buses should be examined to make sure traditional high emission processes are not being used.

In addition to analyzing the infrastructure necessary for electric buses, further research should be done to improve upon the battery technology currently used within buses. The faster buses can be recharged and the longer buses can last without being recharged, the sooner electric buses can serve as a reliable and efficient source of transportation.

9 Conclusion

Research in energy technology, and in particular battery technology, has found a greater focus through improving energy capacity as the field for potential component materials has become more diversified and complex. Functionally, battery design is focused on eliciting the maximal
energy density and/or power density from its constituent materials, and concerns in producing more environmentally and cost-efficient modes of transportation have led to questions of how to produce a safe, capable, and efficient rechargeable battery. Advances in the materials sciences, especially in the realm of silicon and the silicon anode, have attempted to solve essential questions of energy capacity, charge cycle lifespan, and conductivity to improve the current rechargeable battery. Additionally, novel materials in energy research such as perovskite show potential not only do to their physical characteristics and efficiencies but also do to their scalability factor, as ease of production process and abundance of base material become essential elements of the innovation equation. These improvements in battery technology are fundamental to the private automobile market, public transportation systems, and electric grid storage. The advancement of batteries within these industries will allow new energy technologies to become more reliable alternatives, and therefore, further the incentive to invest in these technologies. However, currently due to the high cost and need for further advancement of these technologies, governments must find ways to stimulate further innovation. To stimulate innovation within these industries, governments have created incentive programs, as have been discussed throughout the paper.

It is obvious that developed countries are more aptly positioned than developing countries when seeking to enact new energy initiatives. Developing countries do not have the same capabilities to finance expensive projects. Since developed countries already having these advanced and modern economic capabilities, they are able to comply and slow down their growth to more reasonable long-term levels. Nonetheless, developed countries’ ability to focus on the long-term was achieved by relying heavily on fossil fuels. Therefore, many developing countries feel that their economic growth is being stifled by developed nations as carbon emission caps and renewable energy requirements are being placed upon them before they have achieved the same economic capabilities as developed countries.

China and India appear to have taken the lead among developing nations, which can be
attributed to their renewable energy policies. It can be seen that they are approaching the problem of renewable energy in slightly different ways; while China’s policies seem to favor domestic production and innovation while at the same time not forgoing foreign technologies, India appears to be more centered on attracting foreign investors to build its renewable energy systems while focusing itself on economic development. The most effective policy’s found within China and India are the encouragement of foreign investment and technology. These policies allow for faster implementation of renewables as well as the advancement of technology. Furthermore, foreign investment allows for economic and energy development without governments incurring massive costs. Ultimately, the government policies of both China and India allow for extensive development especially considering their future trajectories.

More than fifty Indian cities are already home to over a million people (Urban South Asia 2014). With an expected urban population increase of 404 million by 2050, India’s urban regions are bound to become even more crowded, which will lead to a higher demand for general infrastructure. In order to support this growth, renewable energy and access is key as well as development in public transportation infrastructure such as buses, trains, and cars. Such development relies on the technology driving these vehicles and systems, which are being encouraged by the incentives provided.

While these countries do provide subsidies, these subsidies represent a negligible investment compared to the costs associated with research and development and deployment of technology. Furthermore, the urbanization currently taking place within these countries will only increase the demand for renewables. In turn, this will stimulate the development of smart, efficient cities, which rely upon new energy technology for transportation and electric grid storage.

Ultimately, China’s approach should be a model for other countries as it is inclusive and forward looking. Their international approach to encouraging investment is validated by their superiority in the renewable energy sector. In addition, countries should focus on implementing new energy technology within the private sector over the public sector because the efficiencies
of the private market. The next five years should allow for more concrete conclusions as to which countries’ policies best encourage private sector development as the rate of technological advancement in each country is observed.

In parts of this paper the changes in vehicle propulsion technology, energy technology as well as alternative fuels were addressed. It is largely known, that car usage leads to a broad range of air emission that can directly contribute to smog formation and climate change (Frenken et al. 2004). In more recent history the biggest car manufacturers were looking for a substitute for the internal combustion engine (ICE) (Pinkse et al. 2014). The solution they came up with were the low-emission vehicles (LEVs) which can be further divided into electric vehicles (EVs), hybrid electric vehicles (HEVs), fuel cell vehicles (FCVs), plug-in electric vehicles (PEVs) and compressed natural gas vehicles (CNGVs) (Frenken et al. 2004; Pinkse et al. 2014; National Research Council 2013). Nevertheless it remains very difficult to make LEVs attractive to mainstream customers, as it does not only require product innovation of the vehicle but also of connected technologies (Pinkse et al. 2014). Even though a lot of money is invested in R&D there has not been a breakthrough yet when it comes to solutions concerning the cost efficiency of LEVs and the fuel infrastructure. The supercharger network of Tesla Motors shows the only successful introduction of a broad developed infrastructure of alternative fuels.

In addition to looking at the private automobile sector, investment in new energy and battery technology was analyzed within the public transportation industry. In particular, the analysis focused on the state of bus transportation in China and the United States. We found that China is leading innovation within new energy bus transportation due to its goal of reducing the use of diesel within its fleets. In addition, this success can be attributed to the economic advantages of international trade. China’s open borders allowed for competition within the market, whereby pushing suppliers to innovate. In contrast, the United States does not have the same ability to innovate due to its government’s policies. In particular, the Buy America mandate has limited the competition faced by domestic suppliers, and therefore, slowed the pace of innovation.
result, much of the current investment in the United States’ public transportation industry has been in alternative fuels as opposed to more fuel efficient and greener technologies. Therefore, when assessing the future of public transportation, we will look to China. In China the use of hybrid and electric is at the forefront of innovation, meaning investment in these technologies will continue to increase into the future. However, the success of hybrid and electric buses is highly dependent on the improvement of battery technology. Therefore, further research should be done to advance the battery technology discussed at the beginning of this paper. In addition, government policy should focus on incentivizing further research within battery technology. This will lower the price of hybrid and electric buses, and therefore, help eliminate the hindrances to investment and further the government initiatives already in place.

The last part of the paper focused on the electrical grid storage. Grid storage in general is essential to future improvements of reliability and resilience of the grid. However, private providers of electricity from the grid care mainly about the costs of grid storage – more specifically in terms of lithium ion batteries, whether battery storage costs are below costs of traditional gas-fired power plants. At peak demand times, having to fuel gas plants to create more electricity is expensive and damaging to the environment, but using battery storage allows energy to be stored when demand is low and used when demand is high. This flexibility is most helpful when the original source of electricity is renewable – solar or wind tends to be an inconsistent source of energy that cannot meet peak demand. Therefore, storage makes using renewables more environmentally friendly and cost efficient – however if we look at total costs over the lifespan of batteries, it is unclear whether battery storage is actually less expensive than gas – that is something time and research will have to determine.

Other battery technologies such as flow batteries are being researched as well, but since there are no signs of other technologies replacing lithium-ion as the premier technology for the next ten years, it seems safe that most companies are ramping up lithium-ion battery production.
Further, with the market for long-duration (2-4 hours plus) applications vastly exceeding the market for short-duration applications (such as frequency regulation, where lithium-ion currently excels), companies are rightly trying to profit by adapting lithium-ion batteries to long-duration applications. It is too soon to tell how successful this will be long term – critics claim the batteries will not be cost efficient for long-duration – but companies such as AES Energy Storage and A123 batteries will have answers for those soon. Another concern for costs is gas prices – with gas prices staying relatively low, battery storage becomes relatively more expensive. But, gas prices are very cyclical and will come back up, and weaning off gas dependence from the Arab nations is politically, economically, and environmentally a great move long-term.
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