2004 DOE Hydrogen, Fuel Cells & Infrastructure Technologies Program Review Presentation

Hydrogen Transition Modeling and Analysis: *HYTRANS v. 1.0*

David Greene & Paul Leiby
Oak Ridge National Laboratory

Elzbieta Tworek
Univ. of Tennessee & StrataG

David Bowman
Consultant

Philadelphia, Pennsylvania
May 25, 2004

This presentation does not contain any proprietary or confidential information

Project Objectives:

- Rapidly create an integrated model of the transition to hydrogen as a transportation fuel using methods developed for the Transition Alternative Fuels and Vehicles (TAFV) Model.
- Produce a national-level model, HYTRANS v. 1, by April, 2004.
- Test HyTrans v. 1 and produce 2-3 scenarios of market evolution.
- Produce a regional model by September, 2004.
- Test and generate 2-3 regional transition scenarios
- Publish model documentation and scenarios.

Budget:

- HyTrans v. 1 and v. 2 development supported by EERE/PBFA
- $120,000 received in late FY 2003
- $440,000 in FY 2004
- Total project funding of $560,000

Technical Barriers and Targets

- Sponsored in FY 2004 by PBFA, this project addresses their interests in estimating costs and benefits, and policy analysis.
- The HyTrans project contributes to the HFCIT Hydrogen Delivery goal of,

  "performing an analysis to help define a cost-effective, energy efficient and safe hydrogen fuel delivery infrastructure for the introduction and long-term use of hydrogen for transportation and stationary power."
- It also contributes to overcoming the barrier of,

  "Lack of Hydrogen/Carrier and Infrastructure Options Analysis".

As the NAS study pointed out, there are several good reasons why DOE should build models of the transition to a hydrogen energy system:

- Guide R&D investments,
- Formulate policies,
- Estimate costs and benefits,
- Create a vision.
- And, eventually, plan and execute the transition

Approach: HyTrans applies optimization methods to construct an economic model of the hydrogen transition.

- Represents interdependent decisions of hydrogen suppliers, vehicle manufacturers & consumers from 2005 to 2050.
- Finds competitive market solutions by maximizing producers' profits and consumers' welfare.
- Decision-making to 2050 can be based on perfect foresight, myopia, or other expectation models.
- Version 1 is limited in scope.
  - Only 3 production technologies
    - Centralized SMR
    - Forecourt SMR
    - Forecourt Electrolysis
  - Considers only LDV H2 demand
  - National scale market structure

Safety issues are relevant to HyTrans as they affect system design, cost and consumer perception.

- Neither v. 1 or v. 2 will explicitly include safety issues.
- Safety issues will affect delivery systems design and costs as defined by the H2A group.
- Consumer perceptions are an issue for future model development.
- Safety issues in developing HyTrans itself are covered under ORNL's Research Safety Summary guidelines.

HyTrans has an ambitious timeline.

9/03 – 3/04	4/04 – 9/04	10/04 – 9/05
HyTrans v. 1	HyTrans v. 2	Future Development

- **Version 1.0**
  - **Convert TAFV model**
  - **Develop mathematical representations of hydrogen production, delivery, demand**
- **Version 2.0**
  - **Represent 9 Census Regions**
  - **Add production/delivery technologies**
- **Future**
  - **Stationary demands**
  - **Integration with electricity generation**
  - **Interaction with energy markets & economy**

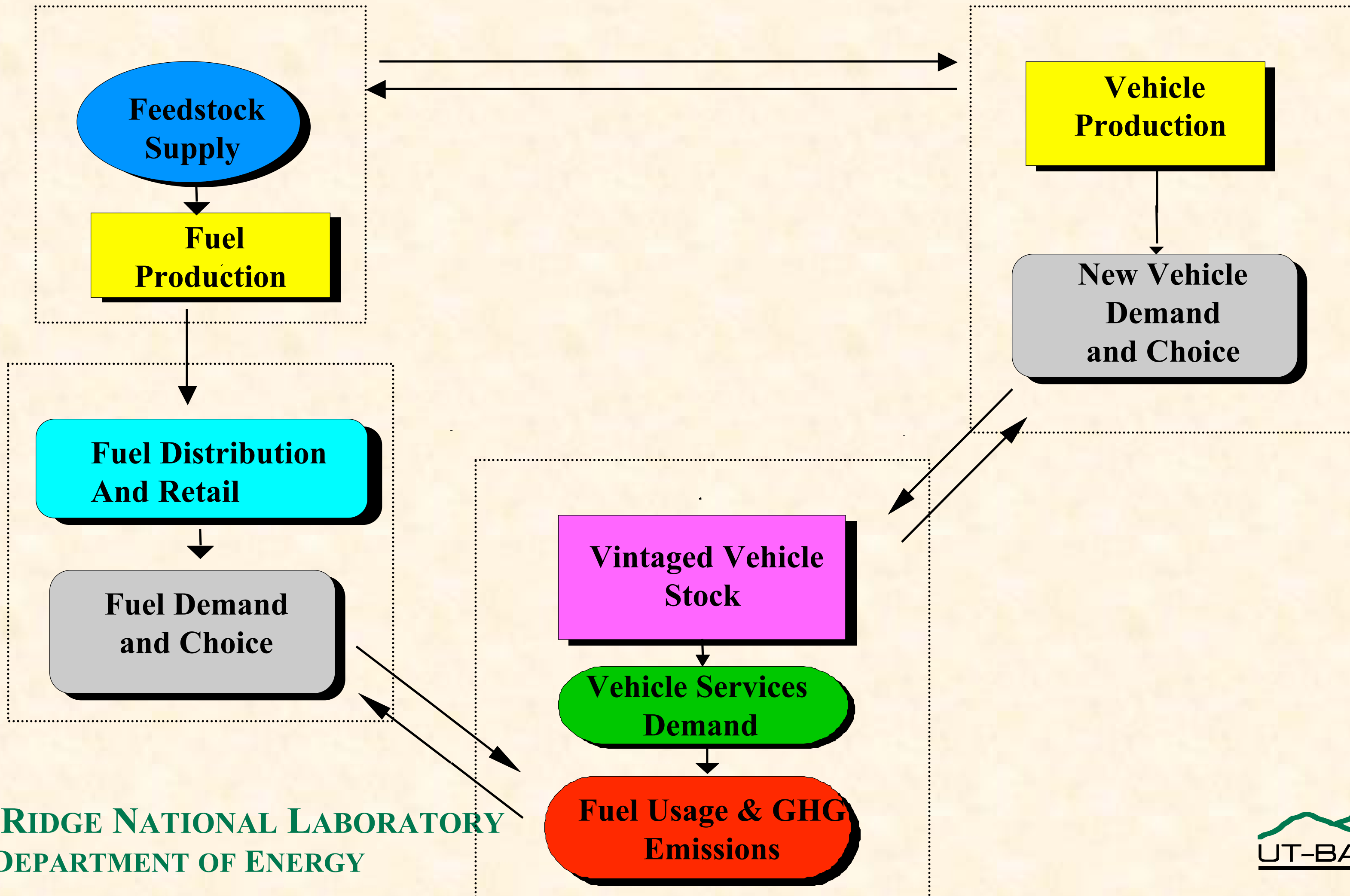
A working hydrogen transition model based on optimization has been created.

- Complete mathematical representation of hydrogen production (3), delivery (3), forecourt (1) system as a function of scale and demand density.
- Representation of vehicle choice and fuel demand, including H2-FCV, Reformer FCV, H2-ICE, as well as hybrids, diesels, conventional gasoline vehicles.
- Working, integrated HyTrans v. 1 completed May, 2004

The “Chicken or Egg” problem is key to energy *transitions*, but economic models generally do not address the real barriers that create it.

- Limited fuel availability depresses vehicle demand, limit fuel demand depresses fuel availability
- Vehicle and fuel infrastructure investments large, and not explicitly coordinated
- Scale economies:
  - costs high at low production
- Limited vehicle model diversity
  - Availability on only a few makes/models limits demand
- Learning-by-doing
- Slow capital stock turnover
- HyTrans represents all these interdependent barriers.

HyTrans finds a simultaneous solution that integrates consumer, fuel producer, fuel distributor and vehicle manufacturer decisions.



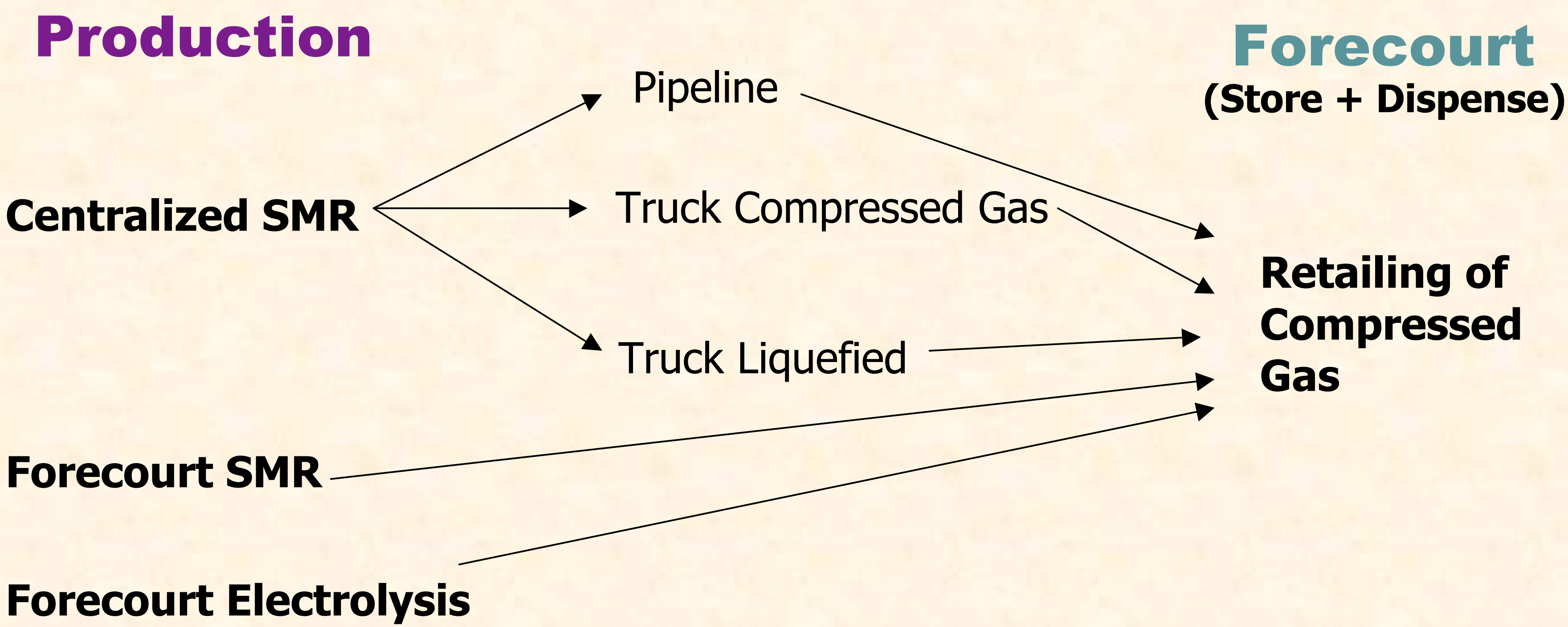
Key, interdependent "Chicken or Egg" variables are solved endogenously.

- Consumer choice
  - Vehicle cost, performance, diversity
  - Fuel availability
- Fuel availability (% stations offering H in region)
  - Volume of fuel demand in region
  - Density of fuel demand
- Fuel supply and cost
  - Production and delivery processes
  - Scale of production
  - Density of demand
- Manufacture of vehicles and cost
  - Consumer demand
  - Scale economies
  - Learning-by-doing
  - Technological advancement

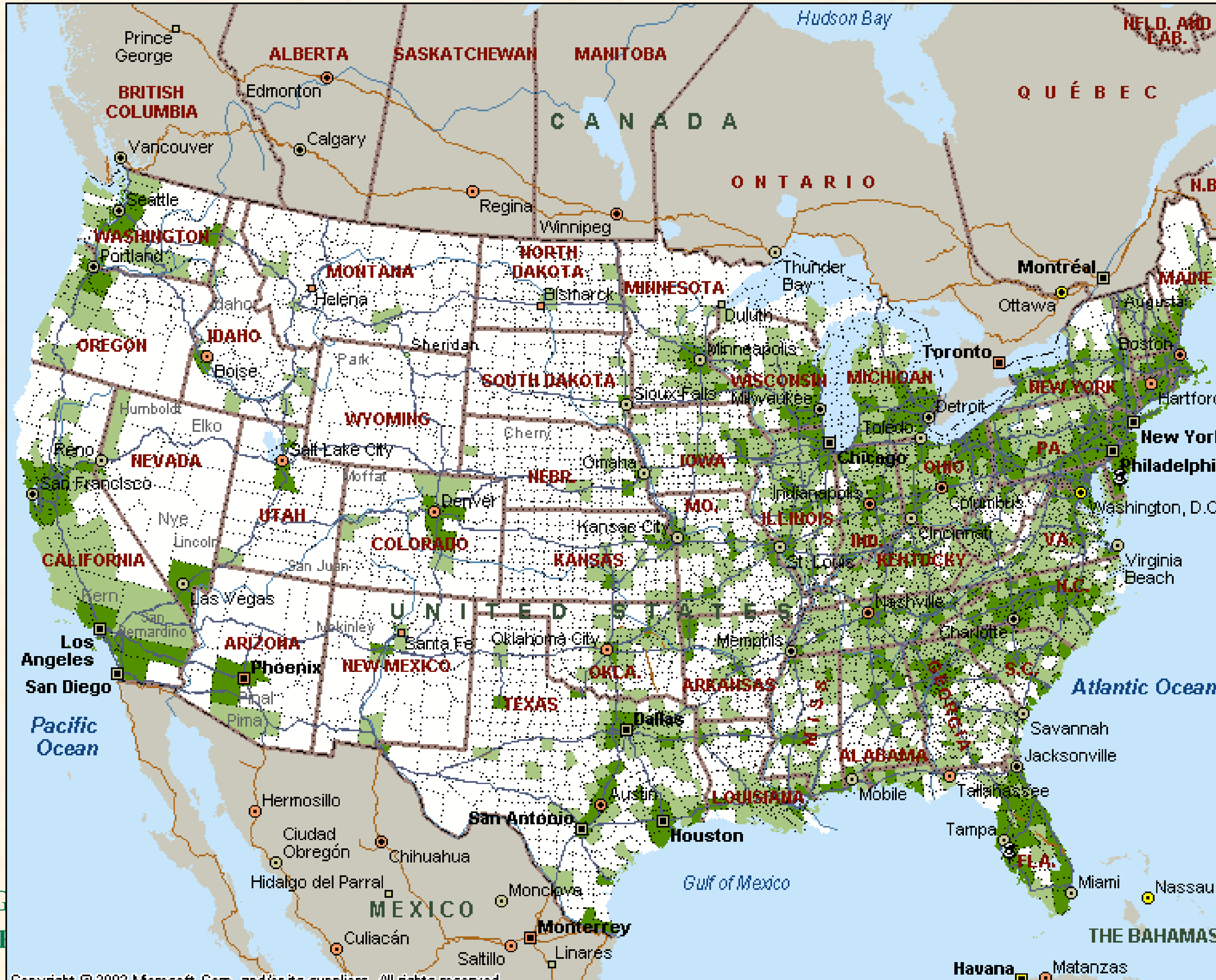
In HyTrans, delivery accepts H_2 gas at 30 atm and delivers to the forecourt compressed to 400 atm.

Delivery

Includes: Compression/Liquefaction+Storage+Dispensing+ Transporting+Storage+Compression/Vaporization

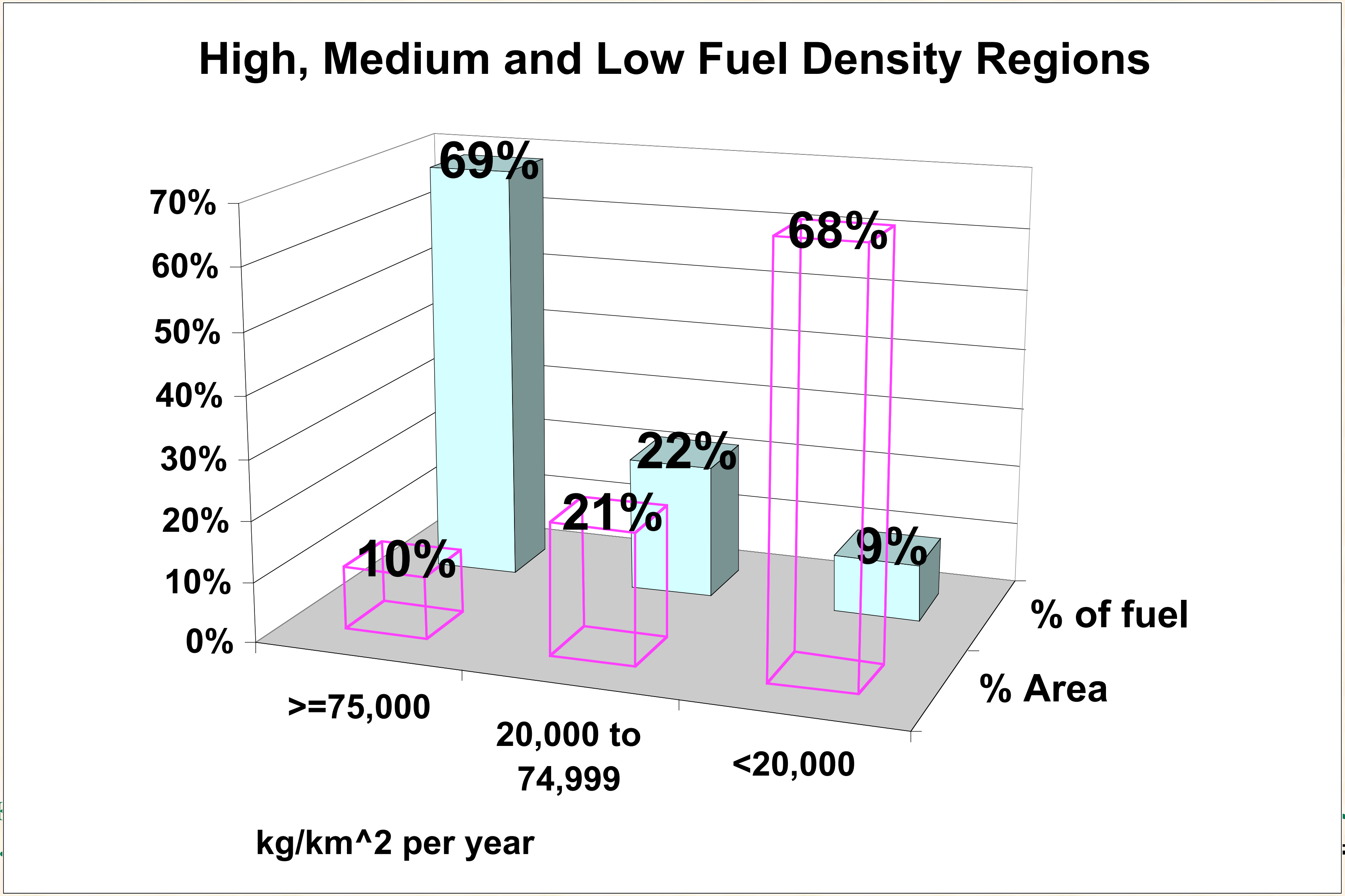


A key factor in infrastructure evolution will be the density of motor fuel demand.

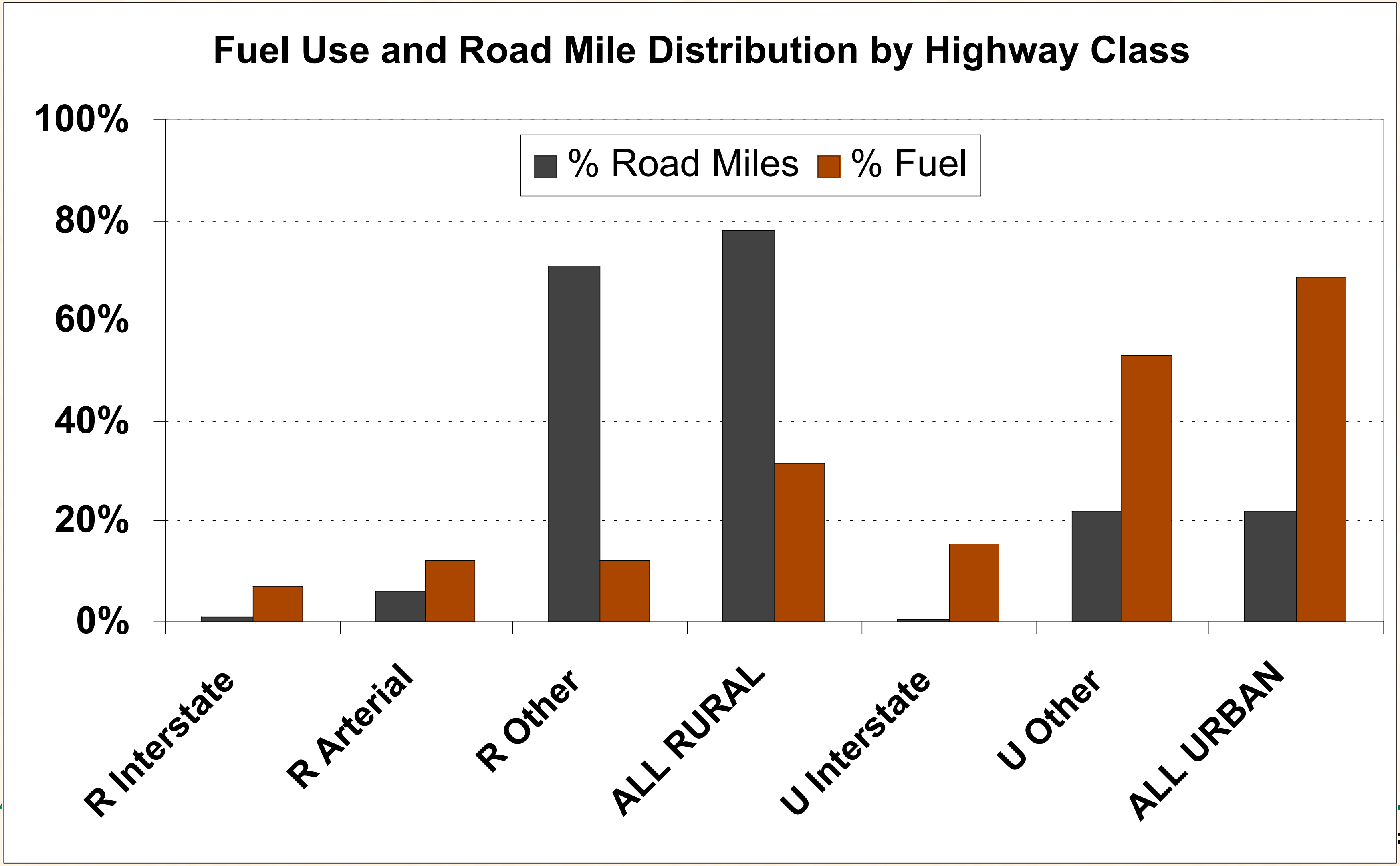


Oak Ridg
U. S. Depa

Most light-duty vehicle fuel is consumed in counties comprising less than 10% of the land area of the US.



Thinking of highways as linear markets, most *rural* fuel is consumed on interstates and principal arterials.

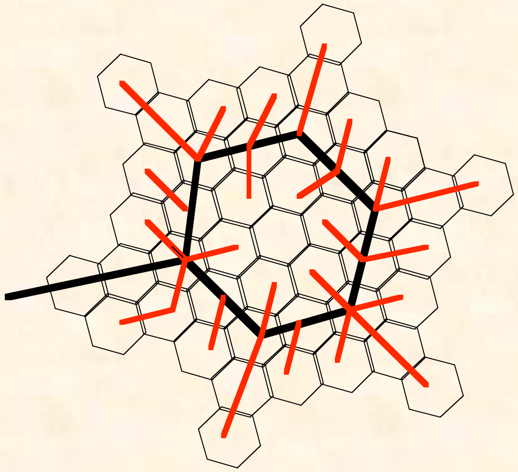


O.
U.

Better understanding of the likely structure, evolution and costs of regional pipeline systems, is needed.

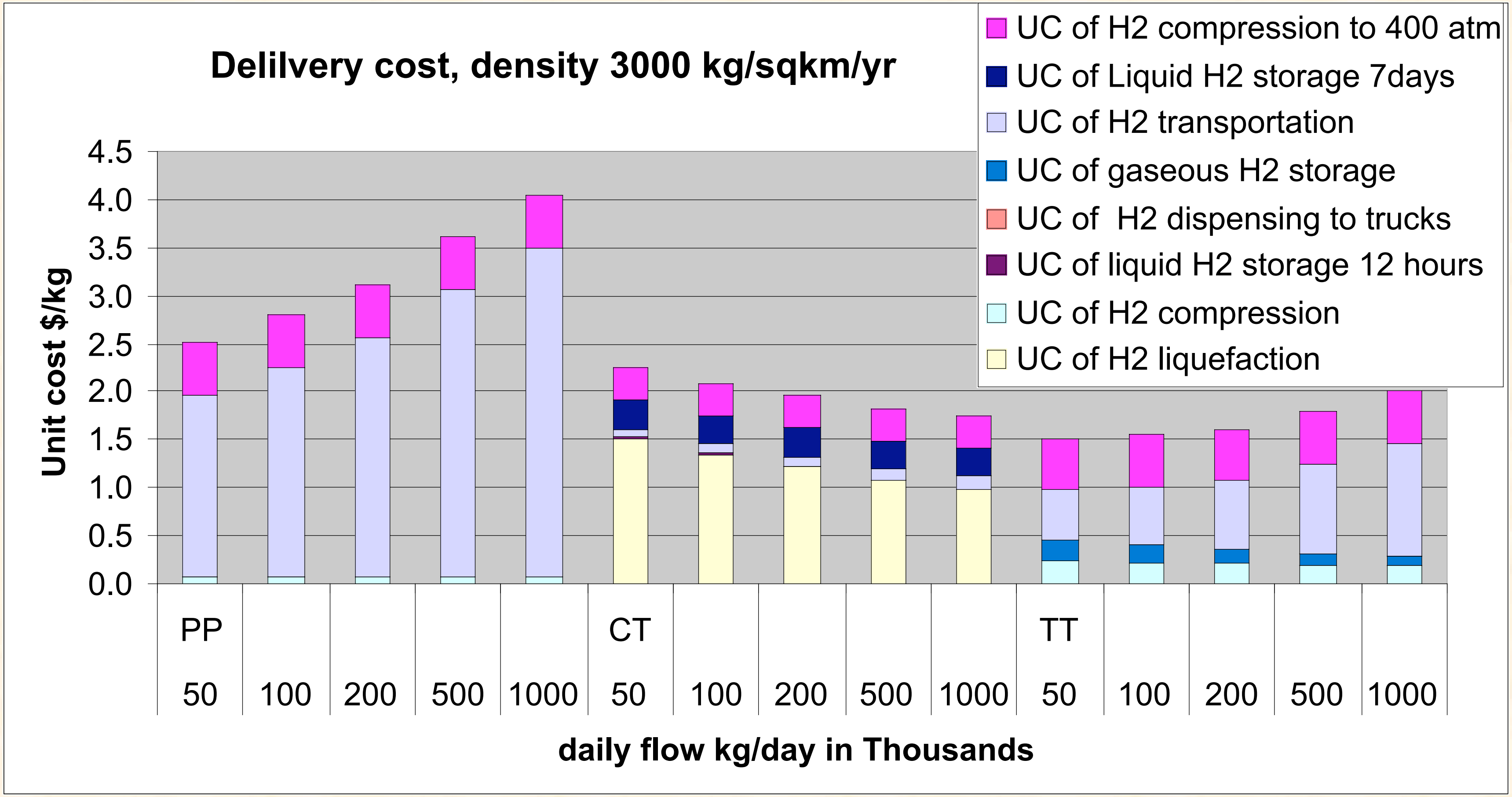
Hypothetical Metropolitan H2 Pipeline Distribution System

43 forecourts with actual capacity of 2100 kg/day
a plant with actual capacity of 90,000 kg/day
Density of hydrogen demand is 10,000 kg/sq km/yr
Capital investment is about $100,316,800

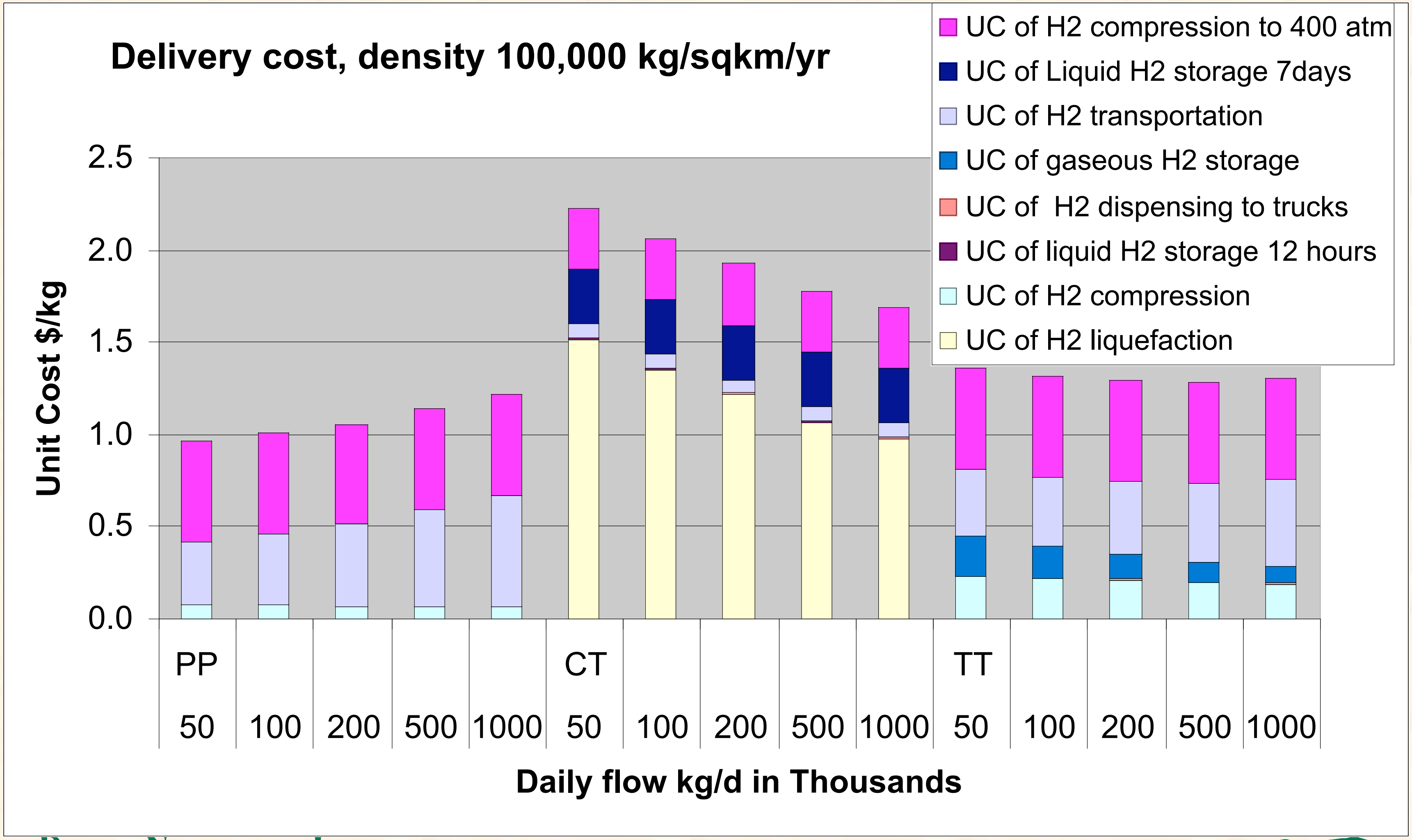


Black line - trunk pipeline P1, 10”diameter
Red line - service pipeline P2, 3” diameter

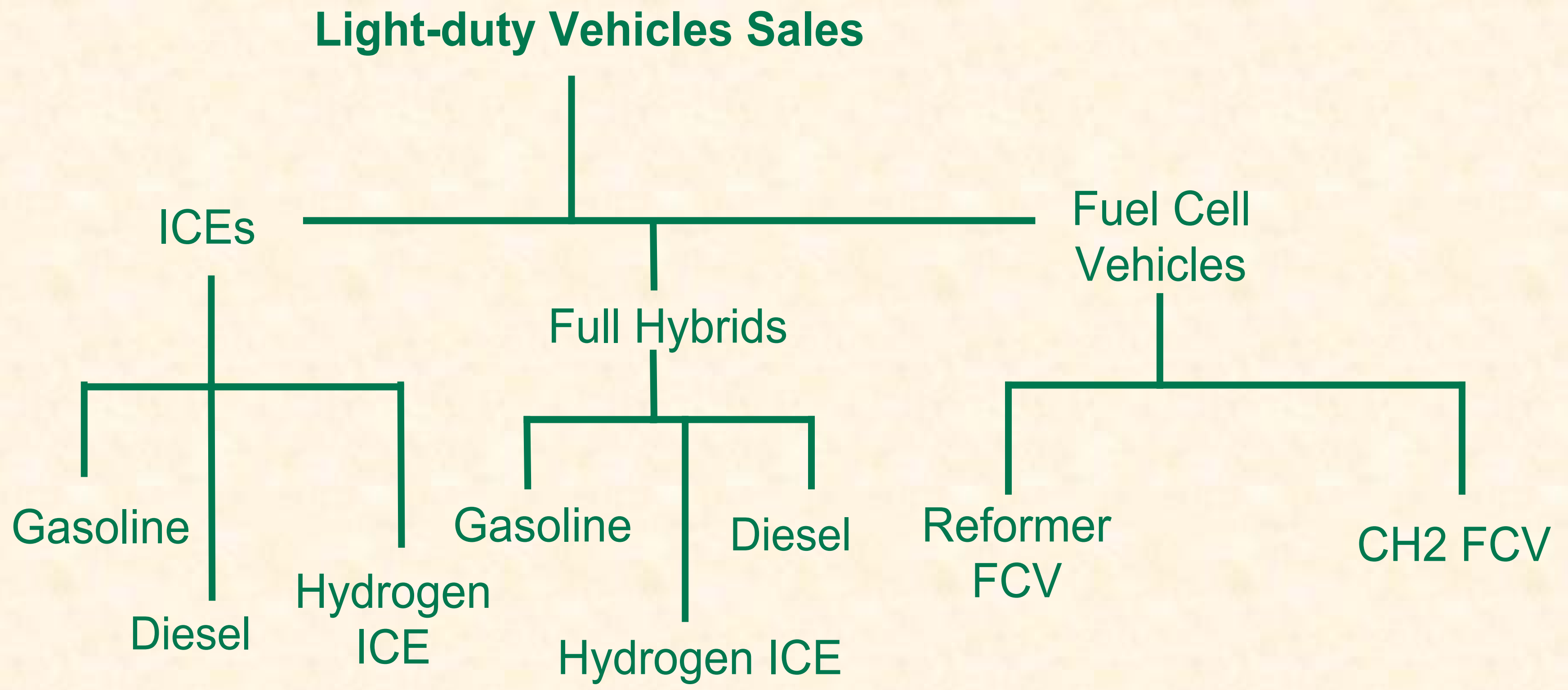
Delivery costs depend on both production ***scale*** and ***density*** of demand.



At high densities, pipelines do appear to dominate, but many questions remain.



The NMNL vehicle choice model determines the market shares of alternative technologies, grouped into “nests” of closer substitutes.



Market shares for vehicles are determined by utility functions of measured attributes.

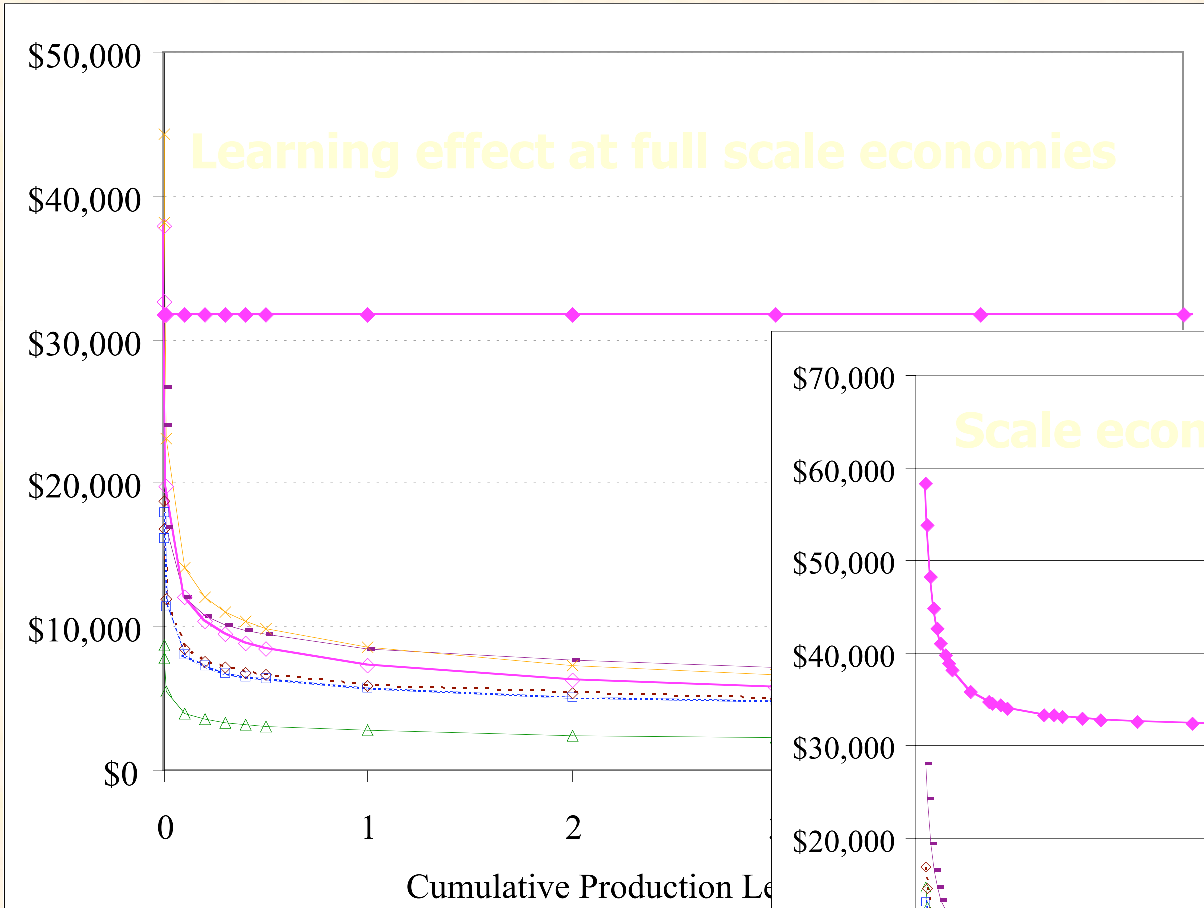
- **Share depends on attributes x_{mi} of alternative *m* and their value**

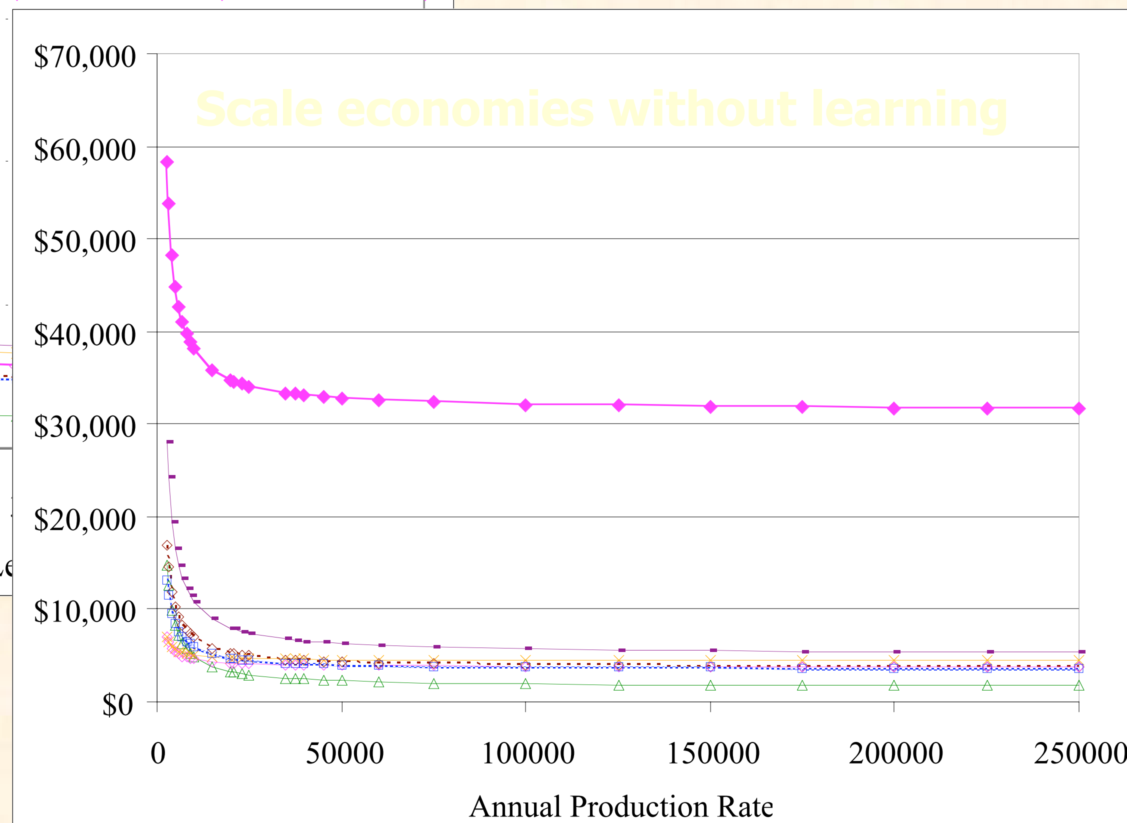
$$S_m = \frac{e^{U_m}}{\sum_{n=1}^{N} e^{U_n}} \quad or \quad \ln(S_m / S_n) = (U_m - U_n)$$

$$U_m = \beta P_m + \sum_i \beta_i x_{mi} + \varepsilon_m$$

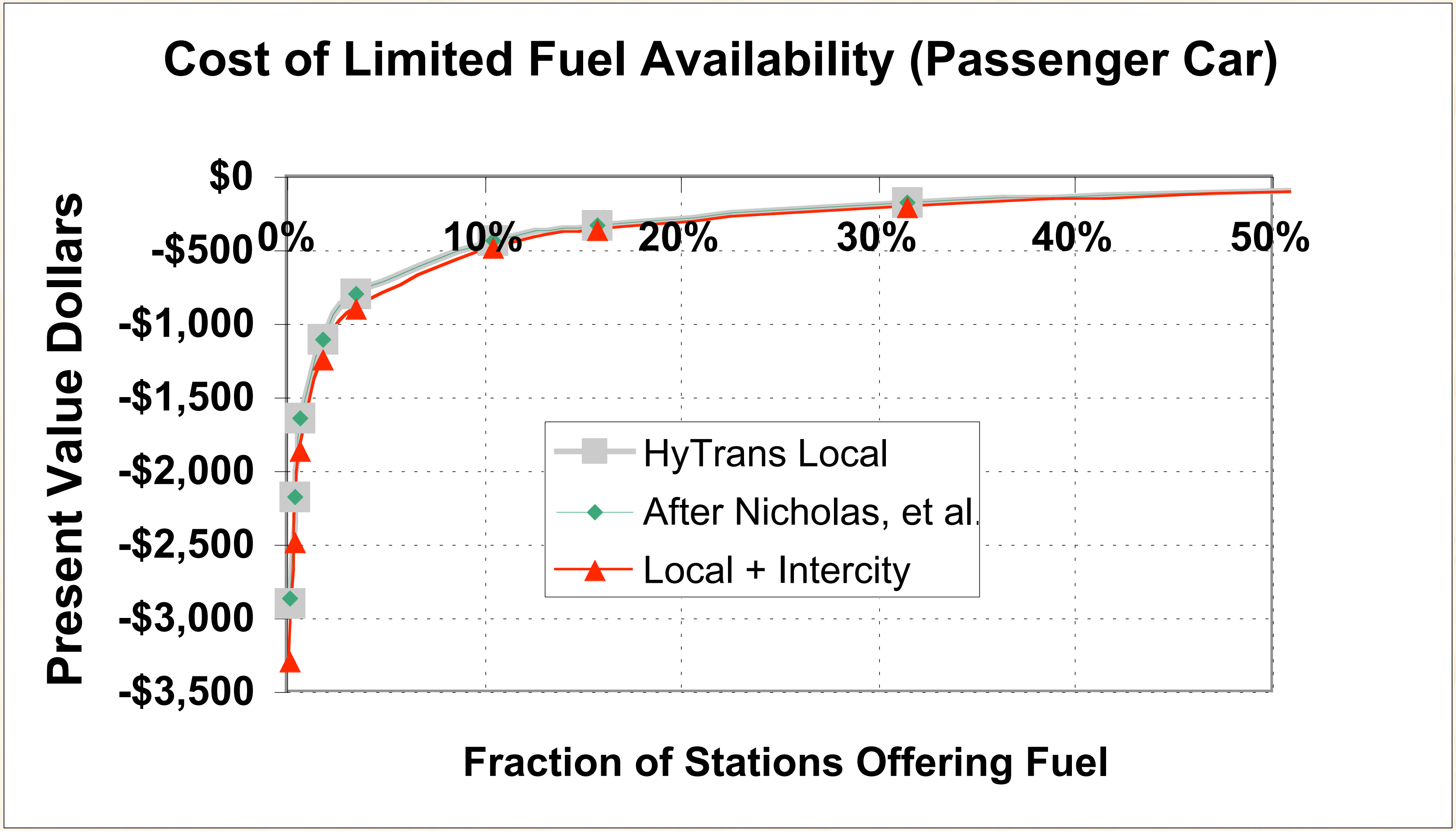
- **Parameters β estimated with combination of survey data & engineering/economic analysis**
- **NMNL has closed-form benefit measure (consumers' surplus) which is included in the objective function.**

The critical barriers of both scale economies and learning-by-doing are represented.





Limited retail fuel availability is a major cost to consumers.



The HyTrans effort is a component of DOE's systems analysis research.

- Collaboration with Marianne Mintz and others at ANL, especially with regard to delivery systems modeling.
- Consumers of H2-A production (NREL), delivery (ANL), forecourt, cost and performance analyses.
- Marc Melaina, U.Michigan researching forecourt modeling at ORNL for summer, 2004.
- Information exchanges with Joan Ogden, UC Davis (e.g., Demand Modeling Workshop, H2-A)
- Have received internal ORNL funding to create an advisory group and hold a workshop on transition modeling.

While we have specific plans for future development, we are also learning-by-doing.

- Future Plans
  - Incorporating stationary demand
  - Representing potential to integrate with electricity generation
  - Links to energy markets and larger economy
- Needs we have "discovered" by doing
  - Apples-to-apples vehicle design not good enough: optimized to consumer's preferences.
  - How to represent evolution of pipeline network? (ANL)
- How far can optimization take us?
  - Geography matters but difficult to include in optimization model?
  - Robust, good solutions more important than finding "THE BEST" solution

The vision for a hydrogen economy includes not only the end state, but the transition, as well.

"Who will spend the hundreds of billions of dollars on a wholly new nationwide infrastructure to provide ready access to hydrogen for consumers with fuel cell vehicles until millions of hydrogen vehicles are on the road. And who will manufacture and market such vehicles until the infrastructure is in place to fuel those vehicles."

"I fervently hope to see an economically, environmentally, and politically plausible scenario for how this classic chasm can be bridged; it does not yet exist."

Joseph J. Romm
"The Hype about Hydrogen"
***Issues in Science and Technology*, vol. 20, no. 3, Spring 2004.**

THANK YOU