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LOW CARBON FUEL AND VEHICLE TECHNOLOGY ANALYSIS

A research report identifying transportation solutions for the Aspen Community

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INTRODUCTION

City of Aspen Council Goal: By July 1, 2015 identify carbon reduction opportunities in transportation and lay out a pathway that infuses appropriate and forward thinking technologies into the Aspen community.

The City of Aspen has established greenhouse gas reduction targets of 30% by 2020 and 80% by 2050, based on 2004 baseline emissions (Figure 1.1). Ground transportation accounts for 20% of those emissions. In a more recent city emissions report from 2014, vehicles still accounted for 19%, only a 1% decrease. The purpose of this report is to address the Aspen City Council's Goal #9 by analyzing and recommending the alternative fuels and technologies available to the Aspen community that are most likely help accomplish the 2020 and 2050 emissions reduction targets.

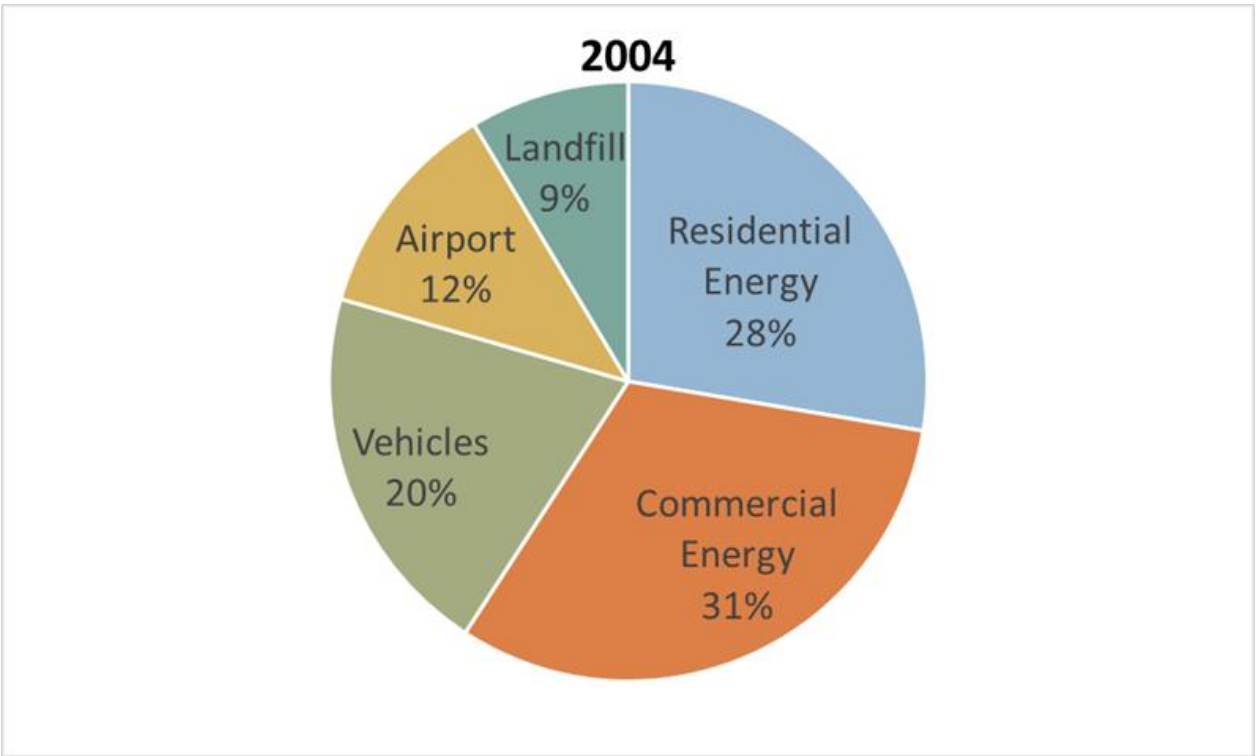


Figure 1.1: Greenhouse Gas Emissions 2004

A thorough analysis by the Denver Metro Clean Cities Coalition (DMCCC) has identified viable low and zero carbon transportation fuels and technologies that will dramatically reduce the greenhouse gas emissions of all on-road transportation in the Aspen area, including personal passenger vehicles. Three alternative fuel vehicle technologies were included in the analysis, including plug-in electric (PEV), hydrogen fuel cell (FCV), and natural gas vehicles fueled with renewable natural gas (RNG). For each fuel type, there are a number of research areas covered in the report, including the benefits, considerations, infrastructure, case studies, and the current and future market for each fuel. Additionally, there is a discussion about some of the unique operating conditions in Aspen, including the temperature, elevation, demographics, and other factors that would affect the successful operation of the analyzed fuels. Finally, recommendations are provided regarding which alternative fuels would be most advantageous for the city to consider, along with specific methods the city can take to expedite deployment.

EXECUTIVE SUMMARY

After analyzing renewable natural gas (RNG), hydrogen fuel cell vehicles (FCVs), and plug-in electric vehicles (PEVs) as possible alternative transportation fuels for the City, PEVs represent the most actionable and meaningful technology for the city to reach its carbon reduction goals. PEVs are the best opportunity to reduce emissions from on-road transportation in the near term by charging on an incredibly clean Aspen Electric grid, and the PEV market as a whole is expected to continue growing to overcome the barriers it currently faces.

The main obstacle preventing RNG as a recommendation is a lack of available biomethane. Pitkin County Landfill was assessed as a possible source, but because it currently vents methane and has no method for capturing the gas, it cannot be treated and used as a transportation fuel. Installing a methane capture system is timely and costly, but the landfill represents a significant emissions source for the region, and if the County decides to install a gas collection system, RNG should be strongly considered as an end-use for the captured landfill gas.

Fuel cell vehicles (FCVs) could arguably provide the greatest benefits to the community in the long term and hold the most potential for convenient, long-distance, and zero-emission transportation among all vehicle classes, but the barriers are too large and the applications too limited for the city to pursue in the near-term. Additionally, there is tremendous uncertainty in the future of the FCV market and whether it will prove to be a better zero-emission option than PEVs in the long term. Aspen should revisit FCV's sometime in 2020 or later as the market develops.

To accomplish the aggressive carbon reduction goals by 2020 and 2050, Aspen will need to exhibit leadership and pursue options that are immediately actionable, but also sustainable in the medium and long term. The recommendations from the Low-Carbon Fuel and Technology Analysis are a reflection of that premise:

> **Recommendation 1:** PEVs provide the strongest short and long-term opportunity for Aspen to achieve their carbon reduction goals in the transportation sector. The city should aggressively pursue PEV adoption in the area by serving as a regional catalyst for adoption and deployment.
> **Recommendation 2**: Action should be prioritized over the next 2-3 years to deploy PEV infrastructure and transition vehicles. Substantial infrastructure grants and vehicle incentives are currently in place that will dramatically minimize the capital cost of implementing cleaner fuels sooner rather than later.

The first recommendation is to leverage the clean grid and aggressively position Aspen as a PEV-friendly community to residents, tourists and regional commuters, and ski traffic. This can be accomplished by providing access to convenient charging, educating and incenting fleets to incorporate PEVs, making sure that PEVs are a visible component of city operations, and educating Aspen residents about the city's investment in electrification. Because the Aspen Electric grid leverages large quantities of renewable energy, there is a unique opportunity for all plug-in electric vehicles charging on the grid to produce zero lifecycle emissions. Replacing one vehicle with a PEV will be the emissions-equivalent of taking one vehicle off the road completely, offering the best opportunity to reduce carbon emissions from many of the fleet vocations, including the general public. For PEVs charging on the Holy Cross Electric (HCE) grid, efforts should be made to pair their wind and hydro offset programs with new PEV purchases, and the city should support HCE efforts to expedite their incorporation of renewable resources.

There are still significant barriers which will limit the wide-scale deployment of PEVs in Aspen; primarily the absence of affordable AWD, truck, and SUV models, but the market is expected to provide those in the next five years. Other prominent barriers are high vehicle cost and range anxiety in a cold, mountainous environment. Both barriers can be addressed in the short term by providing adequate and visible charging infrastructure, leveraging the grants and tax credits available for vehicle purchases, and allowing economies of scale to further develop through the automakers that will reduce capital costs. Also, the Holy Cross Electric (HCE) grid still has significant emissions associated with electricity generation, and many of the residents who may own a PEV live outside of downtown and will be using the HCE grid.

The second recommendation is to leverage existing PEV incentive programs that are currently in place to help overcome barriers like capital cost of vehicles and access to charging infrastructure. The state has the strongest tax credit in the country (up to $6,000 for light-duty) for PEVs that individuals and organizations with a tax liability qualify for (this excludes governments like the City of Aspen), and when combined with the federal PEV tax credit of $7,500, there is a possible $13,500 in available credits.

However, both of these credit programs have a horizon, as the state tax credit begins shrinking in 2019 and disappears in 2022, and the federal credit disappears whenever an individual automakers sells 200,000 qualifying PEVs. Additionally, there are grant funds available through Charge Ahead Colorado that the City can apply for to assist with the deployment of charging stations, up to $16,000 for a Level 3 and $6,260 for a Level 2. That program is only around until funding dries up, which is dependent upon application demand and the registration of new PEVs ($20 of a $50 PEV registration fee goes to a PEV infrastructure grant program). The City should take advantage of and promote these incentives to the community while they are around, as it will minimize financial barriers to greater PEV adoption in the Aspen area and position the city as a regional and national leader. Specific actions the City can take to act on this recommendation are included below, but they include things like electric circulator buses in town, development of PEV infrastructure at strategic locations, incorporation of PEVs where sensible in the City fleet, and serving as an educator, encourager, and resource to the community about PEVs.

Specific vehicle vocations that appeal to the current PEV market include: circulator buses, the city fleet, the general public, the county fleet, Aspen Ski Co., and taxi fleets. Vehicle vocations in the area that that could utilize RNG include, the Roaring Fork Transit Authority, the city fleet, the county fleet, refuse fleets servicing the landfill, food and beverage transportation, package delivery/logistics, and regional trucking.

Because Aspen is a destination location, incentivizing people to make the trip in a PEV will require strategic deployment of charging infrastructure to provide range security and extension. The report suggested three charging categories that will be important to a successful charging network: workplace charging, Level 3 (also known as fast charging) corridors, and public charging. Workplace charging is very effective at increasing PEV adoption – employees with access to charging are 20x more likely to own a PEV than employees who don't have charging access. The City should consider joining the U.S. Department of Energy's Workplace Charging Challenge and work with employers in the area to educate them about the benefits and incentives to provide charging. Level 3 charging, which charges most PEVs in thirty minutes or less, is essential to enabling convenient electric road trips to and from Aspen. Possible locations for Level 3 charging along the highway 82 corridor include Glenwood Springs, Carbondale, Aspen, and Independence Pass. Another important infrastructure component is Level 1 and 2 public charging access at locations like Aspen Ski Company, trailheads, parks, the airport, and downtown.

One important aspect of implementing the recommendations is education and outreach. There are a lot of avenues the city can consider to raising awareness about the benefits of PEVs to the community. There are plenty of grants and incentives available for vehicle and infrastructure costs that fleets, local governments, and the general public may not be aware of; the city could leverage existing programs by better promoting them through their networks and directly to city staff. Organizations like Clean Energy Economy for the Region that is already operating on the western slope providing education and fleet analysis for alternative fuels provide a great partner to the city. Ride-and-drive events with local leadership, celebrities, and the general public provide great media exposure and active education opportunities for participants. There is also an opportunity to highlight the city's efforts and accomplishments by leveraging the national audience that the X-Games attracts annually.

Finally, there are some regulations or policies the city could consider to reduce transportation emissions: alternative fuels could be prioritized in city contracts by awarding higher value to contractors that use alternative fuels, and the city could encourage other businesses and organizations to do the same; building codes could be adjusted to require prewiring for future EVSE installation; Aspen Electric could design a PEV-specific time of use rate to incentivize charging on off-peak hours; and Aspen could require new vehicle purchases to decrease emissions from the vehicle it is replacing by a certain amount.

Additional information is provided at the end of the report that outlines existing grants, incentives, and regulations relevant to alternative fuels, and supplementary resources for more information.

FUEL AND TECHNOLOGY OVERVIEW

Based on the preferences set forth by the City of Aspen, three different low-carbon fuel and vehicle technologies have been identified and are detailed in the report:

- **Plug-in Electric Vehicles (PEV)**
- **Hydrogen Fuel Cell Vehicles (FCV**
- **Natural Gas Vehicles fueled with Renewable Natural Gas (RNG)**

These three fuel types were chosen from an array of alternative fuel options because they represent the lowest carbon fuel alternatives, can be supplied by renewable sources, have net-zero carbon lifecycle potential, and can completely displace petroleum products. Other fuel options like traditional natural gas, propane, ethanol, biodiesel, and hybrids, either don't offer a carbon-free lifecycle, are dependent on petroleum products, or both.

PLUG-IN ELECTRIC VEHICLES

2016 Chevy Volt
Photo: http://www.chevrolet.com/2016volt/exterior-

PEVs are zero-emission vehicles powered by electricity, and have reemerged in the U.S. auto market in response to rising environmental, economic, and national security concerns associated with traditional transportation fuels like gasoline. Electricity as a transportation fuel has many advantages that make PEVs attractive to general consumers and fleets alike. Thanks to several advancements in battery technology, the most recent wave of PEV models came to the U.S. market in 2011 as an answer to increasingly stringent emissions standards from the Environmental Protection Agency (EPA), as well as a growing demand from consumers for cleaner transportation choices. The market for PEVs has grown rapidly and will be discussed in detail later on in this section: in 2011, there were three PEVs models available and they were limited to specific markets. In 2014 there were more than 20 PEV models available in the United States representing almost every major automaker[1], with additional models and technological advancements occurring rapidly. The PEV market has also expanded in to the commercial sector with trucks, vans, and buses covering a variety of duty cycles.

This section will provide background information on PEV technology and infrastructure; discuss the benefits and challenges that PEVs present; review existing case studies of successful deployment; and outline the near and long-term PEV market, with the ultimate goal of assessing if and how PEVs can assist the City of Aspen in achieving its emissions reduction targets.

Technology

What is a PEV?

A Plug-in Electric Vehicle (PEV) is propelled by electricity that is pulled from an external source, stored in a battery, and used by an electric motor that sends power directly to the wheels. There are two types of PEVs: battery electric vehicles (BEVs), and plug-in hybrid electric vehicles (PHEVs). Both share the ability to plug-in to an electricity source and operate at full capacity on electricity alone without tailpipe emissions (which separates them from hybrid electric vehicles like the original Toyota Prius that does not plug-in). The difference between the two is that PHEVs have a gasoline engine or generator that can be used to extend the overall driving range once the electric range is depleted, and a BEV has no gasoline backup at all. When a PHEV uses the gasoline engine, it operates like a hybrid electric vehicle by capturing the regenerative braking energy and storing it in the battery to assist the gasoline engine in achieving greater efficiency[2]. BEVs, like the Nissan Leaf or Tesla Model S, have larger batteries and longer electric ranges than PHEVs, but are limited to their electric range which is typically shorter than the combined electric/gasoline range of a PHEV.

[1] U.S. Department of Energy, Energy Efficiency and Renewable Energy, Alternative Fuel Data Center, Alternative Fuel and Advanced Vehicle Search http://www.afdc.energy.gov/vehicles/search/results/?vehicle_type=light&category_id=27&fuel_id=41,57,
[2] U.S. Department of Energy, Energy Efficiency and Renewable Energy, Alternative Fuel Data Center, http://www.afdc.energy.gov/pdfs/52723.pdf

The battery chemistry in most PEVs on the market today is lithium-ion, a proven technology for maximizing and holding charge, high performance, and extended battery life in both vehicles and consumer electronics[3]. Battery charging speed is determined by the capacity of the onboard charger in the vehicle, as well as the charging source. Electric vehicles have an onboard charger, ranging from 3.3 kW up to 10 kW, which converts the electrical current from AC to DC. The higher kW chargers provide faster charging potential. For example, a Tesla Model S has the option of pairing two 10 kW chargers, allowing the battery to charge at speeds of 58 miles/hour with a Level 2 (240 Volt AC) electricity source[4], whereas a Nissan Leaf with a 3.3 kW onboard charger will charge the battery at 12 miles/hour. PEVs are powered by storing electricity acquired from an external source by plugging-in, as well as energy from regenerative braking, in a battery, and that stored energy is used to power the wheels using an electric motor.

[3] U.S. Department of Energy, Energy Efficiency and Renewable Energy, Alternative Fuel Data Center http://www.afdc.energy.gov/vehicles/electric_batteries.html
[4] Tesla Motors, http://www.teslamotors.com/charging

Benefits

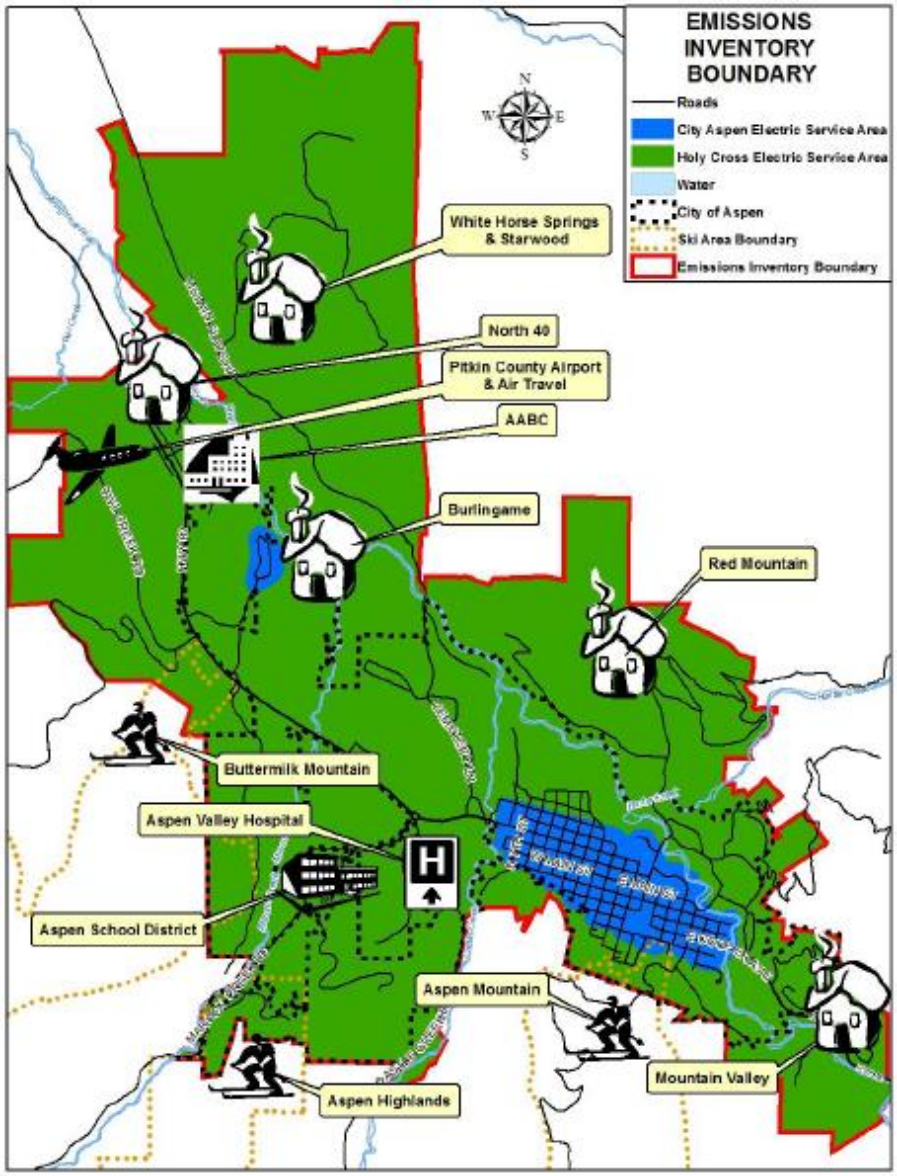


Figure 1.2: Aspen's Utility Boundaries

Emissions

When operating on electricity, PEVs produce no tailpipe emissions as the utilization of electricity in an electric motor does not create exhaust[5]. However, there may be emissions associated with electricity production, depending on the grid or generation sources where the vehicle recharges. According to the Colorado EV Market Implementation Study conducted in December 2014 by BCS, Inc., the average grid electricity generated in Colorado in 2013 produced 37% less CO2 emissions when compared to the typical light duty gasoline vehicle on the road. This percentage will continue to increase as Colorado's grid retires the use of coal-fired power plants and increases electricity production from cleaner sources as outlined in the Renewable Energy Standard. This is evidenced by the 9.5 % reduction in CO_2 emissions from 2010 to 2013, from 1,818.17 lbs/MWh to 1,645.86 lbs/MWh (or 1.8 lbs/kWh to 1.6 lbs/kWh)[6].

PEVs have the potential to be 100% emission-free when charged by renewable power sources such as solar, wind, renewable natural gas, or hydro. The City of Aspen's electricity mix is much cleaner than the Colorado average. Aspen Electric provides roughly 50% of the town's population with electricity, which is primarily concentrated in the downtown area, while the other half is powered by Holy Cross Electric (for a map of Aspen's utility boundaries, see Figure 1.2) that serves a much larger geographic area. Aspen Electric projects that in 2015, 100% of its electricity will be generated from clean, renewable sources like wind and hydro. When PEVs charge on the Aspen Electric grid, they will produce zero lifecycle emissions and are, therefore, the cleanest transportation option available. There are emissions associated with

[5] U.S. Department of Energy, Energy Efficiency and Renewable Energy, Alternative Fuel Data Center http://www.afdc.energy.gov/pdfs/52723.pdf
[6] Colorado EV Market Implementation Study, BCS Inc. and Colorado Energy Office

charging on the Holy Cross Electric (HCE) grid. In 2013, the CO_2 emission rate was 1.8 lbs/kWh with plans to reduce that to 1.4 lbs/kWh by 2020.

Other zero-emission lifecycle vehicle charging options include distributed renewable sources, most predominately photovoltaic solar systems that generate clean electricity on site such as the stations produced by Envision Solar operating in Boulder, CO. Options for on-site renewable generation include solar carports, canopies and parking garages. A growing number of PEV owners have rooftop solar installations that generate enough power to charge their vehicle and offset their home electricity usage. HCE offers two alternative programs for consumers interested in buying renewable energy: Wind Power Pioneers program and the Local Renewable Energy Pool. Both allow customers to purchase either wind or hydro power in 100kWh and 75kWh blocks, respectively. The City of Aspen could market this to PEV drivers as a strategy to further reduce transportation emissions[7].

Vehicle Emissions Comparison

A side-by-side comparison of a 2015 Subaru Outback driving 10,000 miles/year and a PEV driving 10,000 electric miles/year being charged with emissions-free renewable sources would reduce carbon emissions by 10,681 lbs annually, according to the U.S. Department of Energy's Alternative Fuel Data Center's Vehicle Cost Calculator. By the same metrics, a PEV charging on the Holy Cross Electric (HCE) grid in 2013 (the most recent data available) would emit 5,625 lbs CO_2 equivalent at a rate of 1.8 lbs/kWh[8], which is a reduction of 5,056 lbs CO_2, or 47%. Looking forward to 2020, HCE has planned a 30% reduction in CO_2 emissions to a rate of 1.4 lbs/kWh, so a PEV charging on the HCE grid in 2020 would produce 4,562 lbs of CO_2, a reduction of 6,119 lbs CO_2, or a 57% reduction. HCE may take even more aggressive steps to reduce carbon emissions between now and 2020, but the planned reductions were used as a conservative estimate.

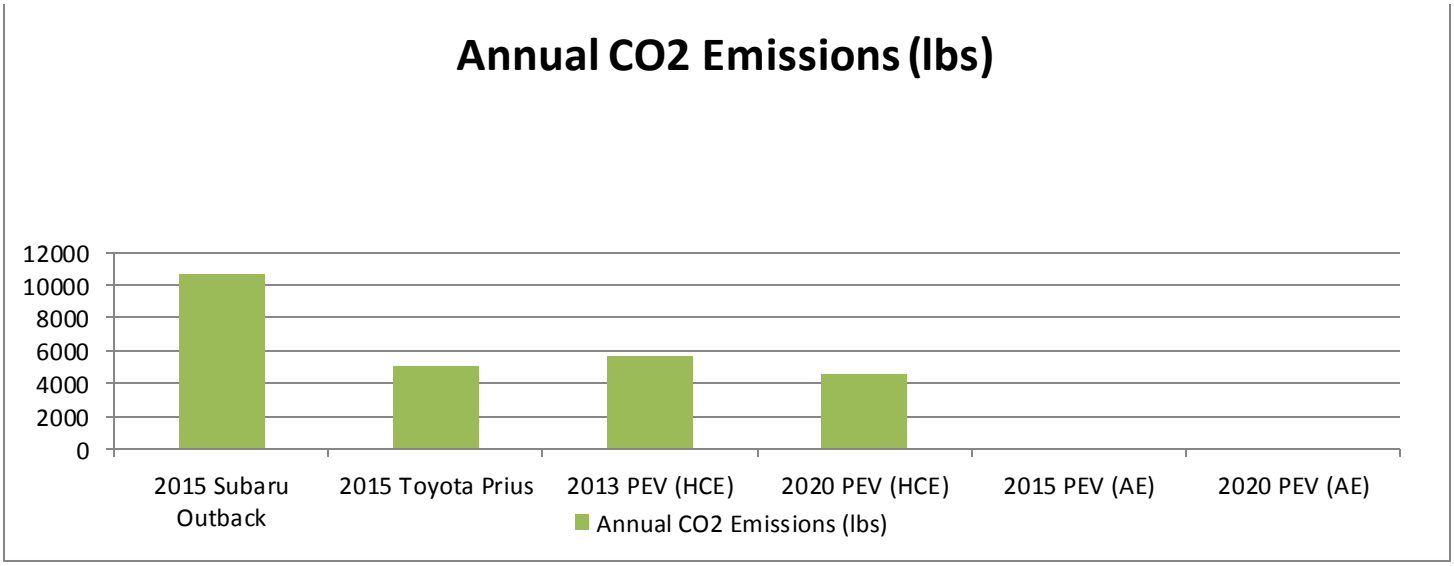


Figure 1.3: Annual Carbon Dioxide Emissions

[7] 2013 HCE 2013 CO2 Emissions Report
[8] 2013 HCE 2013 CO2 Emissions Report

Figure 1.3 shows a graphic representation of the emissions reductions in the previous scenarios, and includes the emissions of a 2015 Toyota Prius hybrid for comparison purposes. Even though the Prius may offer lower CO_2 emissions than the PEV charging on HCE's 2013 grid, the Prius offers no opportunity to change fuel sources to something cleaner, so it will always be fueled by gasoline, whereas the PEV will get cleaner with time making it a better climate investment.

Efficiency

Electric motors are around 80% efficient at converting electricity from the grid into power at the wheels, but the battery charger is also about 80% efficient in converting AC to DC power, so the entire efficiency of PEVs is around 60%[9]. An internal combustion engine is only 17-21% efficient depending on the drive cycle of the vehicle. Internal combustion engines are notoriously inefficient, as they have hundreds of moving parts and processes involved between the combustion of the fuel and the transfer of energy to the wheels. With each of those processes, energy is lost. An electric motor has only one moving part, so fewer processes are involved to transfer the energy from battery to wheels[10]. PEVs are, therefore, about three times more efficient than conventional vehicles, conserving energy and lowering operating costs. Though, in the heavy-duty transit bus market, electric buses can be greater than five times more efficient than their diesel counterparts.

Performance

Acceleration
Electric motors offer 100% of their power at 0 RPM, whereas an ICE needs time and energy to build RPMs before maximum acceleration occurs. The result is that PEVs offer great acceleration and are fun to drive[11]. The graphic below from the Union of Concerned Scientists illustrates this by comparing torque curves.

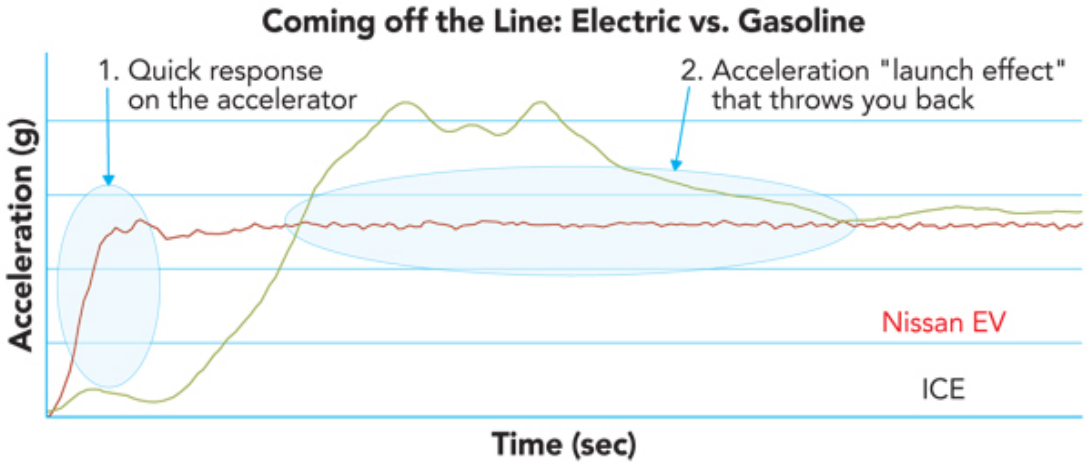


Figure 1.4: Acceleration of Electric vs. Gasoline

[9] U.S Department of Energy, http://www.fueleconomy.gov/feg/evtech.shtml#end-notes
[10] Idaho National Laboratory, "How Do Gasoline & Electric Vehicles Compare?" http://avt.inl.gov/pdf/fsev/compare.pdf
[11] Refuel Colorado http://refuelcolorado.com/ev/performance

Noise Reduction
PEVs are very quiet and do not produce noise beyond a slight hum. This is beneficial in reducing noise pollution and helps create a more comfortable, peaceful driving experience that connects the driver to the road[12]. Reduced traffic noise would lessen distractions and better connect residents and visitors to the surrounding environment.

Elevation
Because electric motors don't use combustion to generate power, lower oxygen levels at higher elevations don't reduce the available horsepower and torque. A PEV has the same power at sea level as it would at 20,000 feet.

Domestic Energy Security

Even with the recent increase in domestic oil and gas production, the United States still imports roughly 33% of its petroleum from foreign countries[13], and 72% of U.S. petroleum use is devoted to the transportation sector. By depending on a fuel market that is highly subject to global conflict and instability, price fluctuations are frequent and costly. Electricity is generated from domestic sources like natural gas, hydropower, solar, wind and coal. By utilizing a domestic fuel like electricity instead of gasoline or diesel, jobs and new industries can be created in the solar, wind, and natural gas industries that will boost economic growth. Perhaps most importantly, by limiting dependence on foreign oil and global markets, the price of domestic fuel is more stable and predictable[14].

Operating costs

Fuel
Electricity has been the least expensive and most stable of all transportation fuels since the year 2000 (see figure 1.5 from the Alternative Fuel Data Center), with natural gas following suit.

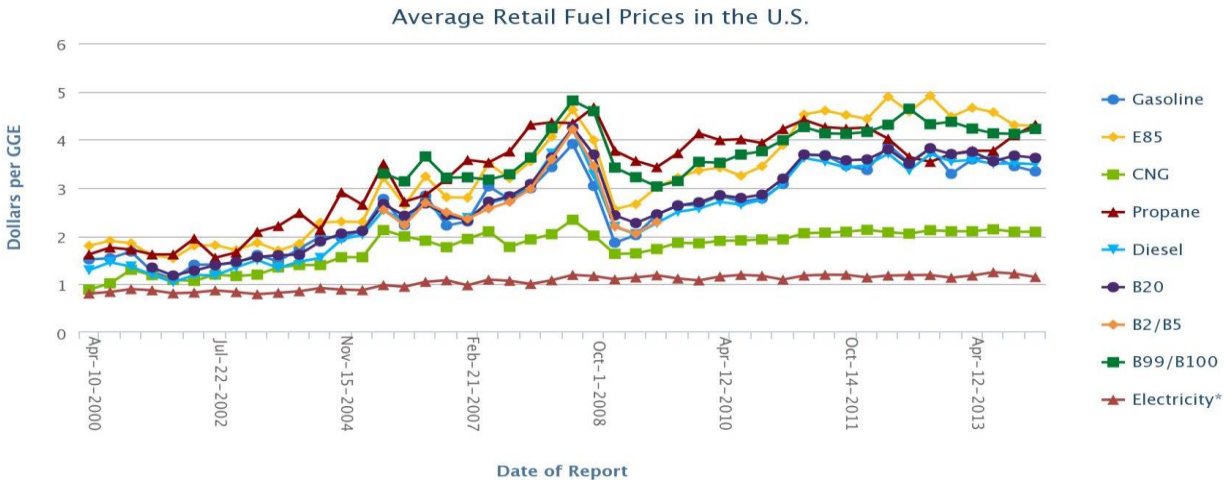


Figure 1.5: Average Retail Fuel Prices in the U.S. in $/Gasoline Gallon Equivalent (GGE)

[12] Refuel Colorado http://refuelcolorado.com/ev/performance
[13] Energy Information Administration, http://www.eia.gov/tools/faqs/faq.cfm?id=727&t=6
[14] Refuel Colorado http://refuelcolorado.com/ev/benefits

As figure 1.6 from the Idaho National Laboratory shows, fueling a PEV falls anywhere between $.02-.04/mile, whereas a 22MPG conventional gasoline vehicle falls between $.09-.30/mile (at $2 and $4 per gallon, respectively). In Colorado, the annual cost per light-duty vehicle is $1,310.66 in gasoline consumption. The average annual cost per EV is $221.03 in electricity costs, which is an 80% reduction in fuel costs—an annual savings of $1,089.63[15]

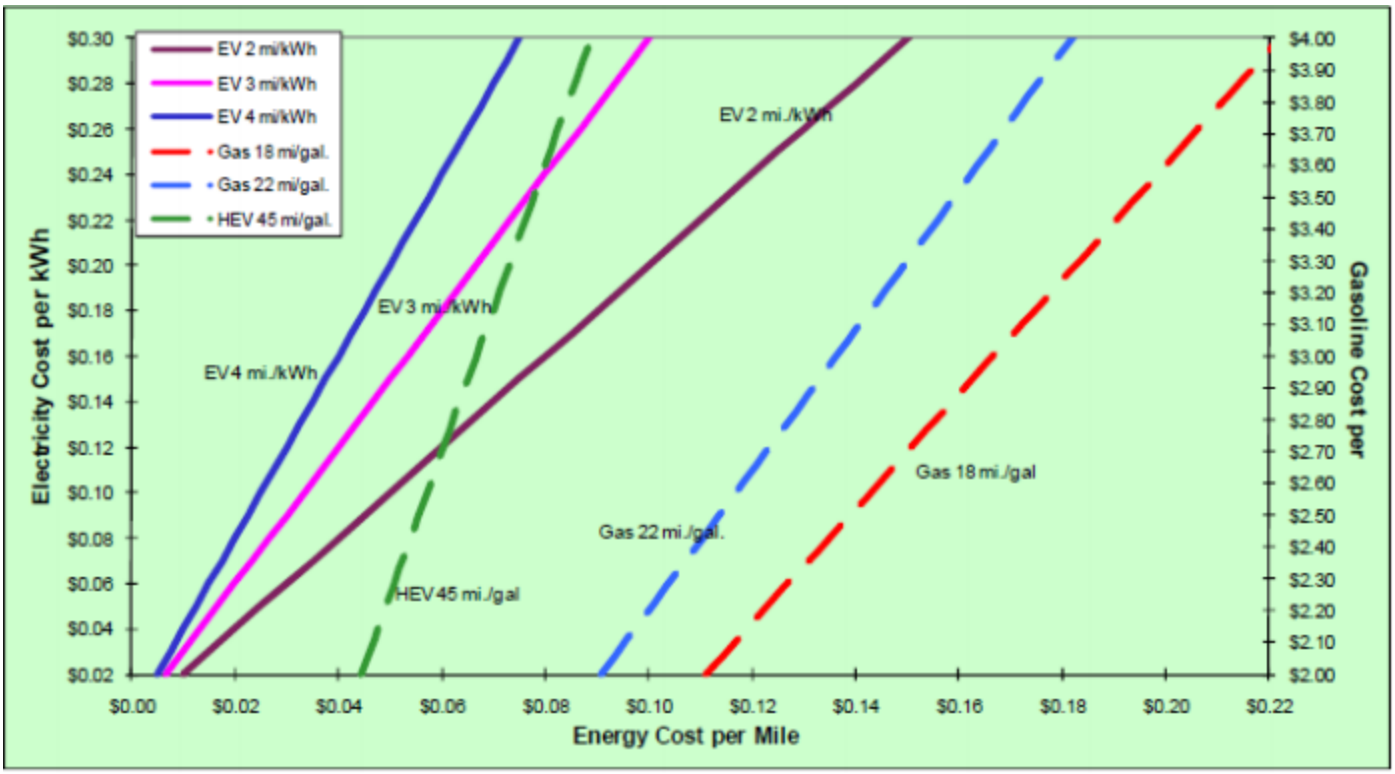


Figure 1.6: Operating Costs

[15] Colorado EV Market Implementation Study, BCS, Inc and Colorado Energy Office

Figure 1.7 illustrates the costs associated with charging the average PEV driving 10,000/year with average PEV efficiency of 3.2 miles/kWh at common electric rates from Aspen Electric, compared to a 25mpg conventional car driving 10,000 miles/year. Average kWh rates for small commercial ($0.106/kWh), large commercial ($0.074/kWh), and residential ($0.104/kWh) were provided by Lee Ledesma, the Utilities Finance and Administrative Services Manager for the City of Aspen.

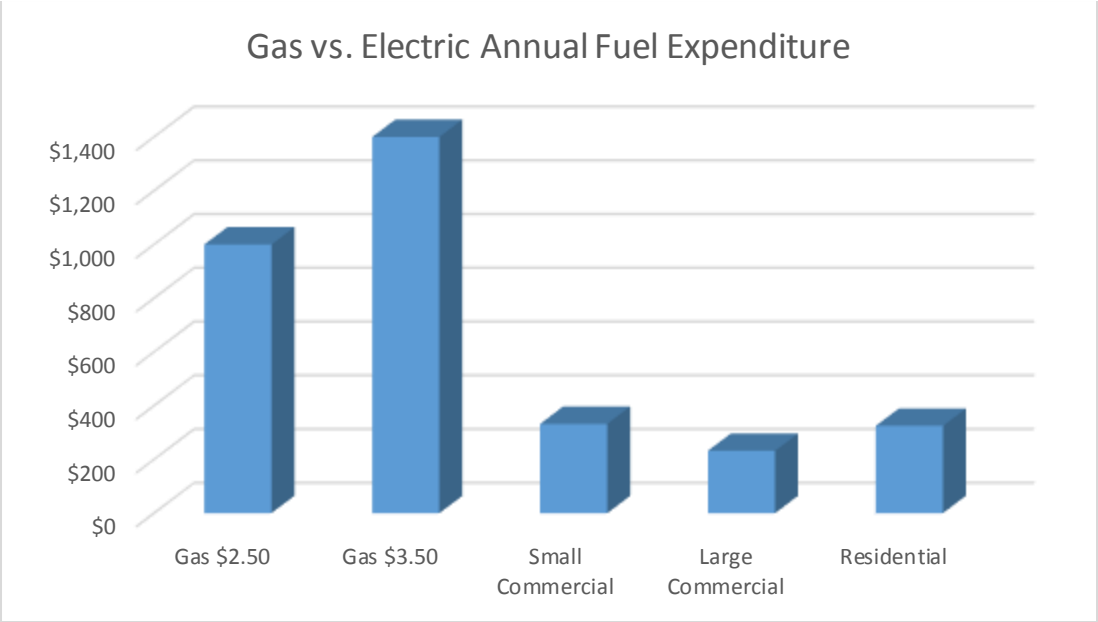


Figure 1.7: PEV Charging Costs

Because PEVs save on a cost/mile basis, higher upfront costs can be offset faster for people or applications where the most miles are driven. Electric buses are a great application for reducing operating costs, as the average diesel bus can consume $500,000-$600,000 in diesel fuel during a 12-year life, and an electric bus would use only around $80,000 in electricity – a $420,000-$520,000 in lifecycle savings that helps justify the high incremental cost for an electric bus[16].

Calculating operational costs for conventionally fueled vehicles is relatively simple – the number of gallons a vehicle consumes, multiplied by the price paid at the pump for each gallon throughout the year, equals annual fuel expenditure. Calculating fueling costs for a PEV is slightly more complex, as the price utility customers are charged per kWh varies depending on the site owners' rate tier and demand. In some instances, the addition of a charging station and/or PEV to an existing electrical load may establish a new, higher demand, or higher rate tier, that can significantly increase the kWh rate and their entire electricity bill. This could be an important consideration for an organization providing

[16] Slate, "Forget Tesla. It's buses, not cars, that will lead the electric revolution" http://www.slate.com/articles/technology/the_juice/2014/09/electric_buses_proterra_wants_to_rid_america_of_emission_spewing_buses.html

workplace charging during the day at peak electrical demand. Scenario planning can provide useful information and it is recommended that the local utility be consulted for more information.

Maintenance

The electric motors in PEVs use no oil or transmission fluid, which can significantly reduce maintenance costs and prolong scheduled maintenance intervals. In addition, regenerative braking lengthens the life of brake pads as energy is absorbed and stored by the battery instead of being lost to heat, and the electrical system doesn't require regular maintenance like an internal combustion engine. Plug-in hybrid electric vehicles that have an internal combustion engine onboard will have regular scheduled maintenance and oil changes, but the suggested maintenance schedule is less frequent than a traditional vehicle as the gasoline engine doesn't work as often and regenerative breaking still occurs. A battery electric vehicle can reduce maintenance costs by 50%, which for a vehicle traveling 11,000 miles a year can equate to a savings of at least $244/year[17]. For electric buses, the maintenance savings can be enormous, up to $135,000 over the lifecycle of a bus by eliminating oil changes and diesel emissions systems, reducing brake replacement, and minimizing moving parts.

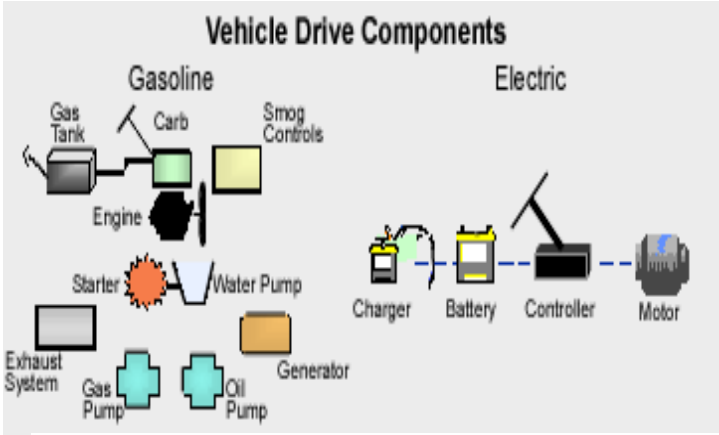


Photo:http://www1.eere.energy.gov/vehiclesandfuels/avta

Figure 1.8: Vehicle Drive Components

Most PEVs come with an 8-year, 100,000 mile warranty on the battery itself, but they vary slightly depending on the manufacturer. A Nissan Leaf battery that is 24 kWh in size costs $5,500 to replace; though, of the 35,000 Leafs sold in Europe so far, only three batteries have needed replacement, meaning 99.9% of them are still operating on their original batteries, many since 2011.[18]

Considerations

Education

One of the largest barriers to the adoption of PEVs is public awareness and perception. Despite the growing number of PEVs on the market, many questions and misperceptions remain regarding the technology, electrical infrastructure, safety, and political support. While some answers will come with further market development, many gaps result from a lack of information and can be addressed through education and outreach. Raising public awareness of PEVs as a viable and optimal transportation option will be crucial to their successful deployment. Highlighting the cost savings and performance advantages of PEVs has proven to be helpful, as often environmental considerations are perceived to be the primary motivator, which hides the other significant advantages and can turn away certain audiences. One of the best ways to communicate that message is through test drive opportunities that allow drivers the ability to experience the cars for themselves. Successful education campaigns can be found in the Electric Ride Colorado, and ideas for outreach can be found in the Colorado Electric Vehicle and Infrastructure Readiness Plan.

[17] Colorado EV and Infrastructure Readiness Plan, pg. 22 http://denvercleancities.org/Colorado%20PEV%20Readiness%20Plan.pdf
[18] Clean Technica http://cleantechnica.com/2015/03/25/99-99-nissan-leaf-batteries-still-operation/

Range limitations

Another barrier to PEV deployment is range anxiety –running out of electricity with no place to quickly recharge. The distance that can be traveled on a single charge varies greatly among EV models (see appendix XXXXX). Most battery electric vehicles have a range between 70-100 miles, which will more than cover the average 16 mile commute for 85% of Coloradans[19]. According to the Federal Department of Transportation Highway Administration, a 100 mile charge is sufficient for 90% of all household vehicle trips. For extended ranges, vehicles like the Tesla Model S can travel 230 to 300 miles on a single charge, depending on the battery option. For drivers who regularly travel long distances PHEVs may be more suitable.

PEV batteries can be greatly affected by temperature variations and driving habits. Up to 35% of range can be lost in extreme weather conditions[20], but there are many tips and tricks drivers can use to maximize their range, including: pre-warming or cooling the car remotely while connected to an electrical source, utilizing heated seats and steering wheels, using available eco-modes, minimizing use of accessories, and using efficient driving tactics. This is an important barrier to consider in Aspen where temperatures are often cold. Figure 1.9 shows illustrates the relationship between temperature and range in real-world scenarios, as analyzed by Fleet Carma.

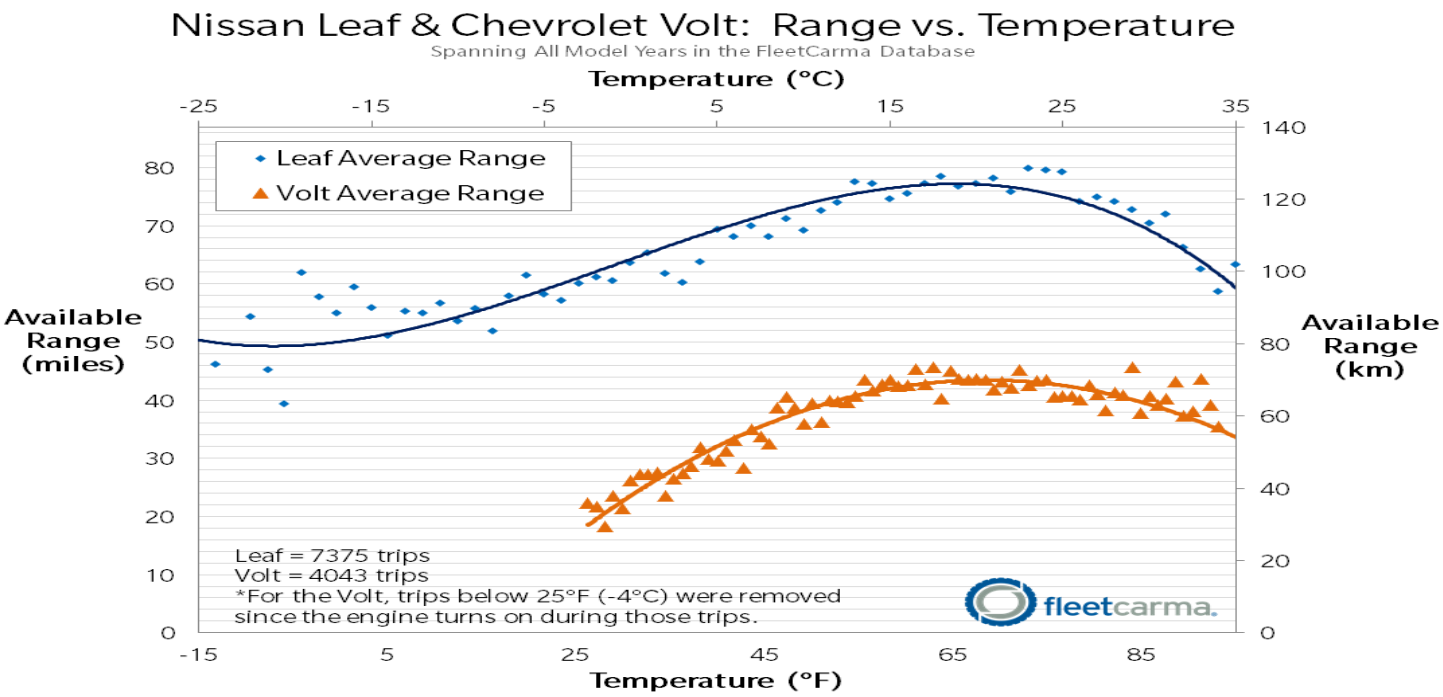


Figure 1.9: Range vs. Temperature

[19] Colorado EV and Infrastructure Readiness Plan, pg 19 http://denvercleancities.org/Colorado%20PEV%20Readiness%20Plan.pdf
[20] Refuel Colorado, http://refuelcolorado.com/ev/performance

Electric buses vary in range as well, from 30-200 miles, but since transit buses are route-specific and have predictable ranges, the range of an electric bus is actually quite manageable. BYD currently has the longest range bus with 200 mile capacity. Proterra's TerraFlex energy system allows the battery configuration and size to be specified to the route of the transit agency, with a maximum range of around 180 miles. Though, when combined with a 500kW fast charger, a bus with a smaller range of around 30 miles can be recharged in less than 10 minutes, which allows for a longer range throughout the day. Proterra buses have ran 700 miles in a 24 hour period using this setup. Ranges on electric buses are very dependent on the specific driving pattern and route of the bus itself, so bus companies have their own proprietary modeling software to get more specific cost and range approximations.

Range anxiety can be combated through education and experience. Most trips fall within the range of a PEV (even if it is cold outside). With advanced planning and experience, range anxiety will quickly diminish. Ample access to public Level 3 chargers and workplace charging stations also help drivers gain range confidence. It is also important to promote PHEVs for people who are very range anxious, for high-mileage fleets, or people who have legitimate concerns about EV range.

Charge time

PEVs can take anywhere from 30 minutes to 20+ hours to fully recharge, depending on the battery size, onboard charger, and method of charging. This refueling model is much different than the conventional fueling model, with gas stations common and refueling times generally taking a few minutes. PEV drivers quickly adapt new habits, so charging the vehicle becomes as routine as charging their cell phone. A more detailed discussion of charging times is documented in the Infrastructure section.

Grid Capacity

In order to accurately assess the capacity of the Aspen Electric grid to support a fast adoption of PEVs, the city should conduct a grid impact analysis. An analysis of Aspen's grid capacity to handle PEV demand is outside the scope of this report, but an overview of the findings included in the Colorado Electric Vehicle and Infrastructure Readiness Plan, which includes utility impacts and projections, will be available. The study included a grid-impact assessment from both Xcel Energy and iCAST, as well as modeling from CU Boulder.

The findings of that study concluded the existing policies and planned utility upgrades are sufficient to support even the most aggressive PEV penetration scenario through 2025. In a market with 10.2% PEV penetration in 2025 Xcel Energy estimated that 4,300-5,100 transformers would be affected by the incremental electricity demand at a cost of $10-13 million. However, the costs would be incurred over a long period of time, and transformers are regularly replaced so it is difficult to directly attribute those costs to PEVs. There was also concern about lateral conductors, but PEVs would not necessarily be the primary contributor. One major consideration for utilities is a concern of clustering. If PEV deployment occurs in dense clusters, this could cause impacts at the transformer level[21]. It is recommended that utilities work with state agencies to determine where PEVs are deployed, along with EVSE to prepare for clustering effects.
Following are some strategies that utilities can use to minimize the impact of PEVs:

[21] Colorado Electric Vehicle and Infrastructure Readiness Plan, pg 88 http://denvercleancities.org/Colorado%20PEV%20Readiness%20Plan.pdf

- *Notification systems:* Utilities should consider developing a tracking and communication system that notifies the utility of a new PEV purchase or EVSE installation within their territory. This will minimize risk at the transformer-level due to clustering or increases in incremental demand.

- *Encourage Off-Peak Charging:* Utilities should actively encourage PEV owners to charge at night, or off peak, when grid demand is low. Xcel Energy's study concluded that the greatest impacts to the grid by PEVs would be between 5pm-10pm as drivers plug in at home after work. Instead, if drivers set their car to begin charging after 10pm, this would mitigate the risk of higher demand charges and create short-term financial protections for the utilities' rate base. There are two options to help encourage off-peak charging by PEV drivers: education/marketing campaigns that inform consumers and rate structures that incentivize off-peak charging through cheaper rates, often known as time-of-use rates.

Currently research is being done on the ability to connect PEVs to the grid while they are charging and utilize their batteries as distributed energy sources to help balance peak electricity demand. This is called vehicle-to-grid technology (V2G), and it is thought of as the future of energy demand management and smart grid applications. While PEVs are plugged in, they can absorb excess electricity from the grid during off-peak times and utilities can buy it back whenever it is needed. PEVs in a study at the University of Delaware averaged selling $110 worth of electrons back to the utility, PJM Interconnection, each month.

Demand response programs like V2G have many benefits if widely integrated. They can save utilities money by delaying upgrades to power lines, transformers and other equipment, reducing the need to buy expensive and polluting fossil-fueled power to meet demand spikes, and; helping utilities manage and smooth out the intermittent flow of energy from renewable sources such as wind and solar generation[22].

San Diego Gas and Electric began a pilot vehicle to grid program where they are using five distributed energy storage systems paired with PEV fleets to help manage grid demand during peak times and maximize the use of renewable energy. Heather Sanders of the California Independent System Operators said, "By having electric vehicles directly participate as a grid resource in the wholesale market, vehicles respond to signals from the grid operator to reduce when electricity is scarce, and continue or resume charging when renewable generation is plentiful. This capability helps maximize the use of energy from renewables while keeping the grid reliable."

V2G is still in a research phase and faces many challenges to its widespread use. Vehicles require a new two-way charger at a cost of about $200 a piece, and the charging station itself needs to handle input and output. Additionally, more research is needed to understand the effects of more frequent charge/discharge cycles on battery life and capacity. There are also policy considerations with utilities, state, and local governments regarding rate structures for selling back to the grid, net metering, and other issues[23]. Research is ongoing with NRG, University of Delaware, PG&E and BMW, the military, and other utilities to better understand how V2G could be integrated with PEVs.

Battery After-Life

[22] PG&E http://www.pge.com/en/about/newsroom/newsdetails/index.page?title=20150105_pge_and_bmw_partner_to_extract_grid_benefits_from_electric_vehicles
[23] Green Car Reports, http://www.greencarreports.com/news/1094990_delaware-vehicle-to-grid-test-lets-electric-cars-sell-power

One concern about the growth of PEVs revolves around what to do with the large batteries after they reach the end of their useful life in vehicles. Much thought and effort has been put into this topic, as the chemicals in lithium-ion batteries can have severe environmental effects if not handled properly. However, if the materials from batteries can be recovered and reused as valuable products, then less raw material needs to be extracted or imported. By repurposing batteries for other applications beyond vehicles, markets can limit their harvesting of rare earth materials, which avoids further environmental impacts and can minimize the cost for materials[24].

The existing batteries in conventional vehicles already have the highest recycling rate of any product on earth at 98%[25], which gives legitimacy to the idea that vehicle batteries will follow the same path. One of the primary markets expected for vehicle batteries is for distributed energy storage, where many vehicle batteries are repurposed and tied together to store large amounts of energy for use as demand-mediators for utilities, or to capture renewable energy generated during off-peak hours that would otherwise be lost. Figure 2.0 is a graphic describing the partnership that BMW has entered into with Bosch and a European utility company.

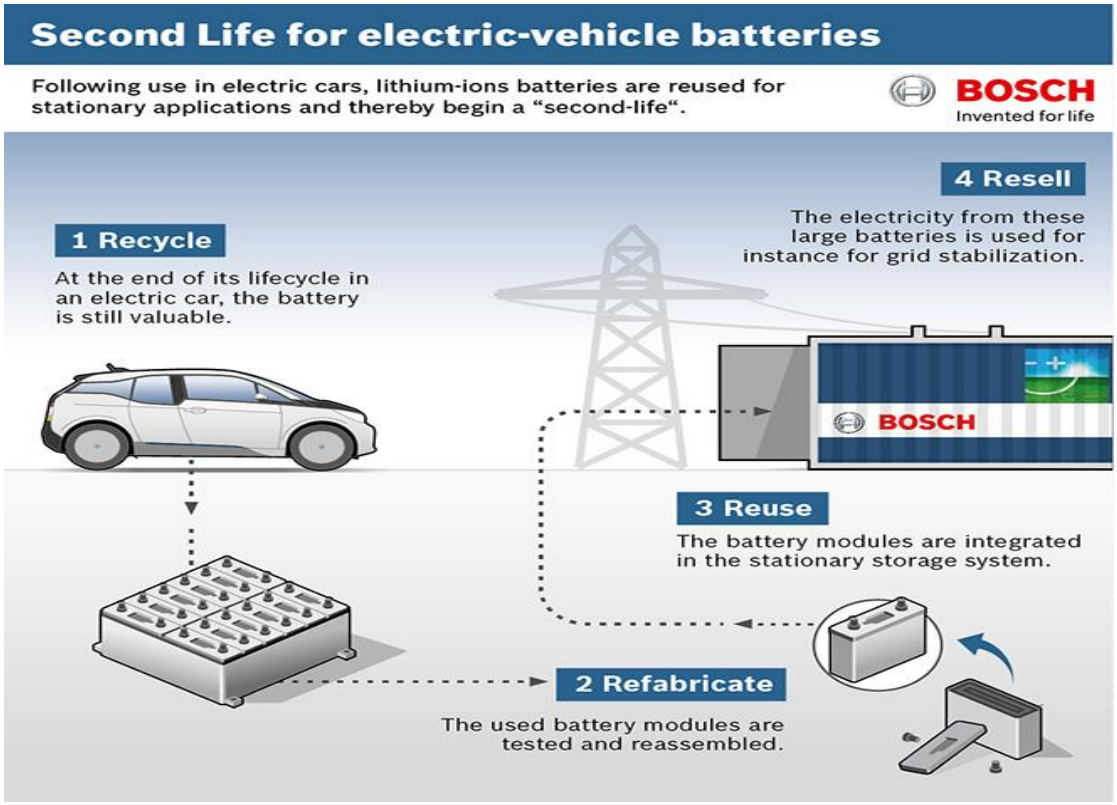


Figure 2.0: Recycling EV Batteries

[24] Argonne National Laboratory, Linda Gaines, "A Look through the Crystal Ball at the Future of Automotive Battery Recycling"
[25] Argonne National Laboratory, Linda Gaines, "A Look through the Crystal Ball at the Future of Automotive Battery Recycling"

Model availability

To date PEV models primarily serve the passenger, light duty market with nearly every major automaker, including Toyota, Nissan, Mitsubishi, Mercedes, BMW, Ford, Tesla, Cadillac, GM, and more having a PEV model available. These models are mostly coupes or sedans, with only one SUV (Porsche Cayenne PHEV), and only one other vehicle exists in the U.S. market today with all-wheel drive, the Tesla Model S P85D (both luxury vehicles). Even without all-wheel drive, PEVs perform well in the snow. Most are front wheel drive, and because the heaviest part of the car (the battery) is located at the center and base of the vehicle, they handle very well. Snow tires may improve performance, especially when decelerating and accelerating.

Several companies are producing vehicles beyond coupes and sedans for both the general public and fleet customers alike. Smith Electric Vehicle produces electric delivery trucks used by companies such as Frito-Lay, and the market for all-electric transit buses like Proterra is growing rapidly. Electric buses can be bought in hybrid electric, plug-in hybrid, and all-electric versions, and they are produced by several companies, including, Proterra, BYD, Volvo, and WAVE. Because buses have more space for batteries, there are much configurations to choose from depending on route length, daily range, charging pattern, passenger capacity, and other factors.

Via Motors produces PHEV pickups and vans on the Chevy platform which get about40 miles all-electric range, and they have plans to sell 50,000/year by 2018. Electric motorcycles are also gaining prominence, offering rapid acceleration and a quiet ride. Companies like Zero Motorcycles produce electric police pursuit bikes, as well as dirt bikes and street bikes, and Brammo offers a lineup of performance street bikes. Overall, PEVs operate in multiple duty cycles, including passenger cars, pickups, vans, and transit buses, but there are limited options to choose from outside of passenger vehicles, and all-wheel drive is something the current market doesn't provide.

Capital Cost

One of the most significant barriers for PEV adoption is the upfront incremental cost compared to the equivalent ICE vehicle. Economies of scale have yet to develop that make large, lithium-ion batteries cheap enough to compete with the internal combustion engine., For example, the Ford Focus, which has a gasoline and all-electric options available, lists an MSRP of $18,625 for the gas/hatchback model, the PEV model starting at $29,170, an incremental price of $10,545[26]. PEV models today have an MSRP between $28,000 and$35,000 base MSRP, with luxury models such as BMW, Tesla, Mercedes, Porsche and Audi priced at $45,000 to $110,000+.

Incentive programs are available to help offset the incremental cost with additional lifecycle savings coming from lower fuel and maintenance costs. Again, using the Ford Focus Electric as an example with an MSRP of $29,170 less the $7,500 federal tax credit and a Colorado state tax credit of $4,984, the final price is reduced to $16,686, about $2,000 less than the conventional Ford Focus. When combined with the operating cost savings, the Focus Electric (and other PEV models) can be much less expensive to purchase and own. Increased education to consumers about available tax credits will increase adoption as drivers learn how affordable the vehicles can be. Only taxable entities qualify for tax credits, so the City of Aspen and other governments do not qualify.

Passenger vehicles are a step ahead of other vehicle vocations when it comes to price , because their batteries aren't as large as those in the heavier duty-cycles needed for fleet applications. Electric buses are significantly more expensive

[26] Ford website, accessed 01/22/2015 http://www.ford.com/cars/focus/models/

than diesel or natural gas models, but because buses travel so many miles and consume a lot of fuel, the payback can be realized quickly. An all-electric 40' bus is almost twice as expensive as a traditional diesel bus (around $800,000 without chargers, compared to a diesel bus around $425,000), but by utilizing a cheaper energy source more efficiently, and by reducing maintenance costs, fleets operating these buses are actually saving money by the end of the bus's 12-year life. Proterra advertises lifecycle savings of $225,000-$365,000 per bus over diesel, natural gas, and hybrid models, which includes $135,000 savings in maintenance costs and is based on a number of assumptions that can be found on their website.

Medium duty electric delivery trucks are priced at $35,000-40,000 over the diesel version, but see a payback if enough fuel is displaced[27]. Verizon and PG&E have placed orders for PHEV trucks and vans that Via Motors just began producing at a cost of around $70,000 each.

The Nissan Leaf, Chevy Volt, Ford Focus Electric all saw $5,000+ price decreases since their release, and as PEV sales increase, battery costs are expected to continue declining. Figure 2.1 is from Pike Research and illustrates the expected trend for battery costs through 2017.

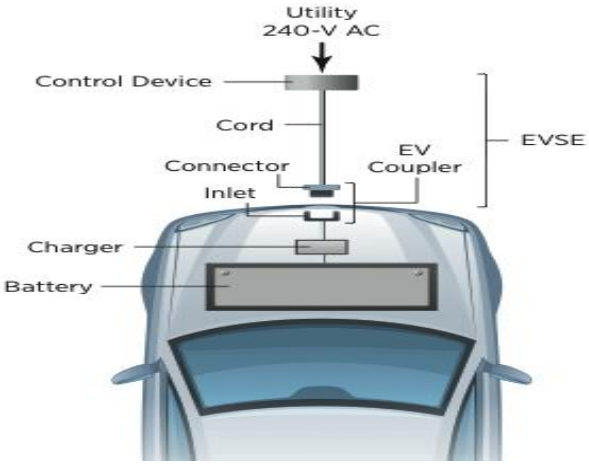
Figure 2.1: Predicted Battery Costs

Ranking Barriers

Understanding PEV deployment barriers is important, but knowing which barriers are the most significant to consumers may be more essential. The recent Colorado Electric Vehicle Market Survey asked residents to rank nine barriers in order of importance when considering the decision to buy a PEV in Colorado. The results from 285 respondents are shown below in order of prominence:

[27] New York Times, http://wheels.blogs.nytimes.com/2010/09/08/frito-lay-adds-electric-trucks-to-its-fleet/?_r=0

1. Up-front price difference for a PEV
2. Limited range of PEVs
3. Availability of charging stations
4. The time that it takes to charge a PEV
5. Vehicle performance
6. Model availability
7. Consumer knowledge of PEVs
8. Elevation impacts and four-wheel drive capability
9. Dealership experience at point-of-sale.



Participants indicated they were most concerned with the range and cost of PEVs, where cost ranked as the number one concern with 35.1% of respondents listing it as a barrier, and 32.6% listing limited range. One interesting finding from the survey is that even though respondents were most concerned with the price of an PEV, they are still willing to pay an incremental cost – 38.6% said they would be willing to pay up to $5,000 more for a PEV, and 24.2% would pay up to $2,000 more. Combined, that indicates 62.8% of respondents would pay at least $2,000 more for a PEV. Only 15.79% of respondents would not be willing to pay an incrementally higher cost. With regards to range, over 53% of respondents want an EV with 150+ mile range per charge, and 32% wouldn't feel comfortable without a 200 mile range. The methodology and full survey results can be found in the Colorado EV Market Implementation Study.

Infrastructure

Electric Vehicle Supply Equipment (EVSE)

EVSE is charging equipment that ensures the transfer of a safe and appropriate flow of electricity from a source into a PEV. There are different levels of EVSE according to the rate at which they charge a battery. Two types—Level 1 and Level 2—provide alternating-current (AC) to the vehicle, with the vehicle's onboard equipment (charger) converting AC to the direct current (DC) needed to charge the batteries. The other type —Level 3 charging—provides DC electricity directly to the vehicle[28].

The following information on charging levels is taken directly from the U.S. Department of Energy's Workplace Charging Handbook, which describes the charging levels and times in a simple, accurate fashion: Charging times range from less than 30 minutes to 20 hours or more (only if battery is completely depleted and charging on Level 1, which is highly unlikely), based on the type or level of EVSE; the type of battery, its capacity, and how depleted it is; and the size of the vehicle's internal charger. EVs generally have more battery capacity than PHEVs, so charging a fully depleted EV takes longer than charging a fully depleted PHEV.

Level 1
Level 1 EVSE provides charging through a 120-volt (V) AC circuit and requires electrical installation per the National Electrical Code. Most, if not all, PEVs come with a Level 1 EVSE cord set. On one end of the cord is a standard, three -

[28] U.S. Department of Energy's Workplace Charging Handbook, http://www.afdc.energy.gov/uploads/publication/pev_workplace_charging_hosts.pdf

prong household plug (NEMA 5-15 connector). On the other end is a J17725 standard connector, which plugs into the vehicle. Level 1 typically is used for charging at locations with longer dwell times such as home, work and airports. Based on the battery type and vehicle, Level 1 charging adds about 2 to 5 miles of range to a PEV per hour of charging time.

Level 2

Level 2 EVSE can easily charge a typical EV battery overnight, and it is a common installation for residential, workplace, fleet, and public facilities. Level 2 EVSE offers charging through a 240-V (typical in residential applications) or 208-V (typical in commercial applications) electrical service. These installations are generally hard-wired for safe operation (although a wall plug connection is possible). Level 2 EVSE requires installation of charging equipment and a dedicated circuit of 20 to 80 amp depending on the EVSE requirements. Most Level 2 EVSE uses a dedicated 40 A circuit, but there are charging stations (like Clipper Creek and Telefonix) made with lower amperage (16-20 amps) that minimize the circuit requirements and overall project costs, but those systems sacrifice charging speed and should be considered for longer-term parking options (workplaces, overnight parking, etc). As with Level 1 equipment, Level 2 equipment uses the J1772 connector. Based on the battery type, charger configuration, and circuit capacity, Level 2 charging adds about 10 to 20 miles of range to a PEV per hour of charging time, depending on the power level of the onboard charger.

Level 3 Charging

Level 3 (also known as DC fast-charging) EVSE enables rapid charging and is generally located at sites along heavy traffic corridors and at public fueling stations. Some Level 3 charging units are designed to use 480-V AC input, while others use 208-V AC input. A Level 3 charger can add 60 to 80 miles of range to a light-duty PEV in 20 minutes. Level 3 charging is not commonly used as a workplace charging option. Workers' vehicles are typically parked for several hours at a time, so they don't require rapid charging at work[29].

Level 3 chargers have a different plug standard from Level 1 and 2. Currently there are three Level 3 charging plug standards, including the CHAdeMO, SAE-Combo, and Tesla. CHAdeMO is used by Asian automakers like Nissan, the SAE-Combo is used by German and American automakers like BMW, Volkswagen, Ford, and GM, with Tesla having its own Level 3 charging standard for their vehicles. This makes infrastructure planning somewhat difficult, though an increasing number of EVSE providers are able to support multiple standards. At present, the only company producing a Level 3 charger that supports all three is GOe3, which plans to deploy their Colorado network in 2015.

Costs

Costs for EVSE projects vary widely, depending on the level of charger, type and capability of the charger, indoor or outdoor, distance from electrical, existing electrical demand and other factors. EVSE manufacturers offer a variety of features, including data collection and monitoring, credit card access and processing software, network service, RFID access, etc. Figure 2.2 provides an overview of the range of capital costs associated with each level of EVSE.

[29] U.S. Department of Energy's PEV Handbook, http://www.afdc.energy.gov/uploads/publication/pev_workplace_charging_hosts.pdf

EVSE Level	Application	Capital Cost Range
Level 1	Longer term parking (4+ hours)	$500-1,500
Level 2 (Residential)	Home charging indoors	$500-2,000
Level 2 (Public/Commercial)	Public or workplace	$1,000-7,000
Level 3 - DC Fast Charging	Public, corridor development	$20,000 +/-

Figure 2.2: Capital Cost Ranges

Capital costs for the charger are only one of the associated costs. Installation costs can be the largest portion of the expense depending on the length and complexity of trenching, amount of conduit, and any electrical service upgrades. If an organization anticipates expanding the number of EVSE units in the future, it should consider adding extra circuits, electrical capacity, and conduit during initial installation. It is less expensive to install extra panel and conduit capacity during initial construction than to modify the site later. For the same reason, it is a good idea to consider electricity infrastructure for EVSE during the planning phases of new facilities.

A typical budget for a workplace EVSE project might include the following line items:

- EVSE unit(s)
- Contracted labor
- In-house labor
- Material/incidentals
- Equipment rental (backhoe, jackhammer, etc.)
- Sidewalk demolition and repair
- Optional EVSE equipment (e.g., RFID card reader)
- Signage and paint
- Permitting and inspection costs
- Incentives (if available)

Typically, maintenance costs for EVSE are low. Common maintenance concerns include cord damage, operator screen issues, credit card processing software, and network connectivity issues. Some manufacturers offer retractable cord reels for example. Only buying features that are required for the project helps minimize the chance of something malfunctioning.

Electricity costs depend on the type and level of EVSE installed, the frequency it is used, and the electric rate applied to the station. The maximum potential electricity use from Level 1 EVSE will total about 4,000 kWh/year. At Level 2, use could range from 6,500 kWh to 13,000 kWh per year, depending on the vehicles using the EVSE and the electrical circuit's capacity. Charging PEVs during peak electricity demand periods may move a customer into a higher rate category and result in higher electricity costs. However, the advanced capabilities of some EVSE products can be useful

for optimizing load management. It is important to discuss the effects of PEV charging on electricity rates and loads with the local utility[30].

Charging for electric buses have all of the same cost factors and considerations as light-duty cars, but because the batteries are bigger more power is needed to charge them. Each bus manufacturer has different charging options – BYD has a 480 volt AC, 96 amp, 60kW charger that fills the bus in five hours, or a 200kW charger that takes only 1.6 hours[31]. Proterra offers a faster charging option with a 480 Volt DC, 500kW charger that can refill a bus in 10 minutes. The cost of Proterra's fast charging station is about $350,000.

Inductive Wireless Charging

Wireless PEV charging is a technology just now coming to market. Wireless charging has many benefits over current EVSE. Eliminating the cord and the plug rids any concern over tripping and safety hazards, minimizes maintenance issues with the plugs, and creates a convenient, effortless charging process that ensures people won't forget to plug-in. Automakers and their Tier One suppliers continue to be reticent on their plans for wireless EV charging. Most wireless charging systems are in the pilot phase and are likely to remain there for another 2 to 3 years. By 2015-2016, however, models with built-in wireless charging capability will be available from several major automakers[32]. Wireless charging has proven efficiencies similar to plugged systems around 90%[33]. There is one system already available from Plugless Power that costs a PEV owner about $2,000-2,500 for the station and the required vehicle charging adapter. Installation costs are not included in that price.

Outside of individual, stationary inductive charging, much research is being done to understand how to incorporate inductive chargers into our existing road network so that PEVs can charge during operation. This is also known as dynamic inductive charging. Fast-charging vehicles while they drive would be the ultimate convenience, and could dramatically limit or eliminate range anxiety with widespread deployment in urban areas. It could also provide the opportunity to lower the battery size and cost required to drive long ranges on electricity by utilizing small, frequent charging periods. The technology has been demonstrated as feasible in research settings, but commercialization of the technology has some significant barriers to overcome. Automakers, research institutions, and utilities are all working together to standardize the technological requirements to bring dynamic inductive charging to the commercial market[34]. Though, there are demonstration projects underway, including in Park City, UT where WAVE partnered with the University of Utah to provide inductively-charged electric buses. Similar projects have occurred in South Korea, and WAVE is planning a 10-bus system in Long Beach, CA[35]. Costs for installing dynamic wireless charging have yet to be commercially established so they are hard to predict, but initial estimates are that they range from hundreds of thousands to a couple million per kilometer[36]

[30] U.S. Department of Energy's PEV Handbook, http://www.afdc.energy.gov/uploads/publication/pev_workplace_charging_hosts.pdf
[31] BYD website http://www.byd.com/na/auto/ElectricBus.html
[32] Navigant Research, "*Wireless Charging Systems for Electric Vehicles*" http://www.navigantresearch.com/research/wireless-charging-systems-for-electric-vehicles
[33] Hybrid Cars, http://www.hybridcars.com/momentum-dynamics-wireless-charging-could-relegate-plugs-to-history/
[34] IEEE, http://electricvehicle.ieee.org/2014/02/04/wirelessly-charge-electric-vehicles-by-induction-while-driving/
[35] Clean Technica, http://cleantechnica.com/2013/10/22/wireless-electric-buses-developed-utah/
[36] IEEE, http://electricvehicle.ieee.org/2014/02/04/wirelessly-charge-electric-vehicles-by-induction-while-driving/

Within a decade, wireless charging could be the primary method of charging EVs. Navigant Research forecasts that wireless charging equipment for light duty vehicles will grow by a compound annual growth rate (CAGR) of 108% from 2013 to 2022, reaching annual sales of slightly less than 302,000 units in 2022[37].

Case Studies and Examples

- Indianapolis to deploy largest municipal PEV fleet in the country (425)
- Medium duty PEV delivery trucks are incorporated into Frito-Lay, Coca-Cola, and PG&E Fleets
- City of Loveland, CO incorporates Nissan Leafs into vehicle pool
- Houston launches municipal PEV car-sharing program with Zip Car
- SDG&E start vehicle to grid pilot program
- Proterra all-electric bus services passengers nationwide
- Massachusetts operates largest electric bus fleet in the country.
  This is the coldest atmosphere similar to Aspen with electric buses operating. Proterra is delivering 6 buses to Duluth, MN, which will be the coldest place operating the buses.
- WAVE inductively charges electric buses in Utah, other cities coming
- U.S. Department of Energy's Workplace Charging Challenge progress report
- Xcel Energy provides $.033 EV off-peak charging rate in Minnesota
- City of Montrose EV Charging Signage – Page 57
- How to not install an EV charging station

Market

Present

In the year 1900, 38% of cars on the road were powered by electricity, and there was an electric taxi fleet in New York City. This was a short-lived technology, however, as internal combustion engines ended up winning the market, with only short spurts of electric vehicle introductions up until the present decade. In 2010, revitalization came to the PEV

[37] Navigant Research, "*Wireless Charging Systems for Electric Vehicles*" http://www.navigantresearch.com/research/wireless-charging-systems-for-electric-vehicles

market in response to public concern and new environmental regulations such as the Corporate Average Fuel Economy standard and Clean Air Act. 2010/2011 was the first year that PEVs hit the U.S. mass market, with only three models available. At the start of 2014, major automakers were selling 16 different PEV models, and by September of the same year there were 23 PEV models available[38]. The Electric Drive Transportation Administration expects an additional 20 models through 2016. This is a sign both of consumer acceptance and of the automaker's unprecedented commitment to the future of PEVs.

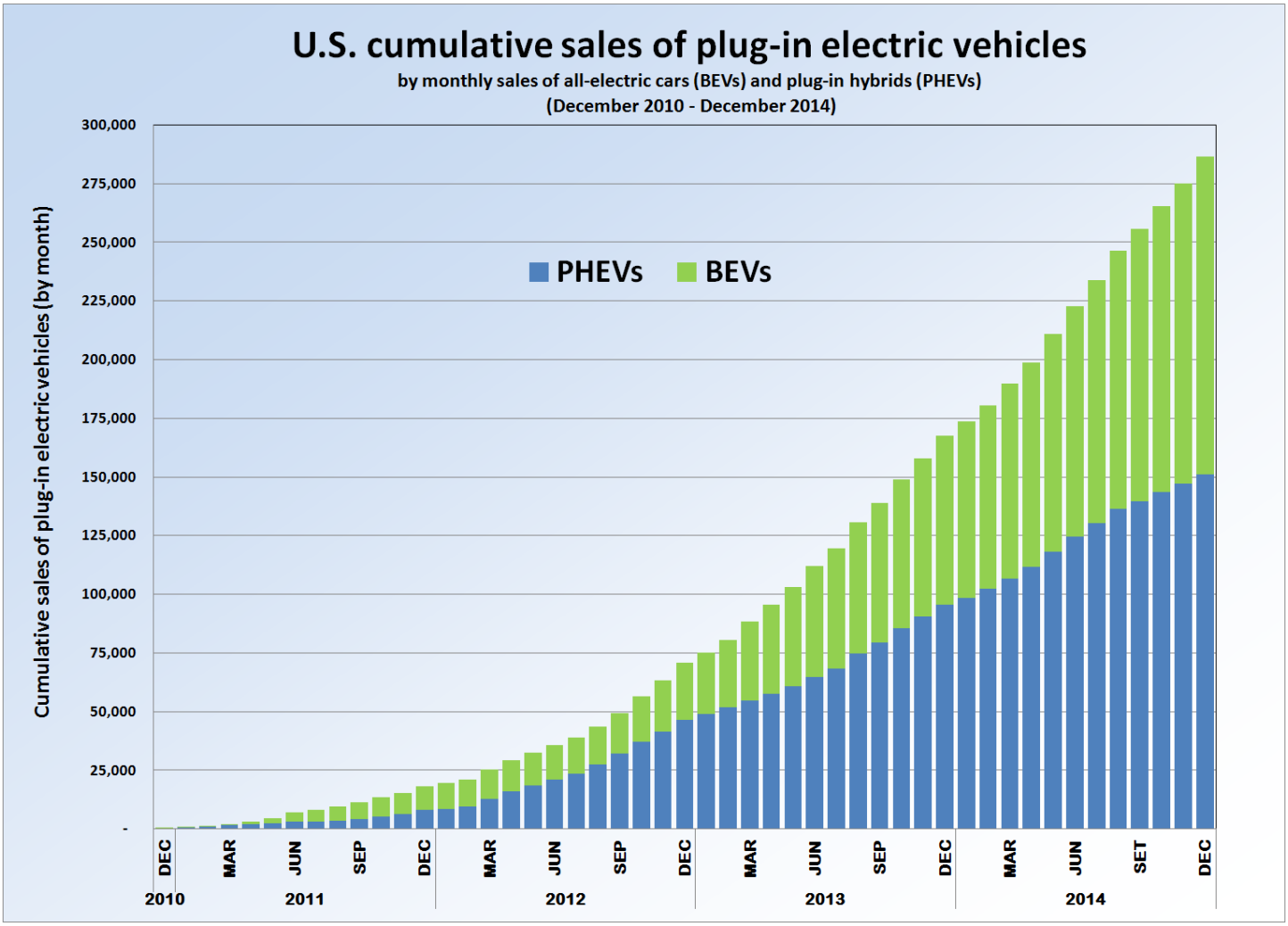


Figure 2.3: U.S. PEV Sales (Wikipedia)

Figure 2.3 from shows cumulative U.S. PEV sales from December 2010 through December of 2014. It is evident that the PEV market is growing continuously, with 225,000 units sold as of May 2014.

[38] Colorado EV Market Implementation Study, January 2015, pg 11

Colorado's PEV sales are also increasing year over year. As many new models entered the market in 2013, there was a 90.3% increase in sales from 795 in 2012 to 1513 in 2013. The most recent data available for Colorado PEV purchases only extends to February of 2014, when there were 3,112 PEVs registered in the state. Colorado currently ranks 8th among U.S. states for total PEV sales, up from 11th in 2012. One of the reasons for this growth can be attributed to the growth in publicly available charging stations, which grew from 103 to 204 between October of 2013 and October of 2014 – a 98% increase[39]. As of January 24, 2015 there were 216 charging stations with 466 charging outlets throughout the state[40]. As of February 2014, there were 30 PEVs registered in Pitkin County. The full year of 2014 data should be made available soon, and it is expected to show growth to above 4,000 registered PEVs. Figure 2.4 from the Colorado EV Market Implementation Study shows Colorado's PEV car sales per month through 2013.

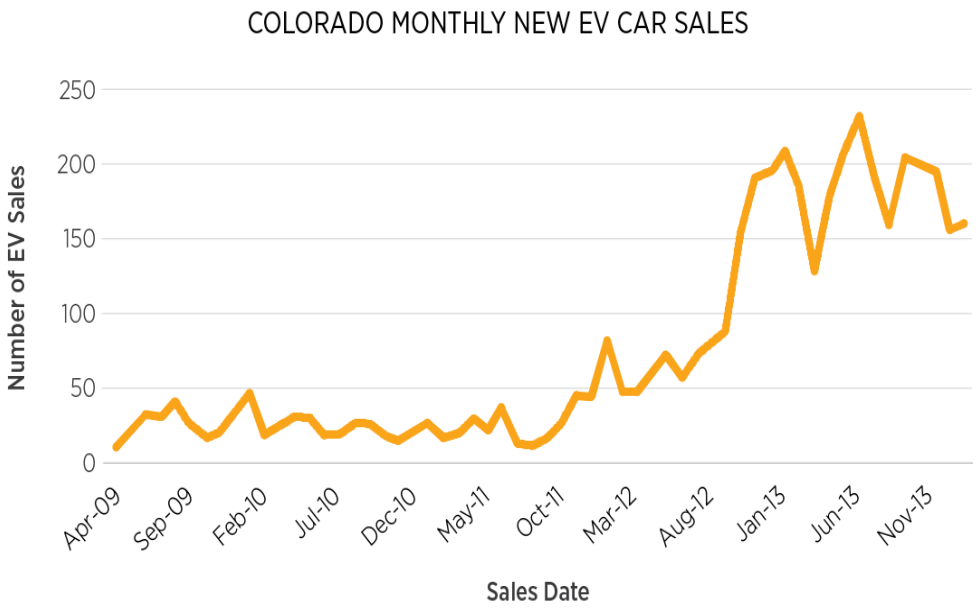


Figure 2.4: Colorado PEV Car Sales

PEV buses only came to market in the United States within the last three years, but since then there have been 130 of them in operation throughout the country. According to their website, Proterra has 63 buses operating in 10 areas throughout the country, and they have orders from several new customers, including a transit agency in Minnesota. BYD is the industry leader for electric buses with 5,200 on the road, 50 in the U.S. and most of the others in China, but they are changing their focus to the United States now and expect to sell 200 this year.[41]

Future

According to Navigant Research, global light-duty electric vehicle sales (including hybrids) will expand from 2.7 million sales in 2014 to 6.4 million by 2023. PEV sales are expected to continue growing rapidly in Colorado. The Colorado EV

[39] Denver Metro Clean Cities Coalition's Annual Operating Plan, http://denvercleancities.org/Annual%20Operating%20Plan%20-%20Denver.pdf
[40] U.S. Department of Energy's Alternative Fuel Data Center, Alternative Fueling Station Locator http://www.afdc.energy.gov/locator/stations/
[41] National Geographic, "Tesla for the Masses: Electric, Fuel Cell Buses Take Off" http://news.nationalgeographic.com/energy/2015/03/150312-tesla-for-the-masses-electric-buses-take-off/

Market Implementation Study conducted an analysis based on low, medium, and high growth scenarios, and the projections are shown in Figure 2.5. In the medium growth scenario, Colorado would see 24.4% year-over-year growth in PEV sales for a total of 302,429 by 2030[42], and Pitkin County would have a total of 986 PEVs.

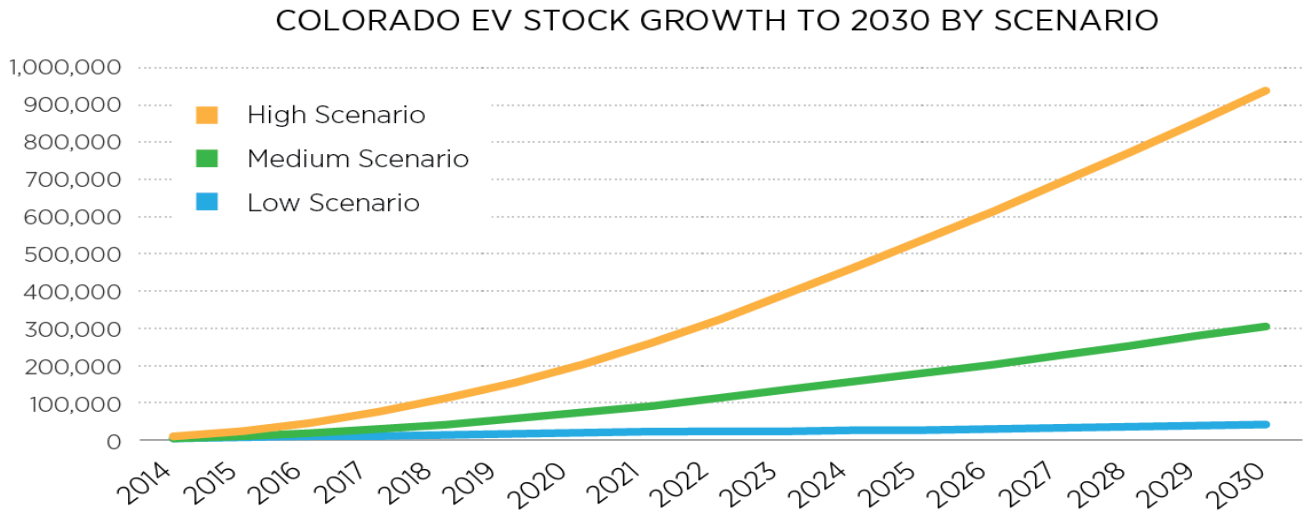


Figure 2.5: Projected EV Growth

Projections from Navigant Research, Energy Information Administration, and many others all conclude PEVs will continue to gain market share, but the question is at what pace. If sales of hybrid electric vehicles are any indicator, then PEVs are certain to continue growing rapidly. PEVs have grown faster in their first three years of introduction than the Toyota Prius did in its first three years, and the Prius has been the top-selling vehicle in California for the last two years in a row (17th in U.S. overall, led by Ford F150 pickup)[43]. The Toyota Prius in its fourth year sold 52,000 units, while the Nissan Leaf and Chevy Volt sold 100,000 and 70,000 respectively.

Sales and a steady rise in available models are all good signs that the PEV market will continue to strengthen. Though, the barriers in front of the market are still significant, and in order for sales to continue rising into new market segments, many of those barriers will need to be addressed. The two primary concerns identified by Coloradans in the survey were upfront cost and driving range, which are currently being address by automakers.

The 2016 Chevy Volt, a plug-in hybrid electric vehicle, will increase its electric range from 38 to 50 miles in the newest generation. Tesla and GM have both announced new all-electric vehicles with a 200+ mile range for less than $30,000 to hit the market in 2017. The main component in PEVs that contribute to a high initial cost is the battery, and as illustrated in Figure 2.5, battery prices are already dropping and are expected to fall as economies of scale increase and research continues. In reference to cost, there are many incentives available to help offset the price tag. Colorado has the most significant state tax credit in the country, where PEVs qualify for up to $6,000 off the initial cost, regardless of tax liability, so consumers will receive a rebate check if they don't owe enough in taxes for a credit (governments do not qualify for tax credits – only taxable entities). Combined with the federal rebate of $7,500, there is potential for $13,500

[42] Colorado EV Market Implementation Study, pg. 19
[43] HIS Automotive, http://gas2.org/2014/05/20/ev-sales-progressing-faster-hybrids-decade-ago/

in price reductions that bring PEVs into a competitive place with conventional vehicles. There are other incentives that are described in more detail in the Incentives section.

Electric buses are expected to grow at a compound annual growth rate of 28.4% through 2020 worldwide according to Persistence Market Research's recent report, as electric bus technology has reached a point where they are outperforming, and out-saving diesel and natural gas bus options. CALSTART, a leading non-profit that specializes in helping transit agencies develop cleaner buses, expects electric buses to double in operation to double next year in the United States from 130 in 2014 to over 250 by the end of 2015. Overall, CALSTART expects zero emission buses to account for 20% of the overall transit industry by 2030.[44]

PEVs will remain prominent in the passenger vehicle market, but expect to see other niche markets like delivery services, taxis, and other high-mileage, stop-and-go applications expand their use of PEVs. Additionally, look for additional model options that venture into the compact SUV, trucks, and all-wheel drive segments that are more attractive to active Coloradans before 2020. There are already a handful of companies like Tesla and Via Motors that have 4WD models like the Model S P85D and Via's lineup of GM trucks proving the technology is possible, but they are costly and inaccessible to many consumers. The availability and prices for these options should continue to decline making them an affordable option for many Coloradans.

Additionally, Colorado is working to expand access to a Level 3 charging PEV network that will allow cars to charge up to 80% in 30 minutes, similar to the Tesla-only Supercharge network that is currently located in Glenwood Springs, Silverthorne, and throughout the country. Aspen currently has 7 locations advertising PEV charging, including four chargers at Hotel Jerome, two at Rio Grande Parking Plaza, two at Limelight Hotel, Level 1 outlets at Mountain Chalet, four at the Little Nell, and Aspen Square Hotel – though, only one of those locations is open to the general public (Rio Grande Parking Plaza. Also, there are no Level 3 chargers in Aspen – the nearest one is a Tesla Supercharger station in Glenwood springs that only charges Teslas and no other models. Drivers are much more likely to consider a PEV if they can get to and from the mountains without charging overnight, and if people see and hear about Level 3 fast chargers at the rest area or on television, they are more likely to consider it as a convenient (and therefore legitimate) option for their lifestyle.

What will the market look like in 2020? It's impossible to know, but it's reasonable to expect that Coloradans will have access to multiple all-electric models with a 200+ mile range, 4WD, and a price tag under $30,000. There should also be a network of Level 3 charging stations along Colorado's major corridors that provide range confidence and help establish PEVs as a cheaper, more convenient alternative to gasoline. This would go a long way toward combating the three most significant barriers identified by Coloradans, and it paints a positive picture for the future of PEVs.

HYDROGEN FUEL CELL VEHICLES

Technology

Similar to a Plug-in Electric Vehicle (PEV), a Hydrogen Fuel Cell Vehicle (FCV) is powered by an electric motor, but the electricity used to power the motor is generated from the combination of hydrogen and oxygen inside a fuel cell instead

[44] National Geographic, "Tesla for the Masses: Electric, Fuel Cell Buses Take Off" http://news.nationalgeographic.com/energy/2015/03/150312-tesla-for-the-masses-electric-buses-take-off/

of being plugged in to an external electric source. Hydrogen is stored in a highly-compressed tank onboard the vehicle, and when combined with oxygen inside the fuel cell it generates electricity to power an electric motor. The only byproduct of this process is water, so FCVs are considered zero emission vehicles and can be an important strategy in reducing the impacts of climate change and criteria air pollutants. FCVs can be 2-3 times more efficient than an internal combustion engine, can travel around 300 miles on a single tank, and can take only minutes to refill[45].
This section will provide a summary of the important factors, benefits, and considerations in analyzing whether FCVs should play a role in the City of Aspen's transportation sector.

A fuel cell is similar to a battery. It is made of individual cells grouped together to form a fuel cell stack, and each cell contains an anode, cathode, and electrolyte layer. When hydrogen (H_2) enters the fuel cell stack, it reacts electrochemically and splits into two atoms and combines with oxygen from the surrounding atmosphere to produce electricity, heat and water. Fuel cells will continue to generate electricity as long as fuel is supplied, whereas a battery has a fixed amount of energy that needs to be recharged instead of refilled[46]. The main difference between an FCV and a PEV is the electricity generation source. Figure 2.6 shows the process of putting hydrogen through a fuel cell.

Photo:http://www.todaysmotorvehicle

Hydrogen

Hydrogen is the simplest and most abundant element on the planet, but it is naturally diatomic, meaning it pairs with other atoms in order to reach a balanced state[47]. Molecules like water (H_2O) and methane (CH_4) are primary sources for hydrogen, but to use it, hydrogen must be separated and stored. Hydrogen has the highest energy content per unit weight of all fuels at 52,000 BTU/lbs, which is three times the content of gasoline, but hydrogen also has a very low energy content by volume, meaning it is difficult to store and contain. As a result, hydrogen is stored onboard FCVs at very high pressures up to 10,000psi. One kilogram (2.2 lbs) of hydrogen has the same energy content as a gallon of gasoline, and, therefore, kilograms is the standard measurement used when fueling an FCV[48].

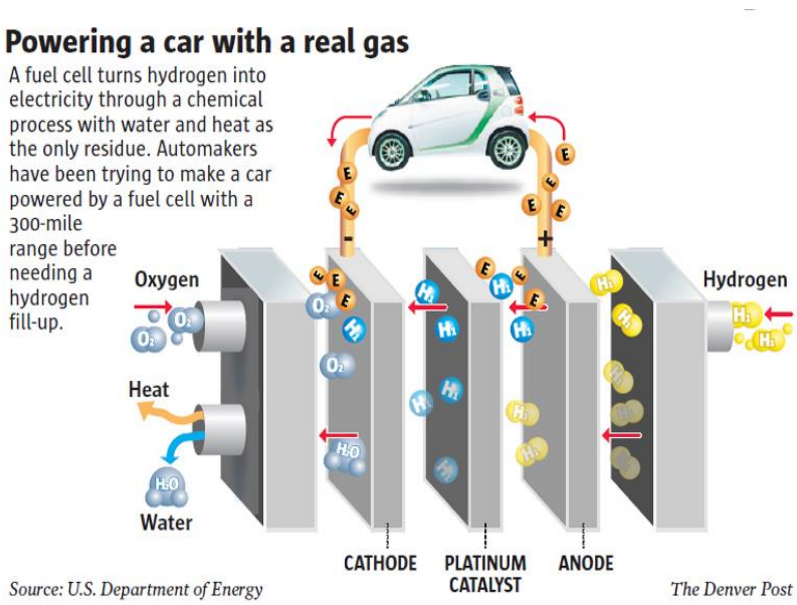


Figure 2.6: Fuel Cell

[45] Refuel Colorado, http://refuelcolorado.com/fuel-cell-electric-vehicle/about
[46] Fuel Cell Energy, http://www.fuelcellenergy.com/why-fuelcell-energy/how-do-fuel-cells-work/
[47] Fuel Cells 2000, http://www.fuelcells.org/base.cgim?template=hydrogen_basics
[48] U.S. Department of Energy's Alternative Fuel Data Center, http://www.afdc.energy.gov/fuels/hydrogen_basics.html

Benefits

Emissions

Fuel cells produce no harmful emissions and are 2-3 times more efficient than internal combustion engines. Fuel cells are used in a variety of applications, including stationary backup and primary power generation, portable power, renewable energy storage, and transportation. Figure 2.7 from the U.S. Department of Energy's Fuel Cell Technologies Offices shows the different hydrogen sources as well as the multiple fuel cell types and applications.

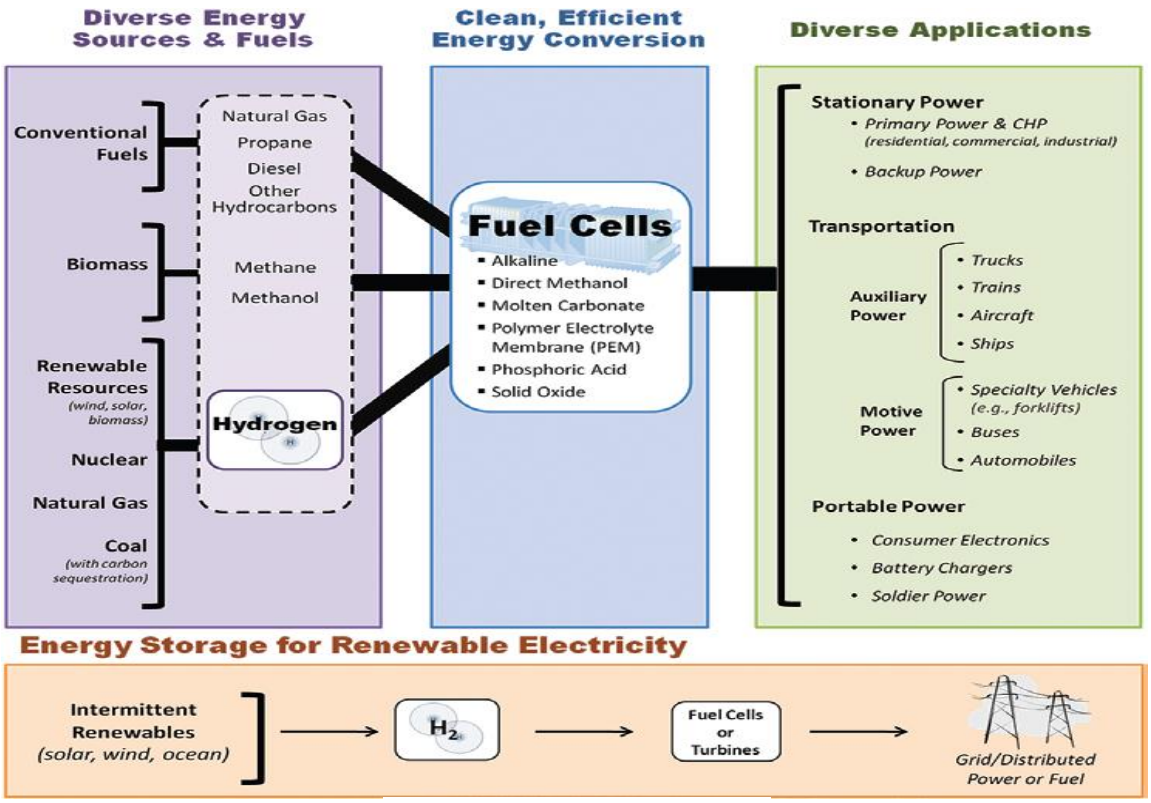


Figure 2.7: Hydrogen Pathways

Hydrogen fuel cells produce no exhaust emissions—only heat and water—so FCVs are considered zero-emission vehicles. However, there are many pathways for the generation of hydrogen fuel, and some of them produce emissions, so FCVs can have lifecycle emissions associated with their use. The majority of hydrogen is generated from a process called Steam Methane Reformation (SMR), which takes methane (CH_4) sourced from natural gas combined with high temperatures and steam to split the molecule into carbon monoxide (CO), hydrogen (H_2), and small amounts of carbon dioxide (CO_2). SMR is the primary production method for hydrogen because it is the least expensive and easiest method for producing large quantities[49]. Even though SMR does have carbon emissions, FCVs powered by reformed hydrogen

[49] U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy http://energy.gov/eere/fuelcells/hydrogen-production-natural-gas-reforming

still have significant air quality advantages over the average internal combustion engine, as shown in the first four scenarios of Figure 2.8[50]. One scenario that isn't shown in Figure 2.8[51] is one where renewable natural gas is used as the methane source for SMR, which would significantly reduce lifecycle FCV emissions even further.
Another pathway for hydrogen production is the splitting of water molecules known as electrolysis. Electrolysis can use renewable electricity from wind or solar to generate hydrogen with zero carbon emissions, but it is currently more than twice as expensive to produce as SMR hydrogen[52].

A side-by-side comparison of a 2015 Subaru Outback driving 10,000 miles/year and a FCV driving 10,000 hydrogen miles/year with gaseous hydrogen generated from on-site SMR would reduce greenhouse gas emissions 50% from 10,681 lbs/year to 5,340 lbs/year. An FCV fueled with hydrogen from renewable electrolysis would reduce greenhouse gas emissions by 100%, or 10,681 lbs annually, according to the U.S. Department of Energy's Alternative Fuel Data Center's Vehicle Cost Calculator. FCVs and PEVs have the same zero-carbon lifecycle potential.

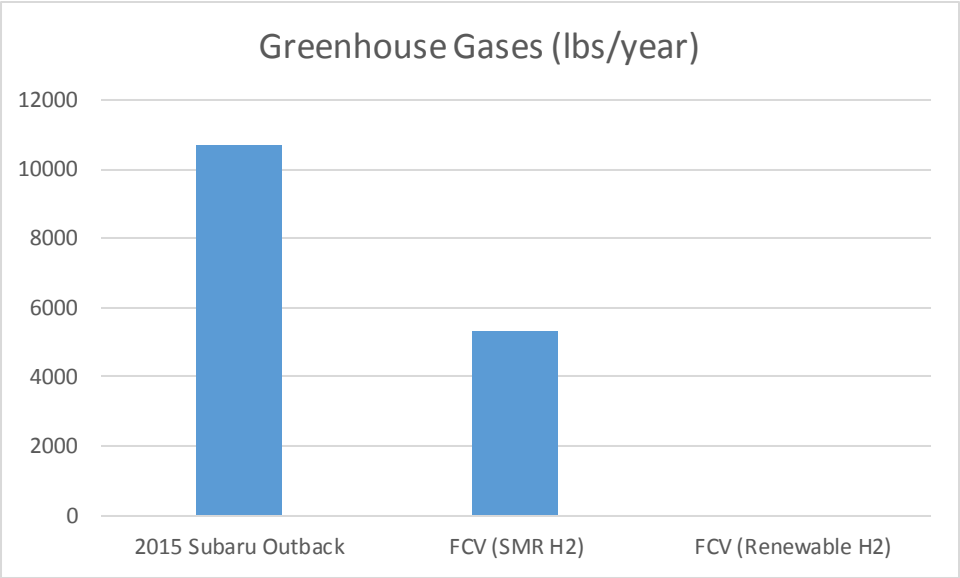


Figure 2.8: Greenhouse Gas Emission Reductions

Performance

Acceleration
The performance of FCVs is similar to PEVs because they both use electric drive trains. FCVs have 100% of their torque at 0 rpm, meaning the operator can use all of the vehicle's power the instant they touch the accelerator. FCVs do not lose power when gaining altitude, which is the case with internal combustion engines and is an essential consideration when operating a vehicle in high altitude environments like Aspen. FCVs provide thrilling acceleration and a fun driving experience[53].

[50] U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, http://energy.gov/eere/fuelcells/natural-gas-reforming
[51] U.S. Department of Energy, Alternative Fuel Data Center http://www.afdc.energy.gov/vehicles/emissions_hydrogen.html
[52] Florida Solar Energy Center, http://www.fsec.ucf.edu/en/consumer/hydrogen/basics/production.htm
[53] Refuel Colorado, http://refuelcolorado.com/fuel-cell-electric-vehicle/performance

Quiet
FCVs are very quiet and don't produce loud, variable noises like an internal combustion engine. This provides the driver with a comfortable, relaxing experience and reduces external noise pollution.

Temperature
Unlike PEVs, FCVs do not sacrifice range in inclement weather. Toyota's test fleets throughout the U.S. consistently meet the advertised 300 miles of range, even in negative temperatures. This is a distinct benefit for operation in cold environments like Aspen[54]

Energy Security
Even with the recent increase in domestic oil and gas production, the United States still imports roughly 33% of its petroleum from foreign countries[55], and 72% of U.S. petroleum use is devoted to the transportation sector. Dependence on a fuel market that is highly subject to global conflict and instability leads to price fluctuations which can be frequent and costly. Research conducted by Argonne National Laboratory demonstrated that regardless of feed stock, hydrogen is petroleum-free[56]. By utilizing a domestic fuel like hydrogen instead of gasoline or diesel, jobs and new industries can be created in solar, wind, and natural gas industries, in addition to the supply chain and research jobs created from the advancement of FCVs that will boost economic growth. Perhaps most importantly, limiting dependence on foreign oil and global markets lessens price instability because the price of domestic fuel is more stable and predictable[57].

Duty Applications
Theoretically, FCVs offer the potential to cover all duty-cycles from forklifts, to passenger to Class 8 semi-trucks. Although initial transportation applications have been mostly limited to passenger vehicles, forklifts, and transit buses, the range, fill time, and power output of hydrogen fuel cells could make them a viable option for all forms of transportation. Fuel cells are much lighter than batteries and internal combustion engines, so enlarging the fuel cell to increase power output is plausible utilizing technologies similar to compressed natural gas to ensure enough fuel is on-board to handle routine driving patterns.

Maintenance
Fuel cells, much like batteries, have no moving parts, and the electric motor the fuel cell is powering is also simple in its design. As a result, FCVs don't require oil changes, and regenerative braking will minimize wear on brake pads. Accordingly, maintenance costs on an FCV will be minimal, similar to a PEV[58].

Range
FCVs can fit enough hydrogen onboard to travel 300-500 miles, comparable to many conventional vehicles running on gasoline[59]. A 300+ mile range is long enough that drivers don't need to change their driving habits and range anxiety is a non-issue.

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[54] Green Car Reports, http://www.greencarreports.com/news/1090078_toyota-touts-cold-weather-performance-of-hydrogen-fuel-cells
[55] Energy Information Administration, http://www.eia.gov/tools/faqs/faq.cfm?id=727&t=6
[56] U.S. Department of Energy's Alternative Fuel Data Center, http://www.afdc.energy.gov/vehicles/emissions_hydrogen.html
[57] Refuel Colorado http://refuelcolorado.com/ev/benefits
[58] Refuel Colorado, http://refuelcolorado.com/fuel-cell-electric-vehicle/benefits
[59] Fuel Cell and Hydrogen Energy Association, Transportation Fact Sheet, http://www.fchea.org/transportation/

Refueling
Hydrogen refueling stations fill FCVs at a rate similar to gasoline, 3-5 minutes. FCVs provide an opportunity for zero-emission driving without sacrificing range or refueling convenience[60].

Efficiency
Fuel cells are 2-3 times more efficient than the internal combustion engine, meaning that an FCV can travel three times as far on the same amount of energy as a gasoline car. Light-duty passenger FCVs get around 60 miles per kilogram of hydrogen, but an internal combustion engine would only travel about 20 miles on the same amount of gasoline energy[61]. Fuel efficiency of future FCV models is not yet known, but the latest FCV to hit the market, the Hyundai Tucson, gets 48 miles per kilogram, and the 2014 Honda Clarity (a limited-production model) gets 60 miles per kilogram[62]. It is expected that future models will hover around that 60 miles per kilogram target.

Considerations

Education

Like many new technologies, the general public is either unfamiliar with hydrogen fuel cell technology or misinformed. Educating both fleets and consumers about FCVs will be essential to their deployment, but unlike PEVs, range anxiety and range fluctuation (due to temperature variability) are not barriers, and refueling is similar to conventional gasoline vehicles.

Hydrogen Cost

Hydrogen production costs are challenging to predict, as they are dependent on the generation method and source. Considering Aspen's carbon reduction goals and renewable electric grid, an assumption is made that any hydrogen station will be using renewable-hydrogen created from emissions-free sources like wind, solar, or hydro. Although these are zero-emission options, they are generally more expensive than steam methane reformation, which does have associated emissions.

Regardless of production method, hydrogen is expected to be relatively expensive until economies of scale are developed. Toyota expects drivers of their Mirai FCV to pay about $50 for a full tank of hydrogen, which equates to about 10/kg (kg = gallon of gasoline)[63], with the goal of getting prices to in line with gasoline as soon as possible.

The 2015 target set by the U.S Department of Energy for hydrogen production costs are $3.10/kg and $3.70/kg for centralized and distributed production methods, respectively. The National Renewable Energy Lab published a study in 2011 that analyzed the cost of producing hydrogen from wind-powered electrolysis, and they found the wholesale price range to be between $3.74-$5.86 per kg for electrolyzed hydrogen from wind, without incentives or distribution

[60] Fuel Cell and Hydrogen Energy Association, http://www.fchea.org/transportation/
[61] U.S. Department of Energy's Alternative Fuel Data Center, http://www.afdc.energy.gov/vehicles/fuel_cell.html
[62] Autoblog, http://www.autoblog.com/2014/11/18/2016-toyota-mirai-fuel-cell-vehicle-likely-to-get-60-mpge/

[63] Ecomento, http://ecomento.com/2014/08/13/bullish-toyota-admits-hydrogen-wont-be-cheap/

included, for production of between 1,000-50,000kg per day. Regardless of where the price range lands, it will still be more expensive to fuel cars on hydrogen (especially renewable hydrogen) than on electricity.

If hydrogen is sold for $3.50/kg (optimistic assumption) and used in a car with an efficiency of 60 miles/kg traveling 10,000 miles/year, it would cost $583/year to fuel. Comparatively, a PEV in the same scenario charging at the residential Aspen Electric rate would use $325 of electricity. But, both the FCV and PEV would demonstrate savings when compared to the 2015 Subaru Outback, which would use $1,400 of gasoline at $3.50/gallon under the same conditions.

Model Availability

The fuel cell vehicle market is in its infancy, making it hard to predict what models will be available in the next 5 to 10 years. Currently, there are nine passenger car concepts that the Fuel Cell and Hydrogen Energy Association references from Toyota, Honda, Hyundai, Mercedes, GM, Nissan, and Volkswagen, which illustrates the widespread interest and possibility of many models in the near future. Only three (Toyota, Honda, and Hyundai) have promised to bring models to the market in 2015/2016, with several other automakers looking toward 2017 and beyond.

Outside of passenger vehicles, there are options for material handling (forklifts). Fuel cell forklifts have significant time and savings advantages over battery forklifts, which are the only two options for operating with zero tailpipe emissions indoors. This is evident in the twenty-five companies cited by Plug Power as using their fuel cell forklifts, such as Coca-Cola, Sysco, P&G, FedEx, and Kroger[64], which operates the largest fuel cell deployment in Colorado with around 200 forklifts at their Stapleton distribution center. The biggest duty cycle for FCVs currently is transit buses, where many transit agencies throughout the country are operating fuel cell buses with the help of research dollars, including the Alameda-Contra Costa Transit District in California.

Overall, fuel cell vehicles from automakers won't be available in Colorado for several years (2018-2020 at the soonest). When they do come, models will be limited. The current FCVs coming to market this year and next will not have all-wheel drive options available, but just like PEVs, as the market grows all-wheel drive models are expected. Additionally, FCVs hold the promise of suiting multiple vehicle classes, including SUVs and trucks, which will certainly have all-wheel drive capability.

Distribution

FCVs face the challenge of moving hydrogen from the generation source to the fueling station. The cheapest way to transport hydrogen is via pipeline, but at present there are only 700 miles of pipeline in the U.S., and they are located near large petroleum refineries – currently the largest consumer of hydrogen. A lack of robust hydrogen pipeline means the hydrogen must be generated on-site or transported to the fueling site in compressed tube trailers or railcars.[65] Transporting adds cost and emissions to the lifecycle process. Steam methane reformation or electrolysis can occur on the fueling site, but centralized or regional hydrogen production in large scale is less expensive. See the centralized and distributed production section within infrastructure for more information.

Capital Cost

[64] Plug Power http://www.plugpower.com/Libraries/Documentation_and_Literature/Whitepaper_Debunking_Hydrogen_Fuel_Cell_Myths.sflb.ashx
[65] U.S. Department of Energy, Alternative Fuel Data Center http://www.afdc.energy.gov/fuels/hydrogen_production.html

At present, FCVs are more expensive than conventional cars, and with fuel costs being at parity with or higher than gasoline, achieving lifecycle savings may be difficult. The only mass-produced FCV on the U.S. market today, the Hyundai Tucson FCV, is offered as a lease at $499/month, and includes fuel and maintenance. The free fuel and maintenance model is expected to be short term, and as new FCVs come to market there will be a more traditional purchasing model. Pricing for the U.S. introduction of the Toyota Mirai FCV, the next model expected to be sold in California in late 2015, will be about $58,000 with free fuel included for the first three years of ownership according to Car and Driver magazine. With the assistance of government incentives the buyer may pay less, but considerably more than PEV models at around $30,000 before incentives, and traditional gasoline cars for less than $20,000. Toyota said that production costs for the main components in the Mirai have come down 95% since 2008[66], so it's difficult to project the cost to consumers and fleets as production development continues.

PEV Development

At present, FCVs and PEVs are the only zero-emission vehicles available with the potential to significantly reduce or eliminate transportation's contribution to climate and air quality concerns. Since they share an electric drive train, they offer many of the same benefits regarding emissions, performance and efficiency. FCVs hold a lot of promise because they avoid two of the largest barriers that PEVs face: range anxiety and refueling time. Batteries take a long time to charge and they are currently limited in the amount of energy they can hold at one time, so drivers sacrifice range, alter driving patterns, and must adopt different 'refueling' habits. These barriers currently keep PEVs from penetrating market segments like heavier duty-cycles and long-haul applications. FCV drivers travel 300+ miles before refilling, which takes approximately five minutes, and with advancements in hydrogen storage, that range has the potential to grow. Advancements in battery chemistry and technology could expand range and shorten recharging times, so FCVs must develop at a similar or faster pace if they hope to gain traction in the market.

H_2 station at the National Renewable Energy Lab's Wind Test Site

Infrastructure Costs and Access

As of February 2015, there are only 10 public hydrogen stations in the U.S. The majority of stations developed were for research and demonstration purposes until this past year, when California partnered with automakers to deploy 50 hydrogen stations throughout the state to compliment the new vehicles coming to market. Finding a hydrogen station outside of California is very difficult. Colorado has one filling station at the National Renewable Energy Lab (NREL) in Golden, CO. This Wind Test Site is not open to the public, another station at their main campus will be finished this spring but will also be limited to research purposes.

[66] New York Times, http://www.nytimes.com/2014/11/30/opinion/sunday/hydrogen-cars-coming-down-the-pike.html?_r=0

The costs associated with constructing a hydrogen filling station can be high. There are different types of hydrogen stations, but a retail, fast-fill station such as those being developed in California, are estimated to cost about $1.6 million - they plan to build 28 for a total cost of $46 million. As California develops their fueling network and the market establishes economies of scale for equipment, the price of stations will come down, but cost and accessibility are sure to be barriers to FCV deployment for the near future.

Safety

Hydrogen has been used safely in a variety of applications outside of transportation for many years, but because it is flammable, like most fuels, and compressed up to 10,000psi, using it as a transportation fuel requires specific safety precautions, codes, and standards. This report will not detail the codes and standards that ensure the safe operation of FCVs, but information on facility permitting, emergency responders, code officials, and best practices can be found at the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy's website, and assistance in working through that process can be found through the National Renewable Energy Lab and local Clean Cities coalition.

Infrastructure

Technology

There are a variety of infrastructure configurations for hydrogen fueling, from mobile applications, to slow-fill fleet applications, and fast-fill applications that will serve as the public station model, and will be the focus of this report. Hydrogen infrastructure is designed to deal with the very light hydrogen molecule, which requires a series of compressors that pressurizes the gas to 10,000 psi, as well as compressed storage tanks that can contain the gas at high pressures, or in some cases the hydrogen is cryogenically stored as a liquid, similar to liquefied natural gas. This style of hydrogen station is similar to compressed natural gas, which is becoming increasingly common throughout the United States and is utilized locally by the Roaring Fork Transportation Authority in Glenwood Springs. One difference is that natural gas (usually) comes into the station directly from the pipeline, but since there is no pipeline infrastructure for hydrogen, the gas is either trucked in or generated on-site.

Centralized vs. Distributed

Hydrogen production can be done in either centralized or distributed fashion, and there are benefits and challenges to both. Producing hydrogen in small amounts at the fueling site is known as distributed production, and this may be the most legitimate option for the initial deployment of FCVs because the demand won't be high enough to justify a large, centralized hydrogen production facility. Two distributed hydrogen production technologies that may offer potential for development and commercialization are; 1) reforming natural gas or liquid fuels, including renewable liquids and; 2) small-scale water electrolysis.

Steam Methane Reformation

The majority of hydrogen is generated from a process called steam methane reformation (SMR), which reacts methane (CH_4) sourced from natural gas with high temperatures and steam to split the molecule into carbon monoxide (CO), hydrogen (H_2), and small amounts of carbon dioxide (CO_2). SMR is the primary production method for hydrogen because

it is the cheapest and easiest method for producing large quantities[67].

Electrolysis

Another pathway for hydrogen production is the splitting of water molecules known as electrolysis. Electrolysis can use renewable electricity from wind or solar to generate hydrogen with zero carbon emissions, but it is currently at least twice as expensive to produce as SMR hydrogen[68].

Costs

Costs for hydrogen stations vary greatly depending on a number of factors like throughput, filling rates, hydrogen production method, new construction vs. site expansion, etc. Retail hydrogen stations such as those being developed in California, are estimated to cost about $1.6 million. California has invested $46 million to build 28 stations. As California develops their fueling network and the market establishes economies of scale for equipment, the price of stations will come down, but cost and access are sure to be barriers to FCV deployment for the near future.

Case Studies and Examples

- Federal Transit Administration's record of fuel cell bus demonstration programs in the U.S.
- Monroe County New York uses hydrogen and other alt fuels as a fleet advantage
- Hydrogen station cost estimates from NREL

Market

Present

The fuel cell vehicle market is just now transitioning from research and development to commercialization, so the market is small in comparison to other alternative fuels. The only measurable U.S. market is found in California, and the future of the FCV market in the U.S. is being fueled by the Multi-Sate Zero Emission Vehicle (ZEV) Memorandum, which has targeted the goal of deploying 3.3 million ZEVs by 2025 within the 10 participating states (CA, CT, ME, MA, MD, NJ, OR, RI, VT, NY). The program created a credit system that requires automakers to attain a certain number of ZEV credits depending on the number of vehicles produced and delivered in the state. FCVs are assigned the highest number of credits in this system because they have the maximum range and the largest zero-emission driving potential. The ZEV program will drive demand for both PEVs and FCVs, and because FCVs are the most valuable under the program, certain automakers have committed to investing in them to reach their credit requirements. Figure 2.9 outlines the ZEV credit program.

[67] U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy http://energy.gov/eere/fuelcells/hydrogen-production-natural-gas-reforming
[68] Florida Solar Energy Center, http://www.fsec.ucf.edu/en/consumer/hydrogen/basics/production.htm

Definition	Vehicle Type	Example	2012-2017 Credits	2018-2025 Credits
Zero emission vehicle (ZEV)	Battery electric or hydrogen fuel cell	Leaf, Tucson	1-9 depending on range	1-4 depending on range
Transitional ZEV	Plug-in hybrid or extended range EV	Volt	1-3 depending on tech	0.4-1.3 depending on range
Partial ZEV	Clean ICE	Ford Focus	0.2	0
Advanced Tech Partial ZEV	Natural gas vehicle, hybrid	Prius, Civic GX	0.2-0.3	0

Figure 2.9: ZEV Credit Program

The Colorado Energy Office has attended Colorado Hydrogen Coalition meetings to stay current on market developments in the state. They also worked to include FCVs in the state's tax credit legislation in 2014, but beyond that they have been focusing their efforts on other alternative fuels. The California Energy Commission (CEC) awarded $46.6 million for 28 new hydrogen fueling stations and another $1.2 million for the operation and maintenance of hydrogen refueling stations throughout the state. 51 stations are expected to be operational statewide by the end of 2015, providing up to 9,400 kg/day of hydrogen. Heavy research over the last decade has brought down the cost of material components substantially, and progress is expected to continue. Here are a couple highlights from the 2013 Fuel Cell Technology Report done by NREL.

- PEM fuel cell cost reduction of more than 50% since 2006, and more than 35% since 2008.
- A greater than 80% reduction in electrolyzer stack cost over the past 10 years.
- Reduction in the amount of platinum (Pt) used by a factor of five since 2005.
- A more than doubling of fuel cell durability since 2006.

Colorado currently has one hydrogen fueling station that is closed to the public located at the NREL Wind Test Site outside of Golden. NREL is constructing a new, modern fueling station on their main campus in Golden, but it will also be limited to research purposes. NREL also holds the only three FCVs in the state, Toyota Highlander research vehicles.

Future

Researchers from UC Davis's Institution for Transportation Studies calculated that a targeted regional investment of $100-$200 million in support of 100 stations for about 50,000 FCVs would be enough to make hydrogen cost-competitive with gasoline on a cost-per-mile basis. This level of investment is poised to happen in at least three places: California, Germany and Japan[69].

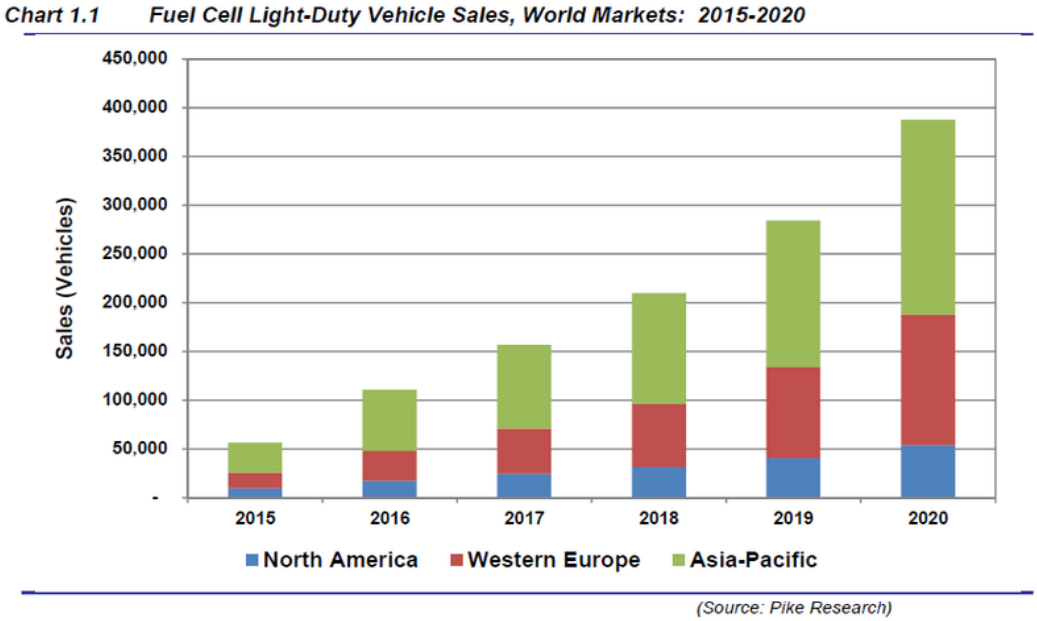

Figure 3.0: FCV Projections

According to NREL's 2013 Fuel Cell Technologies Market Report, since 2006, DOE-supported research has reduced the cost of transport fuel cell systems by more than 50%, from $108/kW in 2006 to $55/kW in 2012/2013. These numbers are based on high volume projections of 500,000 units per year and a platinum price of $1,500/troy ounce. DOE's next target is a 2020 transport fuel cell system cost of $40/kW, with an ultimate target of $30/kW.

If the ZEV states can deploy hydrogen fueling infrastructure and automakers can bring FCV costs down before 2025, then FCVs could make up a significant portion of the 3.3 million ZEVs goal, but because the market is in its infancy, it is difficult to estimate. Pike Research projected FCV sales on a global scale back in 2011 (Figure 3.0), but those numbers now look too aggressive since automakers are late in getting vehicles to market and fueling infrastructure is just now developing. Figure 3.0 illustrates Pike's projections, but those numbers should be moved forward a couple of years because there are not 50,000 FCVs on the road in 2015 and won't be by the end of the year.

Automakers are reticent to release the small number of FCVs they produce outside of ZEV states for several years. Production numbers are locked in for 2015 and 2016, and there are no units currently scheduled to come to Colorado. In the next 3-5 years, groups like the Colorado Hydrogen Coalition will work to lay the groundwork for FCVs, develop a public fueling station network, and work with the automakers to eventually sell vehicles to Coloradans. Though, in light of the barriers, this is not expected before 2018.

[69] UC Davis, Institute of Transportation Studies, http://news.ucdavis.edu/search/news_detail.lasso?id=10990

RENEWABLE NATURAL GAS

Technology

Natural gas is a colorless, odorless substance composed predominately of methane (CH_4), and has been used safely and effectively as a transportation fuel for decades. Natural gas is the cleanest burning of all fossil fuels, with only one carbon atom for every four hydrogen atoms in each molecule of methane. In contrast to FCVs and PEVs, natural gas vehicles (NGVs) ignite natural gas in an internal combustion engine for power, and they do have tailpipe emissions as a result. Because NGVs use an internal combustion engine, the driving experience i n is very similar to gasoline in regards to horsepower, torque, and overall performance. Since natural gas is gaseous at normal conditions it is less dense than liquid gasoline; 5.66 lbs of compressed natural gas is considered a gasoline gallon equivalent (GGE), and a GGE has 100% of the energy content in a gallon of gasoline. NGVs also have comparable fuel efficiency to gasoline vehicles. In other words, a car can travel the same distance on one GGE of natural gas as it would one gallon of gasoline. GGE is the standard measurement for fueling vehicles with CNG, but for heavy-duty applications where diesel is the primary fuel, CNG can also be measured in diesel gallon equivalents (DGE) which is 6.33 lbs of CNG[70]. Also, NGVs are approximately 15% less efficient as diesel vehicles, meaning a car can only travel about 85% on one GGE of natural gas as it would on one gallon of diesel. The result is that in scenarios where NGVs replace diesel vehicles, about 15% more fuel is consumed to do the same job.

The main difference between an NGV and a conventional vehicle is how the fuel is stored onboard. To maximize fuel storage and driving range, natural gas is stored on the vehicle in one of two ways: pressurized to 3600 psi as Compressed Natural Gas (CNG) or cooled to negative 260 degrees Fahrenheit as Liquefied Natural Gas (LNG)[71]. Special CNG or LNG tanks are needed to store fuel on NGVs, which is the main difference from conventional vehicles and contribute to a higher up-front cost. LNG is a more dense fuel than CNG and is used in heavy-duty applications that use a lot of fuel to travel long distances or move heavy equipment like long-haul tractors, marine, rail, and off-road applications. LNG vehicle storage tanks, fuel, and infrastructure are more expensive than CNG. CNG is more common, and because most of the vehicles operating in Aspen would not be appropriate for LNG, CNG will be the only analyzed form of natural gas in this report.

NGVs can come equipped with dedicated, bi-fuel, or dual-fuel systems. Dedicated NGVs only operate on natural gas and have no gasoline or diesel backup, bi-fuel NGVs have a smaller natural gas storage tank paired with a gasoline tank for extended range, and dual-fuel systems use both diesel and natural gas inside a compression-ignited diesel engine. Dedicated NGVs have the longest range on natural gas and can offer the most significant advantages over gasoline/diesel. Bi-fuel NGVs offer the greatest total range and are good for applications where access to natural gas fueling isn't always available, but because they make room for natural gas and gasoline storage they usually have to sacrifice more cargo space and capacity. Unlike bi-fuel NGVs that switch back and forth between the use of natural gas or gasoline, dual-fuel systems are used primarily in heavy-duty applications and inject natural gas and diesel into the engine at the same time so that natural gas is displacing a percentage of the engine's diesel fuel consumption[72].

[70] U.S. Department of Energy, Alternative Fuel Data Center, Fuel Properties Comparison http://www.afdc.energy.gov/fuels/fuel_comparison_chart.pdf
[71] Refuel Colorado, http://refuelcolorado.com/ngv/about
[72] U.S. Department of Energy, Alternative Fuel Data Center http://www.afdc.energy.gov/vehicles/natural_gas.html

Renewable Natural Gas

Natural gas is used in a variety of applications: home heating, electricity generation, transportation, and others. The vast majority of natural gas is produced through traditional extraction methods and hydraulic fracturing, which has associated emissions and other environmental impacts. When traditional natural gas is used as a transportation fuel, there are carbon reduction benefits on a lifecycle basis of less than 5-21% depending on drive cycle and make/model, which will not contribute significantly to the carbon reduction goals that Aspen has set. However, renewable natural gas (RNG), also called biomethane, is becoming more common as a vehicle fuel in the United States. RNG is produced from biogas – also known as swamp gas, landfill gas, or digester gas — which is the gaseous by-product of anaerobic digestion of organic matter. When organic waste like manure, crop residue, and landfills decompose over time they produce methane and other gases that are normally lost to the atmosphere and contribute to climate change. RNG is created when those sources are aggregated and the decomposition process is either expedited in an anaerobic digester or occurs naturally in a landfill, and the resulting gases are captured, processed, and eventually used as natural gas. Figure 3.1 shows a basic overview of the RNG (biogas) process. Landfill gas is roughly 50% methane and 50% carbon dioxide, with some other trace gases like hydrogen sulfide[73]. Both methane and carbon dioxide are greenhouse gases, but methane is 84 times more efficient at trapping heat than carbon dioxide[74]. By preventing those fugitive methane emissions from entering the atmosphere, RNG as a vehicle fuel has a lifecycle greenhouse gas reduction potential of 90-115%, depending on the specifics of the methane source. Since Aspen does not have any significant agricultural operations and does not use anaerobic processes at the wastewater treatment facility, the only potential source of RNG is from the Pitkin County Landfill. RNG from landfills has a lifecycle emissions reduction of around 90%[75] when used as a transportation fuel.

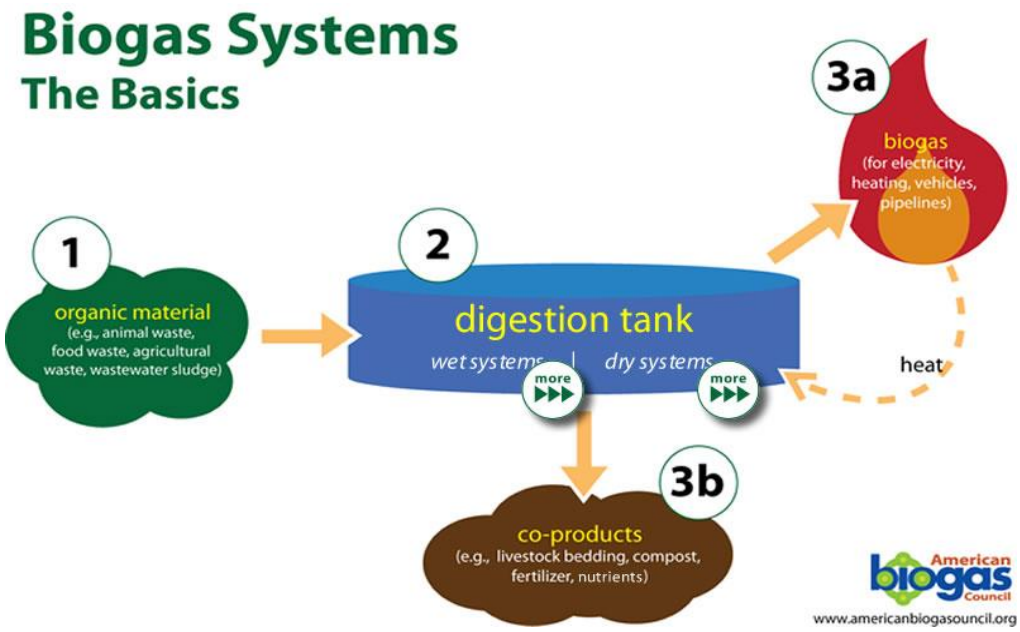

Figure 3.1: Biogas Process

[73] Environmental Protection Agency http://www.epa.gov/lmop/faq/landfill-gas.html
[74] Environmental Defense Fund, http://www.edf.org/climate/methane
[75] Clean Energy http://redeem.cleanenergyfuels.com/

Benefits

Emissions

Because natural gas contains the least amount of carbon per molecule of any fossil fuel, it produces fewer emissions when combusted. However, two factors need to be considered when looking at NGV emissions. First, a well-to-wheels analysis that takes methane leakage from production methods into account, along with all processes involved from production through combustion, new NGVs using conventional natural gas (non-renewable) have a 5-21% reduction in greenhouse gas emissions compared to the gasoline or diesel model[76][77]. A second factor affecting emissions comparisons lies in the use of a variety of emissions filters and equipment required on diesel vehicles to meet stringent EPA emissions requirements. Natural gas burns cleaner, therefore NGVs don't require the emissions equipment that new diesel vehicles need to pass emissions, thus reducing maintenance costs in certain applications.

Renewable natural gas on the other hand, offers significant emissions reductions over conventional natural gas. By capturing and preventing greenhouse gases like methane from being vented into the atmosphere, research by the California Air Resources Board suggests that RNG produced from landfill sites reduces the well-to-wheels greenhouse gas emissions of a natural gas vehicle by 90% compared gasoline.

Figure 3.2 compares CO_2 emissions in grams/mile of gasoline, diesel, conventional natural gas, and renewable natural gas.

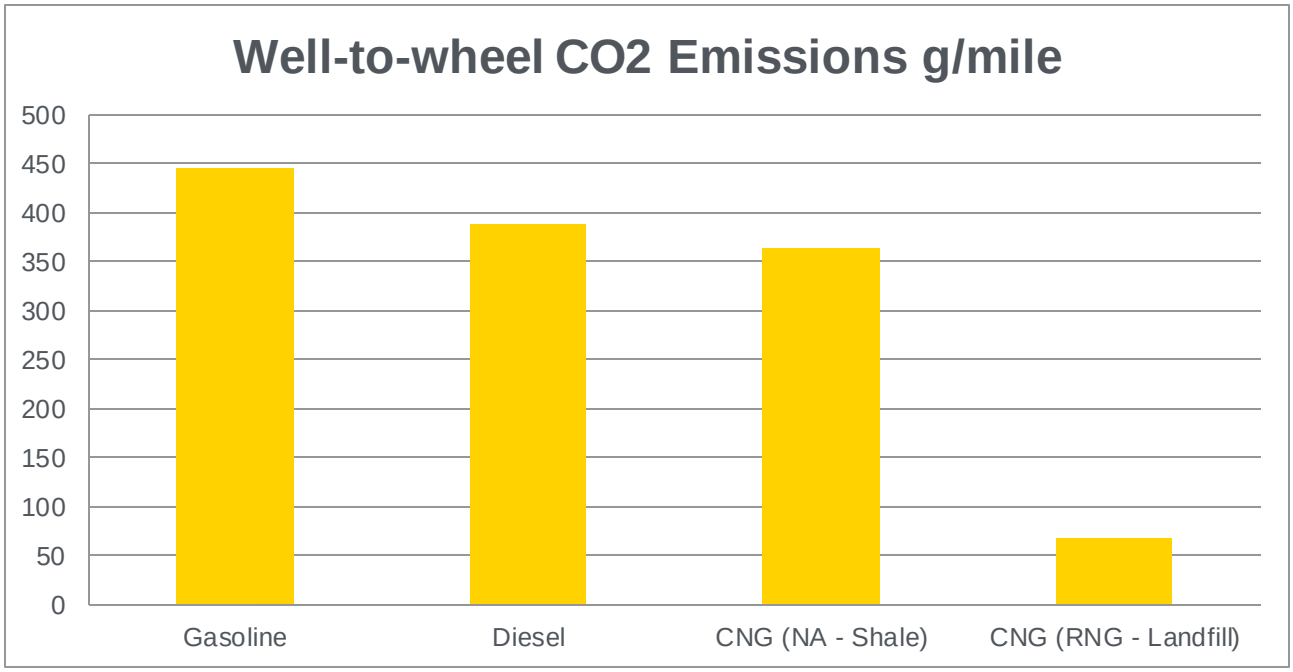

Figure 3.2: CO2 Emissions

[76] Refuel Colorado website, http://refuelcolorado.com/ngv/benefits
[77] NGV America website citing emissions analysis from Argonne National Lab's AFLEET tool, https://www.ngvamerica.org/natural-gas/environmental-benefits/

According to Cathy Hall, Solid Waste Manager at the Pitkin County Landfill, the landfill does not currently collect the gas it produces, which means the gas is being vented and contributes greatly to the greenhouse gas emissions profile in the area. According to Ms. Hall's estimates, the landfill currently produces around 300 standard cubic feet per minute (scfm) of gas from around 2 million tons of waste, which, according to the EPA's Landfill Methane Outreach program, produces about 864,000 cubic feet per day of landfill gas. The EPA estimates that a RNG project that captures 1,000 scfm of gas would offset 126,000 metric tons of methane annually, assuming the gas is roughly 50% methane. Using that assumption, the Pitkin County landfill which produces roughly 300 scfm, could realize reductions of 37,800 metric tons of greenhouse gases annually[78]. These numbers are estimates based off of average landfill gas projects, but in order to understand the true emissions from the Pitkin County landfill, a more thorough assessment would need to be done that takes into account the specific factors including gas composition and volume.

Domestic Energy Security

Even with the recent increase in domestic oil and gas production, the United States still imports roughly 33% of its petroleum from foreign countries[79], and 72% of U.S. petroleum use is devoted to the transportation sector. Utilizing local sources to create RNG for transportation, fuel budgets will not be subject to global pressures and price volatility and will keep money in the local economy.

Model Availability

Because natural gas operates in an internal combustion engine and has similar performance to traditional fuels, it can operate in every vehicle vocation from a Honda Civic to a long-haul truck carrying 80,000+ lbs up steep grades. NGVs have been part of the transportation market for decades, so a variety of vehicle types and models from original equipment manufacturers (OEMs) are available spanning duty classes 1-8. Some of these vehicle applications include passenger cars, pickups, box and delivery trucks, refuse trucks, dump trucks, tractor-trailers, SUVs, vans, and buses. Additionally, many NGVs come with available 4x4 options for off-road or inclement weather conditions, which is important for a community like Aspen.

For a complete list of available new NGVs visit the Alternative Fuel Data Center's vehicle search tool. Also, for vehicles that haven't reached the end of their useful life, there are hundreds of conversion kits available that will retrofit existing vehicles to run on natural gas. A full list of EPA and CARB-approved conversion kits can be found on NGVAmerica.

Range

NGVs generally have a similar driving range to conventional fuels, but can have a smaller range depending on a number of factors. The main difference and limiting factor is the space needed to house the CNG storage tanks, which are specific in size and shape and take more space than traditional fuel storage. In larger, heavy-duty vehicles like refuse trucks, buses, and tractors, there is enough storage space to support multiple tank configuration options depending on the job. Many CNG tank options can support travel of 300-500 miles in a day, but storage tanks are expensive so it is advisable to go with the smallest tank capacity necessary for the job.

[78] Environmental Protection Agency http://www.epa.gov/lmop/faq/lfg.html#07
[79] Energy Information Administration, http://www.eia.gov/tools/faqs/faq.cfm?id=727&t=6

Range is also determined by whether the NGV is dedicated, bi-fuel, or dual fuel. Dedicated NGVs may have a shorter overall range than their gasoline/diesel counterparts, and ultimate range still varies between 200-500 miles depending on the vehicle. Bi-fuel vehicles will have a range as long as or longer than conventional fuels, but the CNG range is limited to 100-150 miles. Generally, the range of NGVs isn't a concern when compared to alternatives like plug-in electric vehicles.

Fuel Price and Certainty

Natural gas as a transportation fuel has been consistently cheaper and less volatile than gasoline or diesel for over a decade, and the Energy Information Administration predicts the cost of conventional fuels will continue rising through 2040. Figure 3.3 is data collected through the U.S. Department of Energy's Alternative Fuel Price Report and illustrates

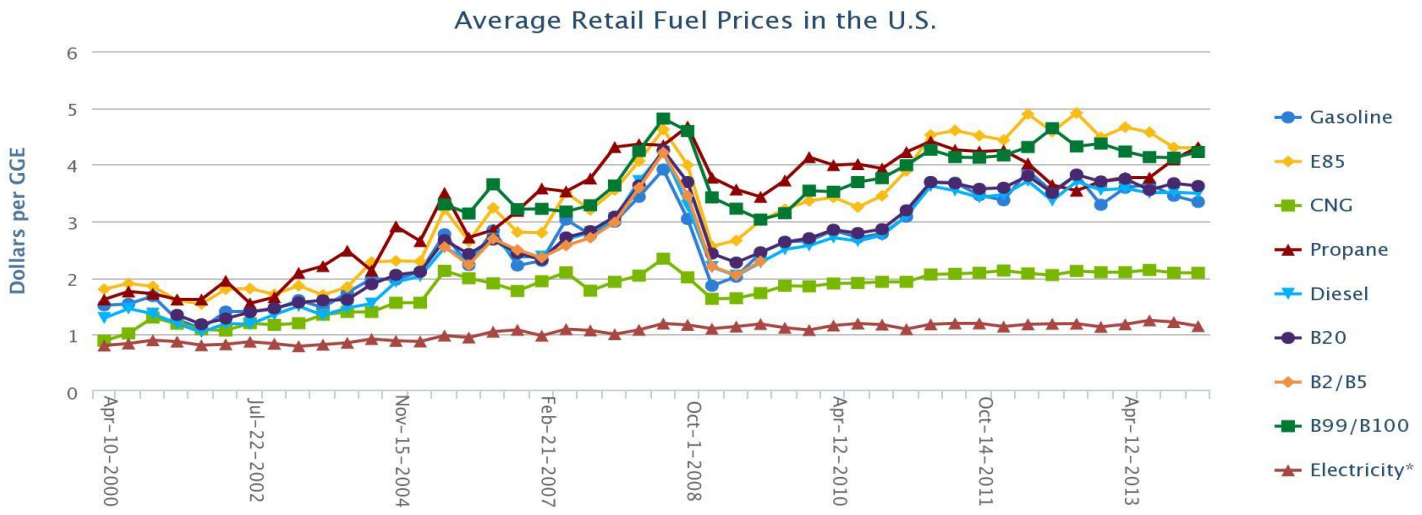

Figure 3.3: Average Fuel Prices

the high cost and volatility of traditional fuels in comparison to other alternatives over the past 15 years. The price of natural gas is the second cheapest and consistent, behind electricity, but those largely reflect conventional natural gas prices and aren't as relevant to the price of RNG.

Conventional natural gas is consistently cheaper and more stable than gasoline and diesel in this century, and this trend is projected to continue. Figure 3.4 from the U.S. Energy Information Administration shows fuel price projections through 2040, where a significant delta is expected to remain

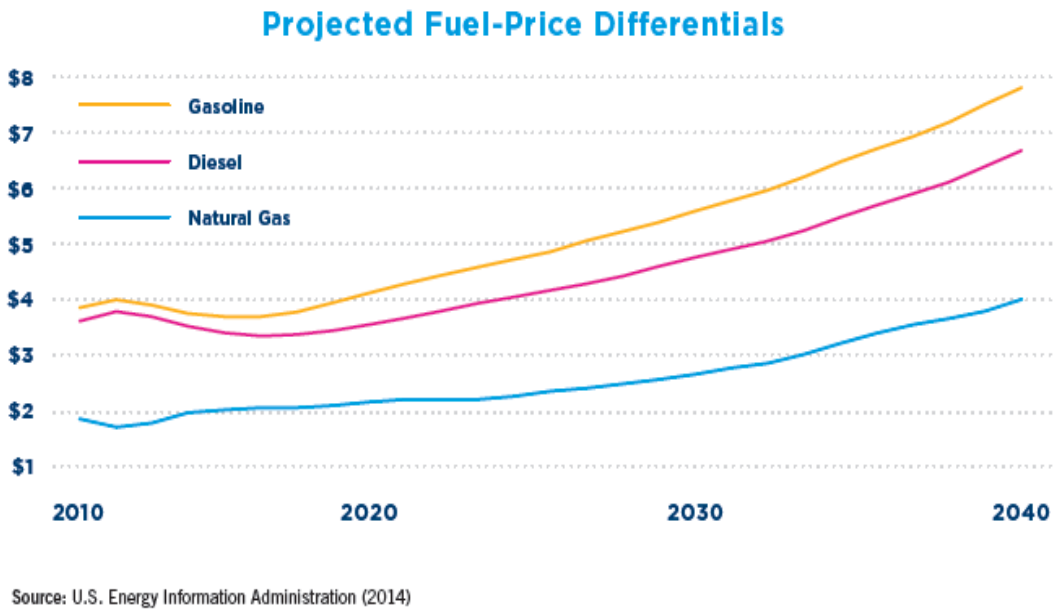

Figure 3.4: Future Fuel Price Projections

The price of RNG is independent of the factors affecting other fuels and is mostly project-specific. RNG price depends on factors like gas output, concentration, and, primarily, financing mechanism for the capital, but in general landfill RNG projects across the country are seeing prices in the $1.00-$2.00 per gasoline gallon equivalent (gge) range, with companies like BioCNG advertising prices between $0.65-$1.15/gge.

RNG also generate RINs (Renewable Identification Number) credits. RINs are identification numbers assigned to each gallon of renewable fuel that is produced under the Renewable Fuel Standard (RFS), a federal program that requires transportation fuels in the U.S. to contain a minimum amount of renewable fuels. RNG qualifies as an Advanced Biofuel under the RFS, which means for each gallon produced, one RIN is issued. Fuel refiners, blenders, and importers are required to meet their renewable volume obligation by generating RINs, but for those companies that don't blend, refine, or import enough RIN-qualifying fuel, they purchase RINs from other producers. Advanced biofuel RINs currently trade between $0.74 and $1, and further reduces the price of the fuel for whomever owns the station[80]. If the City doesn't own the station, then the station developer would pass on a portion of the RINs savings in the form of cheaper fuel.

Not only is there a significant delta between the average price of gasoline/diesel, but RNG isn't affected by global market fluctuations of demand, supply, and conflict. RNG pricing is usually locked in over a 15-20 year period since the resource (landfill gas) is local, dependable, and consistent[81]. Both Figure 3.3 and Figure 3.4 clearly show that gasoline and diesel have been and are predicted to be increasingly expensive, whereas RNG will be consistently cheap and reliable, which is good for budget planning and allocation.

[80] American Biogas Council http://www.americanbiogascouncil.org/biogasProcessing/mgMarket_snapshot.pdf
[81] Environmental Protection Agency, http://www.epa.gov/agstar/documents/conf13/Biogas%20to%20Compressed%20Natural%20Gas%20Opportunities,%20Chris%20Voell.pdf

Convenience

NGVs have similar range, performance, model availability, and fueling rates to conventional fuels, which remove many of the barriers that other alternatives have and provide a sense of convenience and familiarity to the purchasing/operational decision-making process. It is also the closest 'silver bullet' in the current alternative fuel spectrum when fueling with RNG; though, there are still many challenges to the successful deployment of NGVs that need to be considered and addressed that are detailed later in the report.

Considerations

Infrastructure and Gas Collection

Pitkin County Landfill does not currently collect landfill gas, meaning it is passively vented into the atmosphere and is a significant source of greenhouse gas and non-methane organic compounds (NMOCs) that damage our climate and public health. Because no gas collection system is in place, there is no way for the landfill gas to be captured and cleaned for use as a vehicle fuel. To move forward, Pitkin County Landfill would need to install a gas collection system, which the breadth of this report does not include. However, the EPA has a voluntary program, the Landfill Methane Outreach Program (LMOP), which assists in the gas collection and then use of landfill gas for either electricity production or direct-uses like RNG. There are currently 645 operational landfill gas projects throughout the country and 440 candidate landfills. The Pitkin County Landfill is considered one of those candidate projects. A candidate landfill is one that has at least 1 million metric tons of waste, has no current projects planned or in operation, or has expressed interest to the EPA[82].

Once the landfill installed a gas collection system, then there could be a discussion about what to do with the gas. RNG as a transportation fuel is one of those options with a good possibility for return on investment, and has the greatest reduction of greenhouse gases. To go about an RNG project, the County would likely need to partner with an RNG company to build a system capable of conditioning the gas from landfill gas to usable vehicle fuel. More information about the conditioning system, costs and components can be found in the infrastructure section below, but these systems can be costly.

Fueling infrastructure also carries high up-front costs. A series of dryers, compressors, and storage tanks are needed to fill NGVs at a rate similar to gasoline. In addition to the equipment, there are design, construction, and possibly land acquisition costs. To utilize the RNG from the landfill most effectively, a new CNG station would have to be built on-site or nearby to minimize the cost of getting the gas from the landfill to the station. In general, new stations can cost anywhere from $500,000-$2,000,000, depending on factors such as fill rate, throughput, duty-cycle, and number of nozzles. For a retail CNG location with fast-fill capabilities for all duty-cycles, the price is north of $1 million and probably closer to $2 million assuming the landfill location would be a new development and not an extension of an existing facility.

Fortunately, there are a number of business models that will finance the initial station cost by amortizing it into the price of fuel or by aggregating enough fuel demand for a station developer to own and operate the station themselves. If there is enough fuel commitment from interested fleets, station developers are willing to cover the capital costs of the

[82] EPA, Landfill Methane Outreach Program http://www.epa.gov/lmop/projects-candidates/

station in return for fueling agreements. This is the model used for the new Glenwood Springs station to be constructed in 2015. Also, ALT Fuels Colorado is a grant program available from the Colorado Energy Office that will cover 80% of the station's equipment cost up to $500,000. The program plans to fund 30 CNG stations along major transportation corridors in the state to form a fueling network by 2017. More details on that program can be found in the Incentives section of this report, or by visiting the website.

Tailpipe Emissions

Unlike PEVs and FCVs, NGVs still produce tailpipe emissions like carbon dioxide, unburned methane, and criteria air pollutants from the combustion of fuel. That said, tailpipe emissions of greenhouse gases for NGVs are still 20-25% lower than gasoline[83].

Capital Cost

NGVs typically carry a cost premium. The incremental cost for the natural gas option varies depending on the type of vehicle, tank configuration/capacity and procurement channel (state bid, aggregate purchasing, other competitive bids), but below are incremental cost assumptions based on estimates from Argonne National Lab's AFLEET model:

Sedans
$6,000-8,000
Light Duty Pickups
$9,000-12,000
Medium-Heavy Duty ($15,000-70,000)
Medium duty pickup: $15,000
Paratransit/Shuttle: $25,000
Refuse: $40,000-50,000
Transit: $50,000+
Dump truck: $40,000-60,000
Long Haul: $60,000+

The increased cost is primarily due to the size/storage capacity of the compressed storage tanks. The incremental cost can be recovered since natural gas is less expensive than conventional gasoline. The Savings potential will increase in relation to fuel usage, so the more the vehicle is utilized, the quicker the return-on-investment (ROI). Thus, NGVs are great for fleets that use a lot of fuel like the refuse industry.

This is one barrier that Colorado has tried to address. The state offers tax credits from $6,000-$20,000 per vehicle depending on the weight class, and for public-entities that can't take advantage of tax credits (e.g., governments), the Department of Local Affairs will pay 100% of the incremental cost for NGVs that meet certain requirements. For more details visit the Incentives section in this report, or visit Refuel Colorado for a tax credit calculator and other details.

[83] NGVAmerica, "Overview of CAFÉ and GHG Regulations on NGVs" http://www.ngvamerica.org/pdfs/OverviewoftheStructureofCAFEandGHGRegulationsforNGVs.pdf

Maintenance facilities

Because natural gas is lighter than air and is highly compressed, a number of modifications are required to ensure safety. These modifications can be costly depending on the specifics of the facility and the desired functionality. Some of the major up-fits include a detection/sensor system for natural gas, proper ventilation in case of a release, and treatment of open flame or heating elements. Facilities that need to consider upgrades to handle NGVs are major and minor repair facilities, as well as vehicle storage facilities. The codes and specifications differ for each. Each building modification is unique to the facility, and the local fire marshal should be consulted for guidance and approval. The applicable fire protection codes and standards are detailed here, and assistance with the process can be found through the Natural Gas Vehicle Institute. The Roaring Fork Transportation Authority also has great local experience in building a state-of-the-art CNG maintenance and indoor fueling facility, and can provide best practices.

Efficiency

NGVs use an internal combustion engine that is only 1/3 as energy efficient as an electric motor. Between 17-21% of the energy put into an internal combustion engine is converted into power at the wheels, while the remaining energy is lost.

Infrastructure

Landfill Gas Processing

The landfill produces gas naturally, but converting it into usable fuel for a vehicle fuel is a complex process. The gas must be collected, dried and purified to vehicle fueling standards (SAE J1616). This is done by removing the hydrogen sulfide, volatile organic compounds, and carbon dioxide, and then compressing the fuel so it can be dispensed.
Figure 3.5 illustrates the BioCNG system specifically, which is one of a handful of different approaches, but provides a framework of the steps necessary to upgrade landfill gas to vehicle RNG.

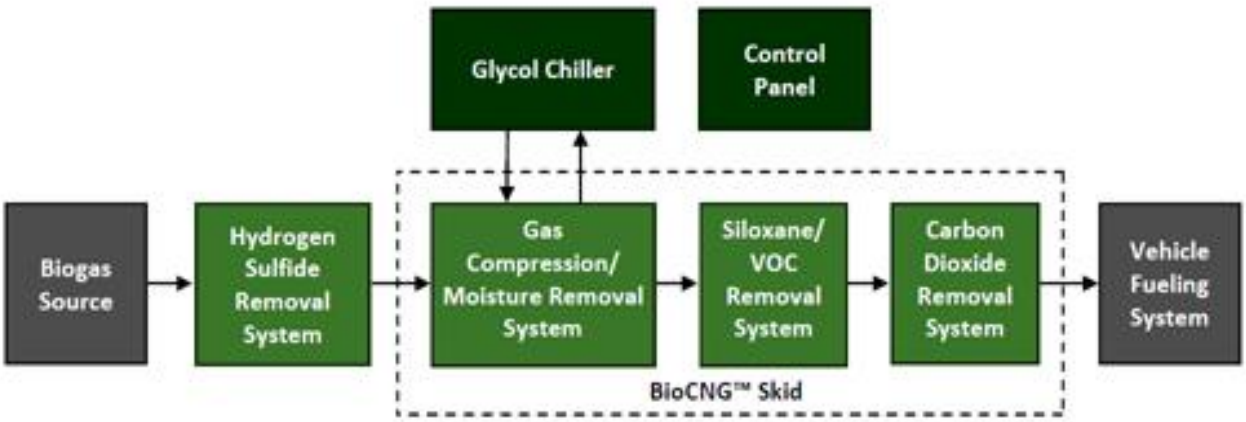

Figure 3.5: BioCNG System

Filling Station

NGVs using compressed natural gas (CNG) require a specialized fueling station in order to safely transfer fuel into the vehicle's storage tanks at a pressure of 3600 psi. There are a number of considerations in developing the appropriate CNG station for the right application. The expected throughput, fill-time, storage capacity, property space and layout, gas pressure, and fleet-types are necessary to making the decision on station specifics.

There are both time-fill and fast-fill stations. Fast-fill stations will fuel a vehicle at a rate similar to gasoline or diesel but require additional compressed storage tanks, redundant compressors, and other equipment that are more expensive than slow-fill stations. Slow fill stations fill vehicles over a long period of time, generally overnight while the vehicles aren't in use. Slow-fill stations are cheaper than time-fill stations and work well for vehicle fleets that return to a home base at night – a common slow-fill application is for refuse fleets. Figure 3.6 shows the components that go into a combination slow-fill fast-fill station.

Aspen will likely need to have a high-throughput, fast-fill station in order to accommodate the RFTA BRT buses along with other fleets traveling through the corridor.

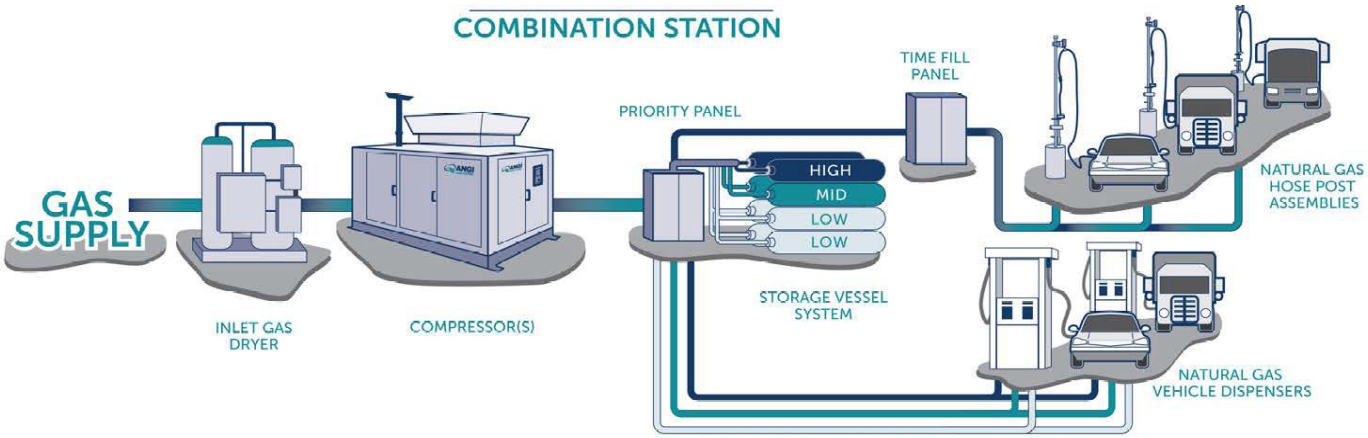

Figure 3.6: Combination Fill Station

Costs

Costs for an RNG project are difficult to estimate because they are dependent on the specifics of each landfill and CNG station location. Two main cost components will be required for the development of an RNG project at the Pitkin County Landfill: gas treatment system, and CNG station.

Following is BioCNG's pricing scenario that will serve as a baseline comparison, as the company offers one of the most prominent RNG systems and real-world cost data, but costs will vary depending on company and financing model. BioCNG offers an 'RNG in-a-box' approach that includes the gas treatment system and/or fueling station construction

combined, and Figure 3.7 offers average BioCNG project costs. When reviewing these costs, please see the notes and assumptions section.

System Size	Biogas Inflow (scfm)	Fuel Production (GGE/day)	Avg. Capital ($million)	O&M ($/GGE)	Avg. Total Fuel Cost ($/GGE)
Biogas 50	50	200-300	1.2	1.06	1.77
Biogas 100	100	375-600	1.5	0.82	1.19
Biogas 200	200	775-1200	2.0	0.64	0.52

Figure 3.7: Average BioCNG Costs

Notes and Assumptions:

1. Cap x includes BioCNG conditioning unit and fueling station.
2. Grants, subsidies, tax credits not included.
3. Assumes 10 year financing at 4%.
4. BioCNG is qualified to receive Renewable Fuel Standard Credits. Financial impact will depend on the project-specific operating scenario, and can be up to $1/GGE.
5. Does not include road tax
6. Assume 60% methane

There are multiple business models that should be considered for an RNG project. RNG companies often build the station and the gas-treatment facility combined. In the case of BioCNG, the capital cost is paid by the owner and BioCNG does not own and operate the station after construction is complete – they leave that up to the host/owner. There are other models that will build, own, operate, and maintain the capital at no initial cost to the host in return for an agreement to purchase the resulting fuel for a set length of time (usually 10 years or longer). At the end of the contract period, ownership of the station and gas-treatment system are transferred to the host. The company makes their money back by charging a premium on the fuel over the contract period. This model will have a higher per-gallon fuel price than if the City put up the capital investment, but it will still be low enough to see a significant operational savings compared to gasoline/diesel and avoids the initial capital investment, which can be cost-prohibitive.

The City of Grand Junction is spending $2.8 million on a RNG project that will fuel their transit bus and refuse fleet with the gas created from the Persigo Wastewater Treatment Facility. This project is unique because there is an existing CNG station where the City's vehicles fuel, so no new station will be constructed. But, the wastewater treatment facility is located 6 miles from the CNG station, so a natural gas pipeline is being built to bring the RNG to the station, which escalated the project's costs substantially.

Additionally, there are a variety of incentives that can help offset the cost of an RNG project. ALT Fuels Colorado offers up to $500,000 to cover equipment costs associated with new CNG station construction. A thorough feasibility analysis should be conducted to determine the project specifics before moving forward with any RNG project.

Case Studies and Examples

- 8 RNG fleet case studies
- Grand Junction's transit and refuse fleet to be powered by renewable natural gas
- Colorado CNG Fleet Case Study: DIA, Republic Waste, City of Grand Junction

- EPA Landfill Methane Outreach Program market evaluation and projects of the year

Market

Current

The NGV market is probably the most robust of the three analyzed transportation fuels. NGVs have been prominent since the 1990s, and today they are available in all duty-classes from major OEMs like Ford, GM, Honda, Chrysler, Peterbuilt, Freightliner, Mack, and many others. Natural gas has primarily been utilized by the fleet fuel market and hasn't been widely adopted by the general consumer. This is primarily due to the fact that NGVs make the most financial sense in applications where large amounts of fuel are consumed, generally in he avier duty cycles where passenger cars, trucks, and SUVs don't operate.

Natural gas powers about 150,000 vehicles in the United States and roughly 15.2 million vehicles worldwide[84]. Natural gas has been niche-specific, growing in popularity for markets like refuse and transit that consume a large volume of fuel and return to a home facility for refueling. Around 60% of all new refuse truck purchase s and 40% of new transit buses are up-fitted for natural gas.

Strong incentives and policy frameworks have established a vibrant market for NGVs in Colorado. By 2017 there will be 30 new CNG stations funded by the ALT Fuels Colorado grant program that will connect major transportation corridors throughout the state. A strong tax credit program that provides up to $20,000 for NGV purchases to cover incremental costs for taxable entities, along with grant funding for public and private agencies helps to minimize the initial capital cost barrier for fleets. There are already a variety of Colorado fleets operating NGVs, including but not limited to:

1. State Fleet – 9 different agencies
2. Roaring Fork Transportation Authority
3. Weld County
4. Weld County School District
5. City of Fort Collins
6. City and County of Denver
7. City of Grand Junction
8. Republic Waste
9. Allied Waste
10. Western Disposal
11. Alpine Waste
12. Waste Management
13. DIA
14. Loveland Ready Mix
15. Boulder Valley School District
16. City of Arvada
17. City of Englewood
18. Clean Energy
19. Encana
20. Noble Energy
21. Pioneer Natural Resources
22. UPS
23. Dillon Transport
24. Core-mark

Of the 2,434 landfill sites throughout the U.S., 555 are using their gas for combined heat and electric power projects, and 39 are utilizing RNG as a transportation fuel[85]. Grand Junction is the only RNG project in Colorado, but RNG is a new, developing market for NGVs and growth is expected in the state, especially in fleets already operating NGVs.

[84] U.S. Department of Energy, Alternative Fuel Data Center http://www.afdc.energy.gov/vehicles/natural_gas.html
[85] American Biogas Council http://www.americanbiogascouncil.org/biogasProcessing/mgMarket_snapshot.pdf

Future

The NGV market is expected to continue on a strong growth trend, especially in niche markets like refuse, transit, and logistics. According to Navigant Research, global annual NGV sales are expected to grow from 2.5 million vehicles in 2014 to 4.3 million in 2024. Two of the main barriers to NGV adoption are access to fueling infrastructure and initial capital cost. Colorado is leading the nation in easing the initial capital cost through tax credits and grant programs, and by 2017 the state's major transportation corridors will be connected with CNG fueling stations allowing fleets and consumers alike to comfortably travel without fueling anxiety.

ASPEN'S OPERATIONAL CONSIDERATIONS

Successful deployment of alternative fuels requires more than an isolated analysis of technologies – it takes careful consideration of how the technologies will coincide with other factors that can affect their operation, including: geography, demography, infrastructure, vocations, climate, and many other macro-level factors. This section will discuss some of the factors specific to operating these technologies in the City of Aspen and attempt to incorporate them into any recommendations that are made.

Aspen is a small, niche mountain community with a narrow demographic spread, limited space and a transient traffic flow from season to season, which presents some unique challenges and opportunities for reducing carbon emissions from transportation through the use of alternative fuels. In the 2010 census, Aspen had a population of 6,658 and is projected to increase to 7,622 by 2022. Over 60% of residents are expected to be 35 years or older by 2017, and both the median household income and per capita income are well above the national or state averages at $70,000 and $50,000, respectively. [86] Based on calendar-year 2013 sales, a study by Experian Automotive found that 55 percent of electric vehicle buyers are between 36 and 55 years old and nearly 21 percent have an average household income of $175,000 or more. By comparison, 45 percent of those driving hybrid-powered models off the lot are 56 years old or older (compared to just 26 percent of new PEV owners), with only 12 percent having an annual income of $175,000 or higher[87]. This indicates that PEV buyers are generally wealthier and younger than hybrid car purchasers and, therefore, conventional car purchasers as well. Aspen's demographics are more aligned to these PEV trends than many cities, and because PEVs are a more consumer-facing alternative fuel compared to natural gas, and FCVs are just hitting the market, PEV purchasing research is being used as an assumption.

Average traffic flows per month averaged 22,288 through the first ten months of 2014, with a total of 222,288 vehicles passing over the Castle Creek Bridge in both directions during the year. Because Aspen is a destination ski community in the winter and outdoor vacation destination in the summer, many of these vehicle trips are from visitors who don't live in the city. This makes it more difficult to influence their vehicle purchasing decisions and to track the associated emissions from transportation sources, but by providing infrastructure and incentivizing technologies through parking policies, visitors and fleets would feel more secure driving their alternative fuel vehicles to Aspen and would increase the likelihood of their adoption inside and outside the city.

[86] Aspen Recreation Division Business Plan Update, December 2014

The climate in Aspen is an important consideration. Cold temperatures and frequent snow November through April will decrease the electric range of PEVs, and since there are few models with all-wheel drive on the market yet, both factors will impact consumer and fleet purchasing decisions. NGVs have available all-wheel drive on many models, but primarily dominate the truck and heavy-duty sectors, whereas PEVs operate in the light-duty passenger car sector. FCVs will not be affected by temperature variation since t range is determined by the volume of hydrogen fuel stored on board, not battery capacity. At 7,890 feet above sea level, the lack of oxygen at that elevation will decrease the performance of an internal combustion engine like those in NGVs by decreasing horsepower and torque similar to conventional vehicles. PEVs and FCVs won't sacrifice performance (horsepower or torque) from operation at high elevations.
Aspen is a small city at just 3.5 square miles, and parking is limited, and primarily on-street. This presents a challenge in terms of distributed PEV infrastructure. Centralized fueling stations like those for hydrogen and natural gas are also difficult to plan for with limited space, and land acquisition costs could render infrastructure development cost-prohibitive. Options to overcome these restraints could be to co-locate fueling at existing gas stations, parking garages, and other sites where longer dwell times occur such as hotel and ski resort parking lots. Centralized refueling could also be located outside city limits along highway 82 in cooperation with Pitkin County and other local jurisdictions.

There are a variety of different vehicle fleets and vocations that contribute to Aspen's transportation-related greenhouse gas emissions. Many of the vocational fleets operating in the area are listed in Figure 3.8, along with assumptions on the types of vehicles that probably operate in their fleet. These fleets would be targets for transition to alternative fuels where applicable and should be provided a copy of this report.

The public, city, county, Aspen Ski Co., and RFTA fleets are some of the bigger contributors to the entire Aspen on-road fleet. Most of the vehicles tend to be in the light-duty sector, with trucks and SUVs playing the most frequent fleet role. Recommendations on fuel and model choices for these fleet types are included later in the report.

One of the challenges with transitioning vehicles in Aspen is access to appropriate dealerships and maintenance. The city fleet can purchase from the state bid where there are a number of CNG/PEV models available, but for other private fleets and the general public, finding the right place to buy their alternative fuel vehicle is more difficult than if they were in Denver. Additionally, both PEVs and natural gas vehicles require a maintenance staff and facility capable of servicing them.

Fleet Type	Passenger Car	SUV	Light-duty pickup	Van	Box Truck	Cutaway Shuttle	School Bus	Transit Bus	Dump Truck	Refuse Truck	Semi-Truck
Public	X	X	X								
City	X	X	X	X					X		
County	X	X	X	X					X		
Aspen Ski Co.	X	X	X	X		X					
Hotels		X		X		X					
RFTA			X					X			

Taxi/Shuttle	X	X		X							
Carshare	X	X	X								
Property Mgmt	X	X	X								
Construction		X	X						X		
Delivery				X	X						
School District	X			X		X	X				
Food Transport					X						X
Refuse										X	

Figure 3.8: Vocational Fleets

One of the challenges with transitioning vehicles in Aspen is access to appropriate dealerships and maintenance. The city fleet can purchase from the state bid list which includes a number of CNG/PEV models, but for private fleets and the general public, finding a dealer which sells and services alternative fuel vehicle is more difficult. Additionally, both PEVs and natural gas vehicles require a maintenance staff and facility capable of servicing them.

Mike Ogburn, Clean Vehicle Technology and Large Building Efficiency Programs Manager with Clean Energy Economy for the Region (CLEER), works closely with stakeholders on the western slope and has a great pulse on the market for alternative fuels in the area. Based on information provided by CLEER, there are two CNG-certified maintenance shops on the Western Slope: Berthod Motors and Columbine Ford, and both also sell NGVs. Additionally, Mountain Chevy, High Country Honda, and Glenwood Springs Ford offer CNG sales. For heavier duty classes, McCandless International sells and supports natural gas models. For PEVs, Columbine Ford in Rifle, Mountain Chevy, and Glenwood Springs Ford all support sales and service in the area. Access to local dealerships is potentially an issue for Aspen fleets and residents regardless of their fuel choice due to the lack of a robust dealership network. Many consumers are willing and able to travel longer distances to access the best deal or preferred dealership, and most automakers offer the capability for consumers to locate the closest dealer online.

In addition to some of the operational considerations already mentioned, there are other externalities that should be considered. One of these is public perception. How will the general public respond to the City's choice? This is impossible to predict, but some general assumptions can be made about the concerns the public may have with these technologies:

- **Environmental impact:** When discussing plug-in electric, natural gas, or fuel cell vehicles with the general public, some people are unaware of their true environmental benefits. Hydraulic fracturing and other oil and gas development techniques are politically charged and are the subject of ongoing environmental impact assessments.

It is important to distinguish between renewable and conventional natural gas, as renewable natural gas is truly innovative, sustainable, and clean. The environmental benefit of PEVs is sometimes questioned by skeptics that claim the electricity is coming from dirty generation techniques, so it would be important to make clear that the Aspen Electric grid is clean and renewable.

- **Cost:** Alternative fuel vehicles typically cost more up front, but when used in the proper application and driven frequently, there can be a substantial lifecycle cost benefit. It's important to communicate about how alternative fuels are cheaper and less likely to fluctuate in price, which ultimately results in a better long term investment of public funds. It's also important to quantify the costs of poor air quality and climate change on public health and the economy, as this is often discounted or overlooked. For promoting the public's use of these vehicles, the same argument can be made, in addition to the tax credits available to consumers and taxable organizations to help cover that up front incremental cost.
- **Safety:** As with any new technology, safety concerns are common. It will be important to be forthcoming that safety codes and procedures are being adhered to.

RECOMMENDATIONS

This section will make specific recommendations regarding which near-zero carbon transportation options the city and other fleets may want to consider pursuing, as well as suggested actions the city can take to incentivize the public and other fleets to move toward near-zero carbon transportation.

Fuel Recommendations

After analyzing renewable natural gas (RNG), hydrogen fuel cell vehicles (FCVs), and plug-in electric vehicles (PEVs) as possible alternative transportation fuels for the City, PEVs represent the most actionable and meaningful technology for the city to reach its carbon reduction goals. PEVs are the best opportunity to reduce emissions from on-road transportation in the near term by charging with renewable electricity, and the PEV market as a whole is expected to continue growing to overcome the barriers it currently faces.

The main obstacle preventing RNG as a recommendation is a lack of available biomethane. Pitkin County Landfill was assessed as a possible source, but because it currently vents methane and has no method for capturing the gas, it cannot be treated and used as a transportation fuel. Installing a methane capture system is timely and costly, but the landfill represents a significant emissions source for the region, and if the County decides to install a gas collection system, RNG should be strongly considered as an end-use for the captured landfill gas.

Fuel cell vehicles (FCVs) could arguably provide the greatest benefits to the community in the long term and hold the most potential for convenient, long-distance, and zero-emission transportation among all vehicle classes, but the barriers are too large and the applications too limited for the city to pursue in the near-term. Additionally, there is tremendous uncertainty in the future of the FCV market and whether it will prove to be a better zero-emission option than PEVs in the long term. Aspen should revisit FCV's sometime in 2020 or later as the market develops.

To accomplish the aggressive carbon reduction goals by 2020 and 2050, Aspen will need to exhibit leadership and pursue options that are immediately actionable, but also sustainable in the medium and long term. The recommendations from the Low-Carbon Fuel and Technology Analysis are a reflection of that premise:

> **Recommendation 1:** PEVs provide the strongest short and long-term opportunity for Aspen to achieve their carbon reduction goals in the transportation sector. The city should aggressively pursue PEV adoption in the area by serving as a regional catalyst for adoption and deployment.
>
> **Recommendation 2**: Action should be prioritized over the next 2-3 years to deploy PEV infrastructure and transition vehicles. Substantial infrastructure grants and vehicle incentives are currently in place that will dramatically minimize the capital cost of implementing cleaner fuels sooner rather than later.

The first recommendation is to leverage the clean grid and aggressively position Aspen as a PEV-friendly community to residents, tourists and regional commuters, and ski traffic. This can be accomplished by providing access to convenient charging, educating and incenting fleets to incorporate PEVs, making sure that PEVs are a visible component of city operations, and educating Aspen residents about the city's investment in electrification. Because the Aspen Electric grid leverages large quantities of renewable energy, there is a unique opportunity for all plug-in electric vehicles charging on the grid to produce zero lifecycle emissions. Replacing one vehicle with a PEV will be the emissions-equivalent of taking one vehicle off the road completely, offering the best opportunity to reduce carbon emissions from many of the fleet vocations, including the general public. For PEVs charging on the Holy Cross Electric (HCE) grid, efforts should be made to pair their wind and hydro offset programs with new PEV purchases, and the city should support HCE efforts to expedite their incorporation of renewable resources.

There are still significant barriers which will limit the wide-scale deployment of PEVs in Aspen; primarily the absence of affordable AWD, truck, and SUV models, but the market is expected to provide those in the next five years. Other prominent barriers are high vehicle cost and range anxiety in a cold, mountainous environment. Both barriers can be addressed in the short term by providing adequate and visible charging infrastructure, leveraging the grants and tax credits available for vehicle purchases, and allowing economies of scale to further develop through the automakers that will reduce capital costs. Also, the Holy Cross Electric (HCE) grid still has significant emissions associated with electricity generation, and many of the residents who may own a PEV live outside of downtown and will be using the HCE grid.

The second recommendation is to leverage existing PEV incentive programs that are currently in place to help overcome barriers like capital cost of vehicles and access to charging infrastructure. The state has the strongest tax credit in the country (up to $6,000 for light-duty) for PEVs that individuals and organizations with a tax liability qualify for (this excludes governments like the City of Aspen), and when combined with the federal PEV tax credit of $7,500, there is a possible $13,500 in available credits.

However, both of these credit programs have a horizon, as the state tax credit begins shrinking in 2019 and disappears in 2022, and the federal credit disappears whenever an individual automakers sells 200,000 qualifying PEVs. Additionally, there are grant funds available through Charge Ahead Colorado that the City can apply for to assist with the deployment of charging stations, up to $16,000 for a Level 3 and $6,260 for a Level 2. That program is only around until funding dries up, which is dependent upon application demand and the registration of new PEVs ($20 of a $50 PEV registration fee goes to a PEV infrastructure grant program). The City should take advantage of and promote these incentives to the community while they are around, as it will minimize financial barriers to greater PEV adoption in the Aspen area and position the city

as a regional and national leader. Specific actions the City can take to act on this recommendation are included below, but they include things like electric circulator buses in town, development of PEV infrastructure at strategic locations, incorporation of PEVs where sensible in the City fleet, and serving as an educator, encourager, and resource to the community about PEVs.

Affecting change in something as established as the transportation system will not be immediate, but decisions made now will set the stage for Aspen to position itself as a transportation leader by deploying infrastructure, converting operations, educating the public, and laying a policy-foundation. The remainder of the report will provide suggestions as well as specific examples that will be helpful in implementing the recommendations.

Vocation Recommendations

PEV: Circulator buses, city, general public, county, Aspen Ski Co., taxi

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PEV deployment should be prioritized among high-mileage, light-duty vocations with stop-and-go driving patterns, daily ranges under 100 miles and return to a central location daily for extended periods of time. Applications with high visibility and interaction with the public will help promote the transition and familiarize people with PEVs. Additionally, there is an opportunity to incorporate all-electric buses for use in circulating applications in the city and for transporting Aspen Ski Company's visitors. Plug-in hybrid electric vehicles (PHEVs) like the Chevy Volt could be used in applications where longer distances are often traveled, whereas battery electric vehicles are best utilized in applications that fit within the appropriate range requirement (under 80 miles a day). AWD, pickup, and SUV models may not be available in today's market, but several automakers have plans to address those market segments before 2020, which would overcome a major adoption barrier in Aspen and open additional opportunities. The specific fleet niches below are recommendations based on the current model availability, but as SUVs, trucks, and AWD options become available, PEVs represent the most promising technology for long-term emissions reduction.

City: Currently available PEVs don't represent an enormous opportunity for the city fleet to reduce emissions, since the majority of the fleet is comprised of pickups, SUVs, and vehicles with all-wheel drive. Additionally, the city fleet doesn't travel significant miles due to confined geography and smaller routes, so ROIs have a much longer timeline. Incorporating PEVs in applications that make sense will exhibit leadership and gain valuable experience before wider deployment. Based on an analysis of city fleet data, the following opportunities are suggested.

- *Prius/hybrid Replacement* –older hybrids in need of replacement represent low-hanging fruit for transition to PEVs. They don't require bed space or AWD, and a PEV represents a logical evolution from hybrid to plug-in, amplifying the reason the hybrid was placed in that application in the first place. The City Manager fleet has a 2002 Prius soon to be replaced which could be a good candidate, and there is a Prius (#550704) in the parks department with great utilization that will be replaced in 2015.
- *City Leadership* – Walk the talk. Put city leadership in PEVs and wrap the vehicle to create strong branding.
- *Police (non-pursuit)* – Police fleets often consume the most fuel of any city department. Non-pursuit applications like detective work or police chiefs provide good opportunities for PEV deployment. Plug-in hybrid models usually work best - providing the option to use gasoline in case of emergency or longer required distances. The cities of Lakewood, CO and Indianapolis, IN are two of many police fleets that have incorporated PHEVs into non-pursuit applications.

- *Car Share* – Car sharing represents the perfect opportunity to gain visibility and educate the public about PEVs through active exposure. The short driving distances are ideal and operating costs are low. PHEVs could be incorporated first to determine charging patterns and driver feedback, with the ultimate goal of utilizing battery electric models. The current car share fleet looks relatively new (2010-2013), but any expansion or replacement of the fleet should consider PEVs. Electric car share fleets exist in San Diego and Houston, which has a city-owned fleet of 50 Nissan Leafs available for use by city employees. Additionally, eThos Electric Car Share is the first all-electric car share in the country, based in Golden, CO.
- *Downsizing* – Within every fleet there are opportunities to minimize the use of trucks and SUVs in applications where they are not necessary. Drivers often prefer larger vehicles, but many don't need them to perform their function. Efforts should be made to target those applications for replacement with PEVs.

County: The county fleet was not analyzed specifically in this report, but county fleets typically resemble the composition of city fleets with a wide spectrum of duty classes and applications. County vehicles usually travel longer distances to cover a wider geography, so payback could be more significant in many applications.

Circulator buses: Intercity and intra-resort bus operations present an opportunity for plug-in electric technology. Electric bus manufacturers, such as Proterra and WAVE, have the capacity to fast charge their buses while on route to provide operations for long periods. BYD has an electric bus with a 200 mile range, but it charges overnight. Circulator routes are great for electric buses because they have short, predictable routes that start and stop often. This doesn't require a huge daily range, and with a fast-charger setup where the buses can recharge in 10 minutes while on-route, the buses can operate 24 hours a day without the need to charge overnight. Initial costs are quite high ($800,000 per bus, without charging infrastructure, compared to $425,000 for a diesel bus), but fuel savings are tremendous and can realize significant lifecycle cost savings through cheaper fuel and maintenance costs. Additionally, the Federal Transit Administration (FTA) pays a large majority of the cost on a transit bus, so the entire price tag isn't on the transit agency. The buses are also quiet, providing a pleasant rider experience and reducing overall noise pollution.

There are several options to choose from with ranges between 50-200 miles, but since transit buses are route-specific and have predictable ranges, the range of an electric bus is actually quite manageable. BYD currently has the longest range bus with 200 mile capacity. Proterra's TerraFlex energy system allows the battery configuration on the bus to be specified to the route of the transit operator, with a maximum range of around 180 miles. Though, when combined with a 500kW fast charger, a bus with a smaller range of around 50 miles can be recharged in less than 10 minutes on-route, which allows for all-day operations. Proterra buses have ran 700 miles in a 24 hour period using this setup. In order to minimize costs, a bus with a smaller total range that can fast-charge throughout the day would probably be ideal for a circulator route – WAVE and Proterra are the only companies with on-route charging as a possibility. But, for buses traveling intra-corridor, a longer electric range may be necessary

General public: Unlike natural gas vehicles, which are primarily fleet-specific, the PEV market is primarily driven by models that attract the general consumer market. The city does not have authority over what the public buys, but it can educate and familiarize citizens through marketing campaigns and visible demonstrations to expedite the adoption process and reduce barriers. Additionally, the city can make it convenient to own a PEV by ensuring there is appropriate charging infrastructure along corridors and within the city to make ownership easier. In order for PEV adoption to grow, consumers need to be convinced they are benefitting without sacrifice. Accordingly, the city can incentivize PEV ownership through a variety of policies that are discussed in more detail further in the recommendations section.

Aspen Ski Co: The majority of Aspen Ski Company's on-road fleet are pickup trucks and SUVs (141 of 175), which the current PEV market does not supply, with the exception of VIA Motors with a price tag of around $70,000. They do operate ten sedans, all of which are Audi AWD models, and may present an opportunity to run a pilot PEV program.

Taxi: Taxi fleets are typically high mileage and can leverage the cheap operating costs offered by PEVs. They also provide a highly visible demonstration opportunity. Plug-in hybrids may offer the most immediate opportunity to avoid concerns of range anxiety for longer trips and full-day operations. Again, AWD and SUV options for larger seating capacity and snow operation are ideal and will be available soon, but in the meantime pilot projects can be implemented to prepare for wider deployment. The Nissan eNV200 is an electric van platform that is being used for taxi services and can seat 5 spaciously.

PEV Infrastructure Recommendations

Providing adequate charging infrastructure will make trips to and from Aspen in PEVs more practical. Visible charging station deployment will provide range security for existing PEV owners and make PEV ownership sound more realistic. Figure 3.9 shows the recommendations for levels of charging at specific destinations from the Colorado EV Market Implementation Study. More specifically, three methods for charging station deployment are suggested below, along with specific examples of possible locations.

Level 1	Level 2	Level 3
Airports Residential Hotels	Libraries Museums Public buildings Rec centers Restaurants Shopping centers Trailheads	Banks Fast food Gas station Grocery stores Pharmacies Rest Stops Strategic traffic corridor

Figure 3.9: EV Charging Locations

Workplace charging

Having employers provide charging to their employees is one of the most effective methods for increasing PEV adoption. According to the U.S. Department of Energy's Workplace Charging Challenge progress report, employees that have access to charging at work are 20x more likely to purchase a PEV than employees who do not. Here are a couple suggestions for how to increase workplace charging in Aspen:

- Provide workplace charging for city employees. Join the 180+ organizations in the Workplace Charging Challenge and promote involvement locally. Provide leadership and installation example for the community.
- Work with other large employers in the area to explain the benefits of workplace charging and educate them about available grants through Charge Ahead Colorado that will minimize costs. Encourage them to also join the Workplace Charging Challenge.

Photo:https://www.dom.com/res

Fast charging corridor

Because Aspen is a destination location for the general public that is at the far end or beyond the electric range for many PEVs, providing convenient fast-charging to, from, and within the city is essential to enabling electric day trips. The development of Level 3 charging corridors along I-25 and I-70 is something the state is focusing on to increase PEV adoption, and Aspen could extend that electric highway up highway 82. The Colorado EV Market Implementation Study used the following criteria for the electric highway development:

- A station located every 25–50 miles
- All stations within ½ mile of the highway
- Safe and convenient access
- Parking spaces
- Restrooms and drinking water
- Shelter and lighting
- 480 volt 3-phase electric power supply
- Amenities (e.g., food and traveler information)

Ideal locations for a highway 82 electric highway would be Glenwood Springs, Carbondale, Aspen, and Independence Pass. Aspen should deploy a Level 3 charging station in the city and work with regional partners to connect the highway in those other three critical junctures.

Level 3 charging is an industry with a strong private business model, so the city would not necessarily have to own and operate the station, but instead just work with private developers to locate host sites and facilitate development. Most developers will own and operate the station and charge flat fees or monthly subscriptions to PEV drivers to recoup costs. Aspen's role in this deployment would be working with the private developer to identify an ideal location in the city for a Level 3 charging location, and encourage other jurisdictions to do the same. Suggested Level 3 charging locations are in Figure 3.9, and two private fast charging companies operating in Colorado are NRG eVgo and GOe3. Because there are still multiple Level 3 charging port standards, prioritize companies that combine standards into one unit.

Public charging

Providing Level 1 and 2 charging to the public may not be highly utilized, since most charging occurs at home or at work, but it is important to combatting range anxiety and enabling access to specific destinations like trailheads. Public charging is effective at areas where cars will be parked for one hour or more and can extend or replace the range that was lost getting to the destination. Providing visible charging locations in the scenic areas in and around Aspen will help people make the connection between the car they drive and the impact it has on the beautiful environment they're surrounded by. Considering Aspen's specific environment and circumstances, a few suggestions for public charging sites that should be prioritized are below:

- *Aspen Ski Company* – The Colorado EV Market Implementation Study references a study done by the Denver Regional Council of Governments that researched average dwell times in common locations in the state. Of the numerous locations included in the study, ski resorts had the longest dwell time of any destination at 281 minutes. This would be an ideal location for Level 1 charging, which would minimize costs and allow for the installation of several chargers. The resort would get recognition for being proactive and exhibiting environmental leadership, and resort visitors

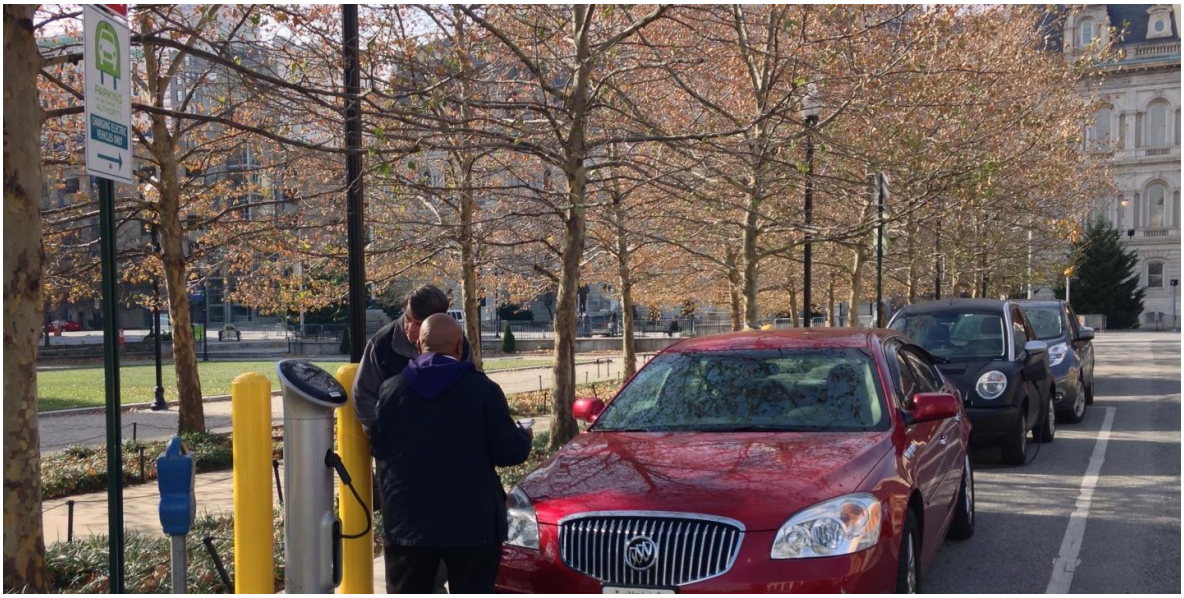
would be much more likely to consider PEVs as a viable option that wouldn't interfere with their 'Colorado lifestyle'. This would garner good media attention and serve as a very public, visible reminder that PEVs are a legitimate option.

- *Trailheads* – Trailheads are the gateway to Colorado's iconic outdoors, and since the Aspen area has many trailheads they provide a great opportunity for charging station deployment. Trailheads are very high traffic areas in the summer, and by providing charging at the trailhead the city would be incentivizing people to make the trip on electricity. This message resonates with Colorado's high quality of life and outdoor lifestyle, and it incorporates a new edge in the 'healthy living' mindset. Many trailheads take a lengthy drive to access, and charging would provide the range security for people to feel comfortable accessing the outdoors in zero-emission fashion. Average dwell time at state and national park trailheads is 67 minutes, so Level 2 charging is most appropriate.

- *Parks* – Parks have an average 60 minute dwell time and provide a comfortable area for people to wait for their car to charge. They also fit into the theme of active/outdoor/scenic locations that Aspen is known for. Level 2 is also most appropriate here.

- *Airport* – The Aspen-Pitkin County Airport should also be prioritized for EV charging. Residents that own PEVs should be able to plug-in while they leave the city, and the chargers could be visible as a symbol of what Aspen represents. Airports are a very common place for EV charging throughout the country. DIA has ten Level 1 chargers with plans to build many more, and the parking facilities outside of DIA also have EV charging available. Level 1 is most appropriate for long-term parking.

- *'Electric Avenue'* – Aspen should consider a very publicly visible, centralized block of parking spots where EV charging is offered and prioritized. Portland, OR (below) used this model on Portland State University's campus and it has been successful. This would give PEV drivers access to the bars, restaurants, and shopping located downtown, and since parking is limited it would give people a significant incentive to consider a PEV acquisition. The project could start small (2-4 spots) with prewiring done during construction for additional spots, and if utilization grows more spaces could be added cheaply. These spaces could be branded with a logo or slogan like 'Electric Boulevard' or 'E-Spaces'. Since much of the parking downtown is on-street, a photo is provided below of on-street charging in Baltimore. Level two would be the most appropriate level of charging for bars, restaurants, and shopping – dwell time is around 60 minutes for all three.



Signage

Labeling EV charging with the appropriate signage is important on a number of different levels. Signage gives visibility and familiarity to PEVs with the general public, and it serves a very practical directional purpose for drivers looking to locate charging options. There are generally four types of signage for EV charging stations:

- *Wayfinding* uses the blue charging station image to the right so drivers recognize there is charging nearby. Signage is often combined with arrows to point drivers in the correct direction.
- *Permissive* (such as signs that allow parking for a certain amount of time) that are green and black on a white background
- *Prohibitory* (such as no parking signs) that are red and black on a white background.
- *Regulatory* used for electric vehicle charging, which are needed to restrict access to charging stations and parking areas, or to limit the time of use.

Photo:http://www.afdc.energy.go

The Alternative Fuel Data Center has examples and more information on signage for charging stations. Also, a great case study example is the City of Montrose, which is highlighted in the Colorado EV Market Implementation Study on page 57.

Education and Marketing

To encourage adoption of these recommendations among the general public and fleets, Aspen can take an active education role through a variety of methods.

- **Leverage existing incentives** – Colorado has the strongest tax credit in the country for alternative fuel vehicles. There are also strong grant programs like Charge Ahead Colorado and Alt Fuels Colorado that will help fund infrastructure and limit the incremental vehicle cost. Aspen should be proactive in working with stakeholder organizations that operate fleets to let them know of these incentives and the reasons for transitioning to alternative fuels. For the general public, Aspen could create an education campaign to make them aware of the available tax incentives and focus on the environmental and economic benefits of PEVs.
- **City staff education** – host a lunch n' learn for city staff and work with fleet or dealerships to provide test drive opportunities. Hands-on experiences are powerful educational tools.
- **Ride-and-drive event –** work with an organization like Clean Cities or CLEER to setup an EV ride-and-drive event for Aspen visitors and residents. Host a National Drive Electric Week event in September and work to involve dealerships, PEV owners, city leadership, celebrities, and the general public to raise awareness and publicity around Aspen's efforts to promote PEVs.
- **Leverage X-games audience –** Work to promote the RNG and PEV accomplishments/plans of the city/region during the X-games. Highlight charging stations at trailheads, interview PEV owners that traveled to Aspen for the games, talk about the clean Aspen Electric grid, and utilize other messages to publicize alternative fuels during the popular event.
- **Refuel Colorado Fleets -** Work with CLEER and the Refuel Colorado Fleets program to help implement these recommendations, collaborate regionally with other municipalities and organizations on infrastructure deployment and targeted fleet analysis.

Possible City Policies, Regulations, and Incentives

In addition to leveraging existing policies and incentives, there are several things the city could do to prioritize alternative fuels:

- Mandate or prioritize clean fuel transportation in City contracts and encourage other local businesses and organizations to do the same.
- Adopt building codes that require 240 volt prewiring for a percentage of parking spaces in new parking lots, multi-unit housing, and commercial development. Require prewiring at new residential construction. This will dramatically lower costs associated with charging station installation.
- Become one of 23 US utilities to offer off-peak charging (i.e. time of use rates) for PEV charging. Time of Use (TOU) rates have been identified in other states such as Alabama, Alaska, Arizona, California, Georgia, Hawaii, Indiana, Kentucky, Maryland, Michigan, Minnesota, Nevada, Texas, and Virginia. These rates are used as an incentive to encourage EV owners to plug in their cars during off peak hours to minimize impacts on the electrical grid. It allows consumers to save money, and it helps electric utilities to better manage their grids by encouraging people to shift electrical usage away from peak demand periods.
- Prioritize alternative fuels in fleet purchasing by establishing a carbon reduction requirement (e.g. new vehicle replacements must reduce lifecycle carbon emissions by 10% over the model it is replacing)

RELEVANT GRANTS, INCENTIVES AND REGULATIONS

Charge Ahead Colorado - GRANT

This grant program will fund 80% of the incremental cost, up to $8,260/vehicle, of a plug-in electric vehicle for entities located within the seven-county Denver Metro area that are ineligible for the state tax credit. The grant will also cover 80% of project costs associated with charging stations. Total awards differ according to the level and type of charger, but the range is between $3,260-$6,260 for Level 2 and $13000-$16,000 per station for entities located throughout the state. The grant is jointly administered by the Colorado Energy Office and Regional Air Quality Council. Full details and information can be found at their website.

ALT Fuels Colorado - GRANT

This grant program will fund 80% of the equipment cost associated with compressed natural gas (CNG) fueling stations, up to $500,000. The grant will also fund propane and Level 3 charging stations, up to $50,000, if they are co-located at an awarded CNG station. This portion of the grant is being administered by the Colorado Energy Office. The application and full details can be found at their website.

- Applications open twice a year - summer and winter

Department of Local Affairs (DOLA) Alternative Fuels Funding Program - GRANT

In partnership with the Colorado Energy Office and Regional Air Quality Council, DOLA's Energy and Mineral Impact Assistance Program Tier II application cycle will fund alternative fuel vehicles (AFVs), alternative fuel infrastructure, and maintenance facility upgrades that support AFVs. Only public entities (local governments and special districts) qualify. Infrastructure projects require a 25% minimum match. For vehicles, 100% of the incremental cost between an AFV and its conventional equivalent would be funded. Full details and applications can be found at their website.

- Next application due April 1, 2015
- Applications due three times a year: April 1, August 1, December 1

Colorado Alternative Fuel, Advanced Vehicle, and Idle Reduction Tax Credit – INCENTIVE

Colorado offers a substantial tax credit for alternative fuel vehicles that are purchased new or converted, as well as idle reduction equipment, aerodynamic technologies, and clean fuel refrigerated trailers. Tax credits are categorized according to the fuel or technology type and vehicle weight class, and each category has a credit cap ranging anywhere from $6,000-$20,000. Credits are fully refundable regardless of tax liability, but only taxable entities qualify. Details can be located on the **Refuel Colorado website**.

Federal PEV Tax Credit – INCENTIVE

Plug-in electric vehicles with a battery at least 5 kWh in size qualify for a federal tax credit between $2,500-$7,500 (depending on battery size and vehicle weight). Credits will be phased out after 200,000 qualified PEVs are sold by a specific manufacturer in the United States. Credits are not refundable and are dependent on federal tax liability, but

only taxable entities qualify. Though, some dealerships will take the full credit and pass along the savings to the purchaser.

Colorado Low-Emission Vehicle Sales Tax Exemption - INCENTIVE

Alternative fuel vehicles weighing more than 10,000 lbs are exempt from state sales and use tax. City and local taxes may apply. For detailed information visit the Department of Revenue website.

EVSE Multi-unit Dwelling Installations and Access – REGULATION

Tenants are allowed to install Level 1 or Level 2 EVSE at a leased premise at their own expense. The landlord may require reimbursement for the cost of electricity, as well as the cost of installation or upgrades to existing equipment. The landlord can charge a fee for use of a parking space if EVSE is placed in a parking area otherwise accessible to other tenants. These actions will make charging accessible to key demographics for the EV market, such as individuals that may have downsized their home to live in a downtown condo.

PEV Registration Fee – REGULATION

There is a $50 fee for PEVs in order to cover uncollected fuel excise taxes that normally come from the pump to fund highway infrastructure - $30 goes to the Highway User Tax Fund, and $20 goes to an EVSE fund dedicated to deployment of charging stations throughout the state.[88]

Alternative Fuel Excise Tax Parity – REGULATION

Alternative fuels like compressed natural gas are subject to a unique state excise tax structure that starts low and increases through 2019. For a table of the excise taxes visit the Alternative Fuel Data Center.

Alternative Fuel Vehicle Weight Limit Exemption – REGULATION

Gross vehicle weight for alternative fuel vehicles are 1,000 pounds greater than comparable conventional vehicles, as long as they use the alternative fuel when operating on a highway that is not an interstate.[89]

Alternative Fuel Resale and Generation – REGULATION

A corporation or individual that resells alternative fuel supplied by a public utility for use in an alternative fuel vehicle (AFV) is not subject to regulation as a public utility. Additionally, a corporation or individual that owns, controls, operates, or manages a facility that generates electricity exclusively for use in AFV charging or fueling facilities is not subject to regulation as a public utility provided that the electricity is generated on the property where the charging or fueling facilities are located and the electricity is generated from a renewable resource. For the purposes of this definition, alternative fuel is defined as propane, liquefied natural gas, compressed natural gas, or electricity[90]. (Reference Colorado Revised Statutes 40-1-103.3)

[88] Colorado Revised Statutes, C.R.S. 42-3-304 (2014)
[89] Reference Colorado Revised Statutes 42-4-508
[90] U.S. Department of Energy, Alternative Fuel Data Center, Laws and Incentives http://www.afdc.energy.gov/laws/10014

Government Energy Performance Contracting for Alternative Fuels – REGULATION

Government fleets may finance the lease or purchase cost of alternative fuel vehicles and alternative fueling infrastructure through energy performance contracts where vehicle operational and fuel cost savings pay for the capital investment. Energy performance contracts must show that the annual cost savings associated with the fueling and maintenance of vehicles with higher efficiency ratings or alternative fueling methods is equal to or higher than the annual contract payments.[91] (Reference Colorado Revised Statutes 24-30-2001 through 24-30-2003 and 29-12.5-101 through 29-12.5-104)

Natural Gas Refueling Requirements – REGULATION

The Colorado Division of Oil and Public Safety regulates natural gas fueling station design, construction, installation, and operation. Reference 7 Code of Colorado Regulations 1101-16 and Colorado Revised Statutes 8-20-102 and 39-27-123

Expired Federal Incentives – INCENTIVES

There are two relevant incentives that expired at the end of 2014 and are not currently available at the time of this report, but they may be retroactively reinstated, as they were in 2014. Incentives include a $0.50/gallon discount on alternative fuels like natural gas, and 30% of alternative fuel infrastructure costs up to $30,000 or $1,000 for residential installation of a charging station.

PEV RESOURCES

- **2015 Colorado EV Market Implementation Study**
  - Most recent state-specific market assessment with EV projections, policies, incentives, recommendations
- **Colorado EV and Infrastructure Readiness Plan, 2012**
  - 106 partners worked to identify PEV deployment barriers and solutions. Document includes research, case studies, analysis, policy, incentives for PEVs and serves as the state/community guide for deployment in Colorado.
- **Electric Ride website**
  - Consumer oriented, public-facing site about electric vehicle models, facts, figures, information
- **Refuel Colorado website**
  - Fleet and general public site with basics on all alt fuels, ran by the Colorado Energy Office
- **U.S. Department of Energy's Alternative Fuel Data Center**
  - Federal government's information repository for all alt fuels: publications, research, station locator, case studies, laws and incentives – everything alternative fuels related.
- **U.S. Department of Energy's Workplace Charging Challenge**
  - Voluntary program for employers interested in providing workplace charging. In return for committing to try workplace charging, employers/cities/organizations get technical assistance and guidance.
- **Workplace Charging Handbook**

[91] U.S. Department of Energy, Alternative Fuel Data Center, Laws and Incentives http://www.afdc.energy.gov/laws/11490

  - Comprehensive information resource that walks organizations through the process of developing a charging program
- **PEV Model Search**
  - Find PEV models for all fleet vocations

RNG RESOURCES

- Community Guide to RNG
  - Energy Vision is an organization that specializes in RNG. They put together a guide for communities to follow in their pursuit of RNG.
- EPA's Landfill Methane Outreach Program
  - Program similar to the workplace charging challenge, but it works with landfills to capture and use landfill gas for electricity or transportation.
- U.S. Department of Energy's Alternative Fuel Data Center
  - Federal government's information repository for all alt fuels: publications, research, station locator, case studies, laws and incentives – everything alternative fuels related.
- Alternative Fuel Vehicle Model Search
  - Find CNG models for all fleet vocations

BACKGROUND AND QUALIFICATIONS

Supported by the U.S. Department of Energy's Vehicle Technologies Program, Clean Cities is a government-industry partnership designed to reduce petroleum consumption in the transportation sector through the development of local markets for alternative fuels and advanced vehicle technologies. Clean Cities operates via local coalitions throughout the country, which serve as the ultimate conduit and consult for information on current and future transportation technologies. The Denver Metro Clean Cities Coalition (DMCCC) is administered by the American Lung Association in Colorado, and together they work to improve air quality and lung health through the displacement of petroleum.

One way the DMCCC displaces petroleum is by educating and assisting fleets in understanding the costs and benefits that alternative fuels and vehicles present. Alternative transportation fuels like hydrogen, natural gas, propane, biofuels, and electricity present an opportunity to significantly reduce operating costs, minimize vehicle emissions, support domestic energy sources and diversify a fleet. By providing an unbiased analysis of the dynamic and complex nature of alternative fuels and advanced vehicle technologies, DMCCC was chosen to assist the City of Aspen as they navigate the transition away from gasoline and diesel.

The DMCCC has exhibited leadership in the alternative fuel industry through the creation and management of the Colorado Electric Vehicle and Infrastructure Readiness Plan and their significant role in conducting fleet analyses through Refuel Colorado. The Readiness plan was developed with 106 project partners and identified and addressed many of the barriers to further adoption of electric vehicles, presented relevant case studies and provi ded recommendations to overcome those barriers.

The plan includes a well-to-wheels emissions analysis of operating plug-in electric vehicles in the state, along with projections on utility emissions through 2020 as the renewable energy standard is realized. The plan serves as the state's

ultimate resource for planning, policy, and market projections, and since its release many of its recommendations have already been adopted.

Tyler Svitak, Clean Cities Manager at the American Lung Association in Colorado
Tyler Svitak manages the Denver Metro Clean Cities Coalition (DMCCC), and has been a part of the organization since 2011. During his time with the DMCCC, Mr. Svitak has developed knowledge and skills that are directly transferable to this report:

- Conducted alternative fuel fleet analyses for the City and County of Denver, City of Aurora, City of Lakewood, Boulder County, Jefferson County, and continues to work with fleets to help them understand the costs, benefits, and factors involved with alternative fuels through the Refuel Colorado program funded by the Colorado Energy Office (CEO).
- Understands the vast array of alternative fuels, vehicles, and advanced technologies available, in addition to their advantages and disadvantages.
- Fosters and maintains relationships with 130 stakeholder organizations related to alternative fuels and technologies and utilized these relationships to harness local case studies, cost analysis, and relevant research.
- Serves as the Chairman to the Colorado Hydrogen Coalition's Advisory Board, and leads the Colorado Natural Gas Vehicle Coalition.
- Served as subcontractor on the 2015 Colorado EV Market Implementation Plan
- Authored the content and assisted in designing the layout of www.RefuelColorado.com
- Harnesses the knowledge and expertise of the Clean Cities national network of technology experts, OEMs, fuel providers, and case studies through the Department of Energy.