Fueling Good: Planning Design and Program Management for Alternative Fuels

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ABSTRACT

While petroleum-based fuels are expected to dominate supply in the near future, the use of alternative fuels is projected to grow rapidly over the next 30 years. Highlighted by an abundance of domestic natural gas and greater accessibility of electric drivetrains, alternative fuels are enhancing the financial bottom-line of organizations while improving the environment and public health.

Alternative fuels are diverse and include ethanol, biodiesel, electricity, hydrogen, natural gas and propane. Each has a distinct business case that can be applied successfully. Social and environmental benefits vary and must be considered in context with regional and project-specific drivers. For example, natural gas and biodiesel can yield returns on investment for large fleets of heavy-duty diesel vehicles. For smaller fleets with a greater proportion of light- to medium-duty vehicles, propane improves performance. Electric vehicle technology is evolving rapidly and is now well suited for fleets of passenger vehicles.

Businesses, private fleets, municipalities, transit authorities, airports, and federal agencies all benefit from alternative fuels. Strategies to harness the benefits include planning, design and program management. In this article, case studies of each approach are provided to highlight best practices and potential lessons learned. Cases include: 1) a regional planning process involving alternative fuels as a driver for regional economic development; 2) a design process for a utility electric vehicle charging program; and 3) a program management approach for capturing public-private financing for design-build delivery of compressed natural gas (CNG) fueling infrastructure.

FROM DEPENDENCE TO OPPORTUNITY

The economic, social and environmental security of the United States is strengthened by local actions to reduce petroleum dependence. This goal is achieved by alternative fuels, alternatively fueled vehicles (AFVs), increases in fuel economy, and measures to reduce vehicle miles travelled. Alternative fuels simultaneously generate substantial benefits for individuals, organizations and communities. Benefits include greater environmental stewardship, improved public health and enhanced economic competitiveness.

Conventional Fuels

In the U.S. gasoline and diesel are the dominant vehicular fuels. Both are supported by ubiquitous infrastructures. These fuels accounted for about 94 percent of the total vehicular energy use in the U.S. during 2011 [1].

The U.S. consumed about 25% percent of the world's petroleum in 2013—nearly twice as much as China, the second leading consumer. Recent technological advances have made the U.S. the global leader in petroleum production. However, with domestic production at 20% of the global total in 2014, a fraction that may decrease in the near term, imported oil from foreign nations remains important to economically satisfy demand. Further, while imports are expected to decline over the near term, current geological science indicates that the U.S. holds just 2% percent of proven global reserves [2].

The current rate of U.S. petroleum consumption cannot be maintained indefinitely. As a result of complex global market forces, petroleum prices are increasingly volatile, with rising prices expected over the long term, despite near term over-supply and reduced prices. Increasing concerns about the health and environmental effects of pollution limit feasibility of extracting all of the world's reserves.

Mitigating the balance of supply and demand in the U.S. is a forecasted decrease in total gasoline consumption through improved fuel economy. While diesel use is expected to rise through the period, total consumption of the two fuels is expected to remain flat through 2040.

Alternative Fuels

While it is reasonable to expect gasoline and diesel to meet the majority of fuel demand for the near future, alternative fuels are part of a longer term solution to balance supply and demand. Increasing the rate

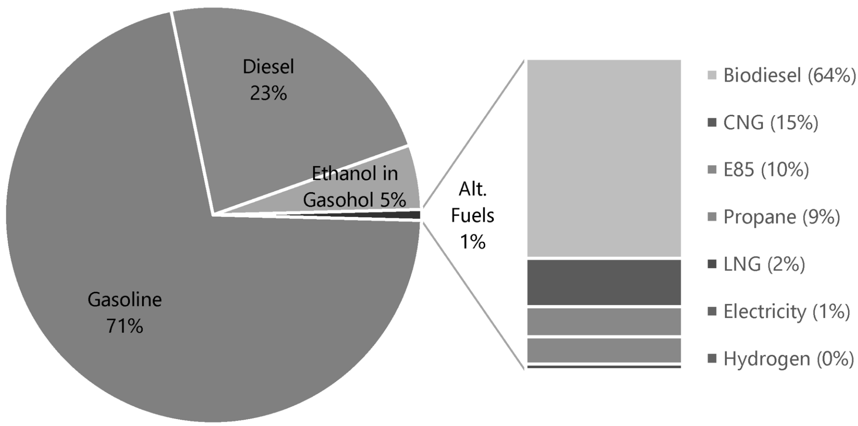

Figure 1. Estimated consumption of vehicle fuels in 2011 [11].

at which alternative fuels replace conventional fuels in the near term can result in a host of benefits, including following:

- Reduced dependence on foreign suppliers
- Enhanced risk management (e.g., reduced volatility)
- Reduced costs of fueling, operating, and maintaining vehicles.
- Improved performance (e.g., energy efficiency)
- Economic development (e.g., infrastructure investment, new markets, etc.)
- Job creation
- Reduced nuisance (e.g., noise, odor, etc.)
- Improved public health
- Reduced toxicity
- Reduced local air pollution
- Decreased greenhouse gas (GHG) emissions

Emerging alternative transportation fuels include biodiesel, electricity, ethanol, hydrogen, natural gas and propane. Several other potential transportation fuel sources are being developed (i.e., "renewable" or "drop-in" biofuels, biobutanol, methanol, ammonia, etc.); however, these emerging fuels are not yet widely used.

Excluding the ethanol blended with gasoline as an oxygenate, alternative fuels comprise less than 1% of the total transportation fuels consumed in 2011. However, the total consumption of alternative fuels nearly doubled from 2007 to 2011 [1] and continues to grow rapidly.

Consumption increased by double-digit rates for hydrogen, E85, biodiesel, electricity and CNG. Liquefied natural gas (LNG) use increased more slowly while consumption of propane declined slightly during this period.

Biodiesel

Biodiesel is a non-petroleum diesel fuel sourced from vegetable oils, waste restaurant grease and animal fats. It is non-toxic, bio-degradable, and considered a renewable energy resource. The fuel is produced domestically via a process called transesterification, which catalyzes fats, oils and alcohol to produce biodiesel and by-products, including glycerol. While this is the most commercial pathway for producing the fuel, other feedstocks including algae and production methods (e.g., collocation at petroleum refineries) are being developed.

Pure biodiesel (B100) is blended with petroleum diesel for use in diesel engines. A 20% percent blend (B20) is the most common alternative diesel fuel in the United States. While blends of any percentage are feasible, blends greater than 40% percent may require modifications to standard diesel engines. The American Society for Testing and Materials (ASTM) standard for conventional diesel fuel allows biodiesel content of up to 5% percent without labeling the fuel as biodiesel.

The sources of biodiesel are diverse, including first-generation and second-generation sources. First generation sources include soybean and rapeseed oil. Second-generation sources include vegetable oils and animal fats, often the waste products of food production or service. Biodiesel is made at production facilities and shipped or trucked to fuel distributors. Distributors supply conventional retail gas stations. Biodiesel is also commonly produced locally from secondary sources.

Biodiesel consumption is forecasted to grow in the near future. However, consumption of most biofuels is expected to decline after 2020 as a result of the U.S. Renewable Fuel Standard (RFS). The RFS sets policies and standards for increasing the volume of biofuels blended into gasoline and diesel. Compliance with the standard is tracked via credits representing gallons of biofuels produced or imported. New federal policies developed between now and 2020 may affect this projection [3].

Electricity

A familiar source of power in buildings, electricity is also used to power all-electric vehicles (EVs) and plug-in hybrid electric vehicles

(PHEVs). These vehicles draw power produced by electric utilities and supplied by a transmission and distribution network (the grid). Electric power can be produced from a variety of primary energy sources including coal, natural gas, oil, uranium, moving water, wind and sunlight. The specific mix of sources varies over time and geographic location.

Unlike most homes, electric vehicles store power on-board in rechargeable batteries. EVs utilize batteries to energize an electric motor. PHEVs pair battery storage with an internal combustion engine (ICE) fueled by gasoline or diesel to enhance fuel efficiency. Standard gasoline/electric hybrid vehicles generate electricity from on-board generators and achieve fuel efficiency gains similar to (although less than) PHEVs.

Electricity is primarily used in light-duty vehicles (LDVs). While its share of alternative fuel use was minimal in 2011, its use is expected to grow by about 17% through 2040 [3].

Ethanol

Ethanol is a renewable fuel derived from fermenting and distilling plant materials in a manner similar to producing alcohol. In the U.S., the primary feedstock is corn. Sugar cane is a common feedstock in warmer climates. Non-food based feedstocks (i.e., cellulosic ethanol) are under development to improve ethanol's energy balance. Energy balance is a comparison of the amount of energy required to produce a fuel to the energy contained in the fuel. Cellulosic feedstocks require fewer resources to grow, but technological and economic barriers have limited commercial-scale production.

Most gasoline consumed in the U.S. includes up to 10% percent ethanol which is an oxygenate. Oxygenates are added to fuels to reduce their air pollution. A blend of 85% percent ethanol to 15% gasoline (E85) is considered an alternative fuel. This blend can be used in flex fuel vehicles (FFVs), those capable of operating using either gasoline or E85. About 10% of total alternative fuels consumed in 2011, corn ethanol usage is projected to decline after 2020. Afterwards, use of cellulosic ethanol is expected to grow rapidly [3].

Hydrogen

Like electricity, hydrogen is technically not a fuel. Instead, it is a way of "carrying" energy produced from other feedstocks. The most abundant element in the universe, hydrogen can be produced from a multitude of sources.

Hydrogen in a gaseous state may be combusted in an ICE or used in fuel cell vehicles (FCVs). Fuel cells generate electricity via an electrochemical process. The electricity is used to power vehicles in a manner similar to EVs.

Hydrogen is currently produced domestically through steam reforming of natural gas. Electrolysis is a less-used method. Research on cleaner and more efficient methods of producing hydrogen is continuing. Hydrogen is primarily produced on site for industrial applications. It can be distributed via pipeline, tankers, rail and truck via high pressure or cryogenic containers. Infrastructure for producing and delivering hydrogen to support the transportation sector does not presently exist on a national scale.

While hydrogen has potential as a highly efficient fuel with advantageous environmental characteristics, it is neither widely available nor economically feasible. Hydrogen's low density presents challenges for storing fuel on-board an automobile. Thus the near-term potential of hydrogen as an alternative fuel is limited.

Natural Gas

Natural gas is predominantly methane, with traces of other hydrocarbons. It is typically a non-renewable fossil fuel extracted alongside oil. It can be produced renewably from organic waste. Before use as a fuel, natural gas is refined to remove impurities. It is delivered via an extensive transmission and distribution network designed to meet demand for heating, cooking, industrial processes and electric power generation.

The majority of natural gas consumed in the U.S. is produced domestically. Until recently, increased consumption was forecast to result in greater dependence on foreign sources. However, technological advances including horizontal drilling and hydraulic fracturing (a.k.a. "fracking") have allowed previously inaccessible sources to be tapped, providing domestic abundance.

Presently, less than 3% percent of U.S. natural gas consumption is devoted to transportation. It must be compressed (CNG) or liquefied (LNG) for use in vehicles. As CNG, natural gas is compressed to about 3,600 pounds per square inch (for comparison, a standard car tire is inflated to about 30 psi) and stored in reinforced containers. LNG is purified and cooled to -260°F and stored in insulated cylinders. LNG occupies about 1/600 the volume of CNG. As a result, more energy can be stored on-board LNG vehicles. Both CNG and LNG vehicles have specialized internal combustion engines.

Processed natural gas generally reaches demand centers via an interstate network of transmission pipelines. New pipeline projects are connecting shale gas producers in the Midwestern U.S. to demand centers. Natural gas is locally distributed to end-users by utilities that operate and maintain gas distribution networks.

CNG is produced near the end-use. Natural gas supplied by the local distributor is dried, filtered and compressed for dispensing to vehicles.

LNG is produced regionally in liquefaction plants. The majority of these facilities have been designed to support export of natural gas or to meet spikes in demand for residential heating. A small minority produce LNG for transportation uses, although this number is expected to grow. LNG is trucked from plants to fueling stations, where it is stored on site and can be converted to CNG.

Less than 20% of total alternative fuel use in 2011, natural gas use is forecast to grow faster than all other alternative fuels. Among freight trucks, natural gas use will increase by 17%. Some believe that natural gas will overtake diesel as the dominant fuel in transit buses by the early 2030s [3].

Propane

Propane is familiar to many as liquefied petroleum gas (LPG)—the fuel that fires barbeque grills. It has diverse applications and has been used as a transportation fuel for decades. As "autogas," propane is the world's third most common engine fuel behind gasoline and diesel.

Propane-autogas is a non-renewable, petroleum-based fuel. It is produced in roughly equal proportions as a byproduct of domestic oil refining and natural gas processing. It is stored on-board a vehicle as a liquid at about 150 psi. When drawn from its storage tank, the fuel changes to a gas and is combusted in an ICE. Autogas is used in vehicles with dedicated fuel systems. It may also be used in bi-fuel vehicles, with separate fueling systems for autogas and gasoline. Autogas vehicles are available via conversions of gasoline vehicles, or increasingly through original equipment manufacturer (OEM) offerings. Propane is transported by rail or truck to bulk storage plants, which deliver propane to wholesale and retail customers. There are over 13,000 such plants in the U.S.

Use of autogas is expected to grow slowly through 2040, with consumption of natural gas overtaking propane by 2020 and eventually supplying about 20 times more energy than propane by 2040 [3].

THE ALTERNATIVE FUELS "ECOSYSTEM"

Alternative fuels are extremely diverse. About the only feature shared in common is that they are not gasoline or diesel. Because of this variety, there is no "silver bullet" for displacement of conventional fuels. Regardless, there is a niche for each alternative fuel. Each fuel's key characteristics and each fleet's operational factors determine the alternative fuel's feasibility.

Figure 2 provides a simplified view of a possible alternative fuels "ecosystem" in which each fuel fulfills a niche conventionally inhabited by gasoline, diesel or other common petroleum fuels.

For freight vehicles, including ships, locomotives and tractor trailers, LNG is often a viable alternative due to the fuel's price, emissions, relatively high energy content and the range requirements of freight logistics.

Biodiesel may also displace diesel and gasoline in some freight vehicles, heavy duty vehicles, specialty vehicles (e.g., transit buses, utility bucket trucks, refuse tracks, cement trucks, etc.) and mid-duty vehicles when emissions are a concern, without compromising price, fuel economy, range or vehicle cost and availability.

CNG can save money in heavy duty or specialized vehicle fleets using large volumes of fuel on predicable routes not limited by vehicle range.

For fleets with smaller specialty vehicles (e.g., shuttle buses, forklifts, etc.) or medium-duty vehicles, propane may profitably improve performance.

Flex fuel vehicles capable of using E85 are available in most mid- and light-duty vehicle types, providing GHG reduction benefits. Future development of cellulosic feedstocks may expand the niches E85 will competitively fill.

Electric vehicle technologies are changing rapidly. EVs are now well suited for fleets of passenger vehicles when fuel prices, emissions and fuel economy are a concern. Range and upfront vehicle cost can often be mitigated.

The niches that may be filled by alternative fuels are even more diverse and complex than the simplified scenarios presented in Figure 2. Fleet managers must consider the key characteristics of alternative fuels along with their particular operational constraints.

Important key characteristics that differ among alternative fuels include energy content, unit price, emissions, range fuel economy, vehicle cost, vehicle availability, infrastructure investment and infrastructure access. Each of these are next examined in greater detail.

Energy Content

Because alternative fuels take a variety of forms that include both liquid and gas, common comparisons are challenging. The energy content of the fuels varies. This influences the cost to operate AFVs and provide alternative fuel infrastructure. Table 1 summarizes the heat content of petroleum fuels and alternatives in their most common unit of consumption. It also compares them on a gasoline gallon equivalent (GGE) and diesel gallon equivalent (DGE) basis. It is important to note that none of the alternative fuels, with the exception of biodiesel, rivals the energy density of conventional fuels. Much alternative fuel technology focuses on mitigating this disadvantage.

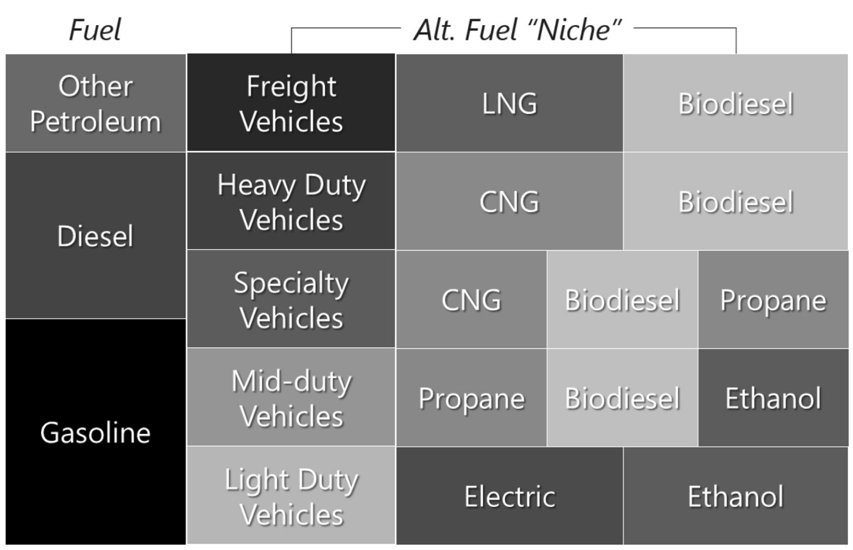

Figure 2. The alternative fuels ecosystem.

Table 1. Energy content of fuels [4, 5, 6].

Fuel (unit)	Heat Content (BTU/unit)	GGE	DGE
Gasoline (gal)	115,400	1.00	0.88
Diesel (gal)	127,500	1.14	1.00
B100 (gal)	117,000	1.05	0.92
B20 (gal)	104,000	1.12	0.98
Electricity (kWh)	3,412	0.31	0.27
E85 (gal)	76,000	0.73	0.64
Hydrogen (gal)	27,800	0.25	0.22
CNG (Therm)	93,000	0.83	0.73
LNG (gal)	71,000	0.64	0.56
Propane (gal)	83,500	0.74	0.65

Unit Price

In addition to varying energy content, which makes comparisons based on price per gallon misleading, production and local markets play a role in comparing the prices of alternative fuels.

Biodiesel is produced, distributed and sold regionally on a commercial scale. Biodiesel may also be produced locally on a smaller scale. The price of biodiesel produced from primary sources for regional distribution may differ substantially from fuel produced from secondary sources for local consumption. LNG prices are generally higher than CNG prices due to the costs of liquefying and transporting the fuel. Electricity is sold on a per-kilowatt-hour (kWh) basis, making direct comparisons between the price of electricity and gasoline difficult. Further, electricity prices vary substantially on a regional basis. Propane prices are typically established via a private contract. Prices for hydrogen are not yet widely tracked and reported.

Figure 3 charts the average retail price of alternative fuels relative to gasoline and diesel over the past 14 years based on data reported by the U.S. Department of Energy (DOE) [4]. Prices are presented in dollars per gaseous gallon equivalent (GGE).

Prices for biodiesel and ethanol have been similar to diesel and gasoline. They have exhibited less volatility since demand for these as transportation fuels is much less. CNG and electricity have been less expensive than diesel and gasoline. They have exhibited less volatility since demand for these fuels is small compared to competing end-uses. The DOE does not presently track hydrogen or LNG prices.

The prices reported for propane are based on residential propane use and does not accurately reflect autogas prices. Autogas prices are typically determined via private contracts between propane marketers and fleet managers. According to the industry, autogas prices are based on the monthly propane spot price plus a markup of $0.80 to $1.00. At such prices, autogas has trended lower than gasoline or diesel but exhibited significant volatility.

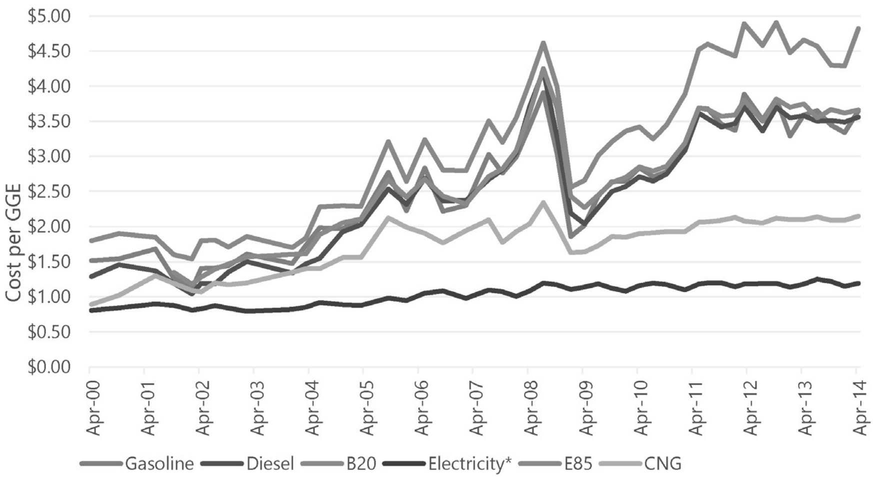

Figure 3. Average retail fuel prices in the U.S. (2000-2014).

Emissions

Alternatively fueled vehicles have the potential to reduce pollution in the transportation sector. Air pollution from transportation includes criteria air pollutants regulated by the Clean Air Act, such as oxides of nitrogen (NO_x), carbon monoxide (CO), and particulate matter (PM). Some pollutants, together with volatile organic compounds (VOC), form ground-level ozone which has health and environmental impacts, including asthma in humans and atmospheric acid rain.

Greenhouse gas (GHG) emissions, including releases of carbon dioxide (CO_2), are also closely linked to transportation. The transportation sector is the second largest source of human-caused emissions in the U.S., nearly 30 percent of the total. Such anthropogenic GHG emissions are a leading cause of climate change, presenting significant challenges to the economy and society.

To evaluate air pollution and GHG reduction benefits of alternative fuels and vehicles, both fuel production and vehicle operation must be considered. Petroleum, natural gas, coal, biomass and electricity are feedstocks used to produce fuels. Each has a different impact on air quality and GHG emissions. These fuels may be utilized by a variety of transportation technologies, ranging from internal combustion engines to fuel cells. Assessing both fuel production and vehicle operation technologies allows common comparisons between the fuels.

Increasingly stringent emissions regulations have led to improved emissions control systems in conventional light and heavy duty vehicles beginning in 2010. Since these technologies are commonly applied after combustion, air quality from transportation is expected to improve regardless of the fuels used or vehicle efficiencies. Several alternative fuels can further improve air quality. A few alternative fuels may have negative effects on air quality relative to standard fuels. An example is propane's VOC emissions, which limits its appeal in locations challenged with ground level ozone pollution. These characteristics are summarized in Table 2. It shows percentage changes relative to standard vehicle emission rates in grams of emissions per mile driven.

Table 2. Estimated air quality emissions of alternative fuels relative to conventional fuels [5].

Fuel / Technology	NOx	VOC	CO	PM10
Biodiesel	3%	(20%)	(10%)	(8%)
Electricity (EV)	(96%)	(96%)	(96%)	(11%)
Ethanol	8%	2%	0%	1
Hydrogen	(96%)	(96%)	(96%)	(1-11%)
Natural Gas (CNG)	(19%)-0%	72%	*	*
Natural Gas (LNG)	(5%)-4%	(72%)	*	(1 – 2%)
Propane	3-26%	600%	0%	0%

Alternative fuels are expected to reduce GHG emissions compared to conventional petroleum-based fuels. Table 3 summarizes the relative rate of GHG emissions of alternative fuels relative to gasoline or diesel. Variations in GHG emissions are related to production feedstocks. Electricity emissions GHG reductions are based on California's grid and will differ in other regions. Emerging research on GHG emissions associated with natural gas production and transmission have increased uncertainty with respect to the environmental benefits of CNG and LNG.

Table 3. Estimated CHG emissions reductions from alternative fuels relative to conventional fuels [5].

Fuel / Technology	GHG
Biodiesel	10-13%
Electricity	48-72%
Ethanol	15-28%
Hydrogen	26-91%
Natural Gas (CNG)	11-30%
Natural Gas (LNG)	11-16%
Propane	18-20%

Fuel Economy

In addition to the energy contents of alternative fuels, the efficiency with which AFVs convert energy into motion differs. Figure 4 compares the energy efficiency (fuel economy) of mid-size, light-duty vehicles, including several AFVs. Efficiency is measured in miles per gasoline gallon equivalent (MPGGE). The energy efficiency of differently-sized cars varies yet the relative differences are similar. The figure indicates that EVs are the most efficient by a significant margin, followed by hydrogen fuel cell vehicles. Vehicles operating on diesel and B20, electric hybrids and hydrogen ICE vehicles follow.

Range

Range is the distance a vehicle can travel without refueling. AFV manufacturers attempt to offer vehicles with a range as close as feasible to conventional vehicles. This varies considerably according to the vehicle application.

The range of EVs depends on battery capacity. Present battery technologies limit the range of EVs to far less than conventional vehicles—about 70 miles (113 km). PHEVs have been developed, in part, to address "range anxiety" inherent with current EV technology. Advances in battery technology and lightweight materials will extend the range of EVs in the future.

Conventional light duty vehicles (LDVs), for example, have a range of about 300 miles (483 km). As with some AFVs, the range of conventional heavy-duty vehicles is largely determined by weight, including the amount of fuel carried on-board.

The energy content of the B20 used in conventional vehicles is similar to conventional diesel fuel. Thus, the range of vehicles using B20 is comparable to diesel vehicles.

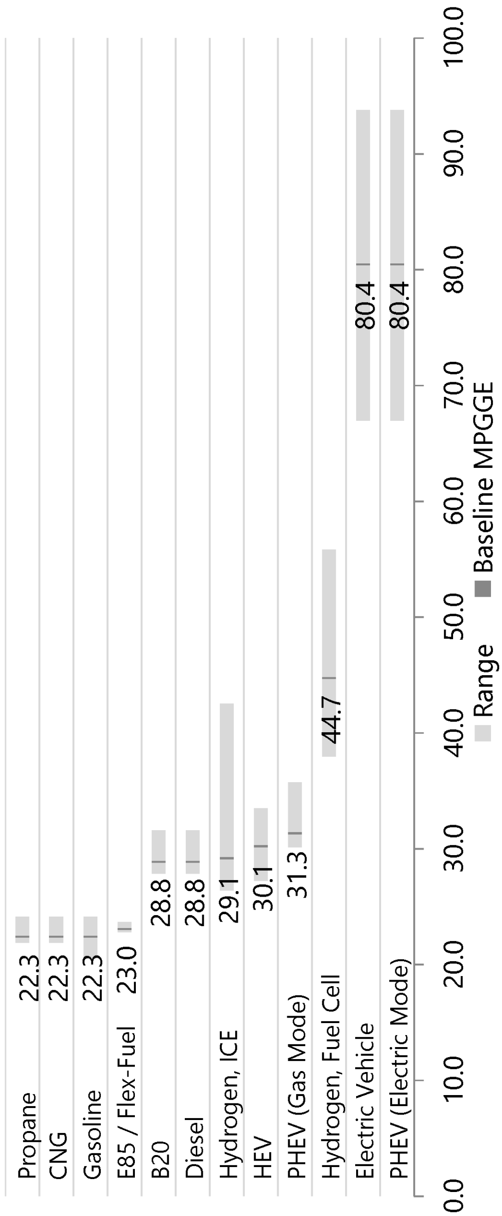

Figure 4. Energy efficiency of mid-sized light duty vehicles [5].

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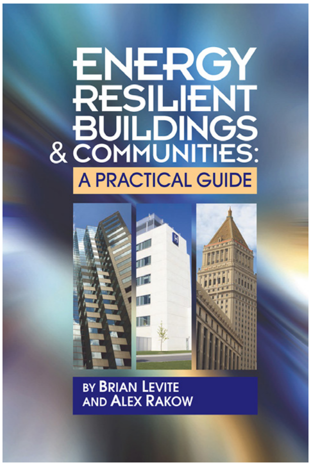

This book is written as a practical guide to those interested in the pursuit of energy resilience at a local scale. Energy resilience is defined as the relative ability of an institution to carry out its mission during a shock to the energy system, and to approach the concept on the level of a single site occupied by a single community or institution. Examples are drawn from four key community types: military bases, healthcare campuses, educational campuses and municipal governments. The book then describes a framework for developing an energy resilience plan that applies to each. While the focus is clearly on the U.S., understanding the energy resilience threat and conducting long-range energy resilience planning will benefit communities all over the globe. Part I describes the specific energy security threats that are facing local institutions and communities, the specific impact of an energy shock, and the advantages offered by pursuit of energy resilience. Part II provides concrete guidance and allows managers to assess where their institution lies on the energy resilience spectrum and they would like to be. Part III describes the three main areas of energy resilience performance: energy efficiency, on-site generation, and emergency planning. Case studies are also provided.

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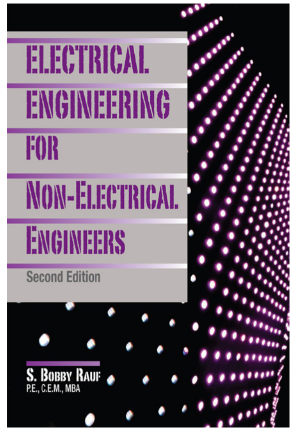

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Ethanol contains about 73% of the energy contained in conventional gasoline. Used in flex fuel vehicles, which are not optimized to take advantage of its higher octane, E85 reduces range by 15% to 25%.

Range affects the two primary natural gas fuels differently. Natural gas has less energy density than gasoline or diesel which reduces driving range. For both CNG and LNG vehicles, manufacturers attempt to optimize the size of fuel storage tanks to reduce range losses. However, the amount of CNG that can be stored on-board a vehicle is limited by space and weight. It is also affected by ambient temperature and the speed with which the tank is filled. This can reduce range by about 25%. Heavy-duty CNG vehicles are commonly used in applications in which range is not a primary concern. The range of LNG vehicles is greater than CNG vehicles. LNG vehicles have ranges greater than 300 miles (483 km), making them a feasible choice for long-range heavy-duty applications.

Propane has less energy density than conventional fuels. As a result, range can be reduced by 15% to 25%. As with natural gas vehicles, manufacturers attempt to size propane tanks to reduce range losses.

The range of hydrogen vehicles is also defined by the storage capacity of on-board tanks. Since it is an extremely low density gas, storing sufficient quantities onboard has been one of the main technological barriers to commercializing hydrogen vehicles.

Cost

Most AFVs cost more than conventional vehicles. The reasons for the higher prices relate to technologies specific to AFVs. Examples include batteries used in EVs and reinforced fuel tanks used in CNG vehicles. These price premiums limit use of alternative fuels and acceptance of AFVs. A variety of federal and state incentives are aimed at defraying the higher costs of certain AFVs.

Conventional diesel vehicles can operate on B20. Consequently, there is no vehicle price premium. E85 flex fuel vehicles carry little or no price premium as well.

Electric vehicles carried an average price premium of about $10,000 (U.S.) in 2012, with higher premiums for PHEVs. However, several manufacturers have recently announced price reductions. The Honda Civic CNG carries a price premium of about $7,500. General Motors recently announced bi-fuel CNG vehicles at $11,000 premiums. For heavy duty vehicles premiums range from about $50,000 for a CNG bus to $90,000 for a LNG tractor-trailer. The cost to convert a conventional truck to operate using autogas ranges from $4,000 to $12,000.

Due to price premiums, the lifecycle financial benefit of adopting alternative fuels often depends on whether the fuel savings adequately offsets the higher upfront cost of the AFVs.

Availability

While the availability of AFVs has been a limiting factor in the past, today they are available for nearly every conceivable application. However, there is wide variation in availability among the various alternative fuels. For instance, any diesel vehicle can use B20, while hydrogen light-duty vehicles are available only in select markets, such as in California.

In the light-duty vehicle (LDV) category, original equipment manufacturers (OEMs) produce dedicated AFV models. In the heavy-duty vehicle (HDV) category, the situation is more complex. AFVs are available from OEMs in standard models in much the same manner as LDVs. There are also discrete or integrated manufacturers of chassis, engines, or fuel systems that specifically accommodate alternative fuels. A multi-stage manufacturing process involving these systems can be used to produce a wide array of AFV configurations aimed at various applications. As a result, heavy-duty AFVs can be customized to meet most needs. After-market conversions are also widely available.

HDVs using biodiesel, CNG and LNG HDVs are available. In the mid-duty vehicle (MDV) category, biodiesel, ethanol and propane vehicles are widely available, with limited CNG offerings. In the HDV category, biodiesel, CNG and LNG vehicles are available. Wider availability of autogas vehicles in the HDV category are expected in the future.

Infrastructure Investment

The infrastructure required for alternative fuels varies. Biofuels can be supported with little change to existing fueling and vehicle maintenance infrastructure. By contrast, hydrogen requires a unique system of production, distribution and dispensing that does not yet exist. Electricity, hydrogen, natural gas and propane have distinct infrastructure needs. Table 4 compares the relative cost of infrastructure for the various transportation fuels.

Table 4. Relative cost of alternative fuel infrastructure.

Fuel / Technology	Cost
Biodiesel	Minimal*
Electricity	Low
Ethanol	Minimal
Hydrogen	Very High
CNG Time Fill	Moderate
CNG Fast Fill	High
LNG	High
Propane	Moderate

*High if production from secondary sources

Owners of electric vehicles require the ability to charge vehicles at home or at the fleet yard. In addition, publicly accessible electric vehicle changing or supply equipment (EVSE) is regarded as essential to support greater adoption of electric vehicles. The EVSE scope (i.e., "level") required to meet private and public needs is determined by the rate at which vehicles can be charged.

- Level 1 EVSE provides charging through a standard U.S. 120 Volt (V) alternating current (AC) outlet. Full charging time for an EV with a 60 mile (97 km) range takes between six and 13 hours. Specialized EVSE is not required.

- Level 2 EVSE charges vehicles via a 208/240 VAC electrical service. Full charging time for an EV with a 60 mile (97 km) range requires between two and seven hours. EVSE with a dedicated circuit of 20 to 100 amps is required. Connectors and outlets for EVSEs and vehicles have adopted the Society of Automotive Engineers (SAE) J1772 standard, which specifies the equipment's characteristics.

- Direct current (DC) fast charging stations use a 480 VDC service to fully charge a vehicle with a 60 mile (97 km) range in under 20 minutes. Highly specialized EVSE is required. Upgraded electrical service may be necessary. This kind of charging has yet to standardize connectors and outlets.

Electric vehicle charging stations are available from a variety of manufacturing sources. They feature various combinations of Level 1, Level 2 and DC fast charging EVSE, with Level 2 being the most common. Stations are often located where electric vehicle owners are concentrated, such as workplaces, shopping centers, airports and hotels. Public Level 2 charging stations cost between $2,000 and $13,000 to install. Private stations can be substantially less expensive, since fully-featured models may not be necessary. The price for electricity at public stations varies (from $0.00 to $0.49 per kWh) and is typically set by the station owner.

Infrastructure requirements for CNG and LNG differ, although the fuels may be co-located. CNG stations require access to natural gas supplied by a local distribution company (LDC) at adequate pressure. Typically, LDCs are willing to extend natural gas lines to a new station if none exist. Equipment must be installed to dry, filter and compress natural gas. CNG may be stored in high pressure vessels. Flow and temperature regulators are often installed to control fuel dispensing, which may be via a bank of "time-fill" dispensers that fuels vehicles directly from the compressor. "Fast-fill" stations dispense fuel from compressors and high pressure (e.g., 4,300 psi) storage tanks in a time comparable to conventional fueling pumps. Time-fill stations are appropriate for hub-and-spoke fleets. Fast-fill stations are suitable for retail situations and the operational needs of some fleets. The cost of CNG fueling stations varies from $200,000 to $8 million depending on the number of vehicles and the speed at which each vehicle must be filled.

LNG stations receive fuel deliveries via tanker truck and store fuel on site. A pump is used to move fuel from storage to the dispenser, where it is dispensed as a super-cooled liquid. Protective clothing is required to fuel a vehicle. CNG can be produced on site by expanding and compressing LNG. The cost of these stations varies from $1 to $4 million.

Adoption of either CNG or LNG also requires significant mechanical, electrical, structural and fire safety modifications to existing maintenance facilities to accommodate gaseous fuels.

The infrastructure required to fuel propane vehicles is relatively simple. It includes a storage tank, a pump and a dispenser. Experienced contractors are widely available and regulatory familiarity with systems is high. Propane infrastructure ranges from $30,000 to $200,000 depending on fleet requirements. Autogas marketers estimate that commercial fleet consumption of about 4,000 gallons (15,142 liters) per year, on average, is sufficient to establish a business case for installing infrastructure. For larger scale infrastructure (e.g., infrastructure supporting a school system's bus fleet) converting more vehicles may be required.

Selection of alternative fuels is influenced by infrastructure costs. As with vehicle cost premiums, projected fuel cost savings are considered when developing a business case.

Infrastructure Access

Access to existing alternative fuel infrastructure varies widely across the U.S. This is a barrier to adopting of alternative fuels. Propane sources are the most available as infrastructure has been developed to service the residential market. However, this infrastructure usually requires upgrades to support vehicles. Propane marketers are typically willing to install infrastructure and recoup this investment via contractual terms.

Both electricity and natural gas fueling stations are growing rapidly in the U.S. Growth of electric infrastructure is predominantly supported by electric utilities, although business models to sustain investment are still emerging. Natural gas stations are increasingly being developed by third-party developers using a variety of business models and project delivery methods.

There is no hydrogen fueling infrastructure beyond limited geographic areas, such as California.

CHANGE IN MOTION: CASE STUDIES

Replacing conventional fuels with alternatives offers important benefits. However, implementation faces many barriers. Barriers include availability of fuel, vehicles and infrastructure, upfront investment, regulatory uncertainty, education and awareness. A portfolio of planning, design and program management strategies can help overcome these barriers. The most successful strategies incorporate multi-discipline techniques from fields such as engineering, law and economics. Innovative partnerships and funding mechanisms are also often required.

The following three case studies highlight some of these planning, design and program management techniques, including how partnerships and funding played an important role.

Planning: A Regional Plan for Alternative Fuels and Economic Development

The North Florida Transportation Planning Organization (TPO) recently led an alternative fuels, vehicles, and infrastructure master planning effort for a six county region in northeast Florida. The plan has helped the TPO become a leader in realizing petroleum alternative projects. Alternative fuels, vehicles, and infrastructure are now a major economic development focus in North Florida. A multitude of public and private projects are underway.

As a result of a 2007 task force on air quality, the TPO, which is the regional metropolitan planning organization (MPO) for northeast Florida, began holding stakeholder meetings to explore interest in alternative fuels. Through continued outreach and education, the TPO built a core group of committed stakeholders. In 2010, the TPO established the North Florida Clean Cities Coalition as a non-profit organization to encourage petroleum reduction for business, government and non-profit agencies in the region.

North Florida's coalition is affiliated with the U.S. Clean Cities program. The program supports local actions to reduce petroleum use by 2.5 billion gallons (9.5 billion liters) annually by 2020. Organized by the U.S. Department of Energy (DOE), the program has fostered nearly 100 local coalitions across the United States. Through these partnerships the program promotes alternative fuels, fuel economy improvements and fuel-saving technologies. Clean Cities provides funding, informational resources, technical assistance and other tools to support of these strategies.

The North Florida coalition is somewhat unique among DOE's partnerships, in that it is sponsored by a MPO. Federal mandates require MPOs to develop and administer specific transportation plans and programs. MPOs budget federal and state funds to accomplish these tasks.

Congestion mitigation and air quality (CMAQ) funding administered by the TPO is the coalition's main funding source. It is used for staffing, planning and programming, including investment in petroleum-displacement activities. Funding has been supplemented by other federal, state and local sources, such as Florida Transportation Regional Incentive Program funds.

The TPO's Alternative Fuels, Vehicles and Infrastructure Master Plan [6] was developed to guide programming of federal and state transportation funds.

To complete the plan, the TPO compiled a baseline and forecast of alternative fuels, vehicles, and infrastructure trends. TPO representatives interviewed national and local experts and formed fuel-specific working groups composed of key stakeholders. The process helped identify barriers, strategies and "shovel ready" projects to accelerate adoption of ethanol, biodiesel, hydrogen, natural gas and propane in the six-county region.

The plan inventoried roughly 1,500 alternatively fuel vehicles in the region in 2013. In total, they displaced more than one million gallons (3.8 million liters) of petroleum-based fuels. Future projects, including several developed during the master planning process, are expected to reduce petroleum usage by more than six million gallons (22.7 million liters) by 2019. These projects will improve air quality, reduce greenhouse gas emissions, and reduce fleet expenses.

A key insight derived from the plan is the role alternative fuels will play in economic development. Due to its proximity to three major U.S. interstate highways, three railroads and the Port of Jacksonville, the region served by the coalition is a hub for logistics and transportation industries. Many national and international logistics and transportation companies are based in the area and the industry is supported by local universities.

The plan included working with the Port of Jacksonville to develop a clean truck program for conversion of port-related trucking to more-efficient vehicles that may use alternative fuels. Following development of the plan, the TPO allocated $162,000 to proceed with the program.

In addition to providing support for on-road vehicles, the coalition has fostered interest in the rail and maritime segments of the region's logistics industry.

The plan articulated a vision in which proximity of LNG production to the region's port operations facilitates the use of natural gas transportation technologies with trains and ships. Advantages include lower operating costs, cost-effective compliance with national and international air emissions requirements and access to new markets for fuel exports. These advantages could lead to new industries and employment in the region.

Several rail and maritime projects have been announced in recent years that promise to expand the use of natural gas transportation fuels in northern Florida. The TPO is contributing approximately $375,000 for a pilot project to test four LNG-diesel hybrid locomotives and two tender cars along a 116 mile (187 km) corridor south of Jacksonville. The project is expected to displace approximately 80% of the current operation's diesel use. TPO funding will purchase the equipment required to retrofit one of the locomotives.

In 2013 TOTE, Inc. / Sea Star Line and Crowley Maritime announced plans to operate four to ten LNG-fueled container ships from Jacksonville's port. TOTE, Inc. awarded a contract to a joint venture composed of Pivotal LNG and WesPac Midstream LLC to supply LNG to its ships. The joint venture will construct a natural gas liquefaction plant in Jacksonville that is expected to be operational in mid-2016. TOTE will receive delivery of two marlin-class LNG container ships in late 2015 that will operate between Jacksonville and Puerto Rico.

Eagle LNG Partners, a consortium of Ferus Natural Gas Fuels and General Electric, announced plans in 2013 to develop a LNG liquefaction and storage facility in Jacksonville. The facility will export LNG to Caribbean markets for power generation. It will have a processing capacity of up to 900,000 gallons (3.4 million liters) of LNG per day, with onsite storage of up to eight million gallons (30 million liters). The project is currently in the permitting stage with plans to open in 2018.

By championing alternative fuels—and budgeting federal and state funds—the North Florida TPO has raised the visibility and importance of these fuels to the level of major regional transportation initiatives. Once considered a "feel good" initiative, these solutions are now viewed as integral to the region's transportation system, reaping economic benefits, improving quality of life and protecting the environment.

Design—A Utility Electric Vehicle Program

JEA, the electric, water and sewer utility serving greater Jacksonville, Florida, has designed a comprehensive program to establish electricity as an alternative fuel in its service territory.

Electric vehicles help meet the utility's objectives to provide electricity in an environmentally responsible manner. For motorists, the high fuel economy of electric vehicles results in fuel costs half that of comparable conventional vehicles.

The business case for electric vehicles depends on the degree to which fuel savings from efficiency outweigh higher upfront costs. A barrier to adoption of electric vehicles is limited range. JEA's program has been designed to address the barriers of vehicle cost and "range anxiety."

A rebate incentive provides $500 for electric vehicles with a battery size less than 15 kWh and $1,000 for vehicles with larger battery storage capacities. A joint venture between JEA and the North Florida TPO leverages private partnerships to develop up to 30 electric vehicle charging stations. The utility offers the full cost of a Level 2 electric vehicle charging station, two years of network fees and up to $7,500 towards installation. Incentives are being distributed via a competitive application process aimed at business and institutional owners.

To ensure that the partnerships provide regional electric vehicle charging infrastructure and mitigate range limitations, the competitive selection process was supported by a geographic information system (GIS) analysis. This analysis used publicly available economic, demographic, land use regulatory data and other available information to identify and prioritize workplaces and activity centers where vehicle charging would be needed. Kernal density analysis calculated the frequency of workplaces within a grid established for the region. A similar analysis was conducted for parks, shopping centers, drugstores, restaurants, supermarkets and multi-family housing (activity center category 1) and schools, hospitals, parking facilities, airports, municipal facilities and regional parks (activity center category 2). The analysis located "hot spots" where applications for program support could be prioritized.

The electric utility also works to raise awareness of electric vehicles. Using the template of the DOE's Workplace Charging Challenge, JEA is organizing educational "ride and drive" events at major employers within its service territory.

Program Management: A Public-Private Partnership Model for Infrastructure Development

The Jacksonville Transit Authority (JTA) is transitioning its bus fleet from diesel to CNG. Over a five year period, JTA will add up to 100 CNG transit buses to its fleet, displacing at minimum 40% of its diesel fuel. JTA will save money, reduce pollution and enhance transit services.

In the first phase of the project, JTA worked with technical advisors to define the business case for alternative fuels. It analyzed fuel consumption, fuel economy, bus routes, fueling patterns, and the condition of existing maintenance facilities to identify CNG solutions and estimate their costs and benefits.

The authority held an industry forum in which representatives from JTA, other transit agencies, and participants from the industry exchanged information and lessons learned. Gas suppliers, permitting authorities, fueling station developers and other industry stakeholders were interviewed to define project parameters. JTA leveraged its relationships with other agencies who had implemented alternative fuels projects to identify best management practices.

In the second phase of the project, JTA worked with technical, legal and financial advisors to evaluate project delivery and procurement methods, including traditional design-bid-build, design-build, and design-build-finance-operate-maintain scenarios. Due to the JTA's large annual demand for fuel and the projected difference in diesel and CNG prices, the authority also considered an innovative design-build-lease-concession delivery model. This approach allows transition to CNG with no up-front cost using a long-term fuel purchase agreement with the developer. It also creates the possibility of constructing fueling infrastructure that is accessible to the public and generates royalties from fuel sales. Under some arrangements, this model may also be used to procure vehicles.

JTA's team drafted a request for proposals that included performance specifications for site improvements, construction of a compressor station, and modifications to fueling station dispensers and maintenance buildings. It also included design of a public-access fueling station and procurement of CNG buses. After selection of the developer, the team drafted a contract that set the terms of the fuel purchase, lease of agency property to the developer, concessions for developer operation of infrastructure and royalties from third-party sales of fuel. Construction administration and commissioning techniques are being adopted by JTA and its technical advisors. The goal is to ensure that the developer designs and constructs new infrastructure and facility modifications on time and in a quality manner.

The result will be a landmark enhancement of JTA's transit service. Transitioning JTA's bus fleet to CNG will reduce emissions of nitrogen oxide by up to 20% and volatile organic compound emissions by up to 70%. Over a 5-year period, greenhouse gas emissions will be reduced by about 9,000 metric tons. With no upfront cost, the fully implemented project will save more than $4 million in fuel expenditures.

SUMMARY

Alternative fuels can reduce dependence on foreign sources of oil. They may lead to substantial environmental and health benefits. They can also reduce costs. Awareness of their diversity and an understanding of implementation strategies are keys to realizing their benefits.

Important characteristics that differ among alternative fuels include energy content, unit price, emissions, fuel economy, range, vehicle cost, vehicle availability, infrastructure investment and infrastructure access. Each fuel's characteristics and each fleet's operational considerations determine whether or not an alternative fuel is technically and economically feasible.

Barriers that may prevent the implementation of an alternative fuel project include the availability of fuel, types of vehicles and infrastructure, initial investment costs and regulatory uncertainty. Strategies to overcome these barriers include planning, design, program management and education. The most successful strategies incorporate multidiscipline teams and innovative project delivery methods.

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