Hydrogen Production in a Greenhouse Gas Constrained Situation

Bill Dougherty and Sivan Kartha

Tellus Institute

Hydrogen, Fuel Cells, and Infrastructure Technologies Program Review Meeting

May 26, 2004

This presentation does not contain any proprietary or confidential information.

Objectives

To examine in a detailed quantitative manner plausible scenarios for a transition to a hydrogen economy.

To explicitly illustrate the staging and sequencing of major phases of the transition scenarios and their implications.

To quantify the the greenhouse gas (GHG) reduction benefits of each of the transition scenarios.

To explore the spatial characteristics of the transition scenarios based on GIS analyses for four greater metropolitan areas of the USA: Boston, Denver, Houston, & Seattle

To account for relevant techno-economic and policy factors:

- demographic and spatial characteristics,
- cost & performance of technologies for H_2 production, distribution, storage, and end-use (both transportation and stationary)
- regulatory contexts
- timing and extent of transition pathways

Budget

- Total funding for project: $309,345
  - Initial tasks: $215,488
  - Proposal modification: $ 93,857
- Funding for FY93: $200,000

Technical Barriers and Targets

- This project is a cross-cutting analysis, linked most closely to the Technology Validation component of the Technical Plan. It seeks to contribute to "testing complete system solutions that will address all elements of infrastructure and vehicle technology and investigate novel new approaches…"
- As a long-term scenario analysis, it helps to "validate whether the technical targets for the individual components (developed within other subprograms) can still be met when integrated into a complex system"
- Specifically, this project relates to the following subtasks within Technical Tasks 6 –"Technical Analysis":
  - Analyze hydrogen and electricity as energy carriers and evaluate potential synergies from "marrying" the electrical transmission and transportation systems.
  - Analyze integrated renewable hydrogen production systems that combine electrolysis powered by wind, solar, hydropower, or geothermal with biomass gasification systems.

These tasks relate to barriers A, B, C, D, F, G, H, & I.

Approach

- This project examines the evolution of hydrogen technologies and a hydrogen infrastructure that meets the objectives laid out in the DOE's *Hydrogen, Fuel Cells & Infrastructure Program Multi-year Plan* to realize energy security, environmental, and economic benefits. The analysis:
  - Takes an integrated approach, considering the entire chain of hydrogen from energy resource to production to distribution to end-use.
  - Considers the use of hydrogen as a transportation fuel as well as a fuel for use in in stationary applications.
  - Takes a long-term perspective, constructing plausible scenarios by which hydrogen could expand in a gradual and orderly manner until it comprises the majority of transportation fuel use.
  - Accounts for the important spatial aspect of infrastructure development, using a GIS analysis to create realistic infrastructure scenarios for four cities: Denver, Houston, Boston, and Seattle.
  - Quantifies the greenhouse gas benefits deriving from various integrated technological pathways.
  - Relies on techno-economic assumptions of the hydrogen analysis community, research literature, and technology developers.
  - Places the analysis against an energy and policy backdrop derived from the National Energy Modeling System (NEMS) of the DOE.

Project Safety

As a technological analysis, this project has no direct safety requirements, targets, or objectives. However, it is designed to take into account safety requirements in its examination of the evolution of a hydrogen infrastructure. It is based on techno-economic parameters and assumptions that are consistent with appropriate safety regulations and standards with respect to technologies and operating procedures, which affect underlying assumptions regarding labor, materials, etc. This is particularly relevant to the estimated costs and performance of:

- transmission and distribution infrastructure (pipelines and tanker trucks),
- dispensing (refueling apparatus), and
- end-use (vehicles and stationary appliances)

Project Timeline

10/02 – 4/03	5/03 – 10/03	11/03 – 4/04	4/04 – 7/04
Phase I	Phase II	Phase III	Phase IV

- Phase I
  1. Techno-economic assessment (H_2 production, distribution, end-use)
  2. Formulation of references cases and alternative scenarios
- Phase II
  3. Creation of analytical framework, integration of NEMS and LEAP models
  4. Acquisition of city-specific data and GIS information
- Phase III
  5. Finalizing techno-economic assumptions
  6. Encoding data and creation of national and city scenarios
- Phase IV
  7. Refining scenarios
  8. Finalizing results

Technical Accomplishments/Progress

technology		electrolysis	electrolysis	electrolysis	electrolysis	NG reforming	NG reforming	NG reforming	Coal gas/ref	Coal gas/ref	Biomass gas/ref
technology		small-scale distributed (alkaline)	small-scale distributed (e.g., mass-produced PEM based)	large-scale centralized	large-scale centralized	large-scale centralized	large-scale centralized with CO2 sequestration	small-scale distributed	large-scale centralized	large-scale centralized with CO2 sequestration	large-scale centralized
time frame / tech dev't		current	projected	current	projected	current	current	projected	current	current	current
scale		~100 kW	~100 kW	~30 MW	~30 MW	~300 Mscf	~300 Mscf	~0.1 Mscfr	~300 Mscf	~300 Mscf	~100 Mscf
scale	kg/day	~70 kg/day	~70 kg/day	~20 t/day	~20 t/day	~600 t/day	~600 t/day	~250 kg/day	~600 t/day	~600 t/day	~100 t/day
lifetime	years										
installed capital cost	$/kW	$ 800	$ 300	$ 600	$ 250						
installed capital cost	$/(kg/day)	$ 1,110	$ 416	$ 832	$ 347	$ 430	$ 700	$2,000	$ 1,750	$ 1,950	$ 1,650
O&M costs	% of capital	4%	4%	4%	4%	4%	4%	4%	4%	4%	4%
capacity factor		75%	80%	83%	87%	80%	80%	80%	80%	80%	80%
efficiency definition	LHV basis	elec to H2	elec to H2	elec to H2	elec to H2	NG to H2	NG to H2	NG to H2	Coal to H2	Coal to H2	Bio to H2
efficiency value	% (LHV basis)	70%	80%	75%	85%	76%	73%	69%	60%	60%	60%
capital recovery fac	%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%
feedstock price	$/XX	$ 0.08 / kWh	$ 0.08 / kWh	$ 0.05 / kWh	$ 0.05 / kWh	$ 3.00 / GJ	$ 3.00 / GJ	$ 4.50 / GJ	$ 1.00 / GJ	$ 1.00 / GJ	$ 2.50 / GJ
feedstock cost	$/kg (eq)	$ 2.66	$ 2.66	$ 1.66	$ 1.66	$ 0.36	$ 0.36	$ 0.54	$ 0.12	$ 0.12	$ 0.30
electricity requirement	% (LHV H2)	2%	2%	2%	2%	0%	0%	0%	-5%	-3%	-3%
capital costs	$/kg H2	$ 0.41	$ 0.14	$ 0.27	$ 0.11	$ 0.15	$ 0.24	$ 0.68	$ 0.60	$ 0.67	$ 0.56
O&M costs	$/kg H2	$ 0.16	$ 0.06	$ 0.11	$ 0.04	$ 0.06	$ 0.10	$ 0.27	$ 0.24	$ 0.27	$ 0.23
feedstock cost	$/kg H2	$ 3.80	$ 3.33	$ 2.22	$ 1.96	$ 0.47	$ 0.49	$ 0.79	$ 0.20	$ 0.20	$ 0.50
total production cost	**$/kg H2**	**$ 4.37**	**$ 3.53**	**$ 2.60**	**$ 2.11**	**$ 0.68**	**$ 0.83**	**$ 1.74**	**$ 1.04**	**$ 1.13**	**$ 1.29**

- Techno-economic parameters underlying hydrogen production pathways.

Technical Accomplishments/Progress

Technology Comparison (Tank to wheel fuel economy)

	Fraction of stock	*ICE miles/gallon*	*ICE Moderate**	*ICE Aggressive**	*Hybrid**	*Advanced Hybrid ****	*Hybrid (AEO 2003)!!*	*FCV****	*FCV+*	*FCHV****	*FCHV +*	*FCHV^^*	*FCHV Target ^**	*FCHV Target ^^^*	*H2 ICE /HEV#*	
		2000	***2012***	***2020***	***2020***	***2040***	***2000-2010***	***2020***	***2012***	***2020***	***2012***	***2020***	***2040***	***2040***	***2012***	***2020***
Mini	2%	24.6	34.9	38.5	50.6	56.7	35.5	82.9	55.2	101.3	60.0	69.0	116.6	75.9	43.2	49.7
Subcompact	20%	30.8	43.7	48.4	63.4	71.2	45.0	104.0	68.9	127.1	75.7	87.1	146.3	95.8	54.5	62.7
Compact	27%	30.4	43.2	47.7	62.6	70.2	43.9	102.6	68.4	125.4	74.3	85.4	144.4	93.9	53.5	61.5
Midsize car	37%	27.1	42.3	47.4	61.2	69.3	38.8	91.5	61.3	111.8	65.8	75.7	128.7	83.2	47.4	54.5
Large Car	14%	25.4	39.6	44.5	57.4	65.0	36.6	85.7	57.1	104.8	62.1	71.4	120.7	78.5	44.7	51.4
Average Cars	100%	***28.4***	***42.3***	***47.1***	***61.3***	***69.1***	***41.0***	96.0	64.0	117.3	***69.5***	***79.9***	135.1	***87.9***	***50.0***	***57.5***
Small Pickup	12%	23.7	32.5	38.2	49.8	55.9	38.8	80.0	56.8	97.8	61.7	71.0	112.6	78.1	44.4	51.1
Large Pickup	27%	20.0	27.5	32.3	42.1	47.3	36.6	67.6	48.0	82.7	52.2	60.0	95.2	66.0	37.6	43.2
Small van	14%	26.2	40.6	48.5	64.2	73.2	35.5	88.4	62.8	108.1	68.2	78.4	124.5	86.3	49.1	56.5
Large Van	5%	19.8	30.6	36.6	48.4	55.2	45.0	66.7	32.0	81.5	34.4	39.6	93.9	43.5	24.8	28.5
Small SUV	9%	22.2	37.7	43.9	58.3	66.8	43.9	74.8	53.1	91.4	57.7	66.3	105.2	73.0	41.5	47.8
Large SUV	33%	17.3	29.4	30.8	40.7	46.2	38.8	58.4	41.5	71.4	45.0	51.8	82.2	57.0	32.4	37.3
Average Trucks	100%	***20.6***	***31.7***	***36.1***	47.5	***53.8***	***33.8***	69.7	49.5	85.2	***53.8***	***61.8***	98.1	***68.0***	***38.7***	***44.5***

	stock	new
Total cars	1.28E+08	8.85E+06
Total trucks	7.38E+07	8.39E+06
	2.01E+08	

*DeCicco, An, and Ross (2001). Note, for hybrids, we assume the "Full" package, and move to 2020, the 2012 assumptions incl. weight optimization + 40% peak elec. Propulsion.
***MIT (Weiss et al, 2003) cf. Ogden et al (2002) with 58 mpg. MIT study assumed 2020
^* Toyota (Wheel to tank) http://www.futurecarcongress.org/fcc2002/presentations/nakamura.pdf
# Assume 80% of FCHV (Keller and Lutz, 2002) and 10% penalty for dual fuel
^^ 15% increase over 2012 numbers
^^^ 10% increase over 2020 numbers
!! EEA numbers
+ Ford except for Light Trucks -- which is proportional to hybrid improvement for cars

- Vehicle techno-economic parameters

Technical Accomplishments/Progress

Run Status

Vehicle type:	HDVs	
Scenario:	Business-as-usual (AEO2003)	
Area:		
Total number of runs:	1	
Processing Run #:	1	*Setting up run according to user specifications... please be patient...*

Incorporating assumptions

- Annual vehicle sales
- Vehicle miles traveled per vehicle type
- Existing vehicle fuel economy
- New vehicle fuel economy
- Hydrogen production technology shares
- Hydrogen production technology capital costs
- Fossil fuel prices
- Vehicle incremental costs
- Upstream inputs to fuel and hydrogen production
- Upstream inputs to power generation
- Electric sector expansion characteristics
- Carbon emission factors
- New vehicle survival rates
- Vehicle stock shares in 2000

Computing energy, carbon, and cost outputs

- Vehicle stock levels
- Vehicle VMT levels
- Vehicle energy use
- Hydrogen use in new fuel cell vehicles
- Vehicle carbon emissions for existing and new conventional vehicles
- Vehicle incremental costs for high efficiency and fuel cell vehicles
- Vehicle fuel costs for existing vehicles
- Vehicle fuel costs for new vehicles
- Upstream energy use & carbon emissions by existing conventional vehicles
- Upstream energy use & carbon emissions by new conventional vehicles
- Upstream energy use & carbon emissions by new fuel cell vehicles
- Upstream fuel costs for existing conventional vehicles
- Upstream fuel costs for new conventional vehicles
- Upstream fuel costs for new fuel cell vehicles
- Capital costs for H2 infrastructure for new fuel cell vehicles
- Standardized output tables

Technical Accomplishments/Progress

Run Status

Vehicle type: LDVs
Scenario: BAU (AEO2003)
Area: All cities and regions
Total number of runs: 10
Processing Run #: 5 *(now processing the New England region for the selected scenario)*

Incorporating assumptions

- Annual vehicle sales
- Vehicle miles traveled per vehicle type
- Existing vehicle fuel economy
- New vehicle fuel economy
- Hydrogen production technology shares
- Hydrogen production technology capital costs
- Fossil fuel prices
- Vehicle incremental costs
- Upstream inputs to fuel and hydrogen production
- Upstream inputs to power generation
- Electric sector expansion characteristics
- Carbon emission factors
- New vehicle survival rates
- Vehicle stock shares in 2000

Computing energy, carbon, and cost outputs

- Vehicle stock levels
- Vehicle VMT levels
- Vehicle energy use
- Hydrogen use in new passenger and fleet rollover fuel cell vehicles
- Vehicle carbon emissions for existing and new conventional vehicles
- Vehicle incremental costs for high efficiency and fuel cell vehicles
- Vehicle fuel costs for existing vehicles
- Vehicle fuel costs for new vehicles
- Vehicle fuel costs for fleet rollover vehicles
- Upstream energy use & carbon emissions by existing conventional vehicles
- Upstream energy use & carbon emissions by new conventional vehicles
- Upstream energy use & carbon emissions by fleet rollover conventional vehicles
- Upstream energy use & carbon emissions by new passenger fuel cell vehicles
- Upstream energy use & carbon emissions by new fleet fuel cell vehicles
- Upstream energy use & carbon emissions by fleet rollover fuel cell vehicles
- Upstream fuel costs for existing conventional vehicles
- Upstream fuel costs for new conventional vehicles
- Upstream energy use & carbon emissions by fleet rollover conventional vehicles
- Upstream fuel costs for new passenger fuel cell vehicles
- Upstream fuel costs for new fleet fuel cell vehicles
- Upstream fuel costs for fleet rollover fuel cell vehicles
- Capital costs for H2 infrastructure for new fuel cell vehicles
- Capital costs for H2 infrastructure for fleet rollover fuel cell vehicles
- Standardized output tables

Total elapsed time up through the city of Seattle for the selected scenario is 2.114063 minutes

Assumption Spreadsheets

Return to Assumptions

Vehicle	Spreadsheet Location and Name	Description
	C:\H2 TRANSPORT MODEL\INPUTS\LDV\SALES-C&N.xls	LDV sales - cities and USA (CHELLA)
	C:\H2 TRANSPORT MODEL\INPUTS\LDV\SALES-R.xls	LDV sales - regions and rest-of-country regions (CHELLA)
	C:\H2 TRANSPORT MODEL\INPUTS\LDV\SR.xls	LDV survival rates and BENCHMARKING to NEMS (BILL)
	C:\H2 TRANSPORT MODEL\INPUTS\LDV\VMT-C&N.xls	LDV vehicle miles travelled - cities and USA (CHELLA)
	C:\H2 TRANSPORT MODEL\INPUTS\LDV\VMT-R.xls	LDV vehicle miles travelled - regions and rest-of-country regions (CHELLA)
	C:\H2 TRANSPORT MODEL\INPUTS\LDV\MPG NEW-C&N.xls	New LDV fuel economy - cities and USA (CHELLA)
	C:\H2 TRANSPORT MODEL\INPUTS\LDV\MPG NEW-R.xls	New LDV fuel economy - regions and rest-of-country regions (CHELLA)
	C:\H2 TRANSPORT MODEL\INPUTS\LDV\MPG EXIST-C&N.xls	Existing LDV fuel economy - cities and USA (BILL)
	C:\H2 TRANSPORT MODEL\INPUTS\LDV\MPG EXIST-R.xls	Existing LDV fuel economy - regions and rest-of-country regions (BILL)
	C:\H2 TRANSPORT MODEL\INPUTS\LDV\STOCK 2000.xls	Year 2000 LDV stock (BILL)
	C:\H2 TRANSPORT MODEL\INPUTS\LDV\V-COST.xls	Incremental capital costs for new LDVs (CHELLA)
	C:\H2 TRANSPORT MODEL\INPUTS\HDV\SALES ASSUMPTIONS-C&N.xls	HDV sales - cities and USA (CHELLA)
	C:\H2 TRANSPORT MODEL\INPUTS\HDV\SALES ASSUMPTIONS-R.xls	HDV sales - regions and rest-of-country regions (CHELLA)
	C:\H2 TRANSPORT MODEL\INPUTS\HDV\SURVIVAL RATE ASSUMPTIONS.xls	HDV survival rates and BENCHMARKING to NEMS (BILL)
	C:\H2 TRANSPORT MODEL\INPUTS\HDV\VMT ASSUMPTIONS-C&N.xls	HDV vehicle miles travelled - cities and USA (CHELLA)
	C:\H2 TRANSPORT MODEL\INPUTS\HDV\VMT ASSUMPTIONS-R.xls	HDV vehicle miles travelled - regions and rest-of-country regions (CHELLA)
	C:\H2 TRANSPORT MODEL\INPUTS\HDV\NEW VEHICLE MPG ASSUMPTIONS-C&N.xls	New HDV fuel economy - cities and USA (CHELLA)
	C:\H2 TRANSPORT MODEL\INPUTS\HDV\NEW VEHICLE MPG ASSUMPTIONS-R.xls	New HDV fuel economy - regions and rest-of-country regions (CHELLA)
	C:\H2 TRANSPORT MODEL\INPUTS\HDV\EXISTING VEHICLE MPG ASSUMPTIONS-C&N.xls	Existing HDV fuel economy - cities and USA (BILL)
	C:\H2 TRANSPORT MODEL\INPUTS\HDV\EXISTING VEHICLE MPG ASSUMPTIONS-R.xls	Existing HDV fuel economy - regions and rest-of-country regions (BILL)
	C:\H2 TRANSPORT MODEL\INPUTS\HDV\STOCK 2000 ASSUMPTIONS.xls	Year 2000 HDV stock (BILL)
	C:\H2 TRANSPORT MODEL\INPUTS\HDV\VEHICLE COST ASSUMPTIONS.xls	Incremental capital costs for new HDVs (CHELLA)
	UNDER CONSTRUCTION	Aircraft seat miles demand - cities and USA (CHELLA)
		Aircraft seat miles demand - regions and rest-of-country regions (CHELLA)
		Aircraft stock efficiency - cities and USA (CHELLA)
		Aircraft stock efficiency - regions and rest-of-country regions (CHELLA)
		Rail ton miles shipping - cities and USA (CHELLA)
		Rail ton miles shipping - regions and rest-of-country regions (CHELLA)
		Rail stock efficiency - cities and USA (CHELLA)
		Rail stock efficiency - regions and rest-of-country regions (CHELLA)
		Water seat miles demand - cities and USA (CHELLA)
		Water seat miles demand - regions and rest-of-country regions (CHELLA)
		Water stock efficiency - cities and USA (CHELLA)
		Water stock efficiency - regions and rest-of-country regions (CHELLA)
	C:\H2 TRANSPORT MODEL\INPUTS\LDV\H2-C&N.xls	H2 production shares for LDVs - cities and USA (SIVAN & BILL)
	C:\H2 TRANSPORT MODEL\INPUTS\LDV\H2-R.xls	H2 production shares for LDVs - regions and rest-of-country regions (SIVAN & BILL)
	C:\H2 TRANSPORT MODEL\INPUTS\HDV\H2 PRODUCTION ASSUMPTIONS-C&N.xls	H2 production shares for HDVs - cities and USA (SIVAN & BILL)
	C:\H2 TRANSPORT MODEL\INPUTS\HDV\H2 PRODUCTION ASSUMPTIONS-R.xls	H2 production shares for HDVs - regions and rest-of-country regions (SIVAN & BILL)
	C:\H2 TRANSPORT MODEL\INPUTS\H2 COST.xls	Capital costs for H2 production - (SIVAN)
	C:\H2 TRANSPORT MODEL\INPUTS\UF.xls	Upstream fuel inputs for H2 production and oil refining (BILL)
	C:\H2 TRANSPORT MODEL\INPUTS\UP.xls	Upstream fuel inputs for electricity production (BILL)
	C:\H2 TRANSPORT MODEL\INPUTS\ELEC-C&N.xls	Electric sector expansion - cities and USA (ALISON)
	C:\H2 TRANSPORT MODEL\INPUTS\ELEC-R.xls	Electric sector expansion - regions and rest-of-country regions (ALISON)
	C:\H2 TRANSPORT MODEL\INPUTS\C EF.xls	Carbon emission factors (BILL)
	C:\H2 TRANSPORT MODEL\INPUTS\FP-C&N.xls	Fuel and electricity prices - cities and USA (ALISON)
	C:\H2 TRANSPORT MODEL\INPUTS\FP-R.xls	Fuel and electricity prices - regions and rest-of-country regions (ALISON)

Technical Accomplishments/Progress

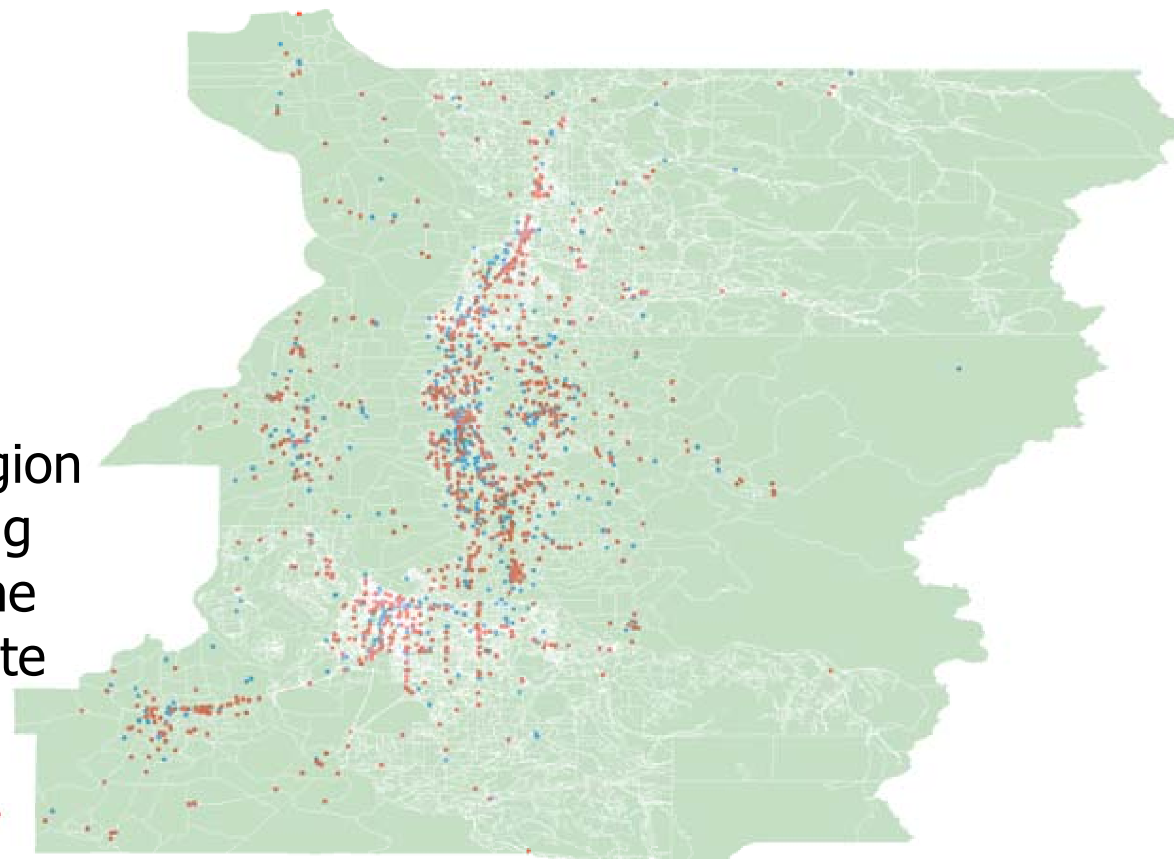
Conventional Vehicle Sales (thousands)

City	Vehicle	Refueling		2000	2010	2020	2030	2040
Atlanta	fleet cars	central refueling		3	2	3	3	3
	fleet light trucks	central refueling		1	2	2	2	2
	fleet cars	non-central refueling		28	24	28	30	30
	fleet light trucks	non-central refueling		14	17	21	22	22
	passenger cars	non-central refueling		104	108	121	132	144
	passenger light trucks	non-central refueling		91	99	118	128	140
			subtotal	*242*	*252*	*293*	*317*	*342*
Boston	fleet cars	central refueling		5	3	4	3	3
	fleet light trucks	central refueling		2	2	3	2	2
	fleet cars	non-central refueling		47	35	36	35	32
	fleet light trucks	non-central refueling		24	25	27	25	24
	passenger cars	non-central refueling		155	135	133	131	130
	passenger light trucks	non-central refueling		136	124	130	127	126
			subtotal	*369*	*326*	*332*	*324*	*317*
Chicago	fleet cars	central refueling		0	0	0	0	0
	fleet light trucks	central refueling		0	0	0	0	0
	fleet cars	non-central refueling		58	44	45	40	35
	fleet light trucks	non-central refueling		30	32	33	30	26
	passenger cars	non-central refueling		225	196	192	186	181
	passenger light trucks	non-central refueling		198	180	187	180	175
			subtotal	*511*	*453*	*456*	*435*	*416*
Denver	fleet cars	central refueling		2	1	1	1	1
	fleet light trucks	central refueling		1	1	1	1	1
	fleet cars	non-central refueling		17	13	15	15	14
	fleet light trucks	non-central refueling		9	10	11	11	10
	passenger cars	non-central refueling		67	65	69	73	78
	passenger light trucks	non-central refueling		59	60	68	71	75
			subtotal	*154*	*150*	*165*	*172*	*179*
Houston	fleet cars	central refueling		2	2	2	3	3
	fleet light trucks	central refueling		1	1	2	2	2
	fleet cars	non-central refueling		25	21	25	26	27
	fleet light trucks	non-central refueling		13	15	18	19	20
	passenger cars	non-central refueling		121	117	126	133	139
	passenger light trucks	non-central refueling		106	108	122	129	135
			subtotal	*268*	*264*	*295*	*312*	*326*
USA	fleet cars	central refueling		141	109	116	114	110
	fleet light trucks	central refueling		73	78	85	84	82
	fleet cars	non-central refueling		1,446	1,118	1,184	1,164	1,129
	fleet light trucks	non-central refueling		751	794	867	856	838
	passenger cars	non-central refueling		7,087	6,369	6,379	6,370	6,364
	passenger light trucks	non-central refueling		6,236	5,856	6,216	6,166	6,160
			subtotal	*15,734*	*14,323*	*14,847*	*14,754*	*14,683*

Results of city-specific aspects of scenario development: vehicle type and penetration

Technical Accomplishments/Progress

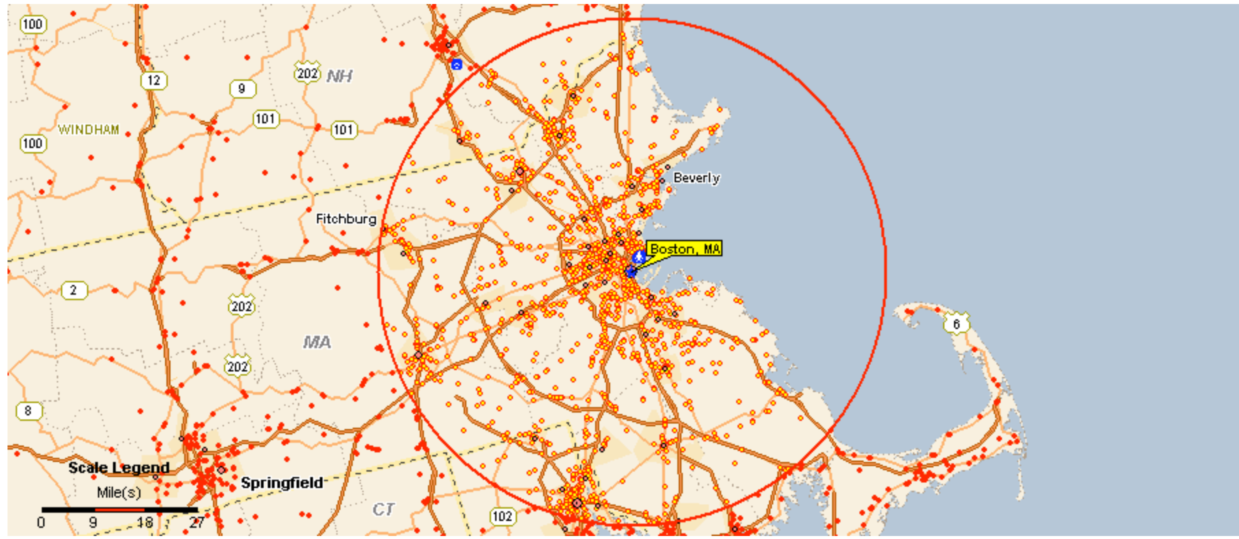
GIS map produced by displaying Seattle CMSA region by census block and layering onto these census blocks the geocoded locations of private (blue) and public (red) refueling stations that currently exist in the region.



Technical Accomplishments/Progress

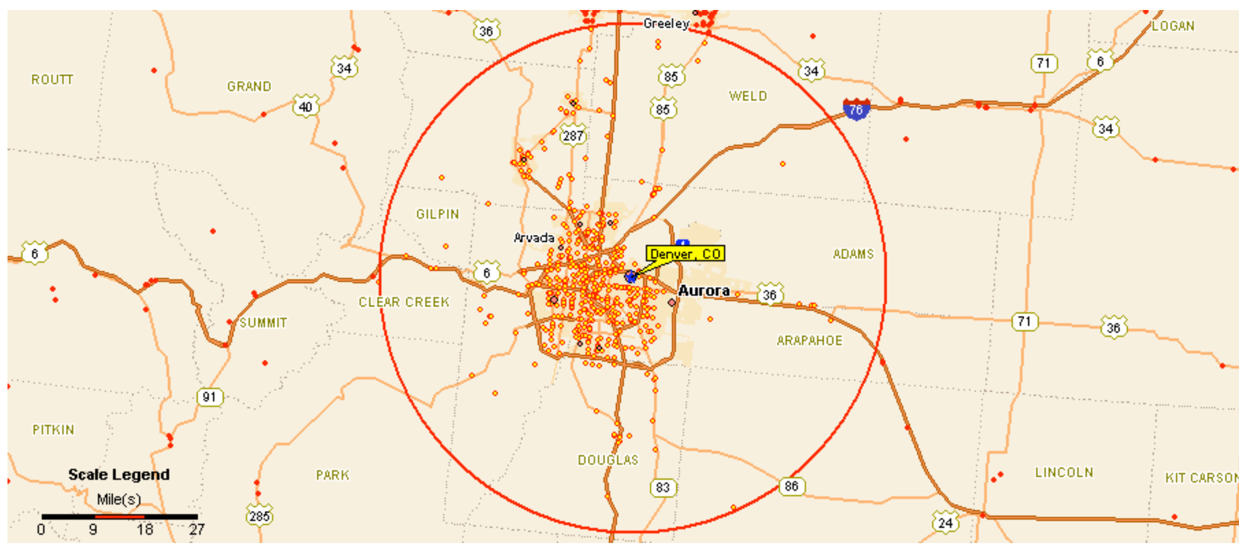
- **Boston**

1,446 refueling stations



- **Denver**

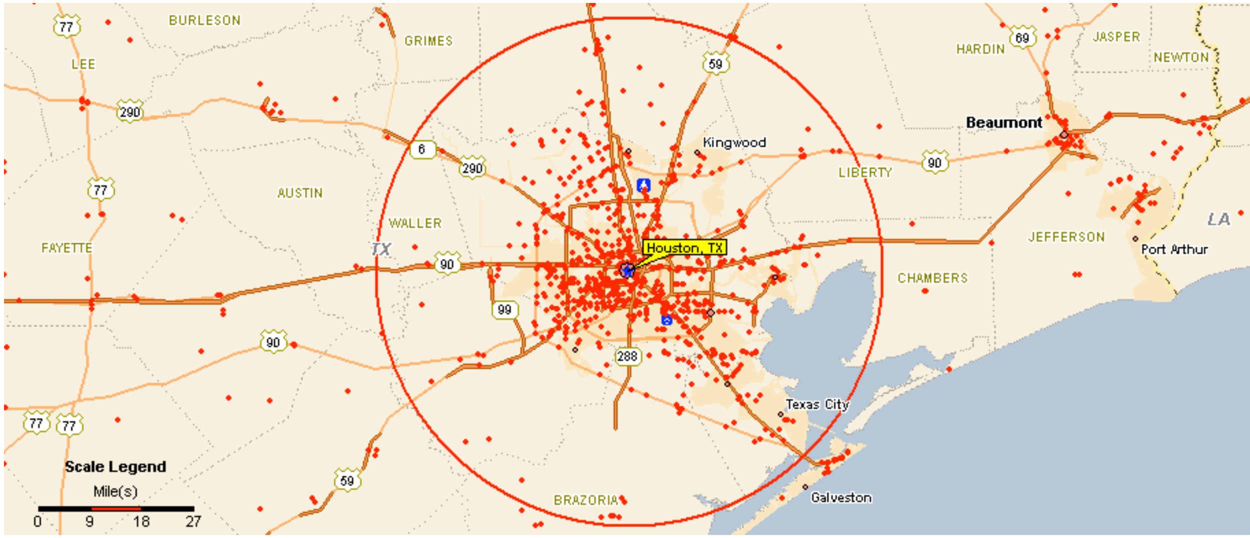
545 refueling stations



Technical Accomplishments/Progress

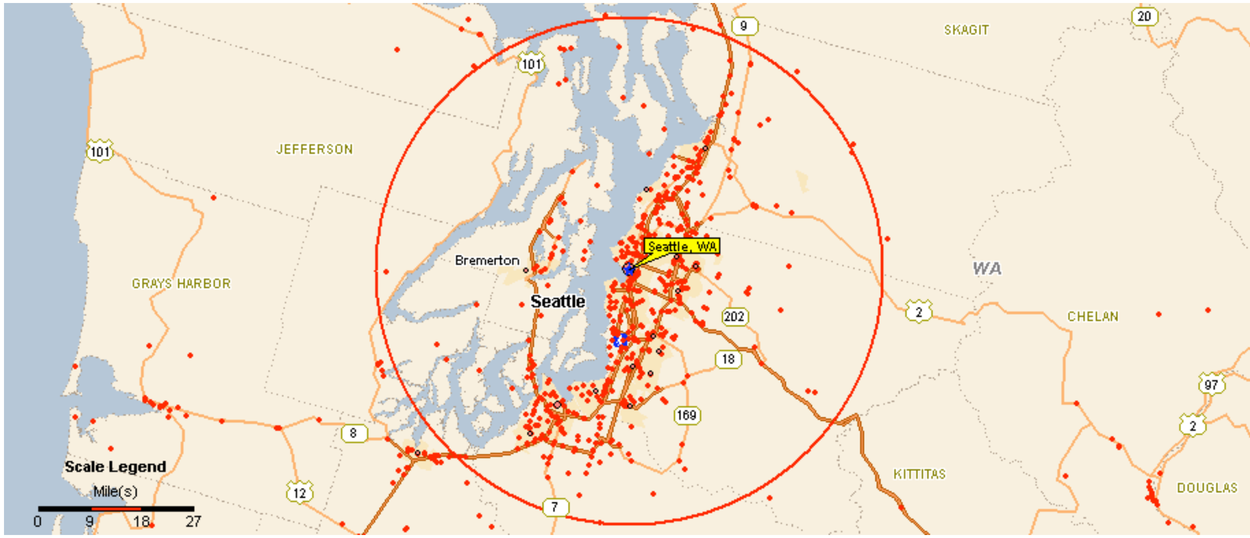
- ## Houston

825 refueling stations

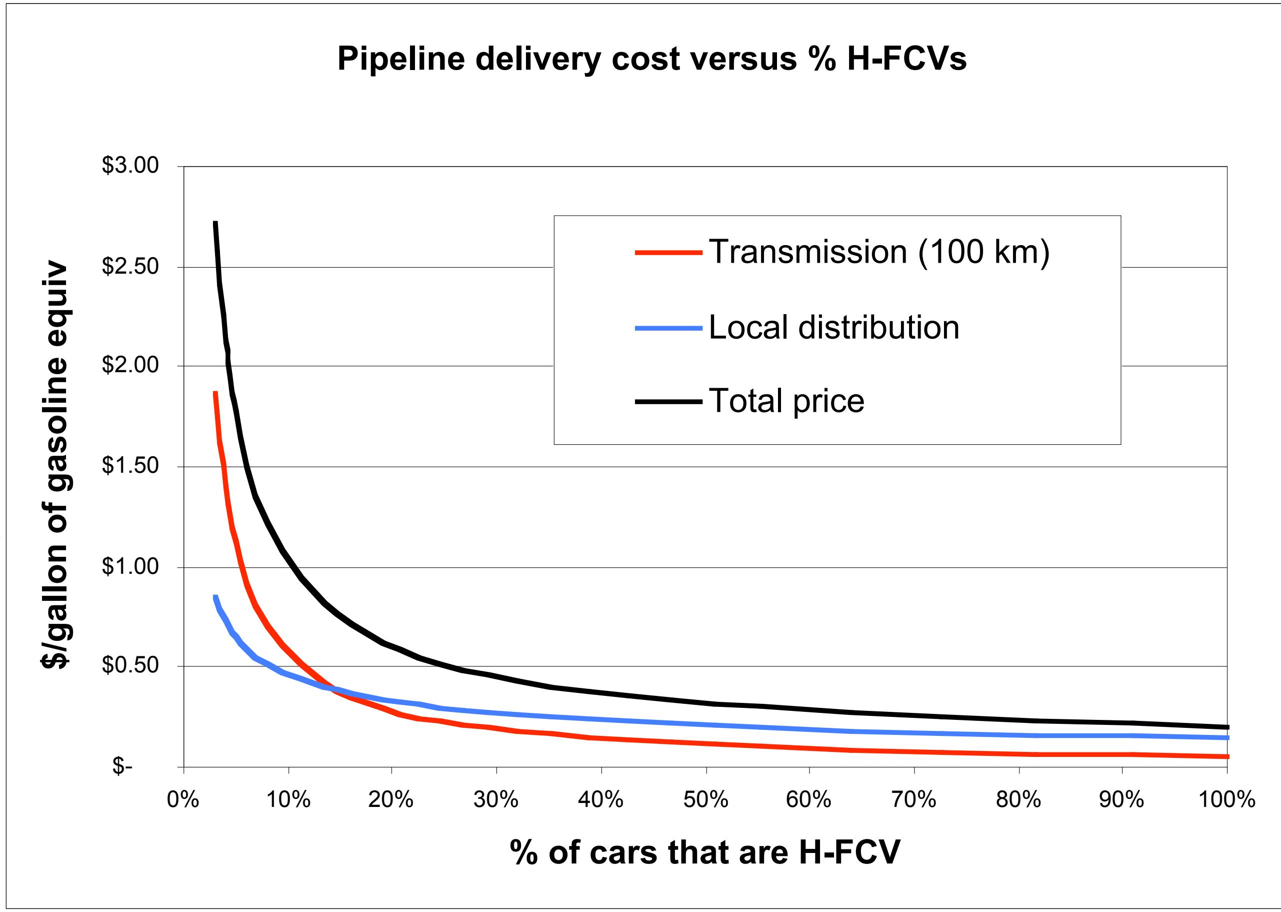


- ## Seattle

604 refueling stations



Technical Accomplishments/Progress



Density and scale of demand strongly influence cost of delivery The spatial distribution of density of demand is determined for each city via the GIS analysis.

Interactions and Collaborations

The "H_2A" group of hydrogen analysts convened by the DOE has provided a major source of interaction and technical exchange for this project. Technical inputs to this project have been checked for consistency with the cross-referenced to the products of the H2A group.

Name	Organization	Name	Organization
Ackiewicz, Mark	TMS (FE)	**Ogden, Joan**	Princeton
Anderson, John	TMS(FE)	**Paul Grant**	EPRI
Anderson, Rodney	NETL	**Pickard, Paul**	SNL
Amos, Wade	NREL	**Placet, Marylynn**	PNNL
Bernow, Steve	Tellus	**Ringer, Matt**	NREL
Berry, Gene	LLNL	**Sandell, Layla**	EPRI
Carole, Tracy	Energetics	**Schmetz, Ed**	FE
Clarke, Leon	LLNL	**Shainker, Robert**	EPRI
Cicero, Daniel	NETL	**Short, Walter**	NREL
Doctor, Richard	ANL	**Spath, Pam**	NREL
Driscoll, Dan	NETL	**Stewart, Jeffrey**	LLNL
Finizza, Tony	IHIG	**Sutterfield, Dexter**	FE
Freitas, Chris	NE	**Turn, Scott**	HNEI
Gray, David	Mitretek	**Wallace, Jim**	IHIG
Greene, David	ORNL	**Wang, Michael**	ANL
Harrison, Ken	EPA	**Wimer, John**	NETL
Henderson, Dave	NE	**Winslow, John**	NETL
James, Brian	DTI	**Maggie Mann**	NREL
Kartha, Sivan	Tellus Institute	**Mark Paster**	DOE
Kauffman, Matt	DOE	**Pete Devlin**	DOE
Lasher, Steve	TIAX	**Campbell, Karen**	Air Products
Lau, Francis	GTI	**Cohen, Steve**	Teledyne
Mears, Dan	TI	**Garces, Luis**	GE
Myers, Duane	DTI	**Jarlsjo, Bengt**	Entergy
Mintz, Marianne	ANL	**Uihlein, Jim**	BP
Molburg, John	ANL	**Twilley**	Framatome

Future Work

- The work for the coming year consists of refining the scenarios and finalizing results. Intermediate results will be used to the refine the details of the scenario construction. In particular:
  - The spatial GIS analysis will determine the growth over time in demand and demand density, and the relative contribution of different hydrogen production pathways (I.e., different feedstocks) and distribution modes (i.e., pipeline hydrogen, delivered hydrogen, and on-site hydrogen production).
  - The demand requirements derived from the national and city-specific analysis will be inputs to the integrated NEMS analysis, yielding impacts on the electric system and energy resource fuel prices.
  - Integrated energy system effects will provide economic results (costs and benefits relative to the corresponding reference scenarios)
  - Net environmental benefits will be examined from the integrated full-cycle perspective.