Northeastern I-95 Corridor and Pennsylvania Indigenous Energy

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PDP30

Overview

Timeline

Overall Project

- Start - September 1, 2004
- Finish - January 31, 2009
- 75% Complete
- HD Analysis Phase II
  - September 2006-May 2008
- HD Analysis Phase III
  - January 2008-January 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 – gasoline gallon equivalent

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 FY07 and FY08 -$0

Partners

Resource Dynamics Corporation
Electric Power Research Institute
Air Products and Chemicals, Inc
Leonardo Technologies, Inc

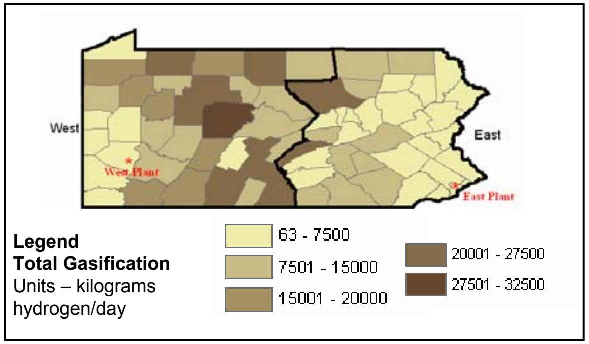
Objectives

- Analyze Pennsylvania as state example, linking several metropolitan statistical areas (MSAs) and rural areas and analyze tradeoffs between alternative hydrogen production, delivery approaches, and commercial and near commercial options focusing on 1%, 10% and 30% light duty vehicle (LDV) penetration (Phase I)
- Determine Pennsylvania's economic delivery scenarios using regional cost of indigenous energy resources (i.e., coal, landfill methane, biofuels, wind, anaerobic digestion and nuclear) using the DOE H2A model (Phase II)
- Evaluate economic delivery scenarios for the I-95 Corridor, focusing on 1%, 10% and 30% LDV penetration (Phase II)
- Identify and evaluate transition scenarios (below 1% LDV penetration) focusing on anchor projects with a need for hydrogen other than LDVs within specific clusters on along the Northeast (NE) I-95 Corridor (Phase III)

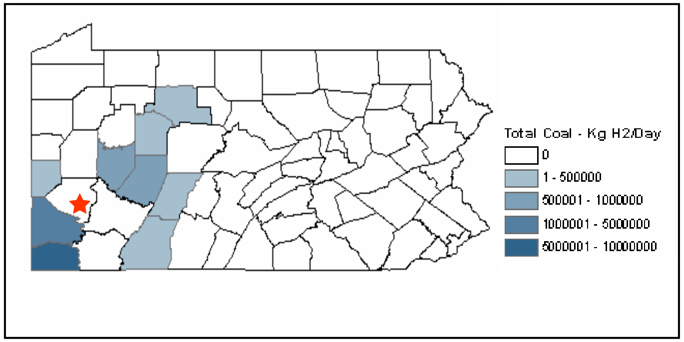
Phase	Geographic Area	Feedstock	Demand
I	Pennsylvania	Coal, natural gas, biomass	1%, 10%, and 30% LDV
II	Pennsylvania	Indigenous energy sources with local pricing – coal, natural gas, biomass, biogas, wind, etc	1%, 10%, and 30% LDV
II	NE I-95 Corridor	Coal, natural gas, biomass	1%, 10%, and 30% LDV
III	NE I-95 Corridor	Indigenous energy sources with local pricing – coal, natural gas, biomass, biogas, wind, etc	Transition scenarios, first adopters

Technical Accomplishments

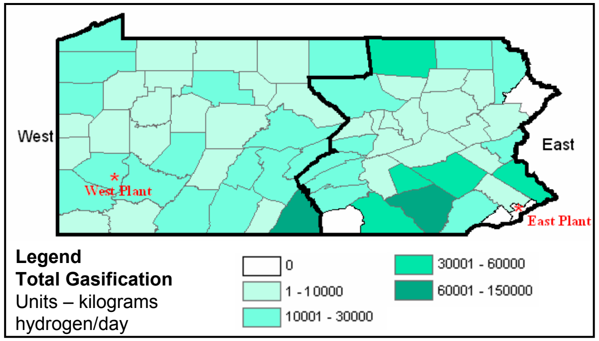
Pennsylvania Indigenous Energy Options Phase II



Woody Biomass Concentrated Away From Demand Centers



Pennsylvania Abundant Coal Resources in Close Proximity to Regional Central Production Plant



Biogas Resources Closer to Demand Centers

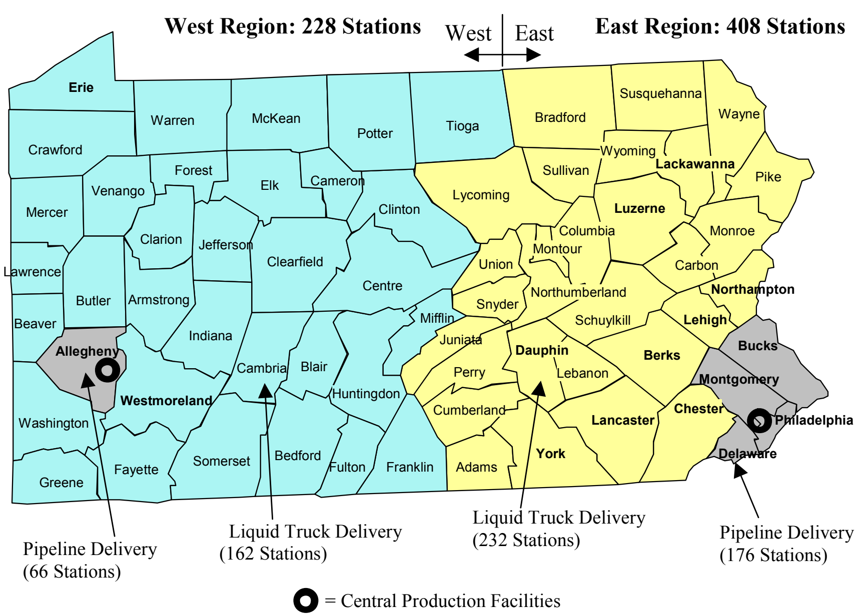
<u>Results</u>

- Feedstocks considered for Pennsylvania case study included coal, coalbed methane, forestry and wood resources, municipal waste, livestock manure, landfills, wastewater, electricity (renewable and nuclear)
- Resources based on current production of primary and secondary wood wastes, no harvesting of growing stock, entire state can provide 10% of hydrogen demand
- Bituminous coal is prevalent in western Pennsylvania, could easily provide 100% LDV demand and could provide 19 times more hydrogen compared to the next resource (manure) considered
- Resources based on digestion of swine and dairy manure , landfill gas production, coal bed methane, producing **“Green” Natural Gas,** entire State can provide 15% hydrogen demand

Pennsylvania Indigenous Energy Study - Phase II Results

<u>Two large central plant option</u>

- Biogas emerges as an important feedstock in early demand scenarios
- Coal is the most economic feedstock for the Pennsylvania hydrogen economy at higher demand levels
- Lowest delivered cost for 1% LDV penetration is $4.28/kilogram (kg) using biogas and pipeline distribution for the East Plant and natural gas for the West Plant.
- Lowest delivered cost for 30% LDV penetration is $4.13/kg using central production, coal gasification, and a combination of pipeline and liquid truck delivery
- Generally, if carbon is sequestered, an increased cost is realized



30% Demand Scenario with Two Central Plants

		1% LDV		10% LDV		30% LDV	
		East Plant	West Plant	East Plant	West Plant	East Plant	West Plant
	Plant Size (kg/day)	74000	19000	428000	239000	1283000	718000
NO CARBON REGULATION	Lowest Delivered Cost ($/kg)	4.28	4.61	3.64	4.13	3.40	3.57
NO CARBON REGULATION	Production and Delivery Method	Central Station Biogas (LFG and ADG); Pipeline Distribution	Distributed Natural Gas	Central Station Biogas (LFG and ADG); Pipeline Distribution	Central Station Coal Gasification; Pipeline/Liquid Distribution		
LOW CARBON	Lowest Delivered Cost ($/kg)	4.28	4.61	3.64	4.48	3.77	3.88
LOW CARBON	Production and Delivery Method	Central Station Biogas (LFG and ADG); Pipeline Distribution	Distributed Natural Gas	Central Station Biogas (LFG and ADG); Pipeline Distribution	Central Station Coal Gasification w Seq; Pipeline/Liquid Distribution		

Pennsylvania Indigenous Energy Study - Phase II Results – Five Regional Plant Operation

Five regional plant option

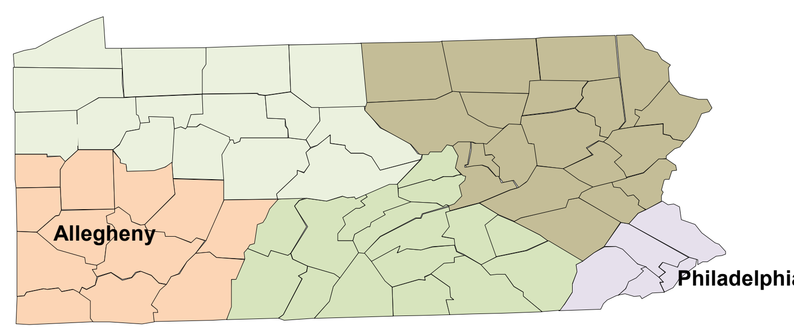
- Biogas is still a viable feedstock in the 10% LDV penetration
- Coal is the most economic feedstock for the Pennsylvania hydrogen economy at higher demand levels
- Lowest delivered cost for 10% LDV penetration is $3.60/kg and for 30% LDV penetration is $3.21/kg using central production, coal gasification, and a combination of pipeline and liquid truck delivery
- Generally, if carbon is sequestered, an increased cost is realized
- The South East Plant generally has the lowest delivered cost of hydrogen due to higher demands

		10% LDV					30% LDV				
		South East Plant	South West Plant	North West Plant	South Central Plant	North West Plant	South East Plant	South West Plant	North East Plant	South Central Plant	North west Plant
	Plant Size (kg/day)	211000	161000	138000	97000	62000	627000	471000	398000	344000	155000
NO CARBON REGULATION	Lowest Delivered Cost ($/kg)	3.60	4.27	4.61	4.33	4.61	3.21	3.64	3.78	3.76	4.31
	Production and Delivery Method	Central Station Coal Gasification; Pipeline/ Liquid Distribution	Central Station Biogas (LFG and ADG); Pipeline Distribution	Distributed Natural Gas	Central Station Biogas (LFG and ADG); Pipeline Distribution	Distributed Natural Gas	Central Station Coal Gasification; Pipeline/Liquid Distribution				
LOW CARBON	Lowest Delivered Cost ($/kg)	3.95	4.27	4.61	4.33	4.61	3.58	3.95	4.10	4.08	4.61
	Production and Delivery Method	Central Station Coal Gasification w/ Seq; Pipeline/ Liquid Distribution	Central Station Biogas (LFG and ADG); Pipeline Distribution	Distributed Natural Gas	Central Station Biogas (LFG and ADG); Pipeline Distribution	Distributed Natural Gas	Central Station Coal Gasification w/ Seq; Pipeline/Liquid Distribution				Distributed Natural Gas

KEY

- (green) Central Station Biogas (LFG and ADG) Production, Pipeline Distribution
- (red) Distributed Natural Gas Production On-Site via Reformation (no Delivery Necessary)
- (blue) Central Station Coal Production, Pipeline/Liquid Delivery (Pipeline for Philadelphia and Pittsburgh, Liquid Truck for remaining areas)

Note: The Data for Central Station Coal Gasification with and without Sequestration is based on June 2007 Coal Prices.



30% Demand Scenario with Five Central Plants

Pennsylvania Indigenous Energy Study – Phase II Summary

Production Scenario	Demand Scenario	State Weighted Average Cost Delivered Hydrogen
Two Central Plants	10%	$3.94/kg
Five Regional Plants	10%	$4.30/kg
Two Central Plants	30%	$3.57/kg
Five Regional Plants	30%	$3.91/kg

- Two larger central plants yield a lower weighted average for the entire state versus five smaller regional plants
- Indigenous resource do influence the most economical source of hydrogen (biogas)
  - Central Station emerges earlier in the 1% demand scenario using two central plants
  - Biogas is still important in 10% demand option for both the two central plant and the five regional plants
  - 30 % demand option coal is most economical in both production scenarios
- The South East Plant (Five Regional Plant Scenario) has the overall lowest cost of delivered hydrogen
- Regional planning may be most prudent along the I-95 corridor, not just a state issue

Technical Accomplishments

Establishing a Hydrogen Economy along the NE I-95 Corridor

Results

- I-95 Corridor worst concentrated carbon dioxide source on east coast and includes many ozone non-attainment areas
- I-95 Corridor contains densely populated areas, 13% of United States (US) population in less than 1% of land and 22 million LDVs(15 % of US)
- Includes 1st, 5th, 8th, and 11th largest metropolitan statistical areas (MSA) in US

	Hydrogen Energy Plan	ZEV Mandates	ZEV Acquisition Requirements	H2 Vehicle Sales Tax Exemption	H2 Fuel Sales Tax Exemption	H2 Vehicle Rebates/ Credits	Infrastructure Rebates/ Credits	Current H2 Stations
DC								x
MD								
PA								
NJ				X		X	X	
NY	X	X			X			x
CT	X			X				
RI								
MA			X					

- Northeastern states are starting to adopt the ZEV (zero emissions vehicle) mandates.
- New York has the highest population, but the lowest LDV% per capita.

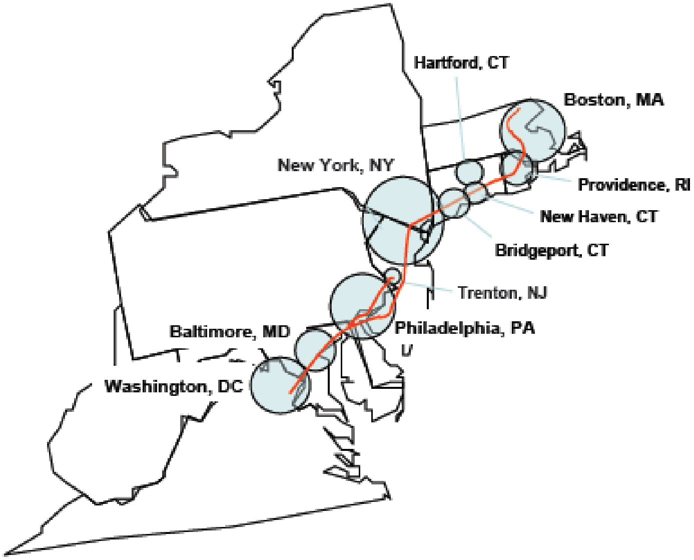
MSA	Includes	Population	Area (mi^2)	Population Density (people/mi^2)	Light Duty Vehicles (LDVs)	LDV% per capita	Avg Miles/yr
Washington, DC	DC, Northern Virginia, Maryland suburbs	3,930,000	1,157	3,400	2,690,000	68%	13,500
Baltimore, MD	Baltimore and surrounding suburbs	2,080,000	683	3,000	1,420,000	68%	13,500
Philadelphia, PA	Philly, Wilmington, PA/DE/MD/NJ suburbs	5,150,000	1,800	2,900	3,310,000	64%	11,200
Trenton, NJ	City of Trenton, surrounding areas	270,000	92	2,900	200,000	74%	12,000
New York, NY	NYC, Newark, NY/NJ/CT suburbs	17,800,000	3,353	5,300	8,980,000	50%	11,100
Bridgeport, CT	Bridgeport, Stamford, CT and NY suburbs	890,000	465	1,900	680,000	76%	12,000
New Haven, CT	New Haven, surrounding areas	530,000	285	1,900	400,000	76%	12,000
Hartford, CT	Hartford and surrounding suburbs	850,000	469	1,800	670,000	79%	13,500
Providence, RI	Providence and surrounding RI/MA suburb	1,170,000	504	2,300	870,000	74%	11,300
Boston, MA	Boston and MA, RI and NH suburbs	4,030,000	1,736	2,300	2,650,000	66%	11,900
	Total I-95 Corridor	**36,700,000**	**10,544**	**3,481**	**21,870,000**	60%	12,200

Source: H2A Delivery Scenario Analysis Model Version 1.0 (HDSAM)

Establishing a Hydrogen Economy along the NE I-95 Corridor

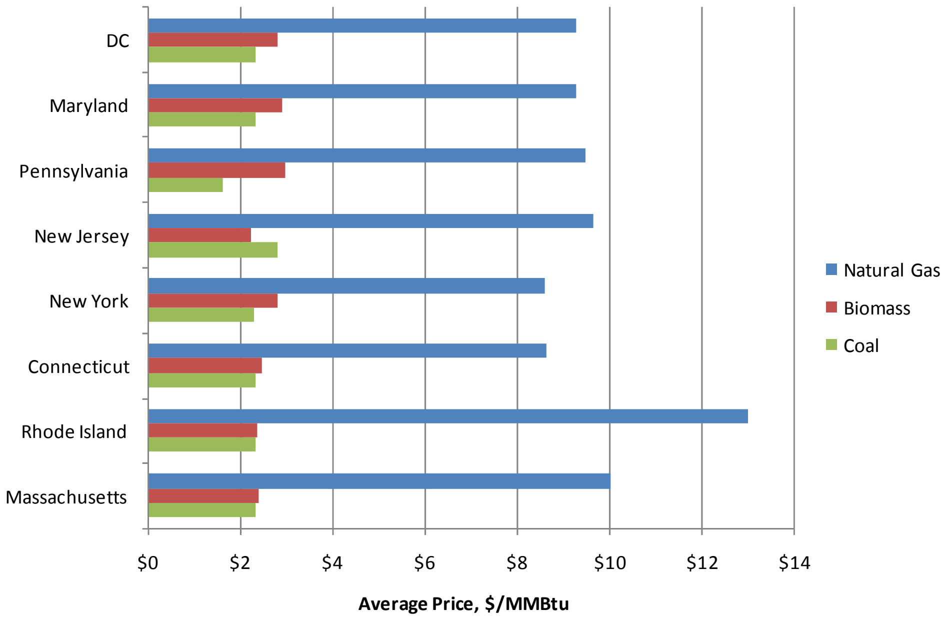
•The I-95 Corridor begins with the Washington, DC and leads though Boston, MA , which encompasses 10,500 square miles.
•Linking each MSA (cluster) together will form the NE I95 Corridor.

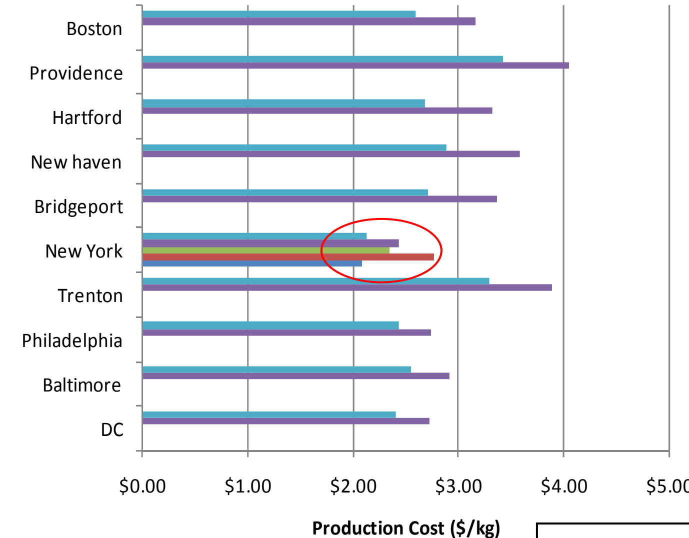
•During the early stages (1% LDV penetration) smaller 100 kg/day stations are needed for drivers to have convenient access to stations. This increases the cost of hydrogen produced on-site in early stages.

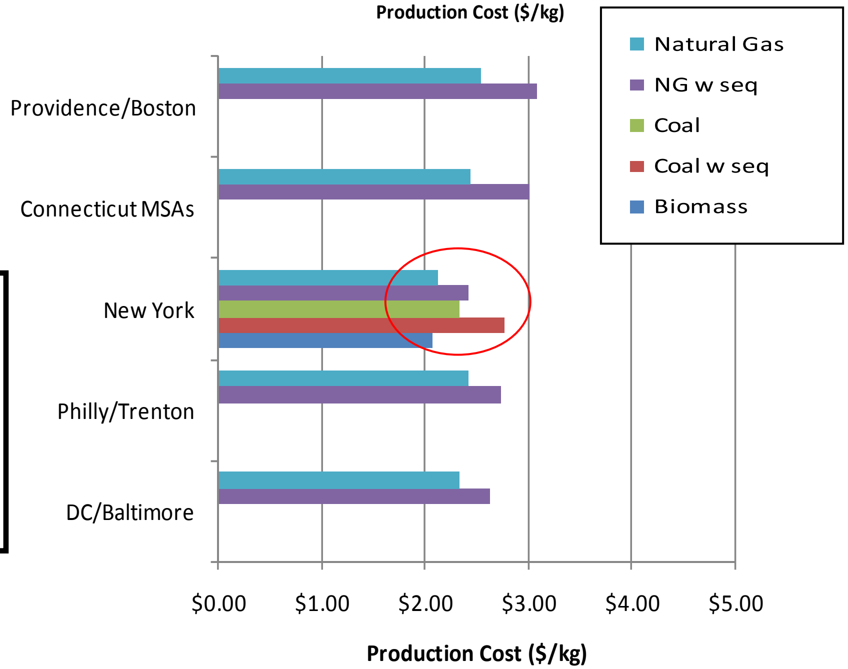


		Proposed Hydrogen Stations		
Scenario	Existing Gas Stations	100 kg/day	1500 kg/day	Hydrogen Station Percentage
1 Percent	10,937	1,708	0	15.6%
10 Percent	10,937	620	1,088	15.6%
30 Percent	10,937	0	3,410	31.2%

Feedstock Pricing Along NE I-95 Corridor Favors Biomass and Coal



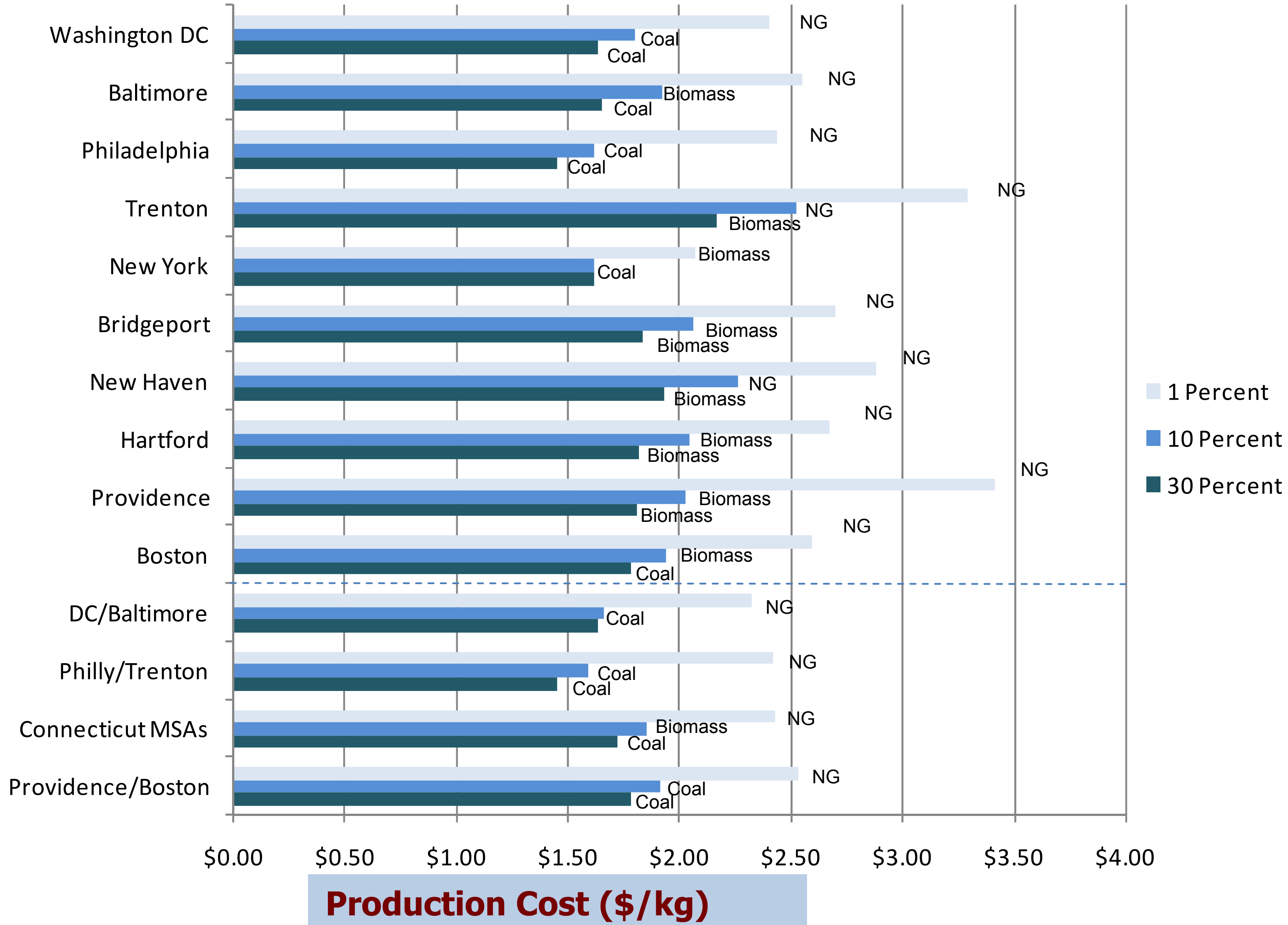




Ranges of costs along I-95 Corridor (Source- EIA):
- Natural Gas: $8-13/MCF
- Biomass: $35-50/ton
- Coal: $35-70/ton

For 1% demand scenario, only New York offers enough demand to surpass the 40,000 kg/day capacity level required by the H2A model to satisfy biomass/coal gasification minimum economies. All other MSAs require natural gas as the feedstock.

Without Carbon Constraints, Natural Gas Gives Way to Biomass, Biomass to Coal

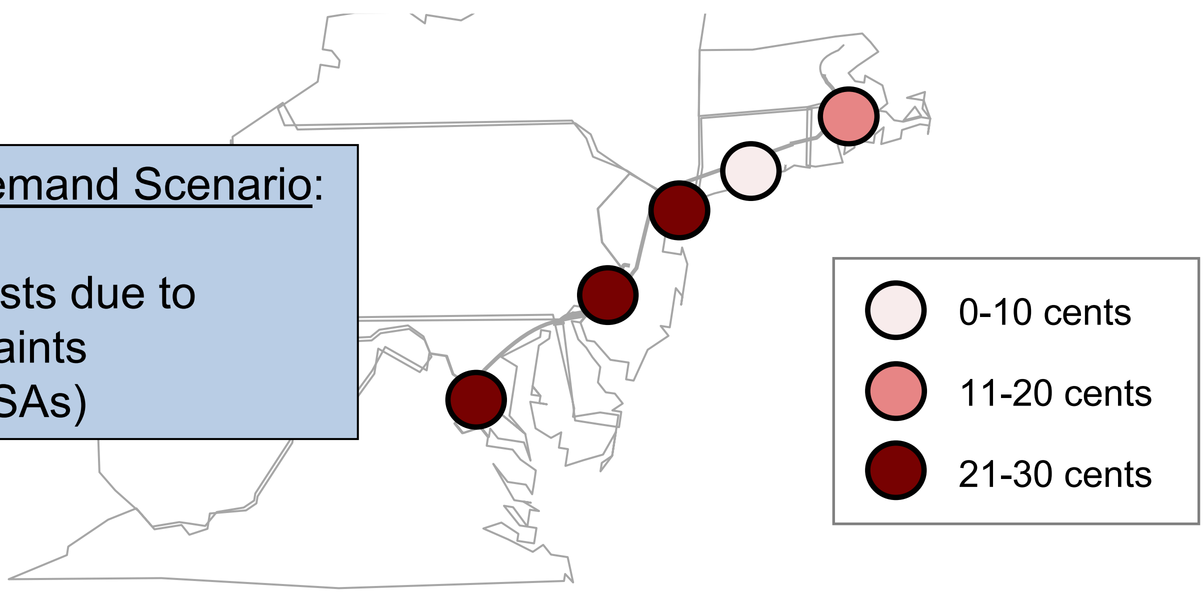


Effect of Carbon Constraints on Production Cost

	Lowest Cost Production Method		
Scenario	**No Carbon Constraints**	**With Carbon Constraints**	**Increase (cents/kg)**
1 Percent	Natural Gas	NG with Sequestration	30-70
	Biomass	Biomass	0
10 Percent	Natural Gas	NG with Sequestration	30-60
	Biomass	Biomass	0
	Coal	Biomass	0-15
	Coal	Coal with Sequestration	25-40
30 Percent	Biomass	Biomass	0
	Coal	Biomass	5-20
	Coal	Coal with Sequestration	25-30

<ins>30 Percent Demand Scenario</ins>:

Increase in costs due to carbon constraints (Combined MSAs)



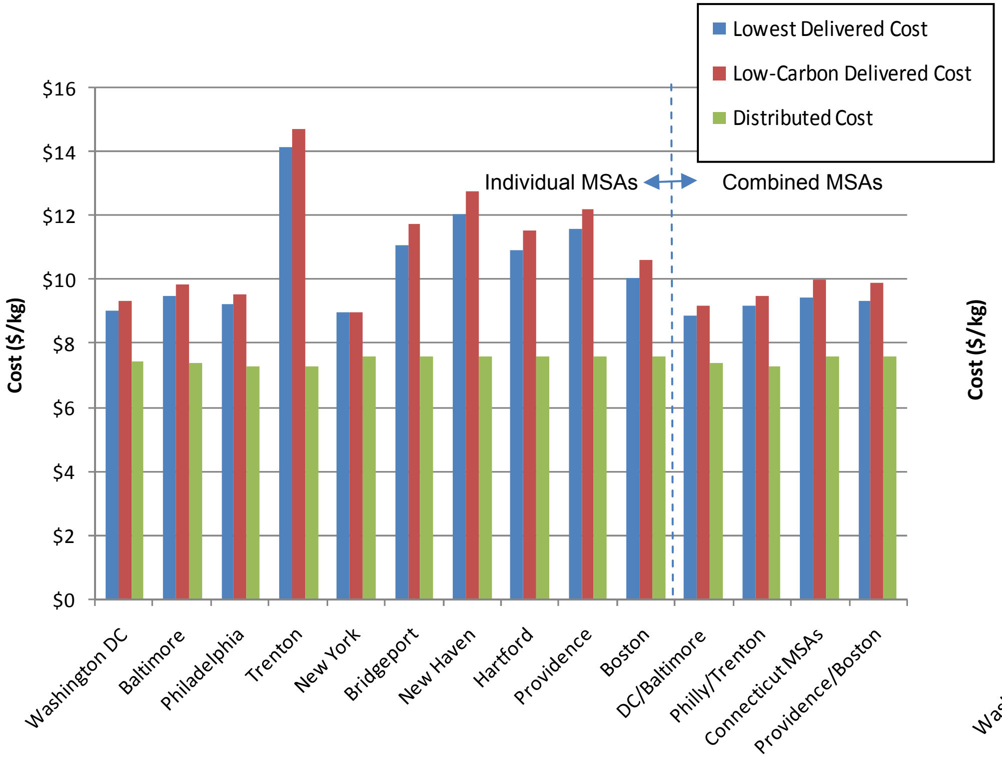
For Hydrogen Delivery Over 10% Demand, Pipeline is Low Cost

	1 Percent Demand Scenario		10 Percent Demand Scenario		30 Percent Demand Scenario	
MSA	**Distribution Method**	**Delivery Cost ($/kg)**	**Distribution Method**	**Delivery Cost ($/kg)**	**Distribution Method**	**Delivery Cost ($/kg)**
Washington DC	Compressed Truck	$6.60	Pipeline	$2.57	Pipeline	$1.91
Baltimore	Compressed Truck	$6.92	Pipeline	$2.48	Pipeline	$1.80
Philadelphia	Compressed Truck	$6.78	Liquid Truck	$2.63	Pipeline	$2.12
Trenton	Compressed Truck	$10.86	Pipeline	$2.75	Pipeline	$1.88
New York	Liquid Truck	$6.91	Liquid Truck	$2.50	Pipeline	$2.36
Bridgeport	Compressed Truck	$8.39	Pipeline	$2.75	Pipeline	$1.88
New Haven	Compressed Truck	$9.19	Pipeline	$2.88	Pipeline	$1.91
Hartford	Compressed Truck	$8.24	Pipeline	$2.67	Pipeline	$1.85
Providence	Compressed Truck	$8.17	Pipeline	$2.68	Pipeline	$1.85
Boston	Compressed Truck	$7.47	Comp.Truck	$2.75	Pipeline	$2.14
All MSAs	**n/a**	**$7.14**	**n/a**	**$2.59**	**n/a**	**$2.13**
DC/Baltimore	Compressed Truck	$6.55	Liquid Truck	$2.47	Pipeline	$2.07
Philly/Trenton	Compressed Truck	$6.76	Liquid Truck	$2.60	Pipeline	$2.14
New York	Liquid Truck	$6.91	Liquid Truck	$2.50	Pipeline	$2.36
Connecticut MSAs	Compressed Truck	$7.01	Comp.Truck	$2.78	Pipeline	$2.03
Providence/Boston	Compressed Truck	$6.82	Liquid Truck	$2.63	Pipeline	$2.23
All MSAs	**n/a**	**$6.80**	**n/a**	**$2.55**	**n/a**	**$2.22**

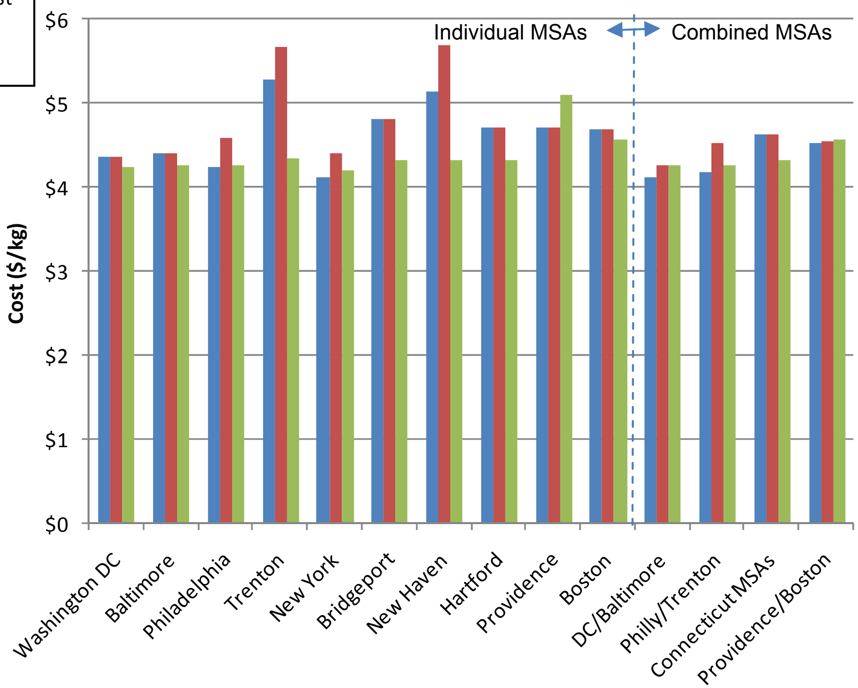
For 1% scenario, compressed trucks are low cost option (except New York, where liquid trucks favored). Pipeline becomes low cost option for most areas at 10%, unless MSAs are combined, then economies of scale favor truck delivery. At 30%, pipeline is low cost option for all areas, and combining MSAs is no longer beneficial.

At Lower Demands, Distributed Production Beats or Challenges Delivered Options

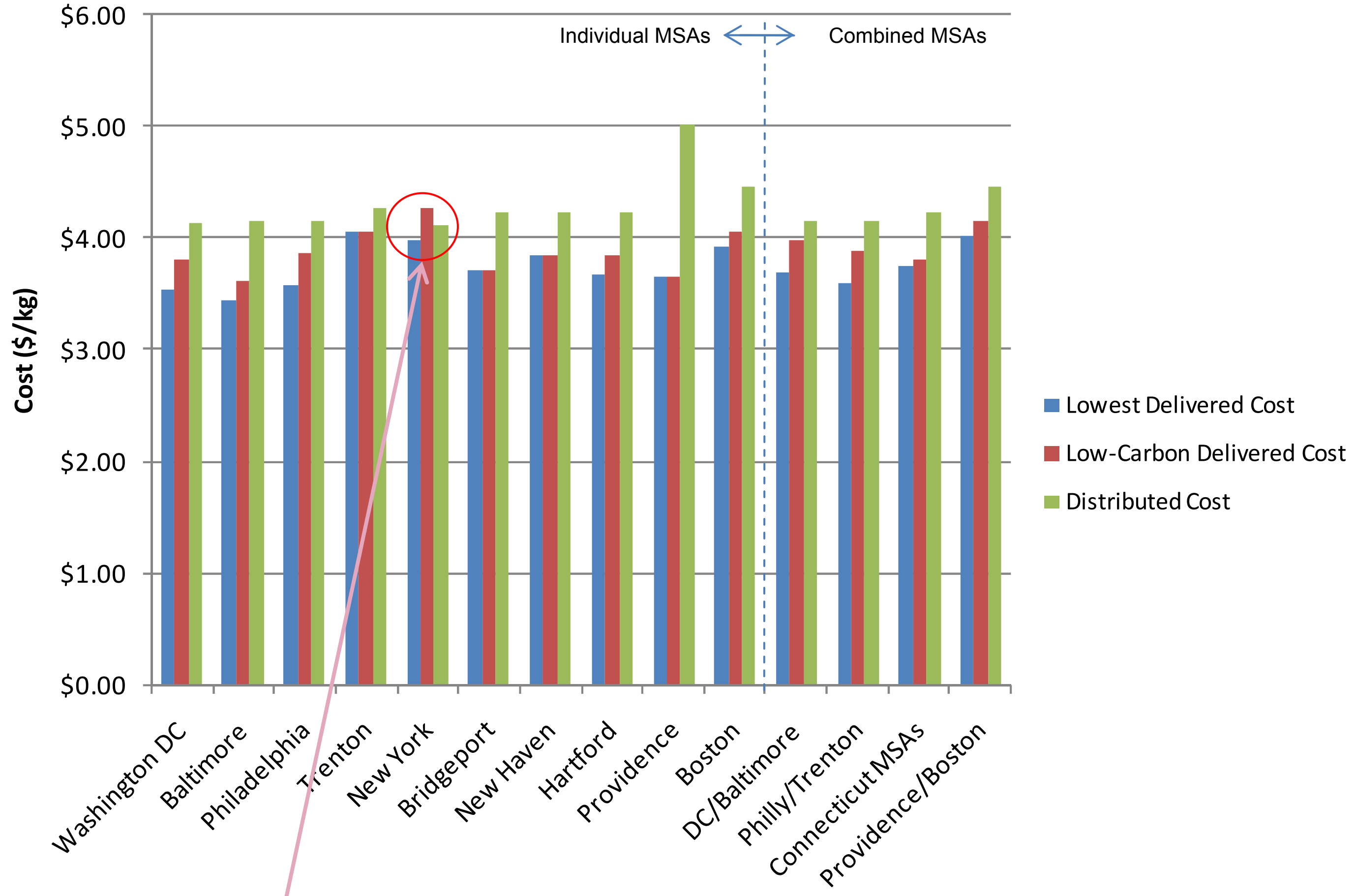
1% Demand Scenario:
distributed production lowest cost for all areas



10% Demand Scenario:
distributed production still ideal in most areas, but delivered hydrogen starting to compete



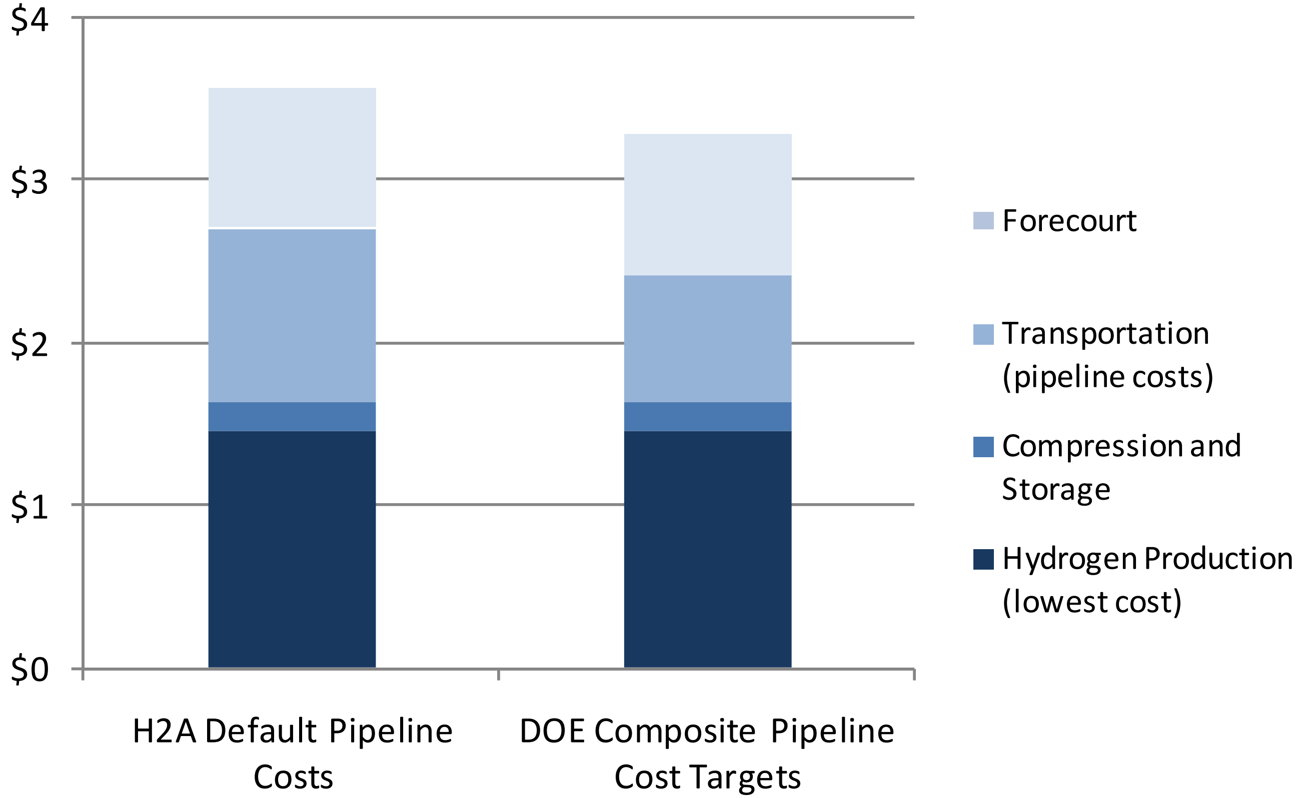
At 30 Percent Demand, Delivered Hydrogen is Less Costly



Only outlier is New York, where carbon constraints would continue to favor distributed production. Also, in New Haven and Providence, biomass and coal are very competitive, so carbon constrained costs are roughly equal to costs without such constraints.

Review of Cost Components: Challenge of Reaching $3/kg

Philadelphia's Delivered Costs at the 30 Percent Demand Scenario

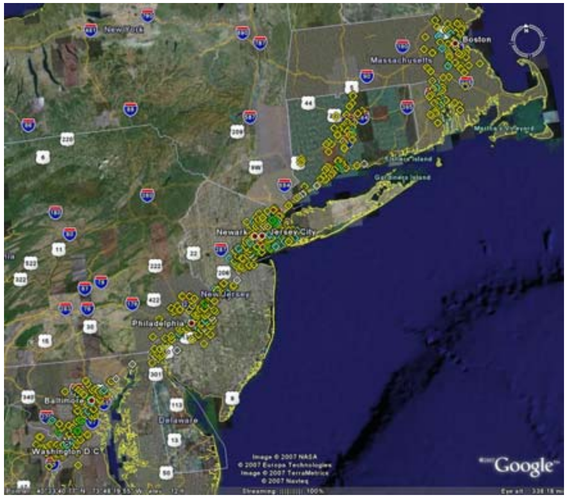


After transportation costs were reduced when using the DOE composite pipeline cost targets, hydrogen production and forecourt are larger contributors to the total delivered cost.

Summary, Phase II-NE I95 Corridor Conclusions and Issues

- Distance is more important than production volume
  - Distributed production competitive through 10% demand levels
  - Multiple plants offer lower delivery cost at higher (30%) demands
  - Production economies matter less
  - Still short of DOE $3/kg cost target
- Reduction in feedstock cost and delivery infrastructure key to long term costs
  - As production volumes increase, coal offers lowest cost as reduced feedstock cost overcome high capital cost
  - As distribution volumes increase, dedicated pipelines offer lowest cost
  - Lower cost composite pipelines would drive down transport costs, but production and forecourt costs need improvement
  - Impact of carbon constraints deters coal with sequestration unless very high production volume
- Differences in production and delivery options define economic tradeoffs along I-95 corridor

Future Work - I95 Hydrogen Corridor Transitions Scenarios



- Investigate the potential dual use options, developing a hydrogen infrastructure
  - Forklifts in warehouse, replacing battery usage
  - Premium power and backup power installations with hydrogen fuel cells providing the power
  - Transmission load pockets where hydrogen can provide local, reduce emission generation
  - Fleets as a first adopter of hydrogen vehicles
  - Airports, looking at hydrogen tugs and other hydrogen vehicles
  - Military installations and their possible need for hydrogen
  - Big box retailers

- Explore the dual use options, identifying anchor projects in the MSA clusters.
- Evaluate indigenous energy resources with an emphasis on renewable feedstocks for hydrogen
- Work with existing organizations to identify opportunities.