Technical Analysis: Integrating a Hydrogen Energy Station into a Federal Building

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Introduction/Background

Over the past decades, "the hydrogen economy" has been the subject of numerous visionary discussions. The potential benefits of hydrogen a vehicle fuel as well as for stationary power generation with heat cogeneration, and the possible combination with the use of renewable resources have been described. At the same time, most accept that significant challenges remain to realize such a hydrogen economy, especially when considering the transition period to such a hydrogen economy. This paper describes a concept in which transportation and stationary uses of hydrogen are integrated with the aim of reducing cost and market potential.

The Hydrogen-Fueled Vehicle

For transportation applications, a direct hydrogen proton exchange membrane fuel cell provides a number of important advantages over reformate-fed fuel cells with on-board reformers. Operating the fuel cell on pure hydrogen eliminates the cost of the on-board reformer, improves efficiency and reduces heat losses from the stack, and possibly results in higher reliability. A convenient way of providing hydrogen could be distributed production, possibly combined with fuel cell power generation.

The Hydrogen Energy Station

The combined production of fuel cell power and hydrogen at the same facility with the possible coproduction of heat has been referred to as an energy station [1]. This configuration can potentially lead to lower costs for hydrogen production because the equipment used for hydrogen generation serves a dual purpose for both vehicle fueling and power generation applications. More subtle efficiency improvements may also be possible since combined electric power demand from the fuel cell and vehicle hydrogen demand result in better load management for the reformer and fuel cell.

A variety of fuel cell and hydrogen production configurations are possible including a direct hydrogen fuel cell that is fed with hydrogen produced for either vehicle fueling or power generation. For stationary fuel cell applications, the conventional wisdom has long been that systems with an integrated fuel cell and reformer, fueled by natural gas or propane are lower in cost and higher in efficiency than direct hydrogen systems.

In addition to higher fuel cell efficiency and lower fuel cell cost, additional benefits of co-locating hydrogen production with building cogeneration and on-site PEMFC power production may accrue. For example:

- The stationary fuel cell systems would have shorter cold-start times, making them more suitable for peaking power applications.
- The capacity of the reformer and hydrogen storage systems could be optimized, as better load matching would be achievable, and as typical load profiles for the fueling station and for the buildings are often partially complementary.
- Early application may be possible, as the technical risk for the entire system could be considerably reduced, and as it is applicable to fleet as well as retail refueling settings.
- For early retail fueling stations, the combination could diminish the financial burden associated with low hydrogen sales during the first few years of operation, when few hydrogen-fueled vehicles are expected to be on the road.

Hydrogen Fueling Requirements

Building hydrogen energy stations requires further efforts to reduce costs, comply with safety requirements, and develop equipment that is suitable for commercial applications.

Investment and Cost Risk. During a transition to commercial sales of hydrogen fuel cell vehicles, private vehicle customers will expect sufficient fueling station availability to be assured that vehicles can be fueled. In the near term, providing these stations will be more capital intensive per vehicle than for a mature hydrogen economy. In addition, local fueling station costs are higher for hydrogen than for liquid fuels. These costs present significant risks to investors in fueling infrastructure. However, the magnitude of the cost risk varies as well as its nature and who bears it. For example, while a direct-hydrogen fueling option might result in the smallest premium for fuel cell vehicle cost and the least technology risk to vehicle manufacturers, it would likely require significant investments in fuel production and distribution infrastructure. This would expose fuel producers and distributors to considerable market risks with enormous investments. Integrating hydrogen production with power generation ("energy stations") provides potential cost reductions, improved efficiency and reduced risk [1,2].

Safety and Liability. The issues about the reliability and safety of hydrogen fueled vehicles include concerns about the requirements for the storage of flammable gases, especially related to leaking vehicles in covered spaces. Local fire officials need to become familiar with hydrogen vehicle requirements.

R&D Priorities. Finally, the R&D priorities for hydrogen fueling stations will depend considerably on the choice of fueling station technologies. Considering the large investments in R&D that are required for a change of this magnitude, it would be inefficient, if not impossible, to develop all fueling system options to the required end state and then make a choice. Rather, the industry and government will have to bundle its resources. As the technology moves to market this becomes even more important, as stakeholders will be extremely unwilling to make the enormous investments if they are not sure whether the option they are investing in will be the winner.

Analysis Needed for Advancement of Hydrogen Technologies

The Hydrogen Future Act of 1996 directed the U.S. Department of Energy (DOE) to conduct a research, development, and demonstration (RD&D) program that would lead to the development of a hydrogen fuel infrastructure. The purpose of this technical analysis is to analyze the development of a hydrogen infrastructure for transportation applications through the installation of 50-75 kW stationary fuel cell modules in federal buildings. The various scenarios, costs, designs and impacts of such fuel cells are quantified in a cost-shared program that utilizes a natural gas reformer to provide hydrogen fuel for both the stack(s) and a limited number of fuel cell powered vehicles.

In addition to analyzing technical feasibility, commercialization and cost issues of this fuel cell system, the use of the stationary fuel cells' electricity and cogenerative heat in federal buildings are also evaluated. As part of the project's goal to explore the different ways by which industry can be assisted to plan a hydrogen infrastructure, the opportunities and possibilities of private/public partnerships are also explored. Further, an assessment is made of the location and size of the public and private fleet vehicles that could utilize this type of hydrogen infrastructure, as well as the cost associated with the infrastructure's development. Such assessment includes the amount of this cost that would have to be provided by the federal government.

In sum, this project assesses the comparative costs as well as the technical and commercial feasibility of the diverse scenarios through which a hydrogen vehicle fueling infrastructure could be developed in conjunction with the efficient use of stationary fuel cells for electricity and cogenerative heat in federal buildings.

Study Approach

The project includes the analysis of energy station configurations combined with identifying hydrogen vehicle operators and the integration of the energy station with buildings.

Task 1 — Analyze System Cost and Performance. The first task conducted in this project is to evaluate all of the competing technologies that could be utilized for each of the components in the entire fuel cell and vehicle fueling system based on the criteria of cost, performance, and technical feasibility. The goal of this initial, broad based assessment is to select the most promising (four to five) system designs and technologies on the basis of the above criteria. The subsystems, components, and issues analyzed in Task 1 include the following: reformer technologies; hydrogen purification technologies; fuel cell hydrogen utilization; reformer sizing options; hydrogen storage and compression; and vehicle fleet size and fueling needs.

Task 2 — Assess Public/Private Fleet Size/Locations. Data on the potential for energy stations with fleets is being collected from a representative and diverse composition of stakeholders. We are coordinating with automakers to obtain information about fuel cell vehicle fleet size, location and type projections. Another key source of information for projecting hydrogen vehicle fleet size and location are the EPAct fleet administrators, who will help us determine their current and projected AFV fleet practices. Finally, other polices, such as the California Zero-Emission

Vehicle (ZEV) Mandate and the ARB transit fleet regulation, that will either directly or indirectly encourage hydrogen fleets, are being analyzed for their potential impacts.

Task 3 — Evaluate Building Integration. Using the results of Task 1 and a limited number of system designs and technologies selected for further analysis, the likely amounts and grades of waste heat that will be produced from the reformer and stack(s) have been determined. With this information, cogenerative heat uses and technologies are being researched and evaluated with respect to beneficial utilization or possibilities in a commercial/ government building setting, as well as the cost and technical feasibility of those applications.

Proposed Work. Upon completion of the above tasks, TIAX will propose to continue the analysis and identification of energy station applications in Federal buildings. The tasks under this second phase include exploring specific public and private partnerships to support the establishment of a hydrogen energy station in a Federal facility. Also, under this second phase, TIAX will analyze the cost, emissions, and energy utilization benefits of integrated power and fueling, identify the key technology, cost, and public perception barriers to hydrogen use, and make recommendations for future development.

Analysis of System Cost and Performance (Task 1)

A hydrogen-producing energy station would use an input fuel such as natural gas – although other input fuels are possible – reforming the fuel to produce a feedstock for fuel cell operation. The reformer output would also be purified, with the resultant hydrogen being stored for dispensing into hydrogen-fueled vehicles. The electrical power generated by the fuel cell and/or the residual heat from the system processes may be used to support energy station and nearby building power and heat loads. Figure 1 shows the various major components that make up a hydrogen energy station.

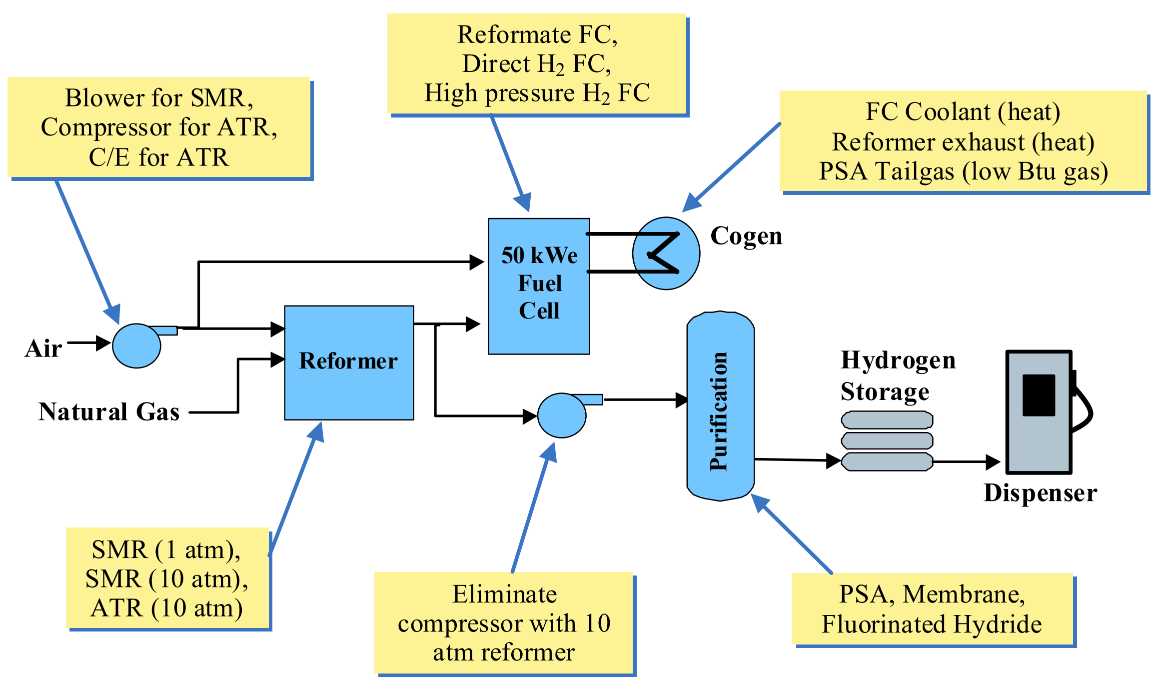

Figure 1. Several Technology Options Exist for System Configuration

In order to determine which system configurations and operational patterns are most viable for an energy station, TIAX developed several criteria for selecting a representative set of technology configurations. TIAX applied these criteria to all possible technology configurations to determine an optimized set, as shown graphically in Figure 2. The remaining cases best illustrate the range of viable energy station configurations and operational profiles.

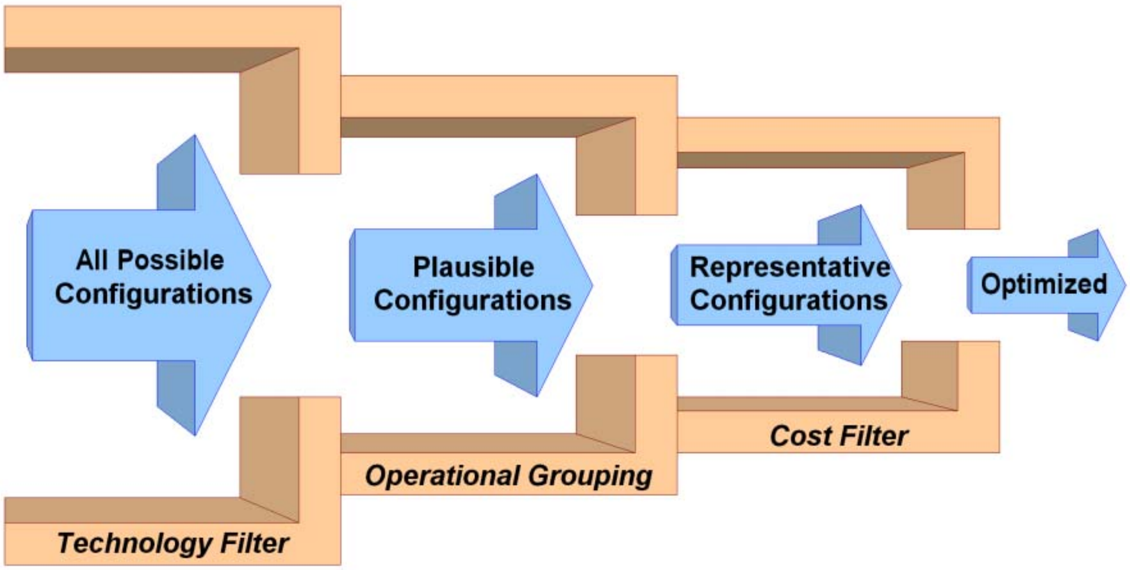

Figure 2. Application of Filters to Determine Optimal Configurations for Analysis

As shown in Figure 2, TIAX started with a list of possible alternatives for each major component of the system and generated a matrix of possible combinations of these components. In order to simplify the analysis of different system configurations (as the number of possible combinations reached over 300), TIAX identified a baseline scenario comprised of the component options that are most commonly used in reformer systems, most readily available commercially, and/or simplest to implement. Three additional representative scenarios were selected that differ from the baseline scenario in both the selection of components and potential operating advantages of the systems. These preliminary configurations, along with the baseline case, will be used to develop a representative cost and energy output estimate for the energy station (see Table 1).

Table 1. Representative Energy Station System Component Configurations

System Attributes	**Major Components**
Conventional system	Air Blower, SMR, PrOx, Reformate Fuel Cell, PSA
Lower cost fuel cell	Air Blower, SMR, PSA, Direct Hydrogen Fuel Cell
Small scale purificaiton	Compressor/expander, ATR, PrOx, Reformate Fuel Cell, Fuorinated Metal Hydride Purification
Simple cogeneration	Air Compressor, ATR PSA, Direct Hydrogen Fuel Cell

Review of Operational Scenarios

Both fuel cell power generation and vehicle fueling can result in a variety of load requirements for an energy station. The possible scenarios within each operation category (*i.e.*, fuel cell operation, reformer operation) are described below in terms of fuel cell requirements. Hydrogen vehicle fueling requirements combined with hydrogen storage and fuel cell operation will affect capacity requirements and operation of the reformer.

Evaluation of Different Fuel Cell Power Utilization Options.

The fuel cell power utilization options include peak shaving, constant baseload, scheduled operation, on demand operation, and/or load following. These options are not necessarily exclusive – in some cases they may be used in combination.

Peak shaving. Under this scenario, the power to be produced by the fuel cell during peak load hours (late morning through afternoon) will offset part of the building power load. Peak shaving lowers the amount of electricity taken from the utility power grid during peak load hours, when electricity rates are most expensive. The FC always will support the energy station power load, which may fluctuate depending upon the level of refueling activity and hydrogen generation/storage. Under the peak shaving scenario, the fuel cell would be operated in one of the following modes:

- Constant fuel cell power output during peak hours, providing a fixed electrical power level to the building and energy station, combined. Since the FC output is fixed under this mode, when the energy station demand rises temporarily–such as during vehicle refueling–this would lead to a corresponding drop in the power level delivered to the building.

- Variable fuel cell power output during peak hours, providing constant power to the building and following the station electrical demand. Should the energy station demand fluctuate, the fuel cell could follow the change in demand so as to leave the power supply to the building constant. The power provided to the building should be selected such that the combined building power and station power demand does not exceed the power capacity of the FC. If such a provision is too limiting with respect to desired building power supply, the station could be designed to curtail certain functions during peak shaving when combined station and building power demand reach the maximum FC power capacity.

- Variable fuel cell power output during peak hours, following the combined building and station electrical load up to the capacity of the fuel cell. Under this mode, the fuel cell would need to be sized to accommodate the anticipated range of power demand. Otherwise, a power management algorithm would be needed to determine when to curtail energy station operation and/or reduce power supply to the building should the FC reach its maximum power output.

Constant baseline load. Under this scenario, the fuel cell runs continuously at a constant rate to support a "baseline" load—a level at or below the minimum building power demand–in one of the following modes:

- Constant FC power level below the minimum power requirement for the building, providing power for both the energy station and the building. If energy station power demand temporarily rises, the power delivered to the building drops proportionally to keep the FC power delivery constant.

- Constant building power, variable FC power would allow the FC to follow the energy station load.

Scheduled use. Under this scenario, the fuel cell would be operated certain fixed hours during the day. This scenario the same operational modes as the peak shaving scenario, except that the operational period could include off-peak hours.

On demand. Under this scenario, the fuel cell is operated when needed by the energy station, and is not used during other times. The fuel cell may provide power to the building while providing power to the energy station, but never provides power to the building exclusively.

Evaluation of Reformer Sizing Options.

The reformer sizing and operational options include peak shaving, constant baseload, scheduled operation, and/or load following. Again, these options are not necessarily exclusive and may be used in combination with other operational modes.

Constant reformer operation. Under this scenario, the reformer is operated at a constant load, providing hydrogen for the fuel cell (FC) use when in operation, and generating hydrogen for storage when the fuel cell hydrogen demand drops below reformer hydrogen output (see Figure 3). Vehicles would be filled using stored hydrogen. Under the constant operation scenario, the reformer would be operated in one of the following modes:

- Matched to the maximum hydrogen demand anticipated from the fuel cell, generating excess hydrogen for storage when the FC is not operating at maximum load. If a vehicle refuels while the FC and the reformer are operating at maximum load, vehicle hydrogen will be supplied from storage.

- Under-powered with respect to maximum FC hydrogen demand, requiring the FC to draw from stored hydrogen when demand exceeds reformer output. When FC load is lower than reformer output, the excess hydrogen is stored.

On-demand reformer operation. Under this scenario, the reformer is operated when hydrogen is needed for the fuel cell and/or vehicle refueling. When hydrogen is not needed by either system, the reformer shuts off. Under the on-demand operation scenario, the reformer would be operated in one of the following modes:

- Reformer follows the demand for the total system. The reformer would be sized to handle the maximum combined demand from the FC and vehicle refueling system. Minimal hydrogen storage requirements–just enough to support FC/refueling during reformer warm-up period.

- Reformer follows the demand from the fuel cell. Reformer is sized to meet the maximum hydrogen demand from the FC. In order to generate sufficient hydrogen for future vehicle refueling and to supplement the reformer output during the next start-up period, the reformer would generate excess hydrogen when in operation and/or continue to operate after the FC shuts off. The reformer would generate enough hydrogen to fill the hydrogen storage system, then shut off. Would operate in absence of FC demand if hydrogen storage drops below specified threshold.

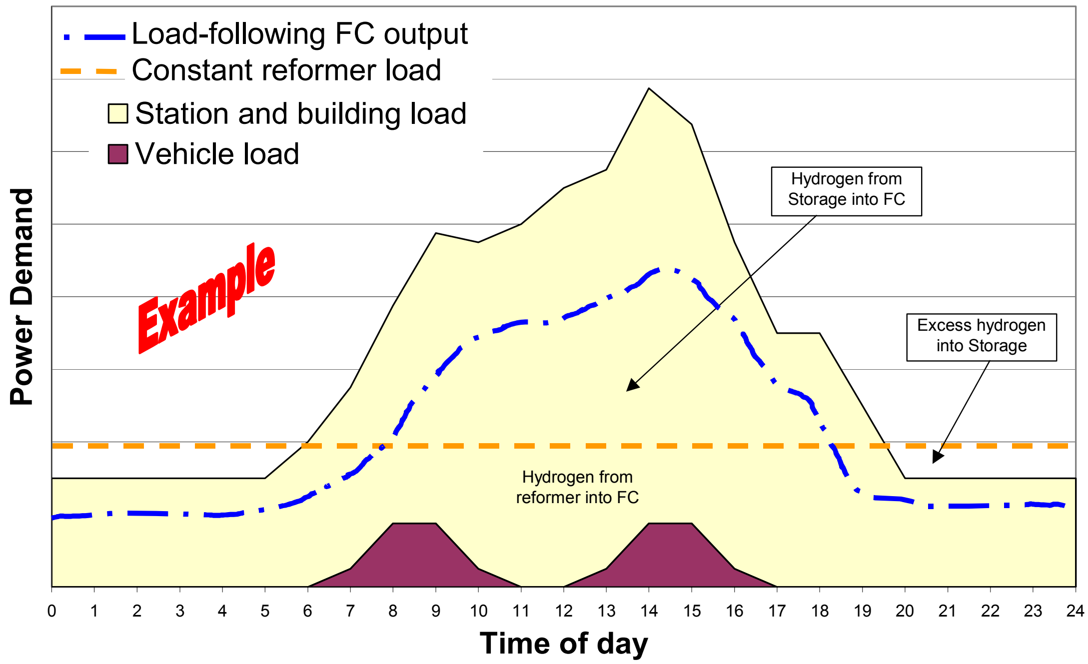

Figure 3. Example Fuel Cell and Reformer System Operation Scenarios

- Reformer follows the demand from the fuel cell. Reformer is sized under the maximum FC hydrogen demand level. Hydrogen demand above reformer capacity is met using stored hydrogen.

Combined baseload and load-following operation. Under this scenario, the reformer is operated at a constant load, just over what is required to support the FC during minimum electrical demand, and storing excess hydrogen. Under the combined baseload and load-following scenario, the reformer would be operated in one of the following modes:

- During peak electrical demand, the reformer increases its hydrogen production to match the increased demand from the FC. In this case, vehicle refueling is supported by stored hydrogen from off-peak excess production.

- Vehicle fueling hydrogen demand is matched by the reformer, if needed. In this case, the FC would run off stored hydrogen from off-peak excess.

- Vehicle fueling hydrogen demand and FC demand are matched by the reformer.

The reformer also could be operated at a constant load lower than what is required to support FC operation during minimum electrical demand. In this case, no excess hydrogen is generated, although part of the hydrogen production stream can be deliberately diverted to storage, if desired.

Timed operation. Under this scenario, the reformer is operated during specific hours of the day. The reformer could be operated at a pre-set time duration and load, generating hydrogen for immediate use and/or storage. Under the timed operation scenario, the reformer would be operated in one of the following modes:

- During peak electrical demand, the reformer operates at a specific load to generate enough hydrogen for the FC to offset desired grid power usage. Part of the hydrogen is diverted for storage to accommodate refueling vehicles.
- During peak electrical demand, the reformer operates to follow FC hydrogen demand. Part of the hydrogen is diverted for storage to accommodate refueling vehicles.
- During specific off-peak hours, reformer generates sufficient hydrogen to support on-peak FC operation and refueling demand. All hydrogen is stored for on-peak use.
- During specific off-peak hours, reformer generates sufficient hydrogen to support baseline off-peak FC load and create stored reserve for on-peak FC operation and refueling.
- A combination of the above on-peak and off-peak operational modes.

Evaluation of Hydrogen Storage and Compression Options

High-capacity storage. This option is appropriate for scenarios where the fuel cell often will operate at loads that require a higher hydrogen feed rate than the hydrogen feed rate produced by the reformer. This option would also allow for greater fluctuation in instantaneous hydrogen demand, as well as allow for demand growth over time from the station, the building, or the hydrogen vehicle fleet served by the station.

Low-capacity storage. This option is appropriate for scenarios where the fuel cell most often operates at loads where the fuel cell hydrogen demand is about equal or lower than the reformer hydrogen production rate. Excess hydrogen is stored in anticipation of small fluctuations in hydrogen demand. This approach is appropriate if the total hydrogen demand from the fuel cell and serviced hydrogen vehicles is fixed or well controlled.

High-pressure Storage (5kpsi). This option offers greater storage system capacity on a volume basis due increased hydrogen density. It also reduces required storage space for a given mass of hydrogen. However, a higher pressure system will require a more powerful compressor.

Single pressure storage. This option would be appropriate for all configurations. It does not involve staging, and would occur at the highest pressure required to accommodate all systems.

Multi-stage storage. This option would be appropriate for reformer systems producing hydrogen moderate pressure that can utilize moderate and high-pressure hydrogen. Having two levels of storage would allow one reserve to be filled quickly at moderate pressure – potentially without the need for a compressor – while the remaining storage would be filled using a high-pressure compressor. This would allow depleted reserves to be regenerated more quickly and reduce the capacity requirements for high-pressure storage.

Assessment of Public and Private Fleet Size and Locations (Task 2)

In its effort to identify candidate federal facilities for the placement of a hydrogen fueling station, TIAX worked with its subcontractor, Bevilacqua-Knight, Inc. (BKI), to create a list of characteristics that the ideal location should possess. These characteristics, shown in Figure 4, formed the criteria by which the facilities would be judged. The process for choosing facilities that would most likely benefit from an energy station involves interviewing the fleet and energy managers to determine whether the facility meets the criteria.

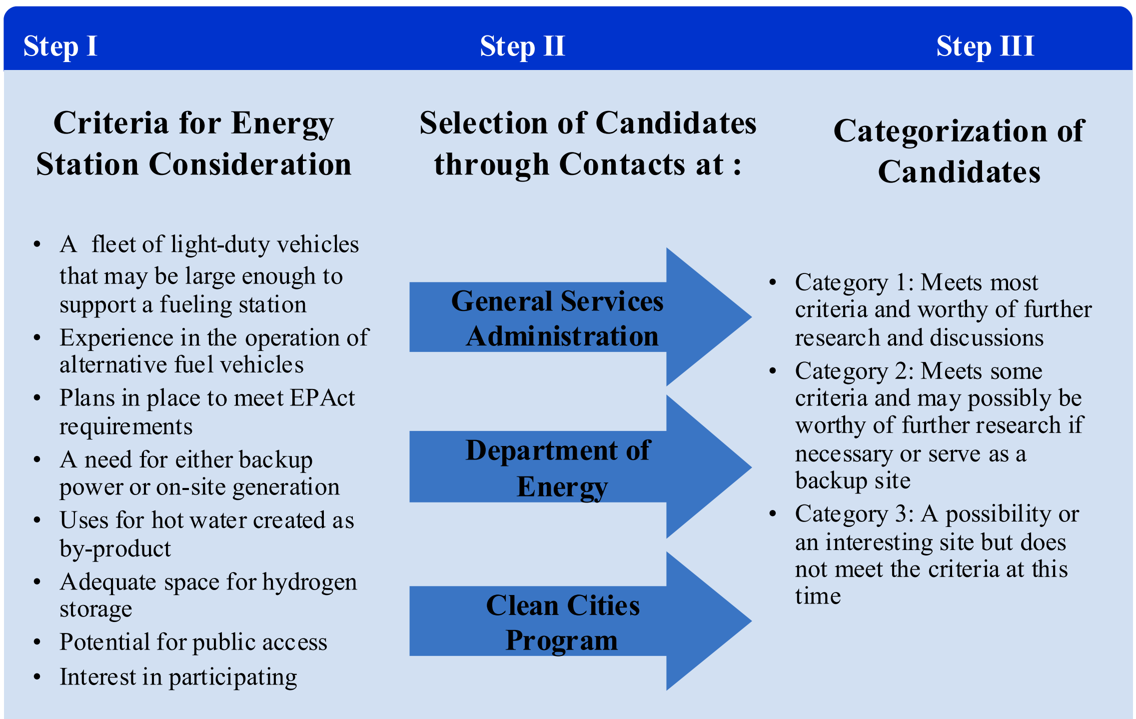

Figure 4. The Process for Choosing Facilities that Would Most Likely Benefit from an Energy Station

Initial contacts were made with local representatives of the General Services Administration (GSA) and the U.S. Department of Energy (DOE). GSA is responsible for acquiring cars for most federal government agencies that in turn lease the vehicles from GSA. GSA provided contact information for representatives from numerous agencies and BKI culled that list for agencies that have separate and distinct facilities in California. In addition, GSA invited a BKI representative to make a presentation about the project to their Northern California AFV User Group. TIAX chose to initially focus on California as a test bed for interest in energy stations since it is a discrete area that is host to many types of federal facilities. Nevertheless, the methodology followed here could be used for any region in the United States.
DOE provided contact information for the National Laboratory facilities in California along with updates about EPAct compliance.

A third source of contact information was the Clean Cities Coordinators throughout California. Clean Cities is a program sponsored by DOE that works to advance AFV use in public and private fleets. Each metropolitan area has at least one Clean Cities Coalition. The Coalition Coordinators were asked to provide contact information for members who represented federal facilities.

For each federal agency contacted, BKI attempted to speak with both the fleet manager and the facility's energy manager. Fleet managers were asked about their existing vehicle fleet, experience with AFVs and plans for future acquisitions. TIAX was particularly interested in facilities that currently operate compressed natural gas (CNG) vehicles since CNG is a gaseous fuel with many of the same properties as hydrogen. In addition, each agency was asked about how their vehicles were acquired. Lastly, TIAX asked how the facility planned to meet future EPAct requirements.

BKI stressed to each interviewee that the proposed hydrogen station would serve multiple purposes and that the facility's energy management practices and environment would be nearly as important as its fleet. Therefore, energy managers were asked about the facility's energy purchasing/generating plans, needs for backup power, and any details about future power needs. TIAX also asked about the facility's use of natural gas and the locations of any distribution and transmission lines. Each facility was categorized in one of three groups, as shown in Figure 4.

As of the date of this draft, at a minimum, all of the questions about the criteria listed in Figure 4 have been discussed with all of the candidate facilities. In some cases, additional information has been requested from the facility. In several other cases, the facility is in the process of obtaining permissions to proceed or to provide greater details from agency headquarters.

The one "wild card" in this investigation is the United States Post Office (USPS). The USPS is by far the largest purchaser of vehicles among federal agencies. They have facilities in all metropolitan areas in California. The USPS also has experience operating alternative fuel vehicles in California and is enthusiastic about introducing more AFVs into their fleet. However, the Western Region of the USPS does not have final authority over fleet purchases and USPS headquarters in Washington, DC has yet to respond to our inquiries. The Western Region is cooperating in our project and has suggested several potential locations. These suggestions are not binding, however, and are listed for informational purposes only. When responses are received from USPS headquarters, further investigations as to the specific sites will be made. The USPS sites are listed separately.

The final point to be mentioned concerning federal facilities is security. In light of recent events, both military and civilian facilities have severely limited access. This affects the potential for designating a hydrogen facility as public access. TIAX is currently investigating the potential for locating fueling facilities along a fence-line and placing dispensers along both sides of the fence. Due to this factor, TIAX has downgraded the public fueling criteria for this initial summary.

Summary of Fleet Opportunities

After conducting initial interviews and collecting facility information using the criteria listed in Figure 4 the information was categorized. As mentioned earlier, the USPS facilities are listed separately. The five USPS facilities were identified due to their geographic location and their previous experience with alternative fuel vehicles (especially compressed natural gas). Again, the list of USPS facilities may change when their headquarters provides input.

Category 1

- U.S. Navy Public Works Center – San Diego
- Lawrence Berkeley National Laboratory – Berkeley
- NASA Ames Research Center – Mountain View
- U.S. National Park Service, Presidio – San Francisco
- U.S. Marine Recruiting Center – San Diego
- Edwards Air Force Base – Mojave
- Port Hueneme Air Force Facility– Oxnard

Category 2

- Point Mugu Naval Base – Ventura
- Lawrence Livermore National Laboratory – Livermore
- Yosemite National Park
- Veteran's Administration – Los Angeles
- Camp Pendleton - Oceanside

Category 3

- Vandenburg Air Force Base – Lompoc
- Jet Propulsion Laboratory – Pasadena
- Lemoore Naval Air Station – Lemoore

U.S. Postal Service Facilities

- Sacramento
- Huntington Beach
- Long Beach
- Stockton
- Irvine

Evaluation of Building Integration (Task 3)

In order to take advantage of potential cogenerative heat uses and technologies, the likely amounts and grades of waste heat that will be produced from the reformer and stack(s) will need to be determined. Using the representative technology configurations above, the opportunities for cogeneration are currently being examined. We are evaluating the potential cogeneration heat requirements in terms of heat load and seasonal variations as well as the hardware requirements required to integrate an energy station into a building.

Conclusions

This project has identified a set of representative technologies and representative operational scenarios that are being analyzed to estimate the size, power output, and cost of a hydrogen energy station. Ultimately, the goal of this project is to identify a Federal facility that could host a hydrogen-producing energy station and make use of residual heat through cogeneration, electrical output from a fuel cell, and provide fueling for on-site or nearby hydrogen vehicles. Several options have been identified for system configuration and operation, with each focusing on a different benefit: conventional system components, lower cost, small-scale operation, and design simplicity. Several Federal facilities have been identified as potential host sites, meeting most of the energy station host criteria developed as a part of this project. Energy and cost estimates will be presented in the final report of this project.

References

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2. Thijssen, J., et al., "Guidance for Transportation Technologies: Fuel Choice for Fuel Cell Vehicles," Phase II Final Report to DOE, Prepared by Arthur D. Little, Inc (Tiax), February 2002.