IX.9 Tri-Generation Fuel Cell Technologies for Location-Specific Applications

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Project End Date: March 31, 2015 (Final Report in Progress)

Overall Objectives

- Assess potential number and location of tri-generation (Tri-Gen) fuel cell systems, producing electricity, high quality waste heat, and hydrogen, in an early fuel cell electric vehicle (FCEV) market scenario (circa 2015) in New York, New Jersey, Connecticut, and Massachusetts
  - Consider use of natural gas and anaerobic digester gas as feedstock
  - Consider viability of the Tri-Gen units serving as a local hub for hydrogen production

Fiscal Year (FY) 2015 Objectives

- Conduct sensitivity studies:
  - Assess the effect that vehicle sales data selection/market distribution has on the resulting necessary tri-generation and/or hydrogen refueling infrastructure. Spanning scenarios:
    - Temporal deployment of fuel cell electric vehicles (e.g., 10,000–50,000+ FCEVs)
    - Spatial deployment of hydrogen refueling stations (e.g., 108, 313, and 774 to cover the top 25%, top 50%, and top 75% of the alternative vehicle sales market based on zip codes)
    - Varied drive time service coverage (e.g., 6, 10, and 15 minutes)
- Complete the identification of candidate Tri-Gen sites using anaerobic digester gas from wastewater treatment plants as a feedstock and operating as either: (1) a hydrogen refueling station dispensing the hydrogen produced, or (2) central hub of hydrogen production
- Complete the identification of candidate Tri-Gen sites using conventional natural gas as a feedstock and operating as either: (1) a hydrogen refueling station dispensing the hydrogen produced, or (2) a central hub of hydrogen production
- Estimate the hydrogen, electricity, and heat production from the aforementioned identified Tri-Gen sites
- Conduct an economic analysis to compare cost of hydrogen across the different scenarios
- Assess the greenhouse gas (GHG) and oxides of nitrogen (NO_X) emissions from the Tri-Gen systems

Technical Barriers

This project addresses the following technical barriers from the Systems Analysis section of the Fuel Cell Technologies Office Multi-Year Research, Development and Demonstration Plan (MYRDDP):

(A) Future Market Behavior

(B) Stove-piped/Siloed Analytical Capability

(E) Unplanned Studies and Analysis

This project will contribute to achievement of the following DOE milestones from the Systems Analysis section of the MYRDDP:

- Milestone 1.9: Complete analysis and studies of resource/feedstock, production/delivery, and existing infrastructure for technology readiness. (4Q, 2014)
- Milestone 1.12: Complete an analysis of the hydrogen infrastructure and technical target progress for technology readiness. (4Q, 2015)
- Milestone 1.13: Complete environmental analysis of the technology environmental impacts for hydrogen and fuel cell scenarios and technology readiness. (4Q, 2015)

FY 2015 Accomplishments

- Completed economic analysis for Tri-Gen system sited at the largest wastewater treatment plants (WWTPs) and supplying hydrogen to an on-site hydrogen dispenser
- Completed economic analysis for Tri-Gen system sited at the largest WWTPs, acting as a central hub of hydrogen

production, and supplying hydrogen to various roll outs of hydrogen refueling stations

- Completed economic analysis for Tri-Gen system operating on conventional natural gas and supplying hydrogen to an on-site hydrogen dispenser
- Completed economic analysis for Tri-Gen system operating on conventional natural gas, acting as a central hub of hydrogen production, and supplying hydrogen to various roll outs of hydrogen refueling stations

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INTRODUCTION

Zero-emission FCEVs are one of the pieces in a portfolio of solutions for the transportation sector to reduce its GHG emissions and lower its negative impacts on air quality. With gaseous hydrogen fuel combined with the oxygen in the air, electricity is generated in the fuel cell to power the vehicle, and the vehicle emits nothing but water in the process. Even though it has zero-emissions at the tailpipe, for the vehicle to truly be zero-emissions, every effort must be made to reduce and minimize the GHGs emitted during the production of the hydrogen fuel.

Tri-Gen fuel cell systems are a distributed generation technology with the capability of producing the three useful products of electricity, high quality waste heat, and hydrogen that could be used to refuel FCEVs. The northeastern United States is currently being touted as the next stationary and mobile fuel cell market after California. As such, this research effort recognizes and capitalizes on the opportunity to strategically site Tri-Gen fuel cell systems while the hydrogen refueling infrastructure in the Northeast is burgeoning.

APPROACH

As a first step, the Spatial and Temporally Resolved Energy and Environment Tool (STREET), in conjunction with geographic information systems, was employed to plan out the location and number of hydrogen refueling stations needed in the aforementioned region based on alternative vehicle sales registration data (STREET was the tool used to plan out the roadmap of hydrogen refueling stations for California). Subsequently, various scenarios of Tri-Gen fuel cell deployments to provide hydrogen to the theoretical hydrogen refueling stations will be assessed with the goal being to minimize delivery distances. Since the number of potential fuel cell vehicles can be estimated and which fuel cell systems are supplying hydrogen to given stations is known, the appropriate size and corresponding economics of the Tri-Gen fuel cell systems can be determined. Any viable site with access to the natural gas pipeline (e.g. the Northeast Interstate/Intrastate natural gas pipeline) will be treated as a candidate for the installation of a Tri-Gen system, and water treatment facilities will serve as the candidate locations for Tri-Gen fuel cell system operating on renewable anaerobic digester gas.

RESULTS

Using alternative vehicles sales registration data as an input, this study estimates that approximately 108, 313, and 774 hydrogen refueling stations would be needed to serve and enable the top 25%, top 50%, and top 75% of the alternative vehicles market, respectively, in the states of New York, New Jersey, Connecticut, and Massachusetts taken as a whole (Figure 1).

In assessing how and where Tri-Gen fuel cell systems producing high quality waste heat, electricity, and hydrogen could support this network, a total of four scenarios were investigated:

- Tri-Gen system supplying an on-site hydrogen dispenser; anaerobic digester gas feedstock
- Tri-Gen system acting as a central hub of hydrogen production supplying nearby hydrogen stations with hydrogen; anaerobic digester gas feedstock
- Tri-Gen system supplying an on-site hydrogen dispenser; natural gas feedstock
- Tri-Gen system acting as a central hub of hydrogen production supplying nearby hydrogen stations with hydrogen; natural gas feedstock.

The location of water treatment facilities (WTF) in the aforementioned states was ascertained from the EPA Enforcement and Compliance History Online (ECHO) database. The 25 largest water treatment facilities in those four states were chosen as candidates for the installation of a Tri-Gen fuel cell system supplying an on-site hydrogen dispenser. The smallest of these 25 can support a Tri-Gen system approximately 1.8 MW in size based on potential biogas supply. Therefore, treatment plants smaller than this size will become less viable for the installation of a Tri-Gen system.

The potential hydrogen demand from FCEVs at WTFs varies widely from site to site. For example, some WTFs may be large in size, but too far away from potential vehicles. To ascertain the potential number of FCEVs within proximity of the top 25 WTFs, the dataset of ~95,000 alternative vehicles were treated as proxy FCEVs and the number of those proxy FCEVs within 6, 10, and 15 minutes of the WTFs were counted. The results are presented in Table 1. One important realization is whether a stakeholder defines his/her market based on the number of FCEVs within 6, 10, or 15 minutes greatly affects what size Tri-Gen system they may want to install and, subsequently, what price of hydrogen they can deliver.

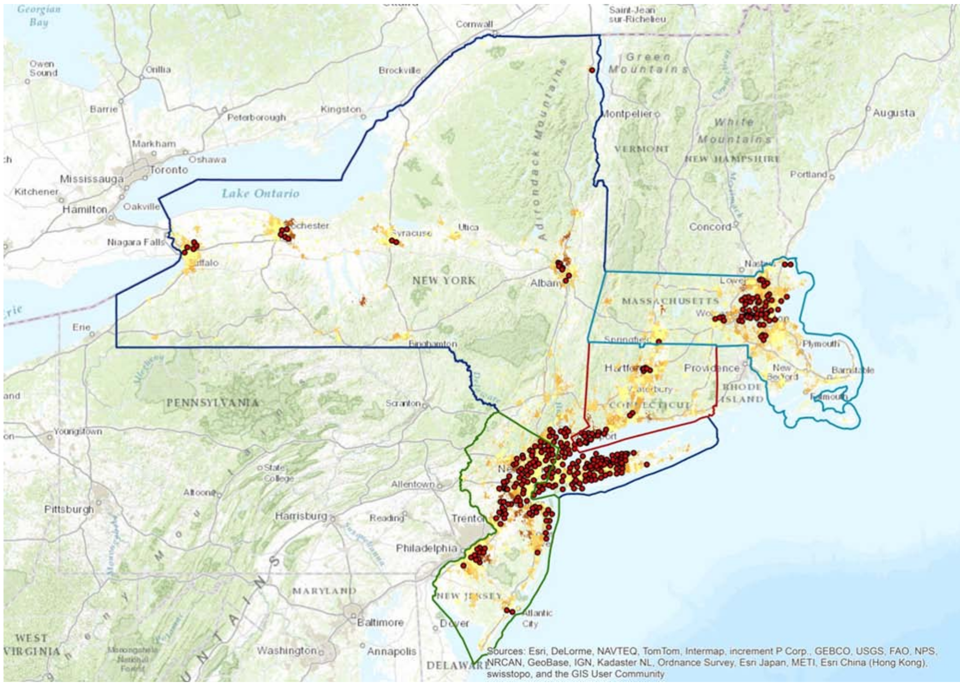


FIGURE 1. Three hundred thirteen stations would be needed to ensure 6 min service coverage to a hydrogen refueling station for the top 50% of zip codes based on alternative vehicle sales registration data. Source: Manliclic et al. [1].

TABLE 1. The top 25 water treatment facilities in terms of millions of gallons per day (MGD) influent size. The number of alternative vehicles (out of the 95,048 total in the alternative vehicle sales registration dataset) within 6 minutes, 10 minutes, and 15 minutes is shown. Source: EPA ECHO

Name	City	State	Rated MGD	6 minutes	10 minutes	15 minutes
MWRA DEER ISLAND TREATMENT PLANT	BOSTON	MA	480	0	31	82
BOSTON WATER AND SEWER COMM, CSO	BOSTON	MA	330	585	2013	4616
PASSAIC VALLEY SEWERAGE COMM	NEWARK	NJ	330	7	111	1512
NYCDEP - NEWTOWN CREEK WPCP	NEW YORK	NY	310	198	1296	2985
NYCDEP - WARD'S ISLAND WPCP	NEW YORK	NY	275	65	602	2497
NYCDEP - HUNT'S POINT WPCP	BRONX	NY	200	5	164	1643
BIRD ISLAND STP	BUFFALO	NY	180	54	133	376
NYCDEP - NORTH RIVER WPCP	NEW YORK	NY	170	10	339	1562
NYCDEP - BOWERY BAY WPCP	ASTORIA	NY	150	140	580	2417
MIDDLESEX CNTY UA	SAYREVILLE	NJ	147	51	144	361
FRANK E VAN LARE STP	ROCHESTER	NY	135	51	105	397
YONKERS JOINT WWTP	YONKERS	NY	120	217	582	2126
NYCDEP - OWLS HEAD WPCP	BROOKLYN	NY	120	161	721	1757
NYCDEP - CONEY ISLAND WPCP	BROOKLYN	NY	110	257	545	1259
NYCDEP - JAMAICA WPCP	JAMAICA	NY	100	100	622	2414
NYCDEP - 26TH WARD WPCP	BROOKLYN	NY	85	108	545	1988
BERGEN CNTY WTP	LITTLE FERRY	NJ	84.28	0	3	92
METROPOLITAN SYRACUSE WWTP	SYRACUSE	NY	84.2	53	272	584
NYCDEP - TALLMAN ISLAND WPCP	COLLEGE POINT	NY	80	134	527	1982
DELAWARE #1 WATER POL CON FAC	CAMDEN	NJ	80	9	126	506
JT MGT OF ESSEX & UNION CNTY	ELIZABETH	NJ	75	10	184	877
CEDAR CREEK WPCP	WANTAGH	NY	72	120	798	1853
BAY PARK STP	EAST ROCKAWAY	NY	70	557	1218	2350
SPRINGFIELD W W T P	AGAWAM	MA	67	41	212	379
HARTFORD WPCF	HARTFORD	CT	60	42	253	927

With respect to Tri-Gen fuel cell systems sited at WTFs and acting as central hubs of hydrogen production, due to the limited biogas potential from WTFs, sometimes a network of 10 or more Tri-Gen central hubs is needed to supply and support the given number of hydrogen refueling stations. Thus, effectively, there are size limitations to the Tri-Gen systems that can be installed, and therefore, a limit on economies of scale, which drop the price of hydrogen that can be offered and be taken advantage of. An example is shown in Figure 2 where 10 Tri-Gen systems sited at WTFs struggle and cannot support a scenario of about 774 refueling stations with ~95,000 FCEVs in the four states.

Conversely, there is a lot more flexibility afforded to a stakeholder when operating a Tri-Gen fuel cell system on conventional natural gas. Candidate sites for the installation of such a system included points along the inter/intrastate natural gas pipeline as well as at the theoretically planned hydrogen refueling stations – i.e., the 108, 313, and 774 stations. Assuming that an unlimited amount of natural gas can be tapped into and ascertained, the resulting effect is that the Tri-Gen systems can be sized as large as needed to meet the FCEV hydrogen demand. As such, scenarios where 1, 5, and 10 hubs set to serve the entire hydrogen station refueling network were analyzed and deemed possible. Due to economies of scale, in all cases, having one large Tri-Gen central hub was the cheapest option (cost of producing the hydrogen plus the cost of delivery). For the most part, this result is due to the capital cost of a Tri-Gen system dropping off faster than the increase in delivery costs as a function of distance. The case of five hubs delivering to the 108 station solution is shown in Figure 3 (a full range of the results will be reported in the project's final report). Moreover, though from a cost perspective, a large single Tri-Gen hub is the most favorable, early results are showing that the long delivery distances from one, or even five, Tri-Gen central hubs to the corresponding stations that are rolled out (i.e., 108, 313, or 774) may be resulting in more NO_X and/or GHG emissions than the emissions offset by the FCEVs driving on the road.

# of WWTP Central Hubs	10*	20	29	40
H2 Fuel Production Cost (Tri-Gen System)	128,157.44	187,455.00	216,368.85	465,510.78
Total Delivery Cost (Gaseous)	50,986.66	72,365.74	72,072.92	69,293.64
Total Delivery Cost (Liquid)	76,070.30	102,290.05	108,567.89	108,245.93
Total Delivery Cost (Pipeline)	107,778.82	154,233.17	151,683.11	147,290.01
kg H2 produced per day	34,802.44	48,311.38	49,739.16	49,739.16
*Hub(s) unable to serve entire H2 station network				

Note: In this instance, 20 hubs are very close to being (but not fully) sufficient to service the network

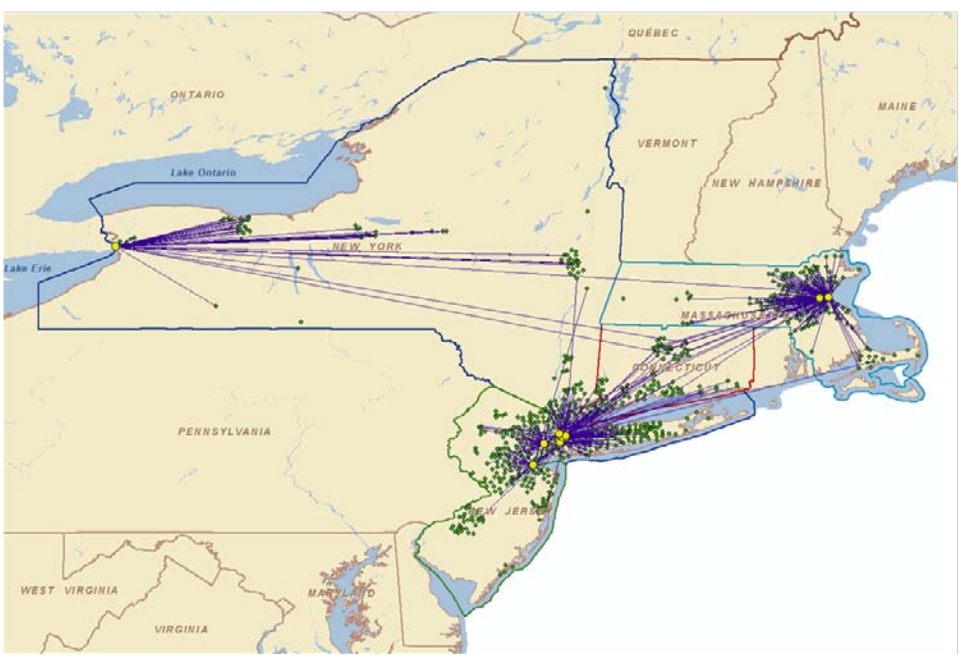
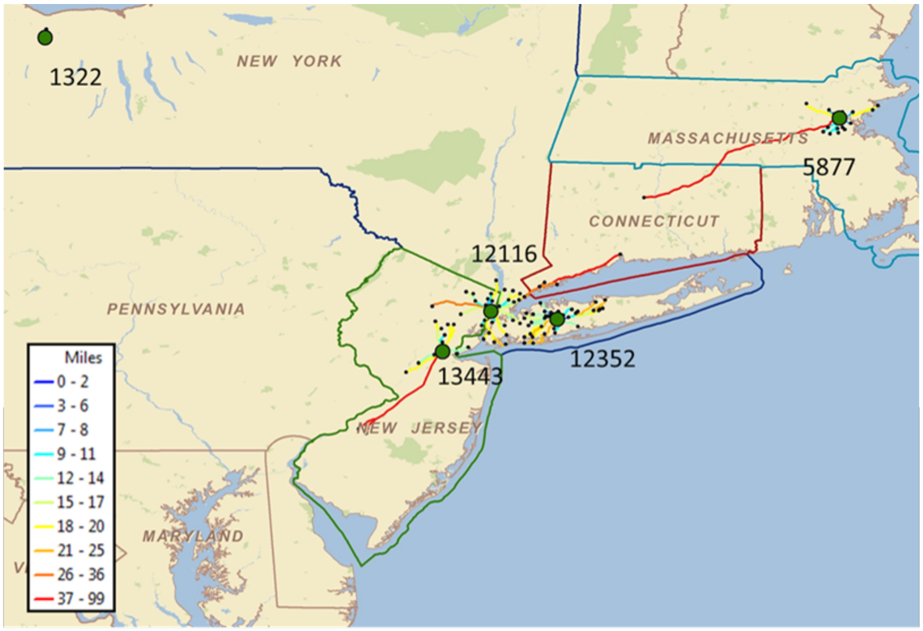


FIGURE 2. Ten hubs can only deliver to 419 of the 774 stations



5 Hubs	# of Vehicles	kg H2	Fuel Cell Capacity (kW)	Electricity Produced (kW)	Heat Produced (kW)	Total Capital Cost ($)	Price of H2 ($/kg)	Fuel Input (kW)
1322	53.29	37.30	83.60	66.10	19.98	993,906	15.41	200.30
5877	806.87	564.81	1,265.74	1,000.73	302.57	4,805,973	6.60	3,032.63
12116	1,249.87	874.91	1,960.67	1,550.16	468.69	7,046,920	5.76	4,697.64
12352	979.68	685.77	1,536.82	1,215.05	367.37	5,680,126	6.21	3,682.12
13443	399.06	279.34	626.01	494.94	149.64	2,743,013	8.22	1,499.87

H2 Fuel Production Cost (Tri-Gen System)		**15,895.32**
Total Delivery Cost (Gaseous)		3,235.46
Total Delivery Cost (Liquid)		5,295.59
Total Delivery Cost (Pipeline)		6,969.96
kg H2 produced per day		2,442.14

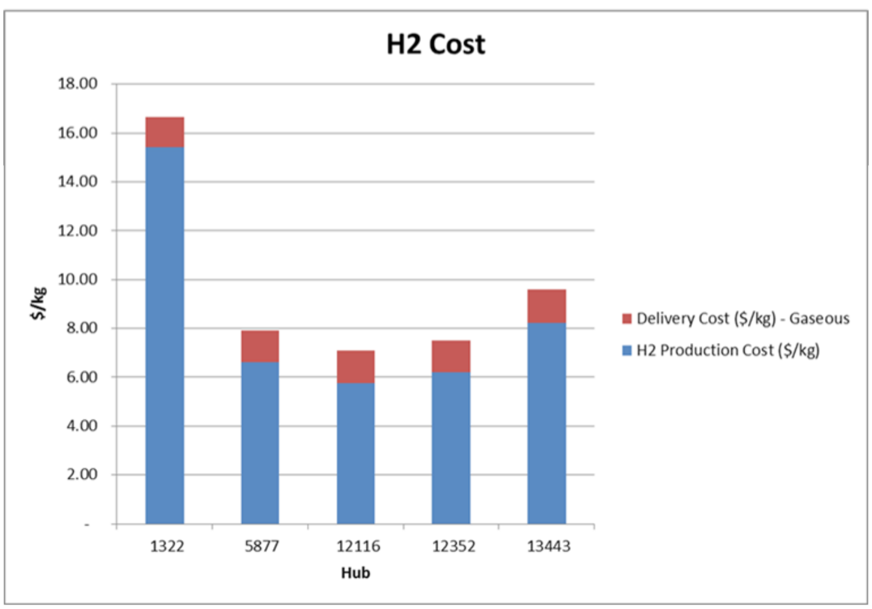


FIGURE 3. Five hubs delivering to the 108 station solution, which serves 25% of the market – i.e., 25% of the 10,000 fuel cell electric vehicles deployed

CONCLUSIONS AND FUTURE DIRECTIONS

- Whether stakeholders interested in installing a Tri-Gen fuel cell system with an on-site hydrogen dispenser deems their customer base to be FCEV drivers within six or, more generously, 15 minutes of their site greatly impacts the size of the system they will want to install as well as the capital cost investment that will need to be made.
- Operating on conventional natural gas offers the greatest opportunity to install large-sized Tri-Gen systems, thereby resulting in the lowest cost of hydrogen. However, the long delivery routes from these "Tri-Gen central hubs" could produce GHG and NO_X emissions (if diesel trucks are used) that are greater than the GHG and NO_X emissions that the FCEVs are offsetting.
- No additional work is planned, but future directions could include:
  - Looking at landfill gas as a Tri-Gen system feedstock
  - Exploring the sale of the electricity to the grid
  - Using the hydrogen as a means of energy storage – e.g., Power-2-Gas
  - Looking at how dairy waste could augment the biogas supply.

FY 2015 PUBLICATIONS/PRESENTATIONS

1. K.S. Manliclic, B.P. Shaffer (presenter), G.S. Samuelsen. Tri-Generation Fuel Cell Technologies for Location-Specific Applications. U.S. Department of Energy. 2015 Annual Merit Review. Washington D.C., June 8–15, 2015.

2. K.S. Manliclic, B.P. Shaffer, G.S. Samuelsen. Tri-Generation Fuel Cell Technologies for Infrastructure Applications in the Northeastern United States. Fuel Cell Seminar and Energy Exposition. Los Angeles, CA. November 13, 2014.

REFERENCES

1. K.S. Manliclic, T.M. Brown, G.S. Samuelsen. The Optimized Siting of Hydrogen Refueling Stations for the New York Tri-State Area. Fuel Cell Seminar and Energy Exposition. Columbus, Ohio. October 22, 2013.