Hydrogen Production in a GHG-Constrained Situation: Major Results & Conclusions

Alison Bailie, Bill Dougherty, Charles Heaps, Sivan Kartha, and Chella Rajan

Tellus Institute

DOE Contractor's Meeting

26 May 2005

 #ANP 1

Objectives

To examine in a detailed quantitative manner plausible scenarios though 2050 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 FY04-5: $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

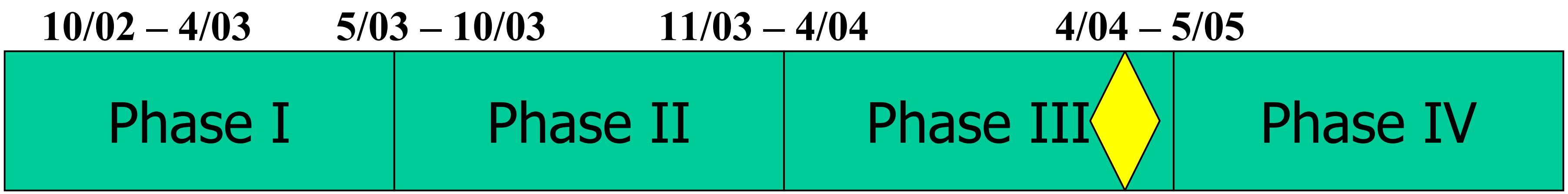
- This project examines the evolution of hydrogen technologies and a hydrogen infrastructure that meets the objectives laid out in the DOE's *Hydrogen, Fuel Cells & Infrastructure Program Multi-year Plan* to realize energy security, environmental, and economic benefits. The analysis:
  - Takes an integrated 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 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 development scenarios to 2050 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

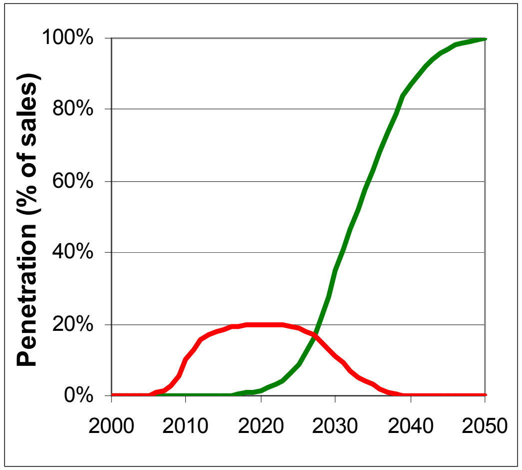


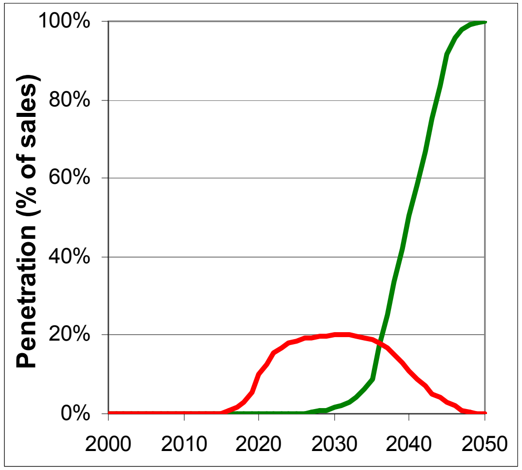
- Phase I
  1. Techno-economic assessment (H_2 production, distribution, end-use)
  2. Formulation of references cases and alternative scenarios
- Phase II
  3. Creation of analytical framework, integration of NEMS and LEAP models
  4. Acquisition of city-specific data and GIS information
- Phase III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

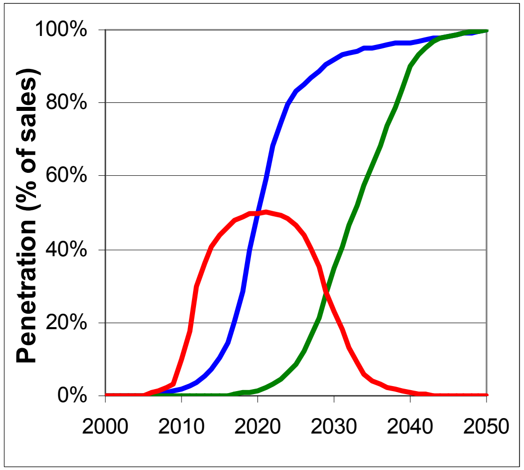
Overview

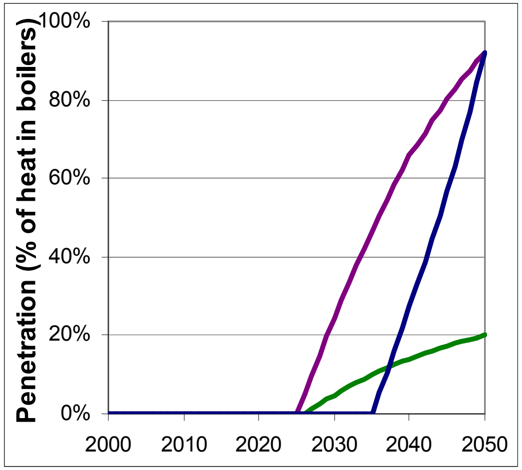
- Hydrogen Demand Assumptions
- Analysis framework – GIS analysis, H2 demand density, infrastructure elements, scenarios
- Major results (USA) – H2 demand, infrastructure required, CO2 emissions, delivered costs
- Major conclusions

Fuel Cell Penetration Schedule – 4 CMSAs & the USA

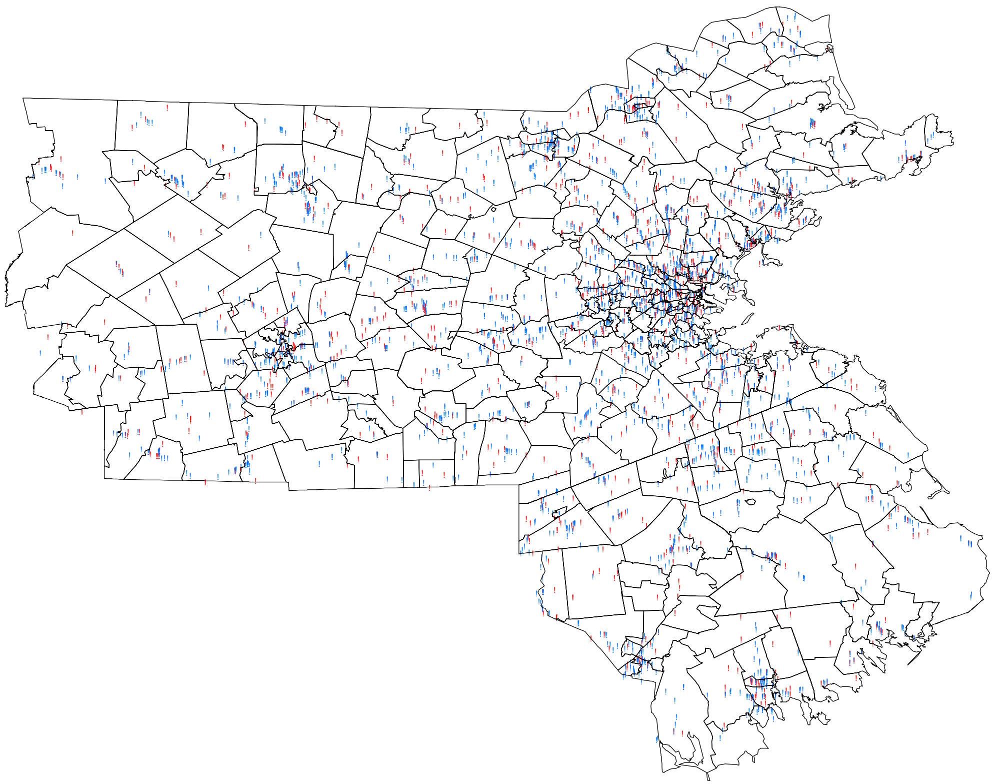




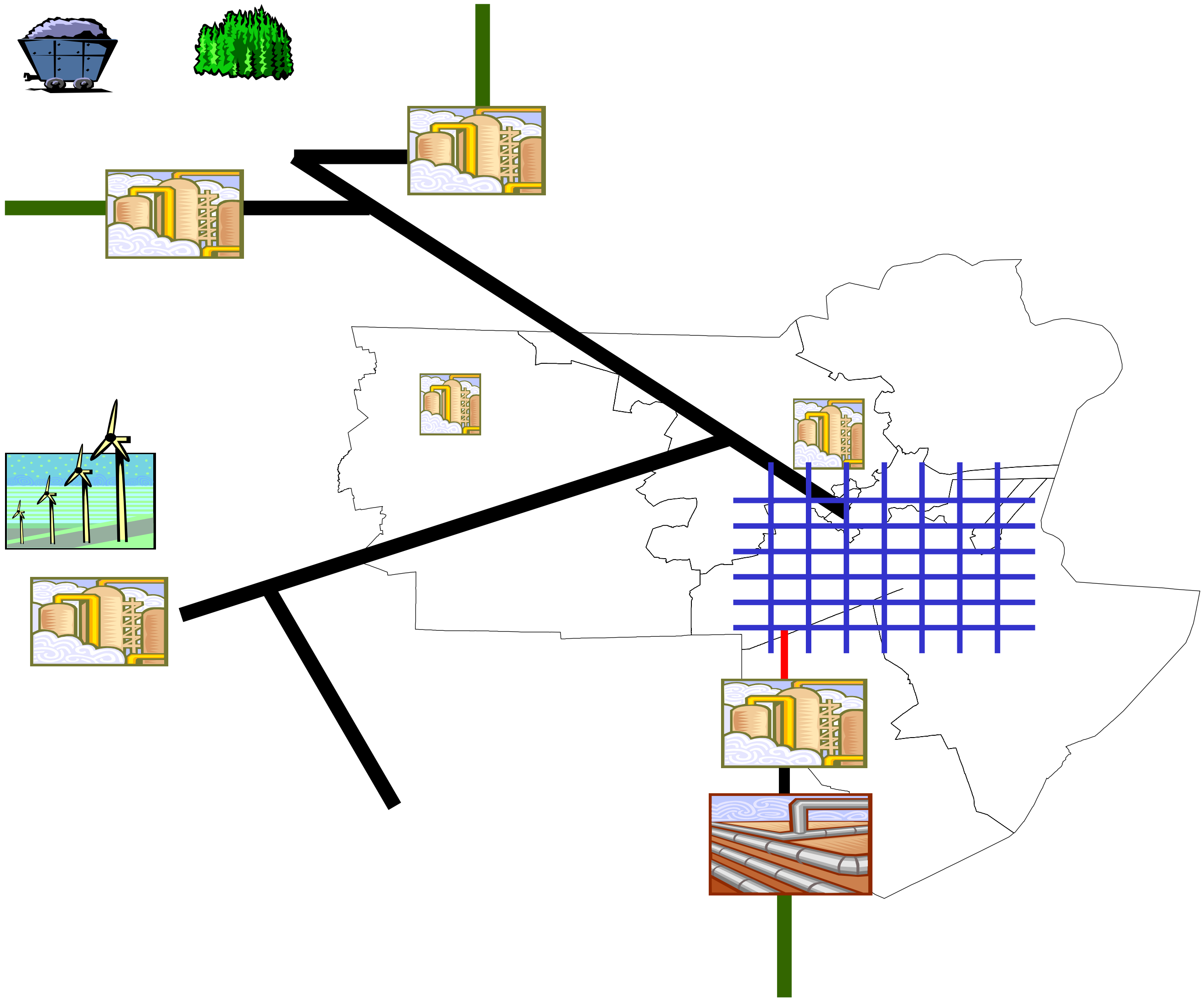




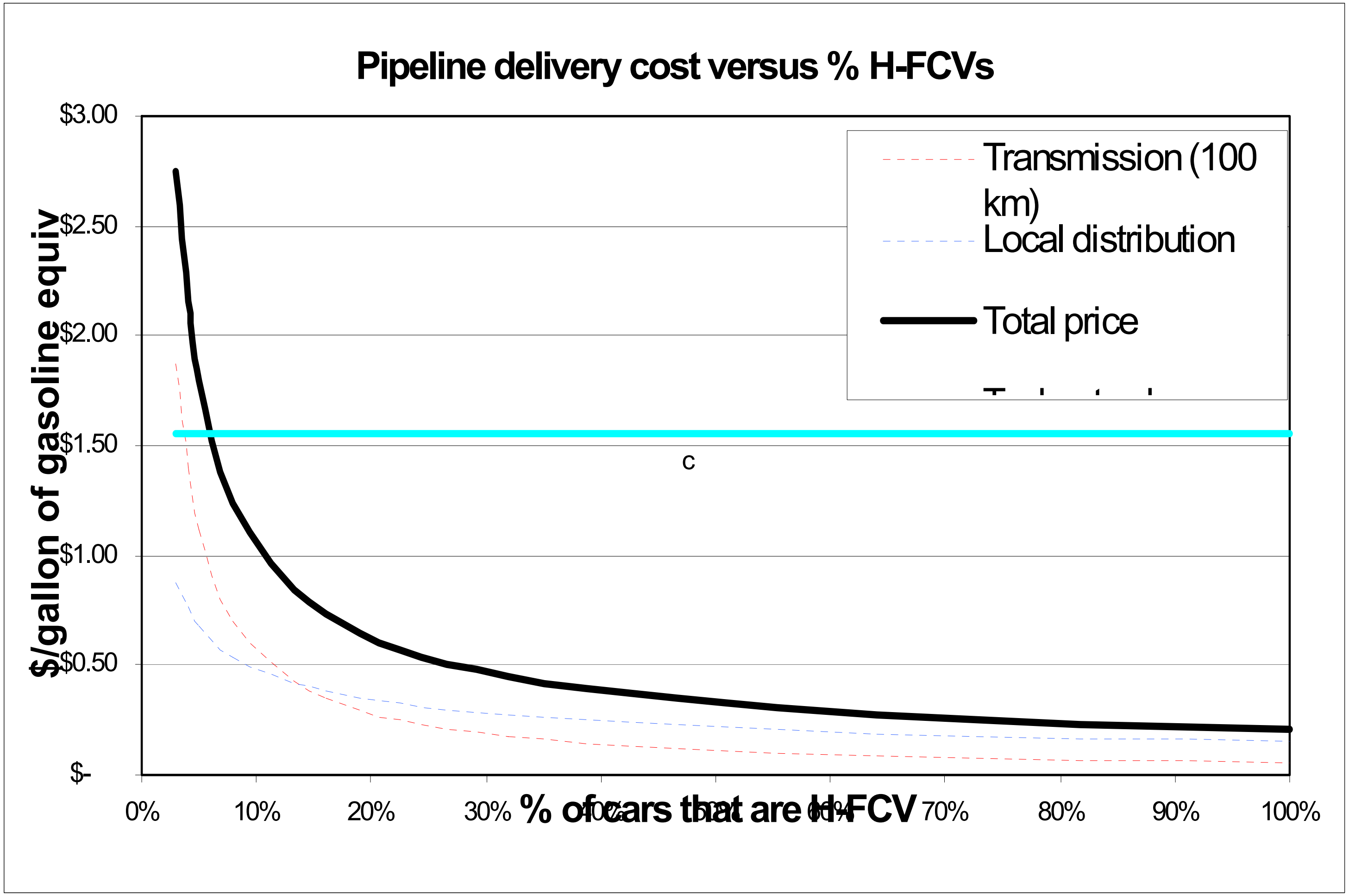
Hydrogen Refueling Stations – Boston Retail and Fleet Stations



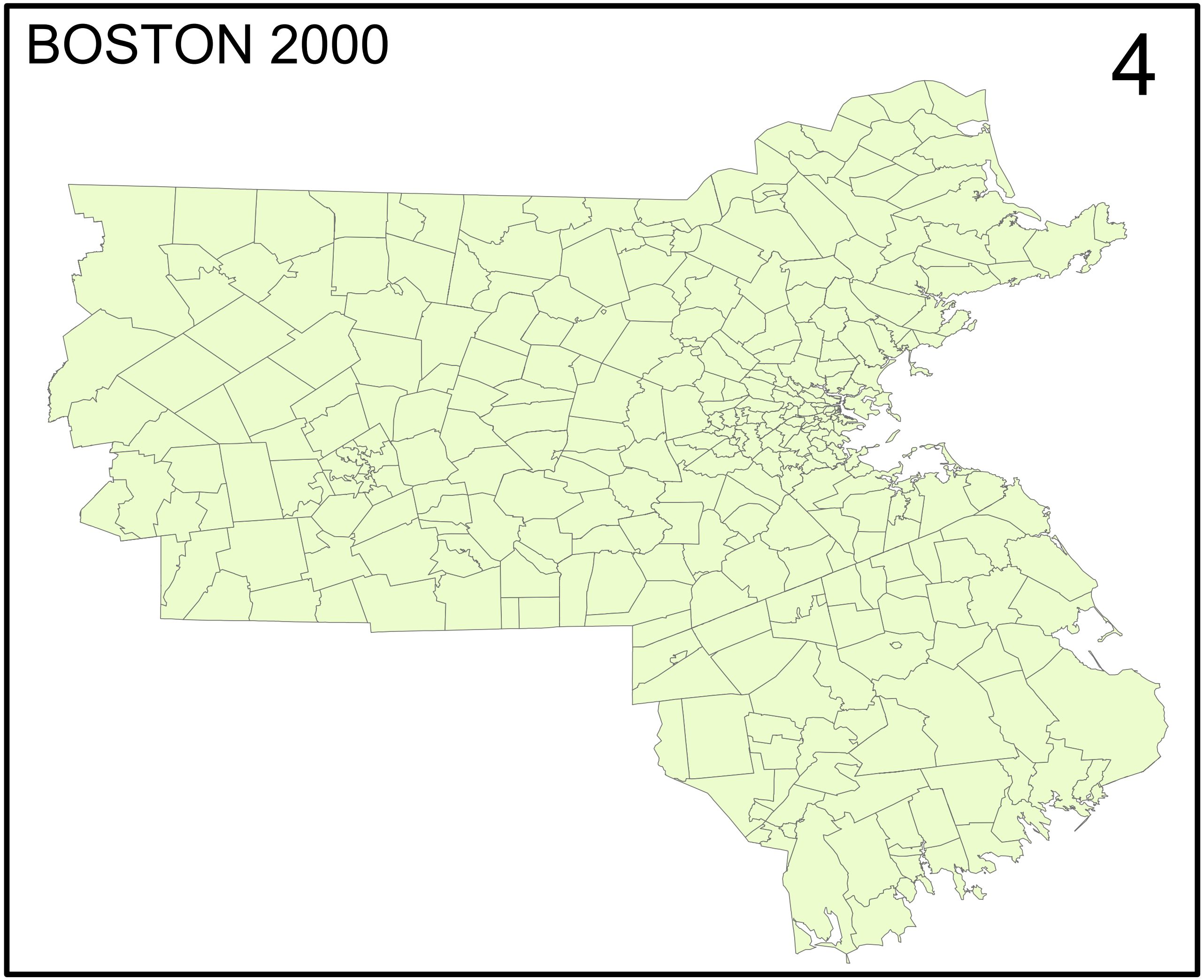
CMSA - Hydrogen Supply Infrastructure Schematic



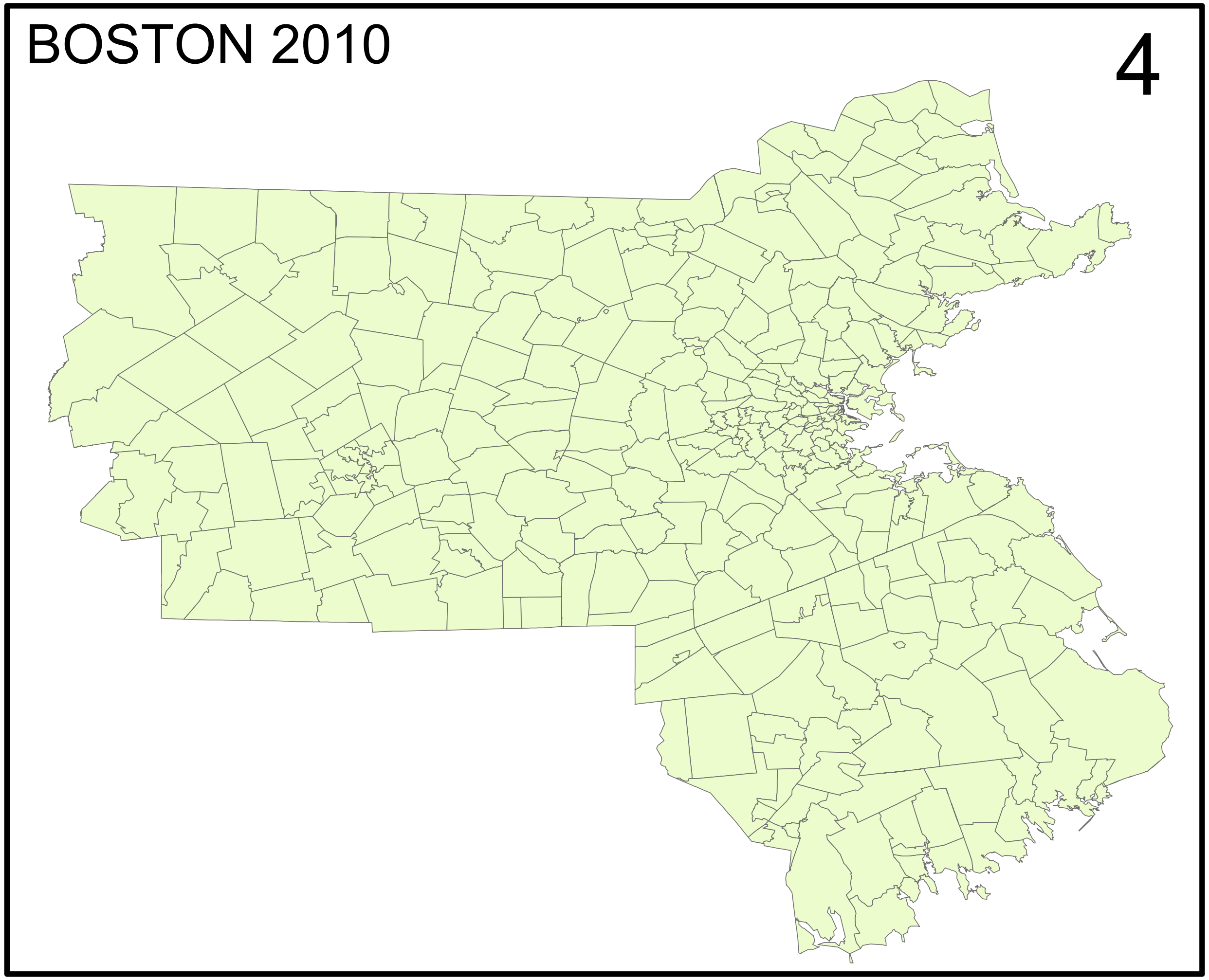
Cost-Effective H2 Delivery



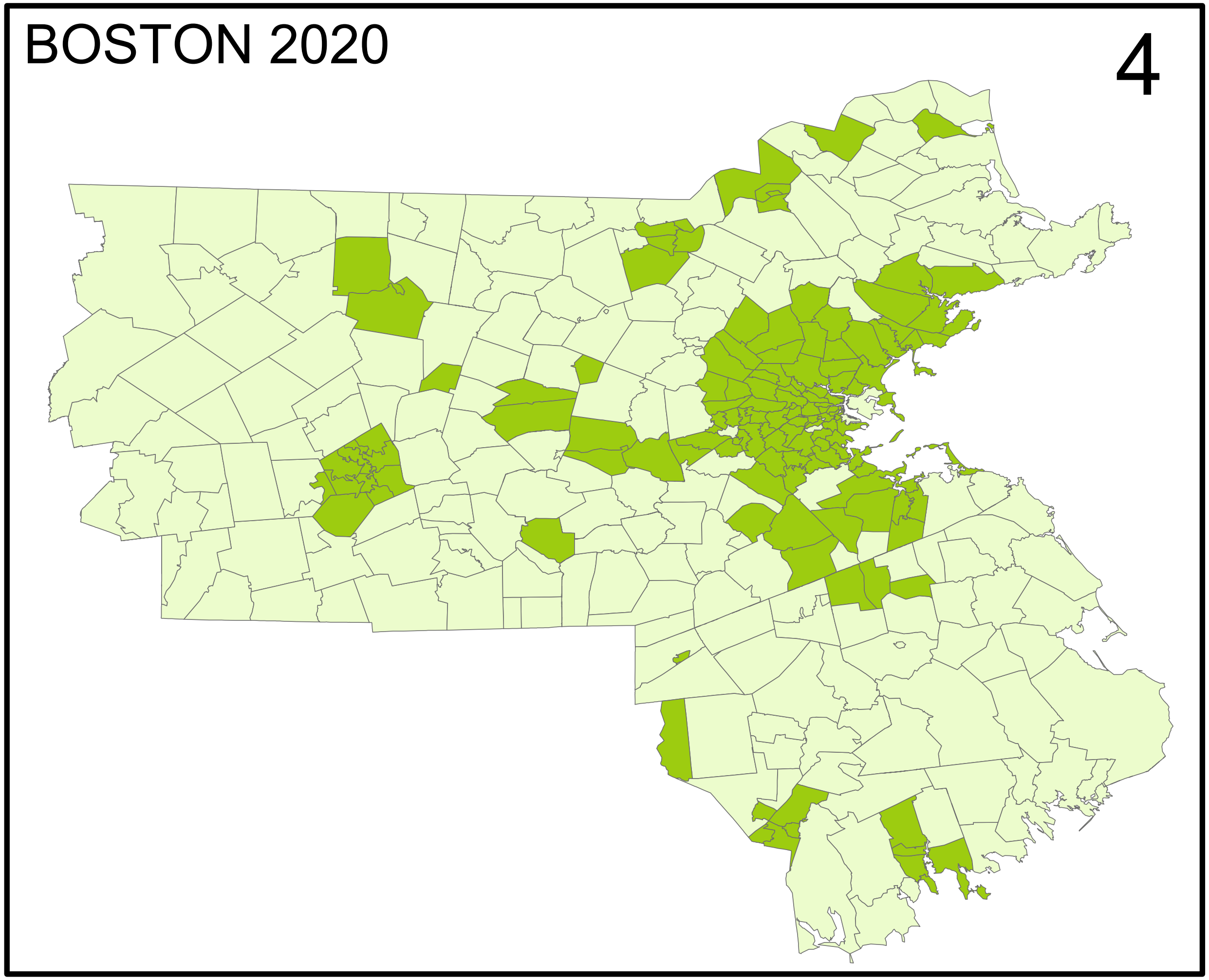
H2 Demand Density over Time/Space



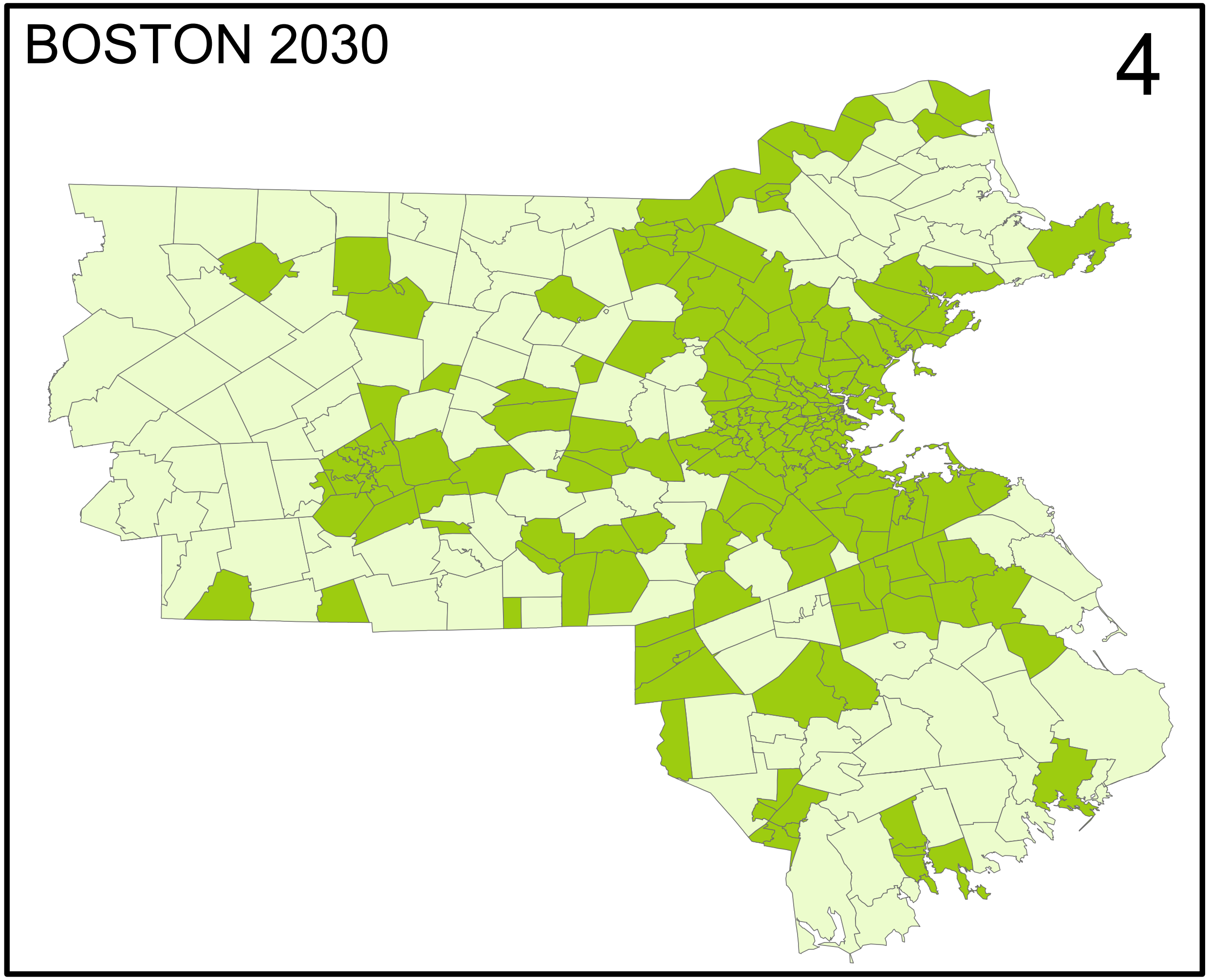
H2 Demand Density over Time/Space



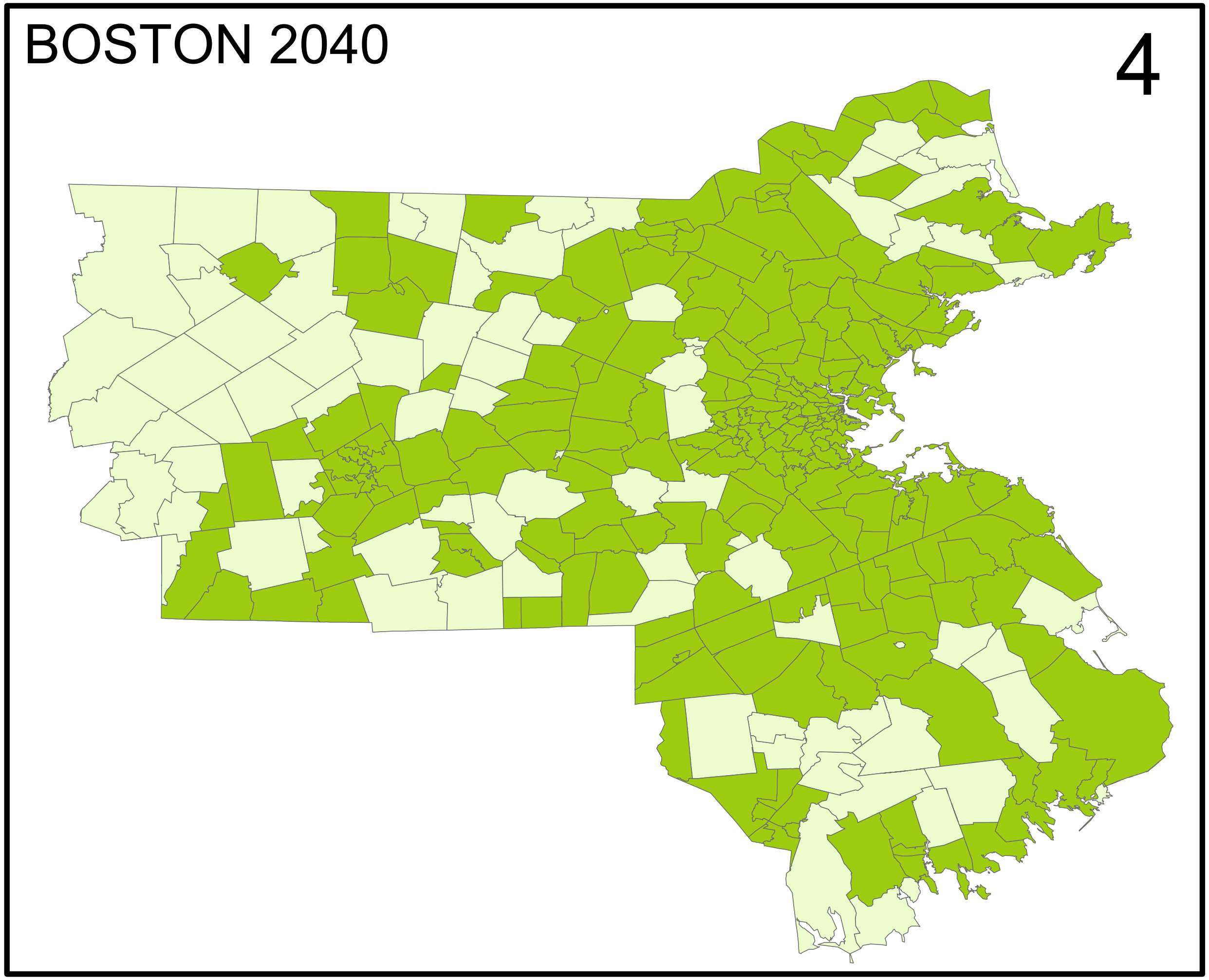
H2 Demand Density over Time/Space



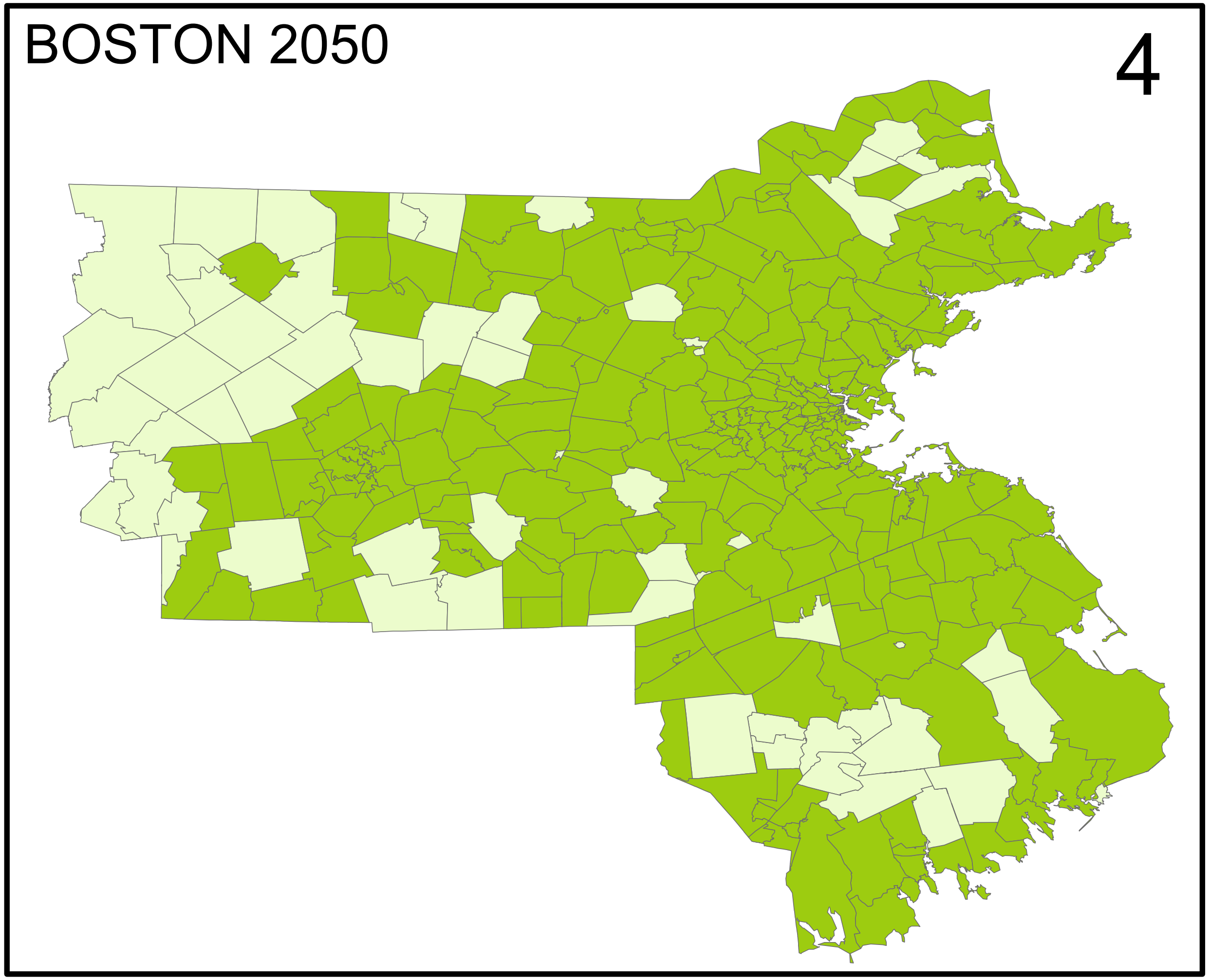
H2 Demand Density over Time/Space



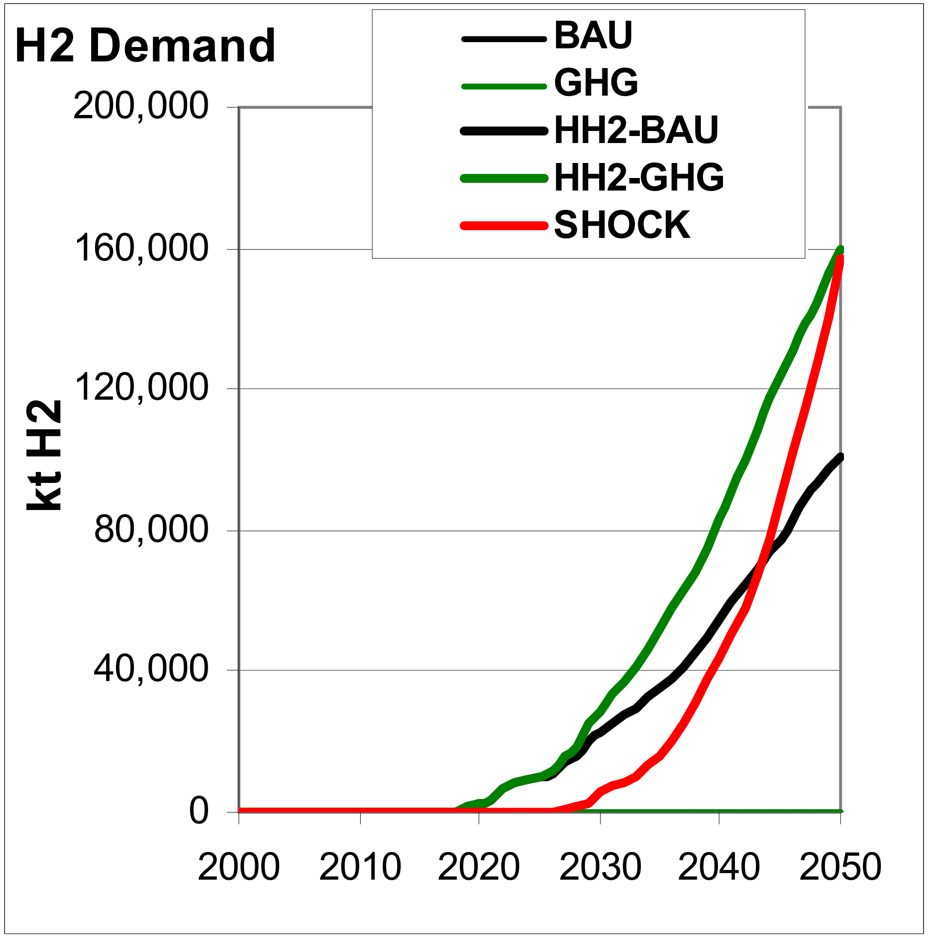
H2 Demand Density over Time/Space



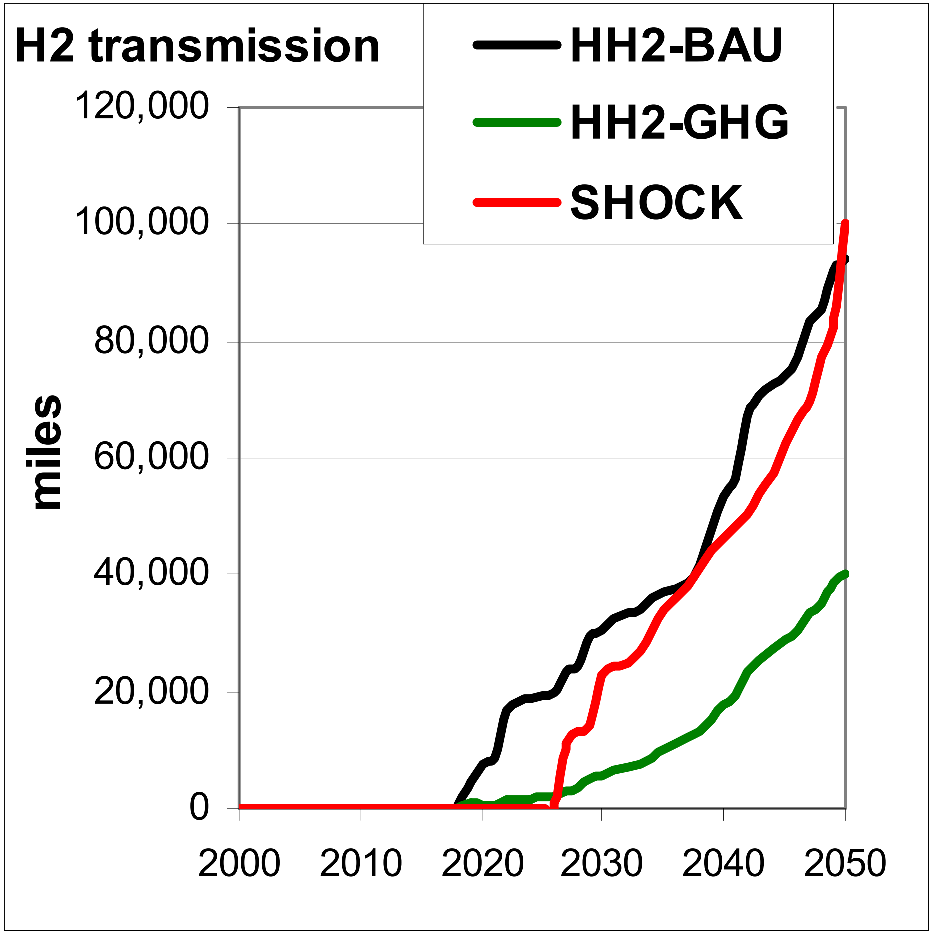
H2 Demand Density over Time/Space



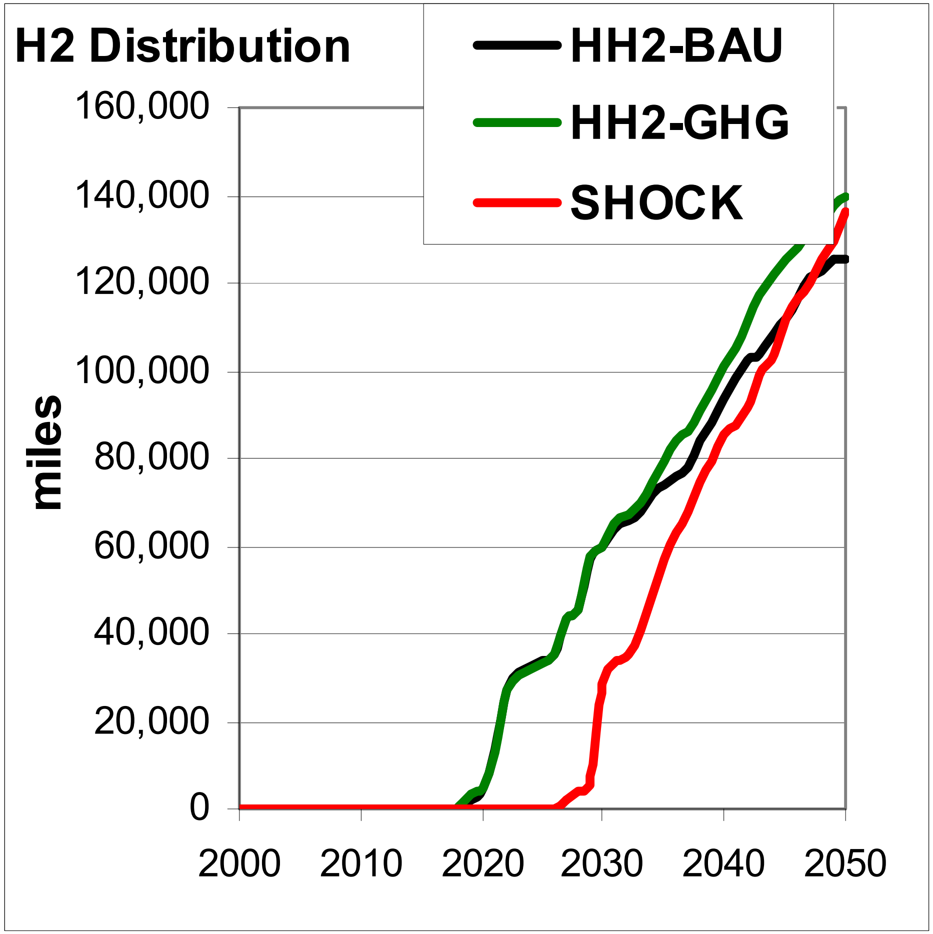
Hydrogen Demand - USA



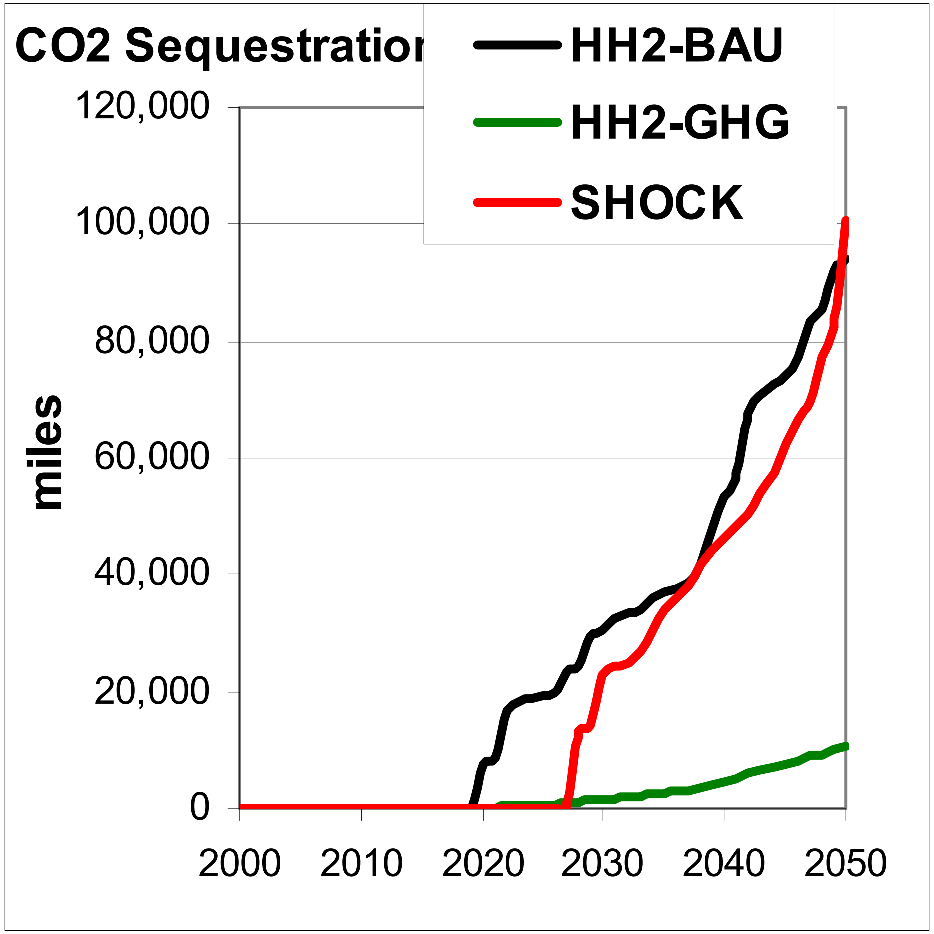
Hydrogen Transmission Pipelines - USA



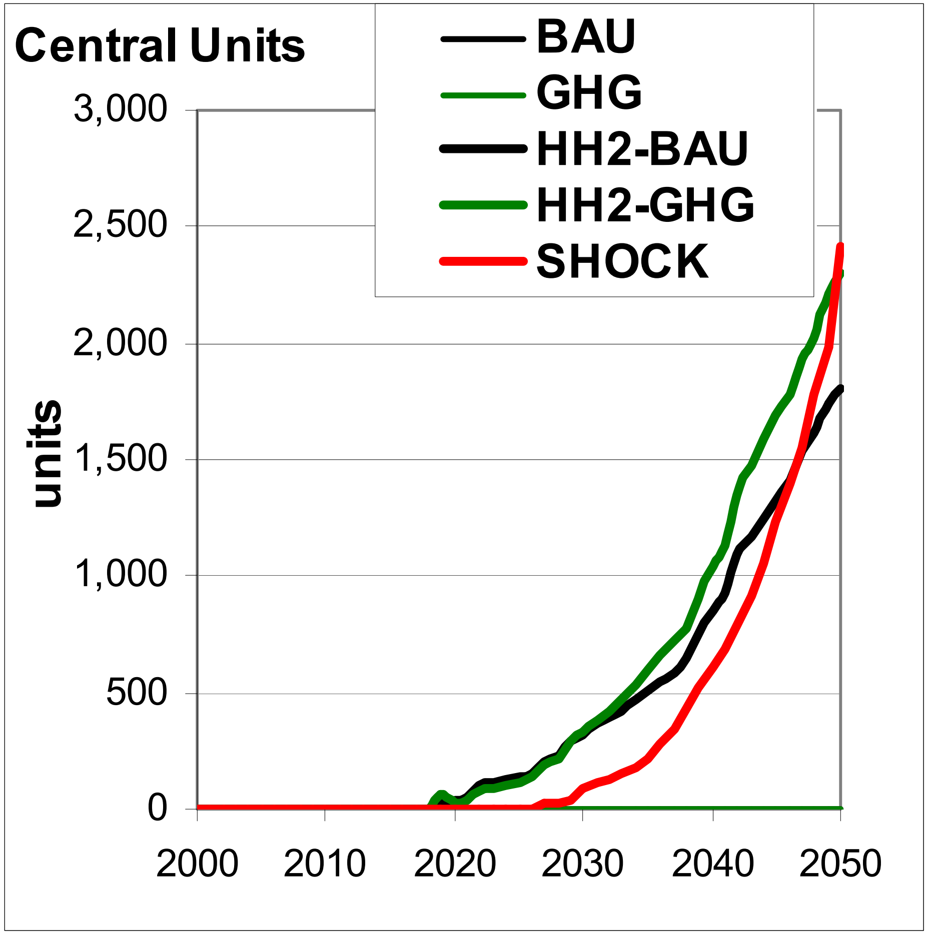
Hydrogen Distribution Pipelines - USA



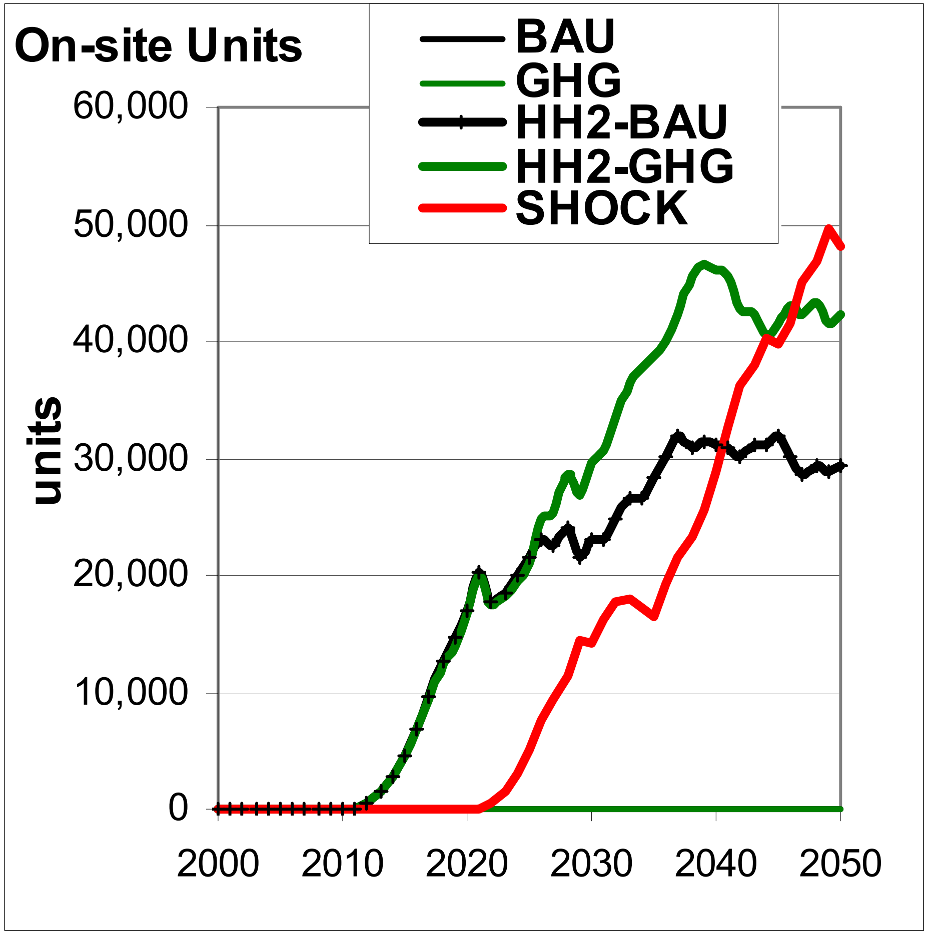
Carbon Sequestration Pipelines - USA



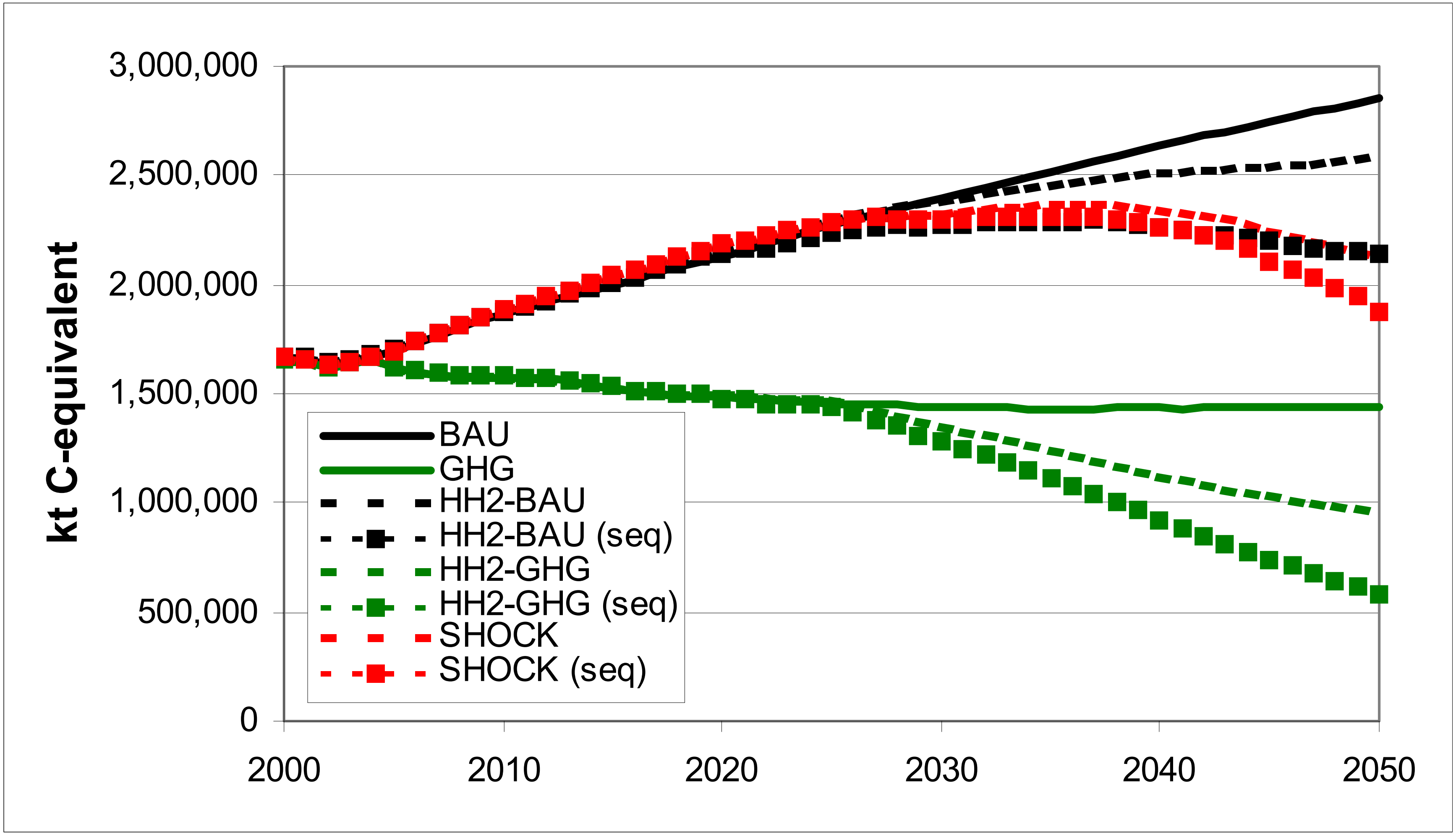
Installed Central H2 Production Units - USA



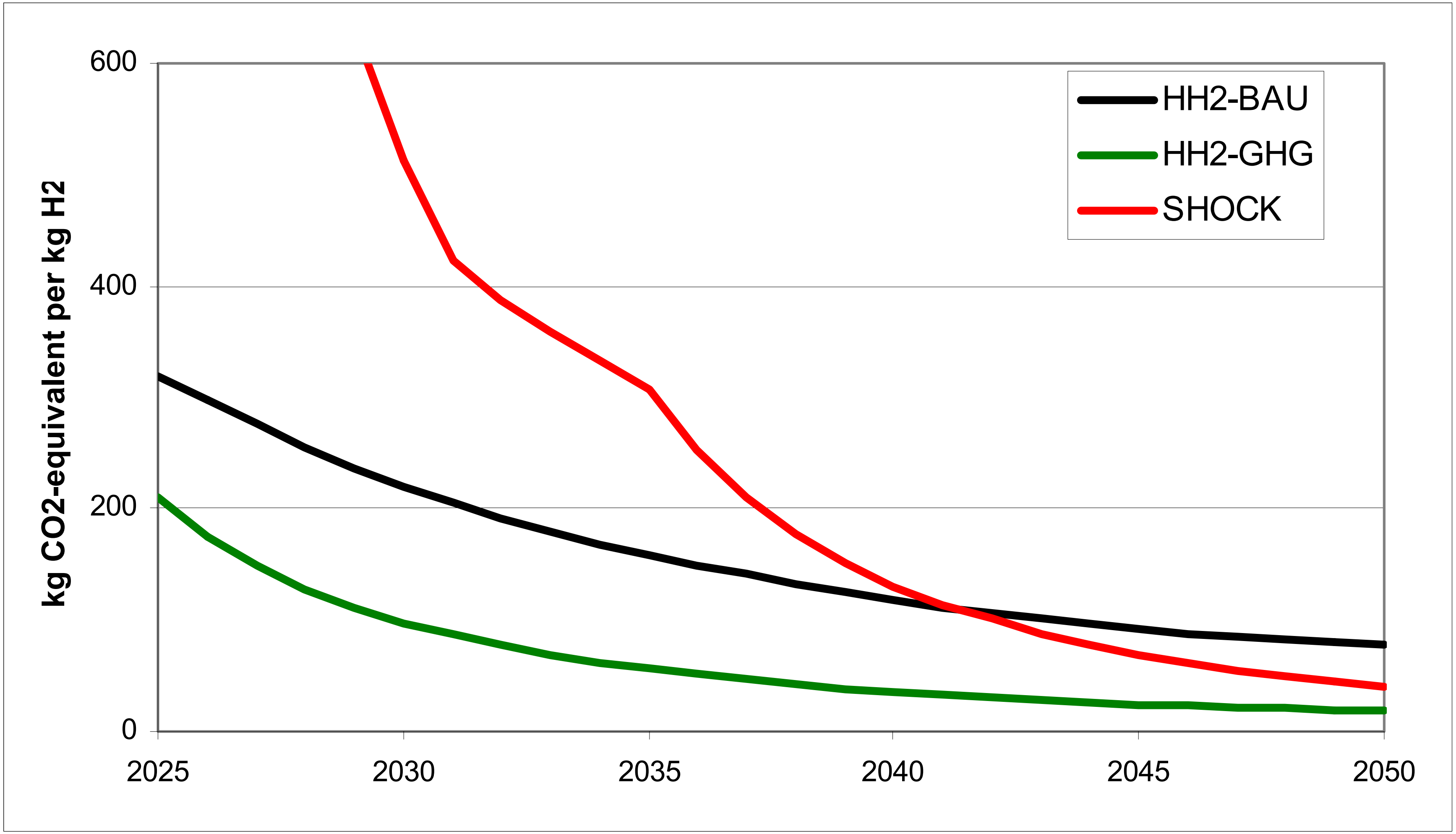
Installed On-site H2 Production Units - USA



Carbon Emissions



CO_2 per H2 Produced



Observations and Conclusions (1)

1. Hydrogen FCVs are unlikely to be cost competitive with gasoline ICEVs (even at a sustained \$40/barrel).

⇒ *A transition toward hydrogen would have to be motivated by GHG, air pollution, energy insecurity, not solely by profit.*

2. Electric vehicles and biofuels are (strong) contenders.

⇒ *Hydrogen is not the only option to address these problems.*

3. On an energy basis alone, hydrogen is not that compelling (owing to energy losses in conversion and distribution).

⇒ *It is only when coupled with zero-carbon supply options that hydrogen becomes interesting.*

Observations and Conclusions (2)

4. The only sources of zero-carbon hydrogen are:
   a. biomass (gasification/reforming)
   b. fossil (gasification/reforming) w/ CO_2 capture & sequestration
   c. renewable and nuclear electricity

First two options require centralized production and pipeline delivery. (LH2 tankers & GH2 tube trailers have negligible long-term role.)

Third option does not require pipelines (it can be done on-site), but this is pointless for cogen and limited value for transport until very high penetration (which is bounded by technical, cost and resource considerations.).

5. It only makes sense to use zero-carbon electricity to make hydrogen to displace gasoline (in hybrid vehicles) after coal-based power has been eliminated.

Observations and Conclusions (3)

6. Without pipelines, hydrogen cannot have any GHG benefit in cogeneration, and or significant benefit in transport sector.

7. Pipelines are only cost-effective when hydrogen demand density is fairly high (~200 cars/km^2 or ~20% of Boston car density).

Eventually, a large fraction (>85%) of hydrogen demand would be in regions exceeding this threshold.

Observations and Conclusions (4)

8. Getting there will take a long period of transition (~decades).
    a. more R&D (primarily storage & FC cost reduction)
    b. stock turnover in vehicles, auto manufacturing, energy infrastructure
    c. chicken-egg problem(s)
9. Transitional steps include:
    a. Fleet (e.g., buses) using centralized refueling
    b. On-site hydrogen production (from NG and grid electricity)
    c. Dual-fuel (gasoline/hydrogen) vehicles
10. Have to venture through some not so attractive options en route to clean hydrogen.

Observations and Conclusions (5)

Institutional and policy issues

1. Given that the drivers are not economic, but environmental/social,

   ⇒ *a hydrogen transition would require public support and political will to address GHG emissions, pollution, and energy insecurity.*

2. In the best case, hydrogen is a long-term solution with inevitable but potentially unsavory transitional implications.

   ⇒ *Hydrogen should not edge out near term solutions.*

(E.g., gasoline hybrid-electric vehicles, NG cogeneration, grid-connected renewables, efficiency)

3. The energy system is highly inertial. A timely transition will require a lot of time.

   ⇒ *Decisions must be made under some degree of uncertainty.*

   ⇒ *Other options (as in GHG Case) must be implemented in the meantime.*

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.

Presentations on this work have been made at Harvard University, Boston University, Cornell University, and MIT.

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

Possible Next Steps

- Approach
  - Explore alternative strategies for deeper reductions
  - Examine costs/benefits/constraints of pure renewables strategies
- Modeling
  - Expand analysis to cover other h2 production technologies and h2 consuming technologies
  - Incorporate existing H2 production from industrial facilities into overall tallies
  - Fine-tune transmission and distribution pipeline module
- Marketing
  - Contact regional planning commissions - adapt H2M to other cities