Oregon Department of Transportation

U.S. Department of Transportation
Federal Highway Administration

Fact Sheet: Improving Alternative Fuel Access Along Clean Freight Corridors

Currently, planning agencies rely on a patchwork of ad hoc models and methods to determine where best to site alternative fuel stations along corridors. This results in inefficiencies as each agency confronts a similar set of challenges in this geo-spatial problem. This fact sheet looks to alleviate these challenges by providing a clear framework for siting alternative fuel stations along clean freight corridors.

Box 1. Chicken-and-egg problem

The chicken-and-egg problem of alternative fuels acts as a barrier to adoption of new fuels. Vehicles owners are hesitant to purchase alternative fuel vehicles without fuel availability. On the other hand, fuel suppliers are hesitant to install refueling infrastructure without vehicles on the road. Which should come first is the subject of great debate and a potential role for government.

As with any network of refueling stations, planning along clean freight corridors requires a deep understanding of the local vehicle and fuel markets over time, as well as recognition of the chicken-and-egg problem (Box 1). A network of alternative fuel stations that serve freight vehicles differs from one that serves passenger vehicles in the minimum spacing of stations (freight trucks have longer range than passenger vehicles) and the relatively small number of stakeholders (even a single fleet can legitimize the cost of stations along a clean freight corridor).

This fact sheet describes five broad steps corridor planners can take to provide access to alternative fuels along clean freight corridors: (1) define the goal of clean freight corridor, (2) engage with key stakeholders, (3) consider the vehicle range, (4) assess alternative fuel availability in the region, and (5) identify and implement a station siting method.

Define the Goal of the Clean Freight Corridor

Clear articulation of the goal of the clean freight corridor will motivate subsequent planning activities, such as the station siting and station roll-out strategies. Regardless of whether the goal of a corridor is environmental and/or economic in nature, the goal should capture the unique circumstances of the clean corridor and should be chosen through a collaborative process with input from relevant stakeholders.

A major challenge in this goal-setting process is the inherent conflict between *maximizing usage* of the stations and *providing equitable access* to fuel for different geographic regions. On one hand, siting stations in locations with dense vehicle populations will ensure the station utilization rate and cost effectiveness of the stations stay high. On the other hand, focusing the network buildout on a single geographic region will disadvantage other regions along the corridor and can limit the use of the corridor to short haul freight.

To complement this goal-setting, corridor planners need to identify performance metrics related to the goal. Examples include: total alternative fuel consumed per year; estimated greenhouse gas or air quality benefits per year; number of vehicles within a certain number of minutes of travel or miles of an alternative fuel station; or total jobs created per year. These metrics can be used help improve the station buildout over time and allow comparison between different corridors.

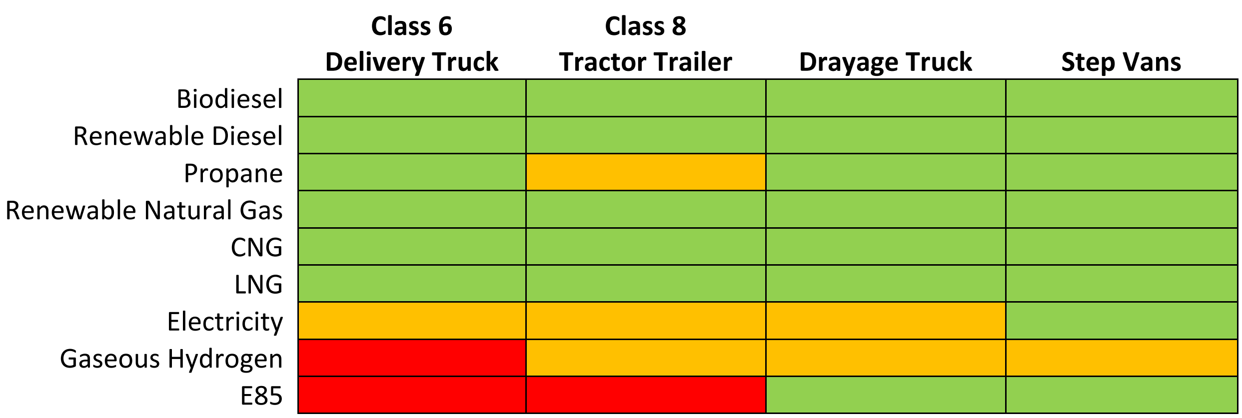
Engage with Key Stakeholders

The next step is to understand the refueling needs of corridor users. Engagement with relevant stakeholder groups, such as trucking associations or fleet managers, will help identify the types of fuels that should be offered along a given corridor and provide information on several relevant questions:

- How quickly will alternative fuel vehicles be integrated into fleets?
- Will fleets use a phased approach to adopting new vehicles?
- Will freight fleets use bi-fuel or dedicated fuel vehicles?
- What are common origin and destinations along the corridor?
- Which types of refueling nozzles and pressures are needed (i.e., compatibility)?

Only certain vehicle-fuel combinations exist in today's market (Figure 1), which limits the alternative fuels to consider. Smaller freight vehicles, like step vans (e.g., UPS trucks), are built to use a wide variety of alternative fuels. Other vehicles like Class 8 tractor trailers are more limited in the diversity of fuel types they can use. Ultimately, stakeholder groups will prefer one fuel over another. Understanding these preferences early in the planning process will help streamline subsequent planning activities.

Figure 1. Availability of alternative fueled freight vehicles



Green = widely available.
Orange = limited availability/demonstrations only.
Red = no availability or prototypes only.
Sources: US Hybrid (2017); CALSTART (2017); US DOE (2017); CARB (2015)

Consider Vehicle Range

Corridor planners also need an understanding about the range and duty cycle of alternative fuel vehicles along their corridor relative to petroleum-based fuels. This information determines the minimum distance between alternative fuel stations and the preferred station rollout strategy. Vehicle range is influenced by both the *quantity of stored energy* onboard and the *efficiency of the vehicle*. Thus, basic understanding about energy density, power density, vehicle efficiency is needed (Box 2).

Liquid fuels, such as liquefied natural gas, biodiesel, and renewable diesel, have comparable energy and power densities as diesel fuel. This means that fuel tanks and range for these vehicles will be similar to the range of diesel vehicles. Although many diesel trucks carry sufficient fuel to drive longer distances between refueling, a distance of 500 miles at road speed limits is representative of a 9 to 10 hour driving shift, at which point it makes sense for the driver to take a break. Thus, 500 miles is a good rule of thumb as the maximum distance between refueling stations needed to ensure sufficient station coverage.

Other fuels entail shorter ranges. The limited volume capacity onboard freight trucks create a barrier for gaseous fuels, which have low volumetric energy and power densities. For example, the volumetric density of gaseous hydrogen is approximately six and a half times lower than diesel (5.6 MJ/liter at 700 bar compared to 35.8 MJ/liter at higher heating value) (NIST, 2015). Even though fuel cell electric vehicles are about 1.7 times more efficient in turning fuel into miles than diesel-powered vehicles (DOE, 2010), the far lower volumetric energy and power density means every available space onboard the truck is needed to achieve range parity (Gangloff et al., 2016). Additionally, unlike liquid fuels, compressed gaseous fuels require cylindrical tanks to store the high-pressure gas, which cannot be easily conformed around other vehicle components. Thus, for hydrogen and other gaseous fuels, the vehicle range is constrained by the *volume* of fuel.

Box 2. Determinants of Vehicle Range

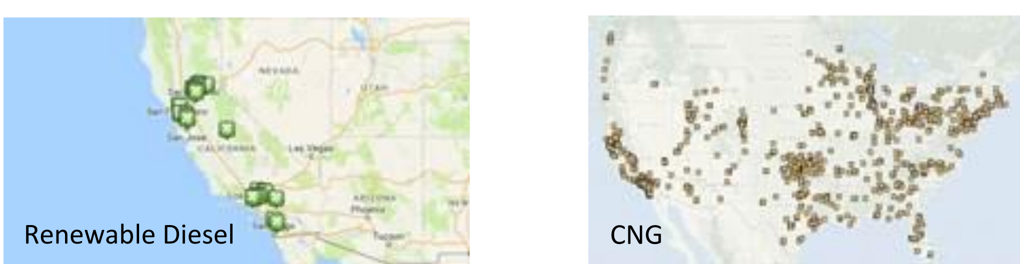
- **Volumetric energy density:** Quantity of energy stored in a fuel per unit volume (e.g., MJ/L).
- **Volumetric power density:** Power output per unit volume (e.g., W/L).
- **Gravimetric energy density:** Quantity of energy stored in a fuel per unit mass (e.g., MJ/kg).
- **Gravimetric power density:** Power output per unit mass (e.g., W/kg).
- **Vehicle efficiency:** the ability of the stored energy to be converted into mechanical energy to turn the wheels of the vehicle (e.g., miles per diesel gallon equivalent).

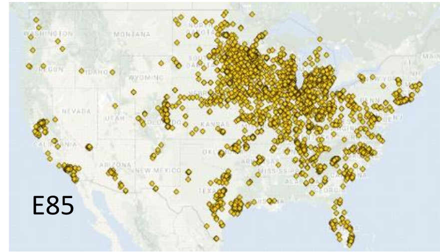
On the other hand, the range of battery electric trucks is typically constrained by the weight of the battery pack – i.e., the gravimetric energy and power densities of batteries relative to diesel fuel (CARB, 2015). As the capacity of the battery pack increases, an ever-greater fraction of that capacity is used to move the mass of the batteries rather than the mass of the vehicle (a phenomenon known as "mass compounding"). Additionally, trucks require high power output to haul freight loads. Large battery packs are needed to produce sufficient power given batteries low volumetric power density.

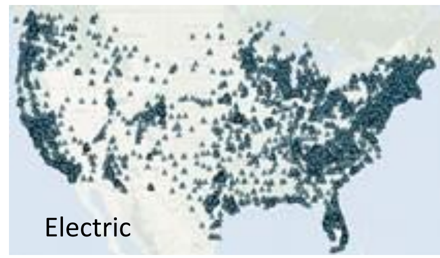
Assess Alternative Fuel Availability in the Region

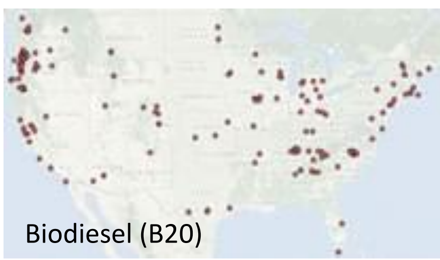
Another critical piece of information needed to conduct alternative fuel station planning is fuel availability. Even if a fleet manager wishes to use a certain fuel type, there is no guarantee that fuel is available in a given region. This requires understanding the location of existing refueling stations and the location of pipelines and supply routes. The U.S. Department of Energy provides a national station locator tool for seven alternative fuels (DOE, 2017). As shown in Figure *2*, most alternative fuel stations are in concentrated pockets of the country. Certain fuels like hydrogen are also quite limited in availability and located primarily in California. Renewable diesel is not listed on the DOE station locator tool, but a station map is available from a fuel supplier (Propel, 2017). At the time of this writing, no data was available on renewable natural gas stations.Figure *1*

Figure 2. Alternative fuel station map for eight alternative fuel types. Click the maps for more information (US DOE, 2017; Propel, 2017)



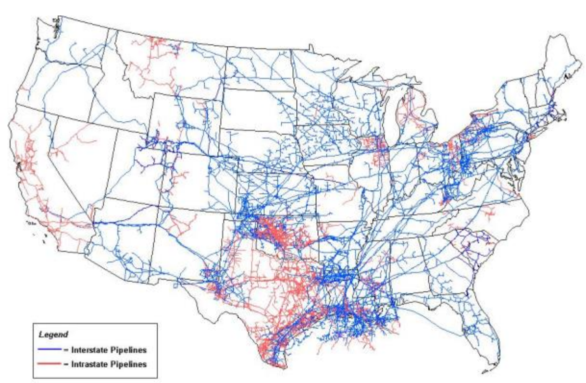






The capacity for fuel suppliers to feasibly supply new infrastructure in a region should also be considered. The natural gas pipeline network in Figure *3* shows that many locations in the U.S. – in particular in the Midwest – have access to CNG fuel supply. On the other hand, fuel supply for fuels like biodiesel could be quite limited in certain regions. New supply chains could be established, but require participation from fuel distributors.

Figure 3. Natural gas pipelines in the United States (EIA, 2017).



Identify and Implement the Station Siting Method

A final step is to identify the optimal configuration of the alternative fuel stations (also known as the "station siting problem"). Research into methods for alternative fuel infrastructure planning has received increasing attention in recent years. These methods have generally been aimed at determining the minimum number of refueling stations or optimizing the location and timing of transportation fueling station deployment (e.g. Kim and Kuby, 2012; Lim and Kuby, 2010; Stephens-Romero et al., 2010; Lin et al., 2008; Dagdougai, 2012).

Models for locating alternative fuel stations for commercial vehicles or for corridors have lagged behind those for passenger vehicles and for urban/suburban environments, perhaps because the first generations of many alternative fuel vehicles (like battery electric vehicles) have been targeted at individual households rather than businesses.

Since vehicles are only able to access refueling stations at interchanges, this limits the total number of possible locations in the station siting problem. Similarly, a road network usually comprises two types of service facilities: (1) single-access facilities which only provides service to traffic on one side of the highway, and (2) dual-access facilities which can serve traffic on both sides. The number and type of each facility further constrains the siting problem.

The simplest approach to station siting is to space the stations at regular intervals along the corridor (Honma and Toriumi, 2014; Melaina, 2003; Nie and Ghamami, 2013). The spacing distance is usually set well below the maximum driving range or even a "safe" driving range to provide a margin of error for closed stations, underfilled tanks, unexpected detours, and alternative fuel vehicles entering and leaving highways between stations.

A number of more complex numerical models include detailed information about the flow of vehicles and characteristics of the travelers. These methods help provide cost savings to the network as a whole. The most common models are described below:

- **Flow-capture model** optimizes the location of a given number of refueling stations within a network with the goal of "capturing" the most flow (e.g., Kuby et al., 2009). Flow is considered captured when a refueling station lies between origin and destination nodes. This model is particularly well-suited to tackle long-distance travel like freight. Kuby and Lim (2005) first applied this model for range-limited vehicles like hydrogen fuel cell or natural gas vehicles.
- **P-median model** minimizes the average population weighted distance from demand nodes to their closest refueling station (e.g., Greene et al., 2008; Nicholas & Ogden, 2006; Up- church & Kuby, 2010).
- **Set covering model** maximizes the number of users of the refueling station located within a given distance of a refueling station (e.g., Wang and Lin, 2009; Frade et al., 2011).
- **Agent-based model** represents the spatial and temporal adoption of alternative fuels by agents (i.e., fleet managers), based on vehicle price, fuel cost, the agent's greenness, social influence, public charging station usage, and charging loads on the grid (e.g., Sweda and Klabjan, 2011). This information can be fed into a geospatial model to estimate travel times to refueling stations as the refueling network is built out.
- **California Hydrogen Infrastructure Tool (CHIT)** is a GIS-based model that allows the the California Air Resources Board to project the potential market for FCEVs where the practical limitations of the auto manufacturer survey cannot provide sufficient data. Full technical details of CHIT will be presented in future public workshops and written documents.

While numerical models like those above are popular in alternative fuel station siting, it is important to note is that the criteria used in the models to site stations differs from the criteria used by FHWA designate the National Alternative Fuel Corridors. In order of priority, FHWA uses the following criteria:

1. Alternative Fuel Facilities
    - Number of, and distance between, existing and planned/projected alternative fuel facilities on the corridor
    - Visibility, convenience, and accessibility to the users on the corridor
    - Past activity/success developing new alternative fuel facilities along the corridor
2. Corridor Scale/Impact
    - Whether the corridor connects to other National Highway System segments, to major metropolitan areas or states, or to major intermodal facilities
3. Emission Reductions
    - Estimated reductions in GHGs or criteria pollutants
4. Development of Team and Degree of Collaboration and Support
    - Degree of collaboration and formation of partnerships regarding alternative fuel vehicles and infrastructure with both public and private sector entities
    - Demonstrated interest and support

Resources for Freight Flows

Many publicly-available data sources will help corridor planners evaluate freight flows and travel behavior along freight corridors.

- **Commodity Flow Survey** (US DOT, 2017). National and state-level data on domestic freight shipments by American establishments in mining, manufacturing, wholesale, auxiliaries, and selected retail and services trade industries. The Commodity Flow Survey began in 1993. The most recent (2012) is here: https://www.rita.dot.gov/bts/sites/rita.dot.gov.bts/files/publications/commodity_flow_survey/index.html

- **Transportation Energy Databook, Chapter 5 (ORNL, 2017).** Designed as a compendium of data on transportation with an emphasis on energy. Designed for use as a desktop reference, the TEDB was first published in 1976 and has continued to Edition 35. http://cta.ornl.gov/data/chapter5.shtml

- **VIUS (US Census, 2002).** The Vius Survey is a nationally-representative survey of approximately 100,000 truck drivers. The survey includes both characteristics of the drivers' vehicles and their travel behavior. https://www.census.gov/svsd/www/vius/products.html

References

- California Air Resources Board (CARB) (2015). Technology assessment: medium- and heavy- duty battery electric trucks and buses. Available at: https://www.arb.ca.gov/msprog/tech/techreport/bev_tech_report.pdf.
- CALSTART (2015) Key Performance Parameters for Drayage Trucks Operating at the Ports of Los Angeles and Long Beach. Available at: http://www.calstart.org/Libraries/I-710_Project/Key_Performance_Parameters_for_Drayage_Trucks_Operating_at_the_Ports_of_Los_Angeles_and_Long_Beach.sflb.ashx.
- Dagdougai, Hanane, 2012. Models, methods and approaches for the planning and design of the future hydrogen supply chain. International Journal of Hydrogen Energy 37 (6), 5318–5327.
- Energy Information Administration (EIA) (2017). U.S. Natural Gas Pipeline Network, 2009. Available at: https://www.eia.gov/pub/oil_gas/natural_gas/analysis_publications/ngpipeline/ngpipelines_map.html.
- Frade, I., Ribeiro, A., Goncalves, G. and Antunes, A.P. (2011) Optimal Location of Charging Stations for Electric Vehicles in a Neighborhood in Lisbon, Portugal. In Transportation Research Record: Journal of the Transportation Research Board, No. 2252: 91-98.
- Gangloff, G., J. Kast, G. Morrison, J. Marcinkoski (2016) Modeling and Analysis of Onboard Hydrogen Storage for Fuel Cell Electric Trucks, Proceedings of the 14th Fuel Cell Science, Engineering, and Technology Conference, # 59337.

- Greene, D. L., Leiby, P. N., James, B., Perez, J., Melendez, M., Milbrandt, A., et al. (2008). Analysis of the transition to hydrogen fuel cell vehicles and the potential hydrogen energy infrastructure requirements, ORNL/TM-2008/3 0
- Honma, Y., & Toriumi, S. (2014). Model analysis of electric vehicle charging infras- tructure development on highways –An approximation of the required scale of electric vehicle charging facilities. Forma, 29, 41–50.
- Kuby, M., et al. (2009). Optimal location strategy for hydrogen refueling stations in Florida. Int' J Hyd. Energy, 34, 6045–6064.
- Kuby, M. J., & Lim, S. (2005). The flow-refueling location problem for alternative-fuel vehicles. Socio-Eco. Planning Sciences, 39, 125–145.
- Lim, S., & Kuby, M. (2010). Heuristic algorithms for siting alternative-fuel stations using the flow-refueling location model. European Journal of Operational Re- search, 204, 51–61.
- Lin, Z., Ogden, J., Fan, Y., & Chen, C. W. (2008). The fuel-travel-back approach to hydrogen station siting. Int' J Hyd. Energy, 33, 3096–3101.
- Melaina, M. W. (2003). Initiating hydrogen infrastructures: Preliminary analysis of a sufficient number of initial hydrogen stations in the US. International Journal of Hydrogen Energy, 28, 743–755.
- National Institute of Standards (NIST) (2015). NIST Chemistry WebBook: NIST Standard Reference Database Number 69. Available at: http://webbook.nist.gov/chemistry/.
- Nicholas, M. A., & Ogden, J. (2006). Detailed analysis of urban station siting for California hydrogen highway network. Transportation Research Record, 1983, 121–128.
- Nie, Y. M., & Ghamami, M. (2013). A corridor-centric approach to planning electric vehicle charging infrastructure. Transportation Research Part B: Methodological, 57, 172–190.
- New York City (2016) Climate Week: Mayor de Blasio Announces NYC Fleet Now Operates More Than 500 Electric Vehicles. Available at: http://www1.nyc.gov/office-of-the-mayor/news/759-16/climate-week-mayor-de-blasio-nyc-fleet-now-operates-more-500-electric-vehicles.
- Propel (2017). Propel refueling stations. Available at: https://propelfuels.com/locations.
- Stephens-Romero, S. D., Brown, T. M., Kang, J. E., Recker, W. W., & Samuelsen, G. S. (2010). Systematic planning to optimize investments in hydrogen infrastructure deployment. Int'l Journal of Hydrogen Energy, 35, 4652–4667.
- Sweda, T., Klabjan, D. An agent-based decision support system for electric vehicle charging infrastructure deployment. In IEEE Vehicle Power and Propulsion Conference (VPPC), pp. 1–5 (2011).
- US Department of Energy (2010) Hydrogen and Fuel Cell Technologies Program: Fuel Cells. Available at: www1.eere.energy.gov/hydrogenandfuelcells/pdfs/doe_h2_fuelcell_factsheet.pdf.
- US Department of Energy (2017). Alternative Fuel and Advanced Vehicle Search. Available at: http://www.afdc.energy.gov/vehicles/search/.
- US DOT (2017). Commodity Flow Survey. https://www.rita.dot.gov/bts/sites/rita.dot.gov.bts/files/publications/commodity_flow_survey/index.html.
- US Hybrid (2017). H2Cargo™ Fuel Cell Plug-In Step Van Specifications. Available at: http://www.ushybrid.com/documents/PDF/2/H2Cargo.pdf.
- Upchurch, C., Kuby, M. J., & Lim, S. (2009). A capacitated model for location of alternative-fuel stations. Geo. Analysis, 41, 85–106.
- Wang, Y., & Lin, C. (2009). Locating road-vehicle refueling stations. Trans. Research Part E: Logistics and Trans. Review, 45, 821–829.