2009 DOE Hydrogen Program Review

Hydrogen Energy Station Analysis in Northeastern US
and
Hydrogen Sensors for Infrastructure

Eileen Schmura

Concurrent Technologies Corporation

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Project PD_32_Schmura

Overview

Timeline

Overall Project

- Start - September 1, 2004
- Finish – April 30, 2009
- 100% Complete
- HD Analysis Phase II
  - September 2006-May 2008
- HD Analysis Phase III
  - January 2008-April 2009

Barriers

Barriers	Task	MYRDDP Reference
Lack of Hydrogen/Carrier and Infrastructure System Analysis	HD	3.2.4.2 A 3.1.1
DOE's 2015 target of \$2.00-\$3.00/gge (delivered, untaxed) at the pump for hydrogen	HD	MYRDDP 3.1.1

HD – Hydrogen Delivery, gge-gallons gas equivalent
MYRDDP-Multi Year Research, Development , and Demonstration Plan

Collaborators

Resource Dynamics Corporation (RDC)
Electric Power Research Institute
Air Products and Chemicals, Inc
Rutgers EcoComplex
Big Box Retailers
Coke Producers
Connecticut for Advanced Technology Inc.

Budget

Analysis Phase II funding – \$414,234
Analysis Phase III funding – \$300,000
Total overall project funding

- DOE share - \$5,917K
- Contractor share - \$1,183K

Funding for FY08 and FY09 -\$0

Phase III
I95 Hydrogen Corridor Objectives

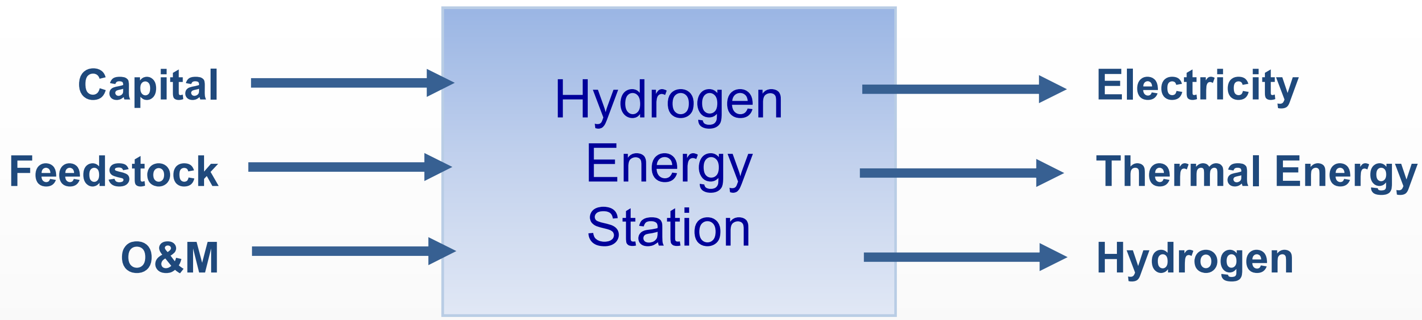
- Investigated the potential dual use options, developing a hydrogen infrastructure
- Analyzed early market Hydrogen Energy Station (HES) fuel cell applications
  - Included four HES options representing stationary fuel cell leaders
  - Analyzed lifecycle cost, State incentives, Federal investment tax credit (ITC)
  - Assessed applications using RDC-developed Distributed Power Economic Rationalization Selection (DISPERSE) model to analyze distributed generation and Combined Heat and Power (CHP) markets
- Focused on the initial transition to a hydrogen economy, where less than 1 percent of vehicles will use hydrogen
- Explored the indigenous energy with an emphasis on renewable feedstocks for hydrogen
- Identified the market readiness of the technologies and processes associated with HES biogas/fuel cell systems.

Technical Accomplishments
Potential Sites: Information Collection

- Early Fuel Cell Market Applications
  - Warehouses/distribution centers
- Biogas Sites
  - Landfills and anaerobic digester gas
    - Rutgers EcoComplex and I-95 Corridor
- Combined Heat and Power (CHP) and Combined Heat, Hydrogen, and Power (CHHP)
  - Big box retailer (various locations)
  - Office Building – Rutgers EcoComplex
  - Current Truck Stops/Fueling Stations (Pilot)*
- Coke Gas Production
  - Sites in PA*

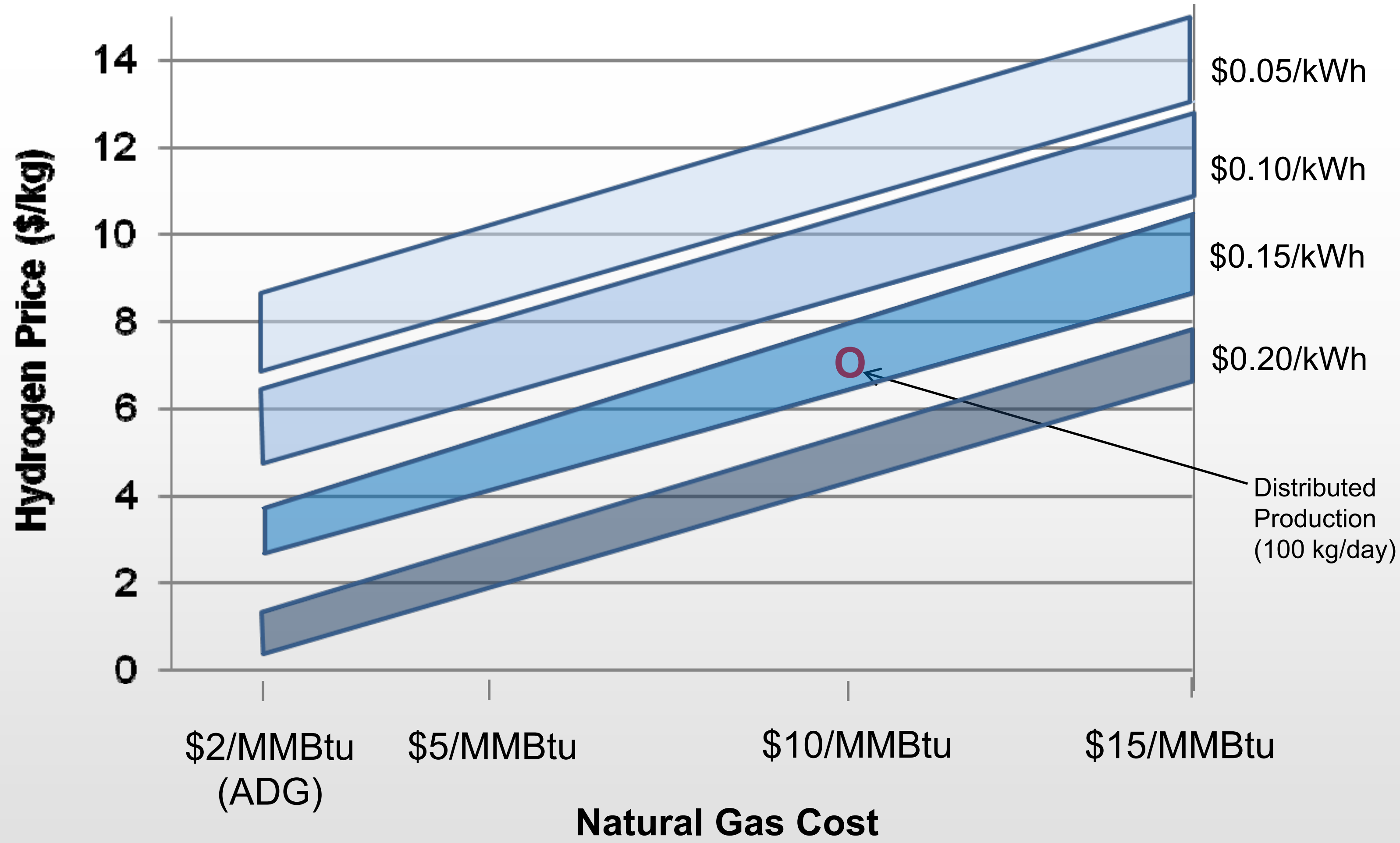
*Data collected, not analyzed

Project Concept Centers on Deployment of Hydrogen Energy Stations



- Stationary fuel cells have become established option for combined heat and power (CHP), particularly where incentives are strong
- Two fuel cell industry leaders have the capability to configure units to produce hydrogen as well as CHP, become hydrogen energy stations (HES) when paired with necessary compression, storage, and dispensing for vehicles
- State CHP or distributed generation incentives can provide substantial funding toward HES projects
- Can diminish risk of stranded hydrogen assets

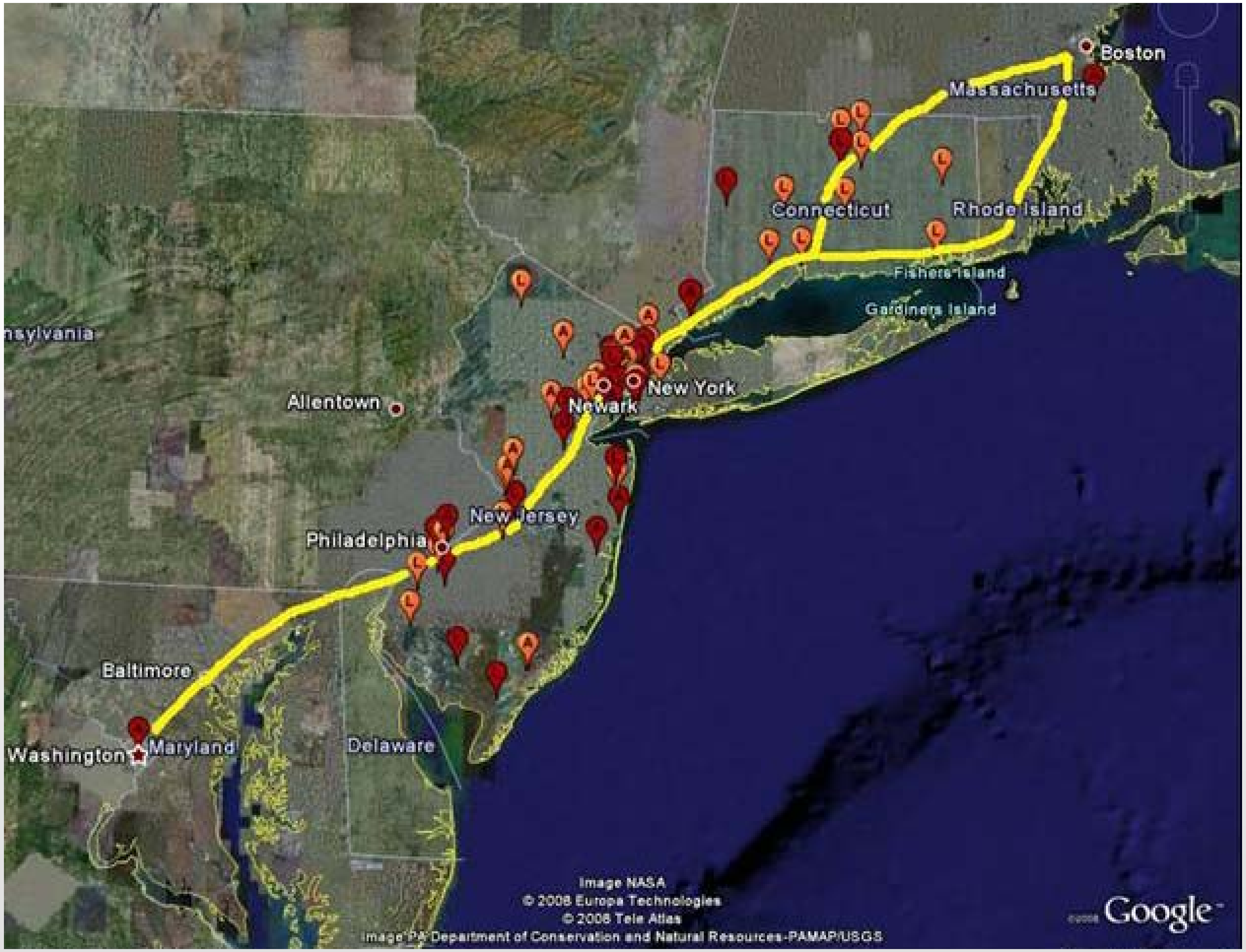
Hydrogen Energy Station Economics Vary with Fuel and Electricity Pricing



Basis: Feedstock = NG; 250-275 kW net power; 125-150 kg/day hydrogen

Source: Fuel Cell Energy and RDC estimates (with Federal ITC incentive)

Renewable Gas Sites Along I-95 Corridor



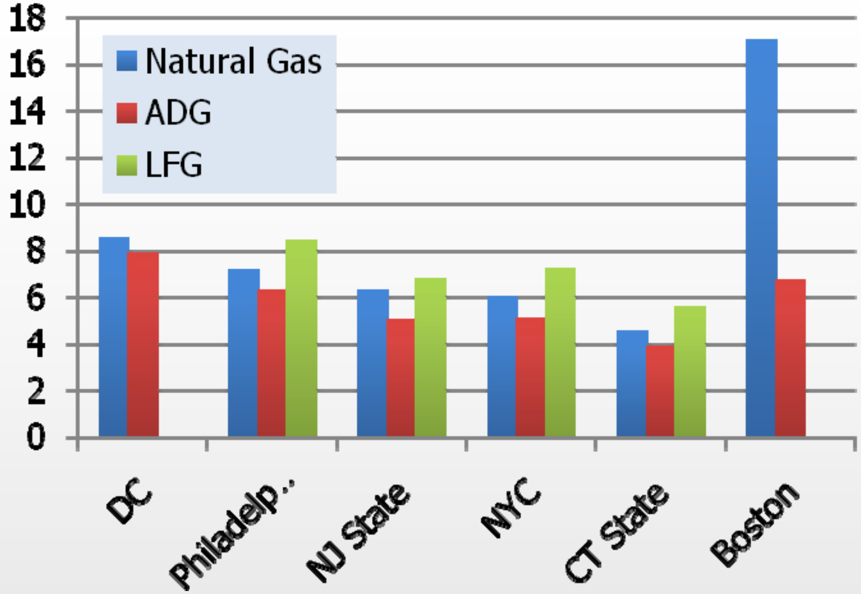
KEY:
A = WWTP (ADG)
L = Landfill (LFG)

WWTP- Waste Water Treatment Plant

Note: Includes entire state of CT and NJ, and cities of Washington, DC, Philadelphia, PA, New York, NY, and Boston, MA.

Where Available, Renewable Gas Competitive with Natural Gas

Typical Payback for HES 250 Investments, Current Cost



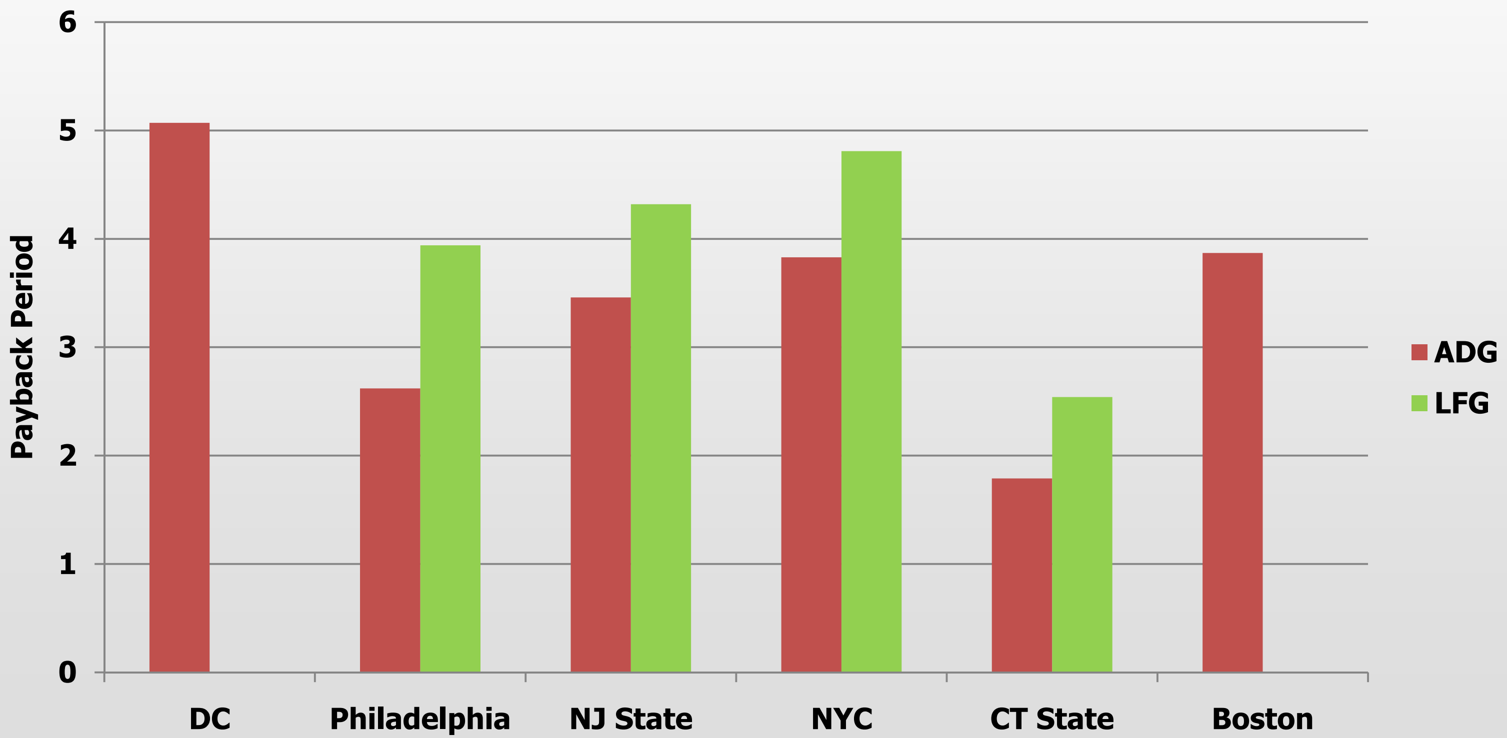
Numerous Renewable Gas Sites Within I-95 Corridor

City, State	Potential ADG Sites	Potential LFG Sites	Total Potential Sites	Total Sites in I-95 Corridor
Entire CT	2	11	13	11
Washington, DC	1	0	1	1
Boston, MA	1	0	1	1
Entire NJ	12	19	31	22
New York, NY	9	5	14	14
Philadelphia, PA	3	1	4	4

- In order to support a 300 kW fuel cell project, the ADG/LFG site must produce about 100,000 cubic feet of biogas each day
- For WWTPs, this corresponds to a wastewater flow rate of about 9 million gallons per day
- For landfills, this depends on a number of variables (waste-in-place, landfill opening year, landfill closure year)

Large Wastewater Plants and Landfills Could Apply Large HES

- HES 1350: 400,000-500,000 cubic feet of biogas must be available daily
- Only the largest WWTPs and landfills are capable of biogas production on this scale (17 facilities identified in our analysis, most in NYC)
- When adequate ADG is available at no cost and all electricity and heat from HES 1350 is utilized, payback periods can become very attractive



Rutgers HES Preliminary Cost Benefit Analysis Using LFG

HES Cost Impact	Annual Value ($)
1) Electricity Savings (@14.9 cents/kwh)	90,500
Avoided Electricity	108,320
Standby Charges	-17,790
2) Net Metering Revenue (50% retail rate)	66,900
3) Hydrogen Revenue ($7/kg)	303,400
4) Natural Gas Use (@$12.7/MMBtu)	-6,900
Savings from Fuel Cell Thermal Output	22,230
Added Fuel Used as Backup for LFG	-29,140
Annual Benefits (1+2+3+4)	483,000
Annual Maintenance (@$0.035/kWh)	-70,000
Net Savings	413,000

Assumptions:

-Standby charges from PSEG tariff based on estimated electricity consumed when fuel cell is down, and maximum potential demand
-LFG available 85% of time, fuel cell available 98% of time; NG used as backup fuel 13% of time, other 2% uses standby electricity
-50 kW of electricity is continuously required to power fuel pretreatment equipment while fuel cell is in operation
-Hydrogen production: 160 kg/day, sold at $4/kg; 60 kW estimated for hydrogen purification, can be deferred for peak site demands
-Excess electricity is sold to utility at an average of half the retail rate ($0.075/kWh) as a proxy for avoided cost

Rutgers HES Preliminary Cost Benefit Analysis with LFG Treatment

HES Costs and Benefits	Value ($)
HES w/ LFG Fuel Treatment System	5,000,000
NJ Clean Energy Incentives	-1,000,000
Federal Investment Tax Credit	-900,000
NJ Fueling Infrastructure Incentives	-50,000
Net Cost	3,050,000
Net Annual Benefit	413,000
Simple Payback Period	7.4 years

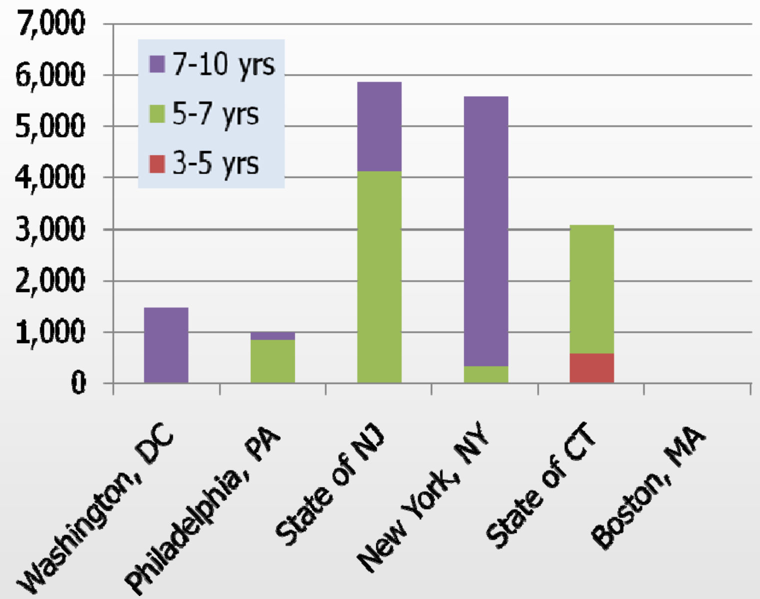
- $4.00/W incentives from New Jersey applied to 300 kW fuel cell, capped at $1 million or 60% of capital cost (not including hydrogen equipment)
- Federal tax credit: 30% of remaining cost, capped at $3,000/kW. Assumes that entire HES qualifies as fuel cell property.

Economic Drivers Key to Project Potential

(HES 250, Current Costs/Performance)

State	Incentives	Net Metering of Excess Electricity	Electricity Price (cents/kWh)	REC Values (cents/kWh)	Potential for Payback Ranges		
					3-5 years	5-7 years	7-10 years
DC	None	Retail	10	2	**No**	No	Yes (major)
PA	$1 million	Retail	7-8	2	No	Yes (major)	Yes (minor)
NJ	$1 million	Avoided Cost	14-15	2	No	Yes (major)	Yes
NY	$1 million	None	14-15	0	Yes (minor)	Yes (minor)	Yes (major)
CT	$4,700/kW	Avoided Cost	15-17	3	Yes	Yes (major)	Yes (minor)
MA	None	None	14-15	3	No	No	No

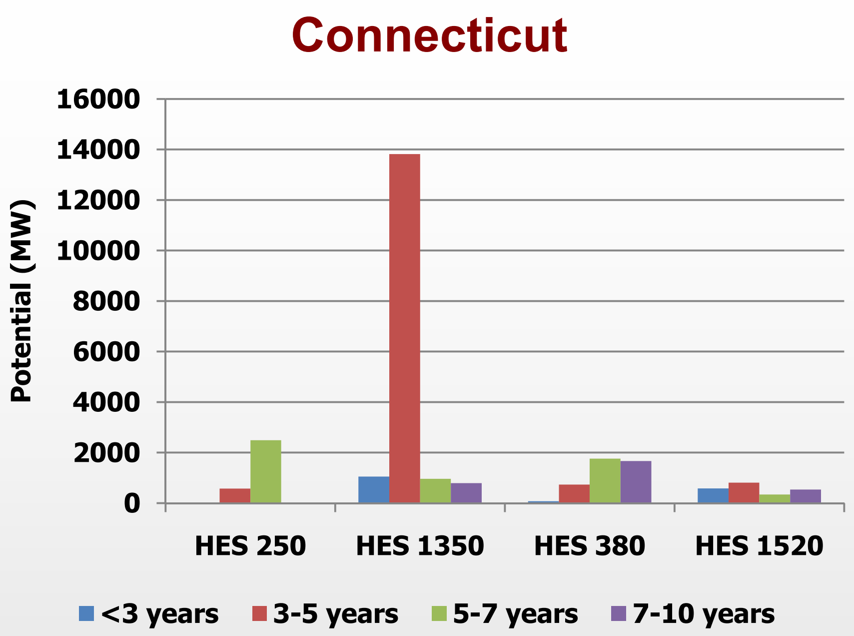
States with Incentives Offer Most Potential for HES

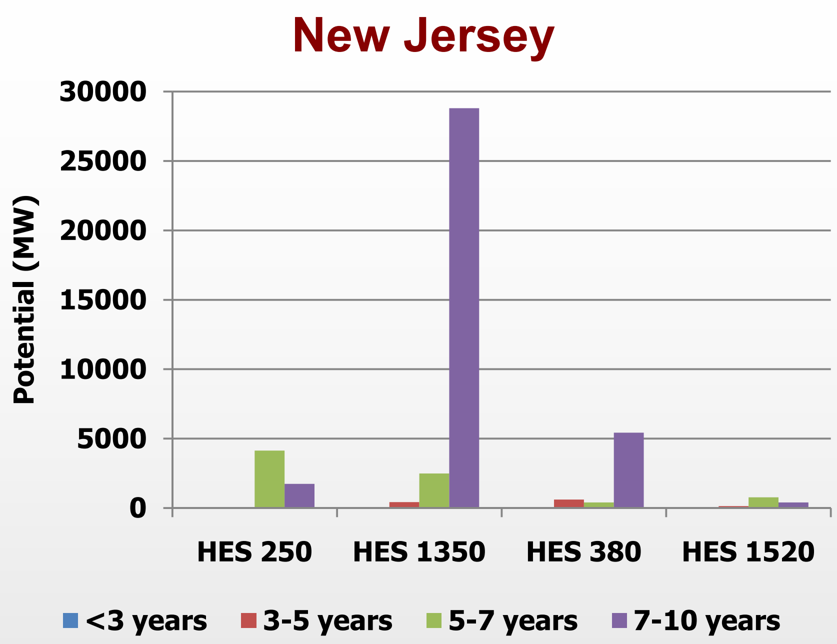


Potential (MW) of HES Sites with 10 Year Paybacks or Better,
Using HES 250 system (current price/performance)

- Only states with a monetary incentive for fuel cell projects were able to achieve paybacks less than 7 years with current fuel cell pricing
- The only states showing major potential for fuel cell projects with a payback period of less than 7 years are Connecticut, New Jersey and Pennsylvania

Potential for HES Options
(Current Price/Performance, Full State Incentives)





- The HES 1350 shows a great deal of potential projects (>14 GW) with a payback period under five years
- Potential is not additive – each option evaluated exclusively

- With current prices, most payback periods fall in the 5-10 year range, but HES 1350 could see great potential with cost reductions or performance improvements
- Potential is not additive – each option evaluated exclusively

Example of HES at New York Big Box Distribution Center

- Monthly electricity demand: 2,000 kW – 2,700 kW over last 12 months
- Average cost of electricity over last 12 months: 14.95 cents/kWh
- Estimated annual bill savings from fuel cell operation: $311,000 (for fuel cell with 250 kW net output)
- Natural gas use: ranges from over 80,000 therms in winter to less than 100 therms in the summer
  - enough demand to utilize all heat from 300 kW HES for seven months of the year
- Average cost of natural gas over last 12 months: $1.07/therm
- Utilizing the available excess heat from the fuel cell, the net annual fuel cost to operate the 300 kW hydrogen energy station is about $219,000

Big Box Distribution Center Preliminary Cost Benefit Analysis

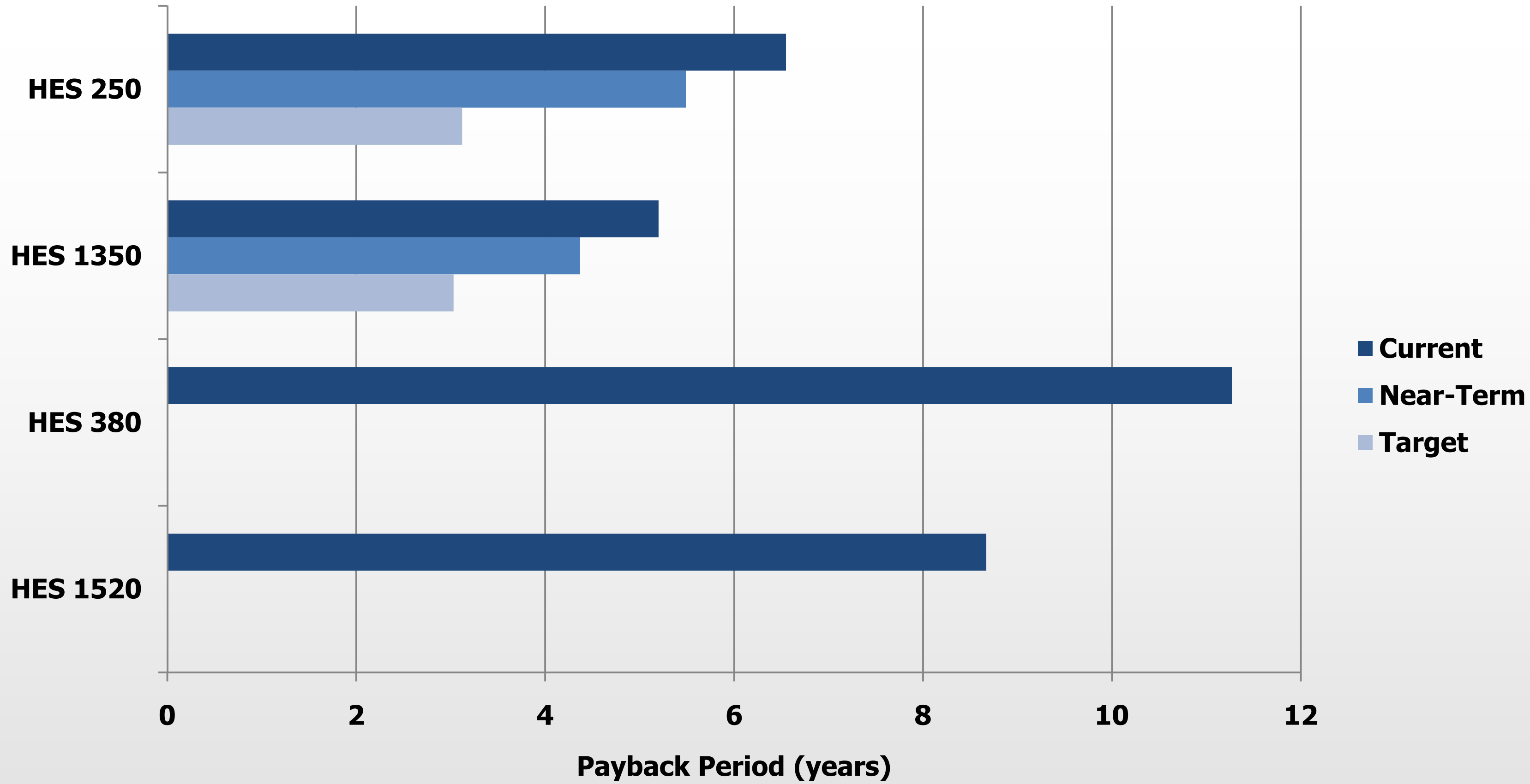
HES Cost Impact	Annual Value ($)
1) Electricity Savings (@14.9 cents/kwh)	310,600
2) Hydrogen Revenue ($7/kg)	303,400
3) Natural Gas Use (@$12.8/MMBtu)	-238,600
Savings from Fuel Cell Thermal Output	20,000
Fuel required to operate HES	-258,600
Annual Benefits (1+2+3)	375,400
Annual Maintenance (@$0.03/kWh)	-74,900
Net Savings	300,500

HES Costs and Benefits	Value ($)
HES Capital Cost/ Hydrogen Fueling Infrastructure Cost	4,000,000
NYSERDA Fuel Cell Incentive	-1,000,000
Federal Investment Tax Credit	-900,000
Net Cost	2,100,000
Net Annual Benefit	300,500
Simple Payback Period	7.0 years

Assumptions:

- Fuel cell available 95 percent, all electricity and thermal output used by facility
- Hydrogen production 125 kg/day, sold at $7/kg, 50 kW needed for purification
- $1 million in funding from New York fuel cell rebate/performance incentive
- Federal tax credit: 30% of remaining cost, capped at $3,000/kW. Assumes that entire HES qualifies as fuel cell property.

Big Box Distribution Center Results With Different HES Configurations



- The thermal demand at this distribution center is lacking from May through October, making it difficult for the HES 380 and 1520 options to achieve positive economics

Coke Oven Gas(COG)

Company Plant Location	Coke (10^3 tons/yr)	COG (10^6 ft^3/yr)	COG Consumed (10^6 ft^3/yr)	COG Flared (10^6 ft^3/yr)	H_2 Flared (gge/yr)
Erie Coke Corporation Erie, PA	160	1,771	Coke Ovens – 1,062 Boilers – 709	0	0
ArcelorMittal S.A. Monessen, PA	349	5,727	Coke Ovens – 3,070 Boilers – 1,683	974	1,579,399
DTE Energy Services Neville Island, PA	290	4,818	Coke Ovens – 2,365 Boilers – 2,278	175	283,773
US Steel – Clairton Works Clairton, PA	4,700	85,775	Coke Ovens – 34,310 Others – 51,465	0	0
Total	5,499	98,091	Coke Ovens – 40,807 Others – 56,135	1,149	1,863,172
Total Available H_2 in COG (gge/yr)		159,060,445			

Component	Volume Fraction (%)
Hydrogen	58.00
Methane	26.00
Nitrogen	5.50
Acetylene	2.25
Carbon Dioxide	2.00
Carbon Monoxide	6.00
Oxygen	0.25
Total	100.00

- COG is mostly hydrogen
- Most COG is used as fuel for thermal applications (supplementing natural gas purchases)
- Most sites are good candidates for
- Maybe the most economic pathway for hydrogen production
- Amount of COG flared warrants the need to study further

Preliminary Findings

- With current costs and assuming State and Federal incentives will continue, economics of larger HES are positive and appear adequate to draw private investment
  - Assumes full value for hydrogen output, which would require a local market for hydrogen
  - Additional funding (up to $1.5 million per project) will likely be required to spur investment in smaller HES projects
  - Funding initial HES projects will lead to near term cost reductions as R&D costs are recovered and HES are improved
  - States with incentives offer numerous potential sites that could leverage Federal funding into successful HES applications, many along I-95 Corridor
- Biogas projects yield economics competitive or superior to natural gas, and provide renewable hydrogen (gas royalties could lead to premium cost for renewable hydrogen)

Hydrogen Sensor - Objectives and Approach

Objective

– Advance current hydrogen-specific sensors and sensor technologies to ensure reliable operation and performance in hydrogen applications

Approach

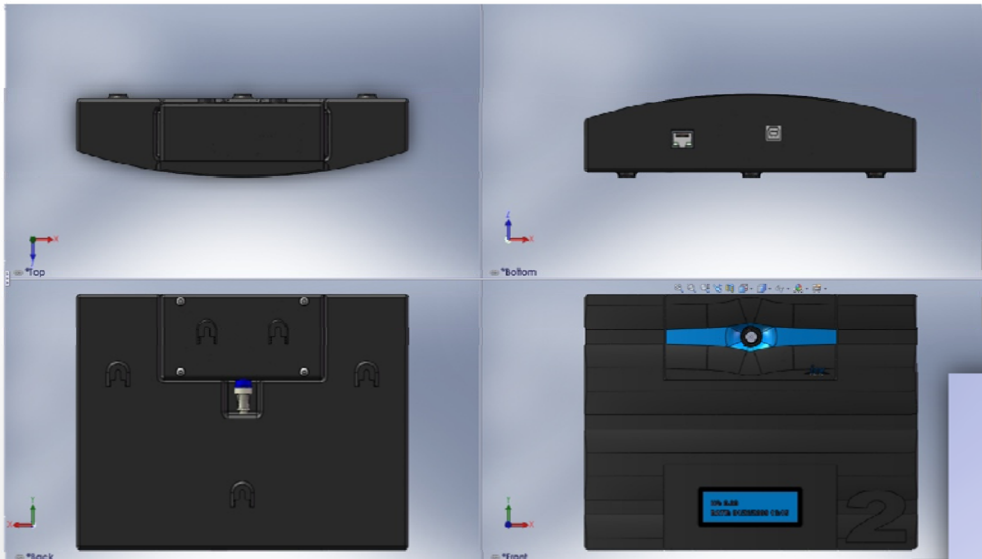
– Development, fabrication and testing of a hydrogen sensor product
  – Capable of wireless network communication using mesh networks and wired communication
  – Capable of a self-test to verify functionality
  – Internal memory for storage of 24 (or more) hours of data
  – Battery-power option
  – Adaptable for handheld use with additional components
  – Adaptable for use in pipeline and other process engineering applications
  – Optional pump or blower to speed up sensor response time relative to 'diffusion-only' version
  – Modular architecture for major components (wireless, wired, pump or blower option, battery, memory, other sensor options, hydrogen sensor verification module)

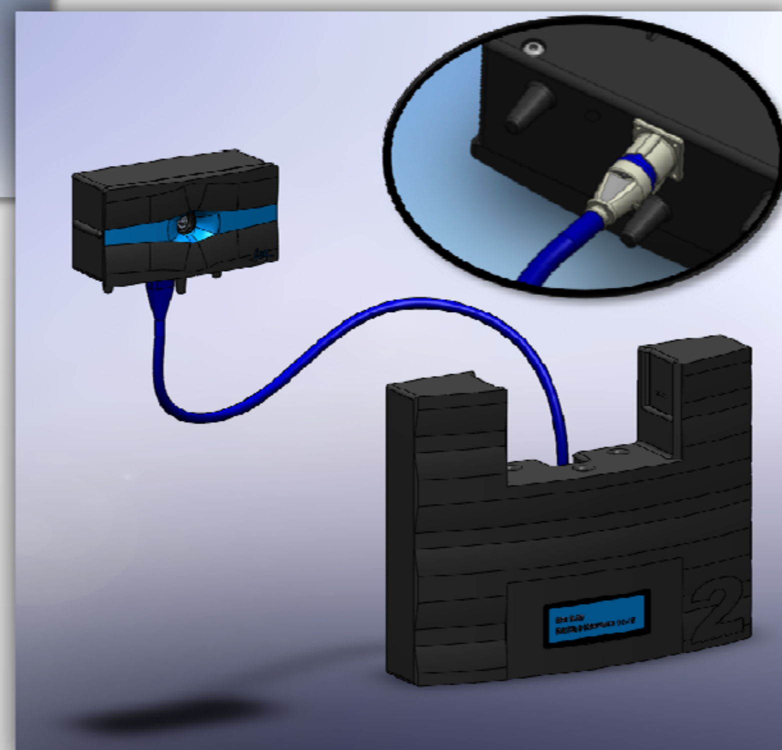
BARRIERS	• High Capital Cost and Hydrogen Embrittlement of Pipelines (3.2.4.2 D) • Hydrogen Leakage and Sensors (3.2.4.2 I)

Technical Accomplishments – Module Features

- Measure and record hydrogen in air
- Indicate an electronic alarm
- Collect and store sensor and system data
- Stamp time and date information on stored and transmitted sensor data
- Sensor Performance Specifications
  - Concentration: 0% to 4.4% H_2in air
  - Accuracy: +/-0.3% (3000ppm)
  - Resolution: 0.02% (200ppm)
  - Response time:
    - Under 3 seconds to respond to increases in ambient readings
    - Under 10 seconds to return to ambient readings in absence of H_2
- Data storage capacity: Minimum 24 hours worth of data
- Stored Data Retrieval
  - Accessible on command via wired or wireless communication
- Wired Communication
- Self Test
  - The sensor will be capable of self-checking to ensure proper operation

Technical Accomplishments – Module Diagram





- Sensor cable connects to Base Station