Optimal Location of Refueling Stations for Hydrogen Railroads

Michael Kuby

Arizona State University

Department of Geography

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Outline of Presentation

1. Why Hydrail?
2. Prior Research on Locating Refueling Stations
3. The Flow-Refueling Location Model
4. Extending the Model to Railroads
5. Conclusions and Future Work

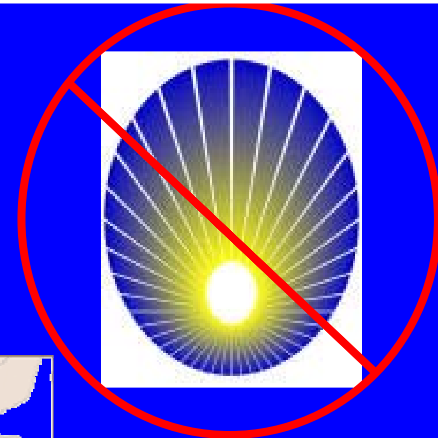
Hydrogen Road Transport Faces a Chicken-and-Egg Dilemma…

Which Comes First?

Mass Production of Vehicles

Refueling Infrastructure

Hydrail: No Dilemma!



Source: **http://www.uprr.com/customers/intermodal/emp/graphics/emp_map_lg2.gif**

Why Hydrail?

	Rail	Highway
Carriers	7 Class I 549 Total Railroads	662,000 motor carriers
Powered Vehicles	20,000 locomotives (53% pre-1990)	79,000,000 trucks 139,000,000 cars
Miles	170,000	3,906,000
Freight ton-miles	1.60 billion	1.26 billion
CO_2 emissions	43 Tg	341 Tg (trucking)

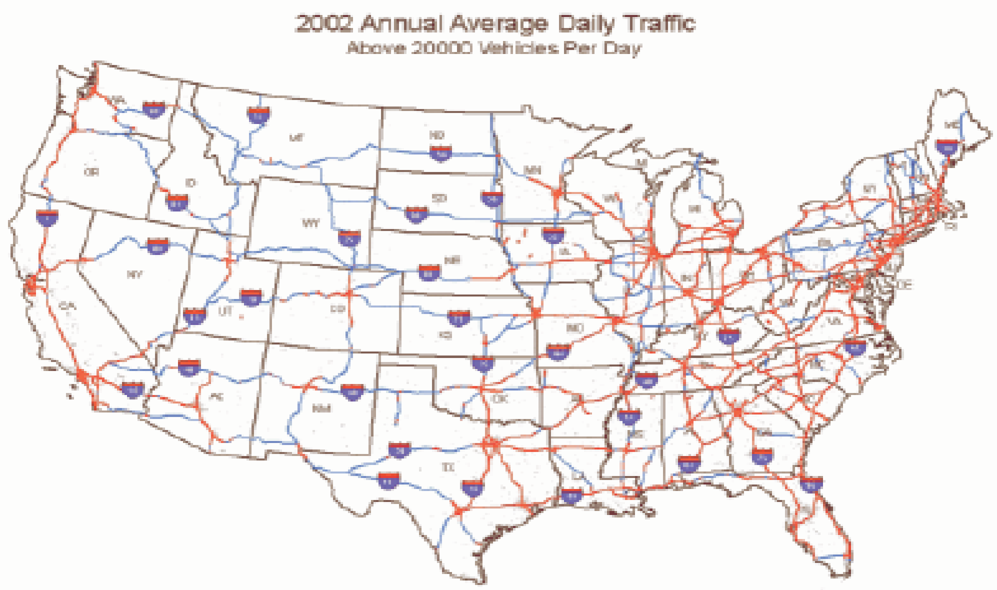
Purpose of Our Research

To facilitate the transition to a hydrogen economy by optimizing the development of the hydrogen refueling infrastructure.

Prior Research on Optimal Location of Refueling Stations

GIS Approaches

National Renewable Energy Lab (NREL)



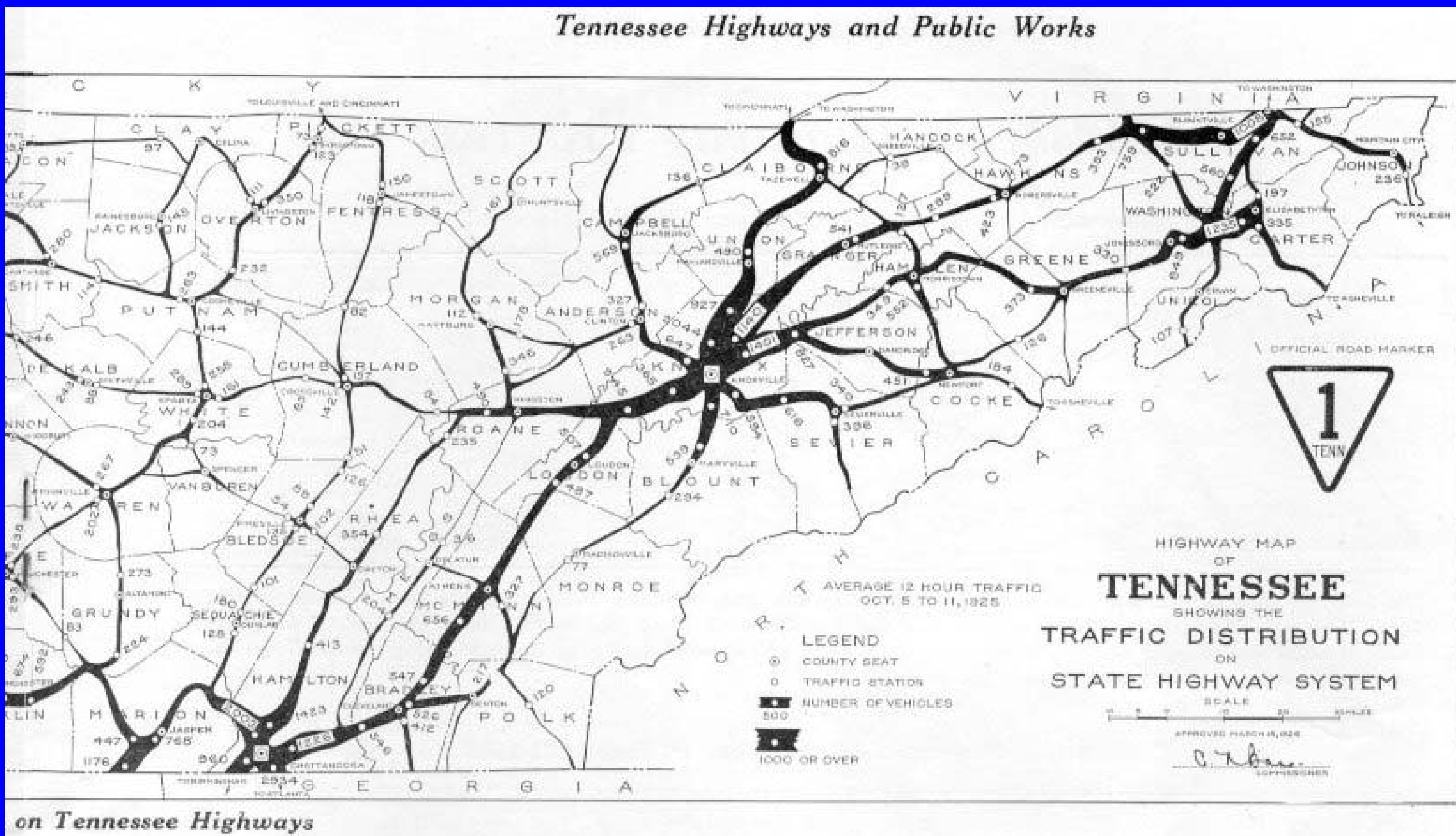
Data Source: FHWA, BTS, and DOT (CO, PA, and IA)

Figure 4. Sample of GIS Data Being Used to Evaluate Optimal H_2 Refueling Station Placement at a National Level

California Hydrogen Highway

Maximize Arc Flows

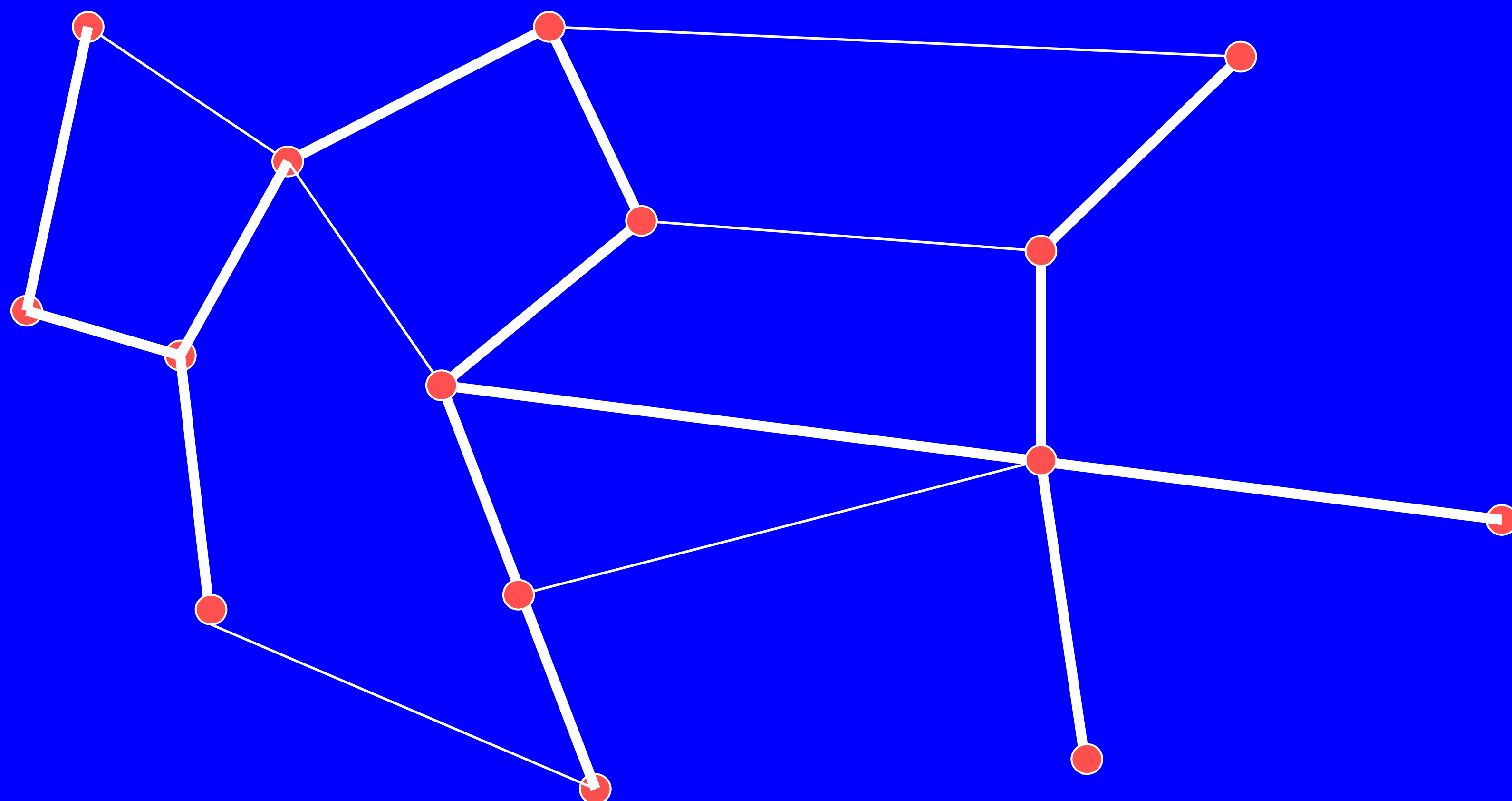
- **Goodchild and Noronha (1987)**



***Note*: Map is not from Goodchild and Noronha, but for illustrative purposes only.**

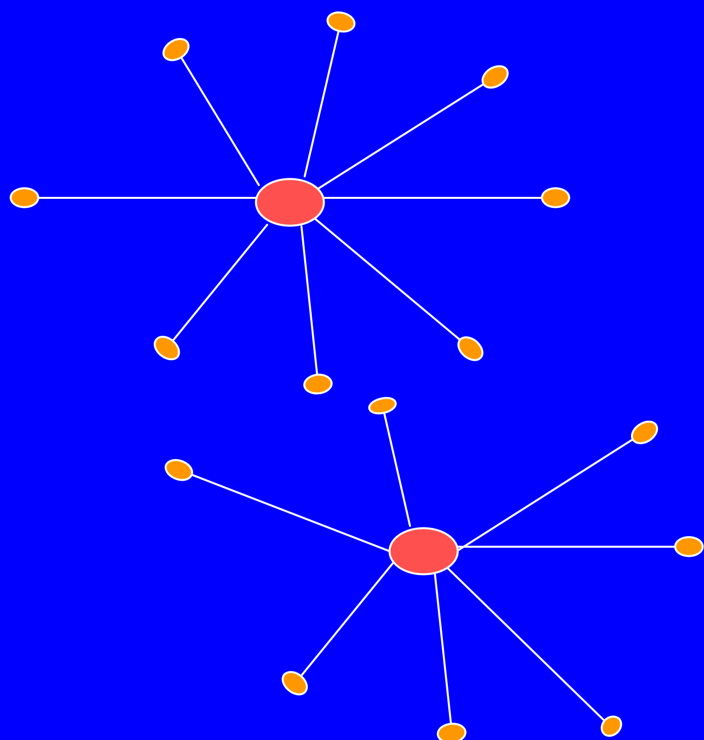
Minimum Spanning Tree

- **Bapna et al. (2002)**



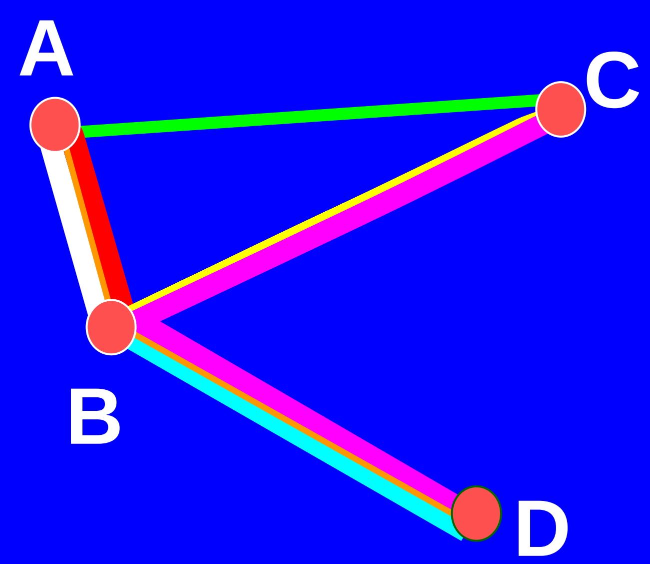
Miminimize Average Distance

- Nicholas (2004)



Flow-Capturing Models

- Hodgson (1990)
- Demand consists of paths, not points.
- Locate *p* facilities to capture the maximum volume of passing flows.



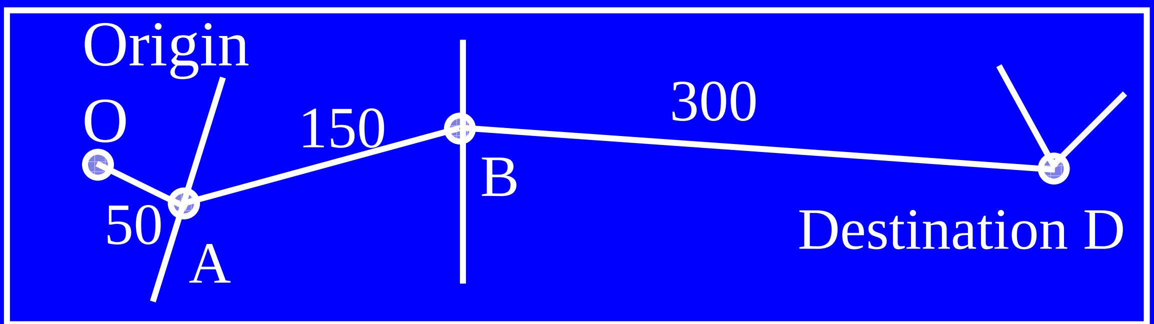
	A	B	C	D
A	-	12	7	2
B		-	3	5
C			-	9
D				-

The Flow-Refueling Location Model (FRLM)

- **Flow capturing assumes that a single facility anywhere on the path can capture the demand.**
- **For flow refueling, however, the *<u>limited range</u> of vehicles* means that some trips require multiple refuelings.**
- **Range = maximum distance a vehicle can travel between refuelings.**

Dealing with Vehicle Range

- Round-trip distance.
- Nodes not necessarily optimal.
- Several facilities may be necessary to refuel a path.



The Flow-Refueling Location Model is an Integer Linear Program

Objective

$$Max \sum_{q \in Q} f_q Y_q$$

Constraints

$$\sum_{h \in H} b_{qh} v_h \geq Y_q \qquad \forall\, q \in Q$$

$$a_{hk} X_k \geq v_h \qquad \forall\, h \in H; k \in K$$

$$\sum_{k \in K} X_k = p$$

$$X_k \in \{0,1\} \,\forall\, k$$

$$0 \leq Y_q \leq 1 \forall q;\; 0 \leq v_h \leq 1 \forall h$$

Variables

$Y_q = 1$ if path q is refueled; else 0

$v_h = 1$ if all facilities in combination h are open; else 0

$X_k = 1$ if facility k is open; else 0

Coefficients

$f_q =$ flow volume on path q

$b_{qh} = 1$ if combo h can refuel path q

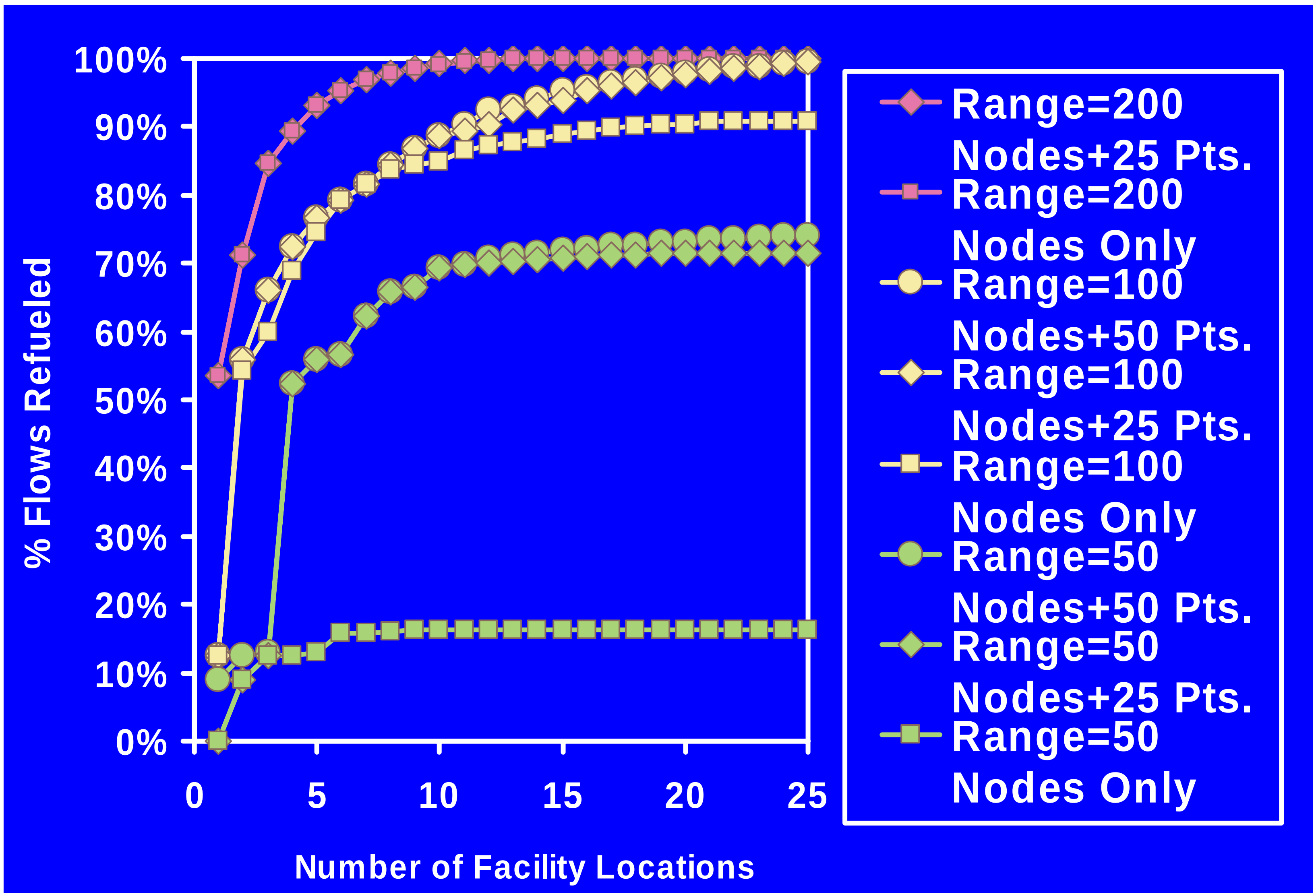
$a_{hk} = 1$ if combo h includes facility k

$p =$ number of facilities to be located

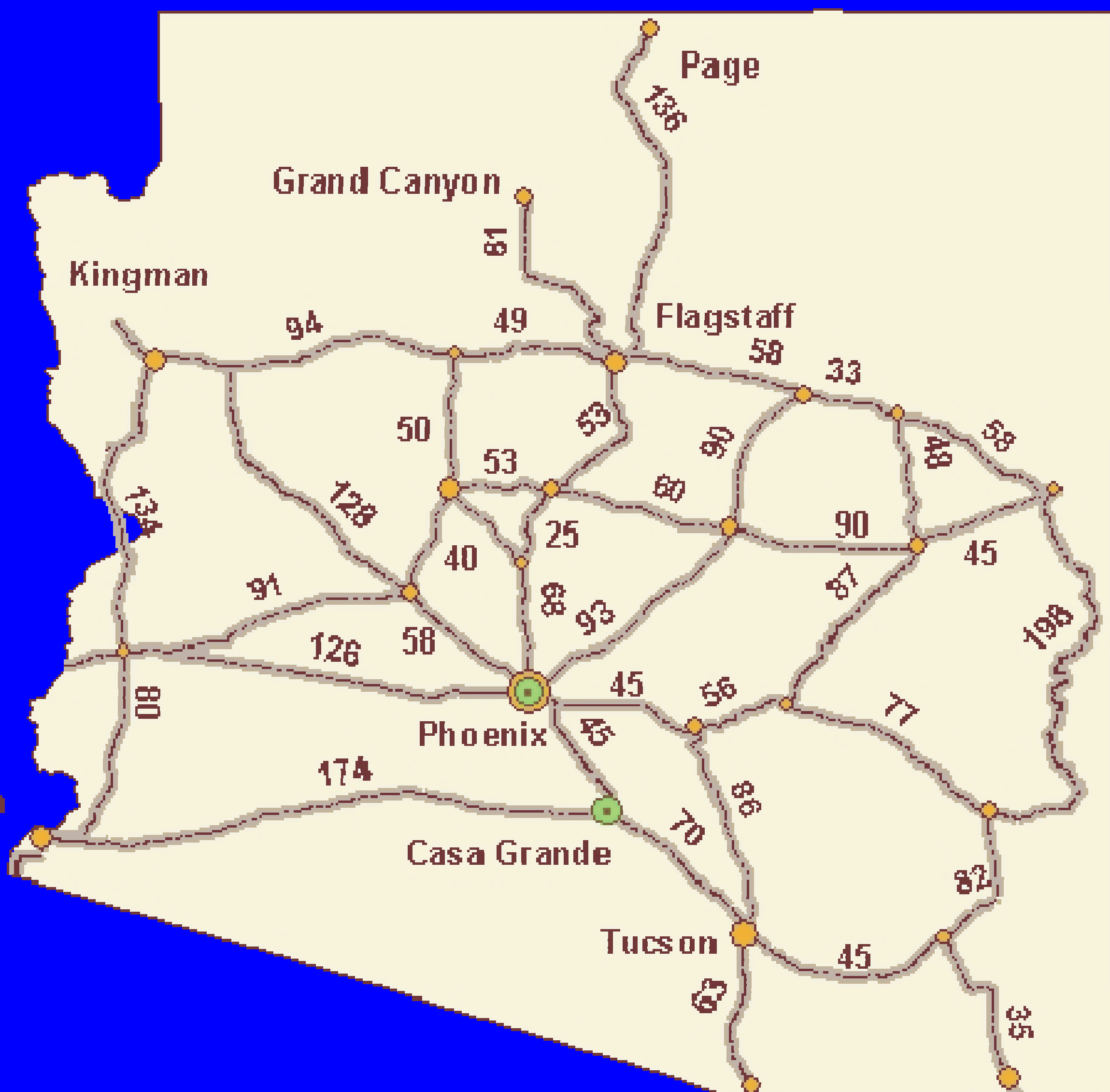
Arizona Highway Case Study

- 25 largest cities.
- Main Interstate, US, and AZ highways.
- <u>Inter</u>-city flows only.

Tradeoff Curve: Refuelable Trips vs. Number of Facility Locations



p=2, Range=50, Nodes Only

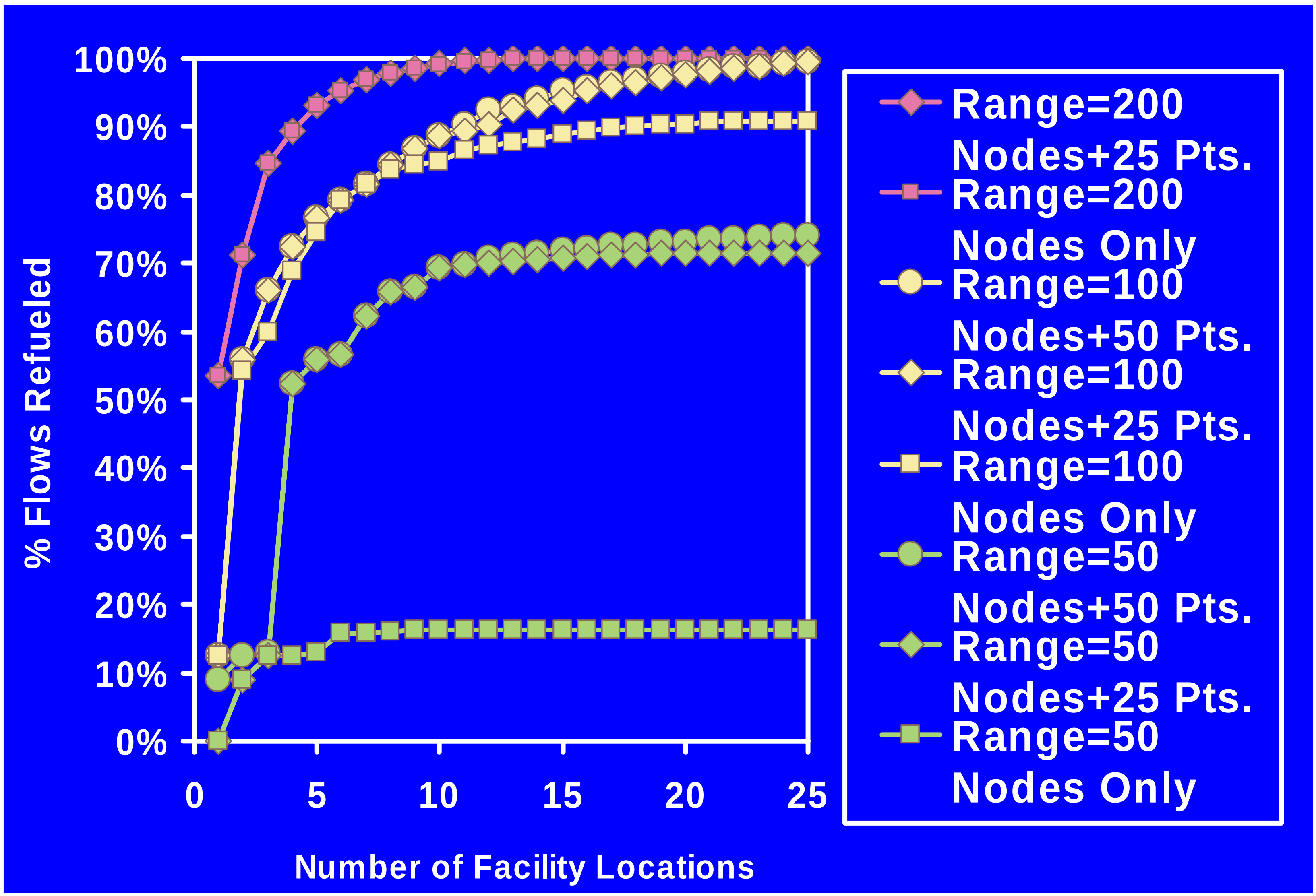


p=3, Range=50, Nodes Only

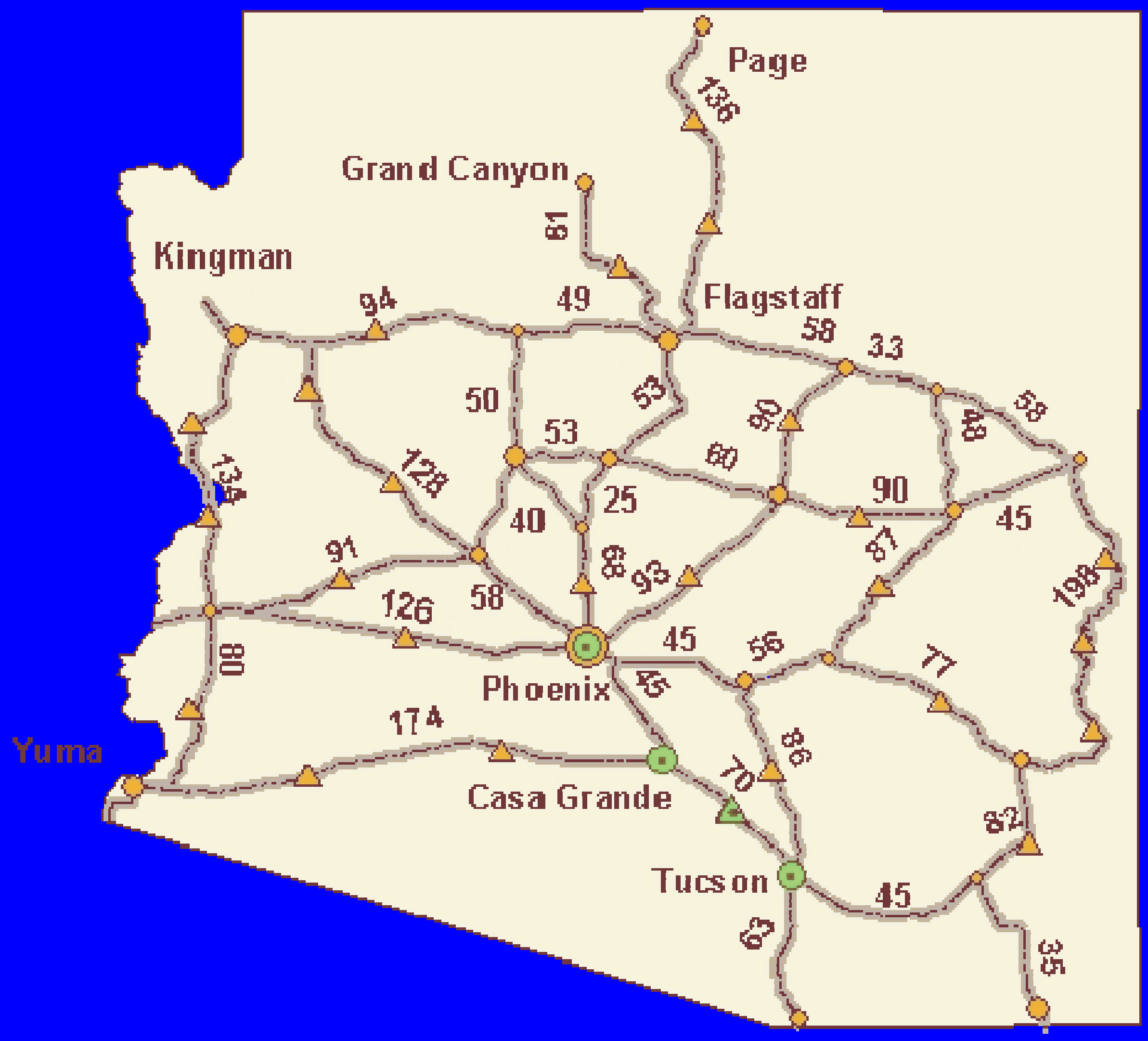
p=4, Range=50, Nodes Only

p=5, Range=50, Nodes Only

Tradeoff Curve: Refuelable Trips vs. Number of Facility Locations



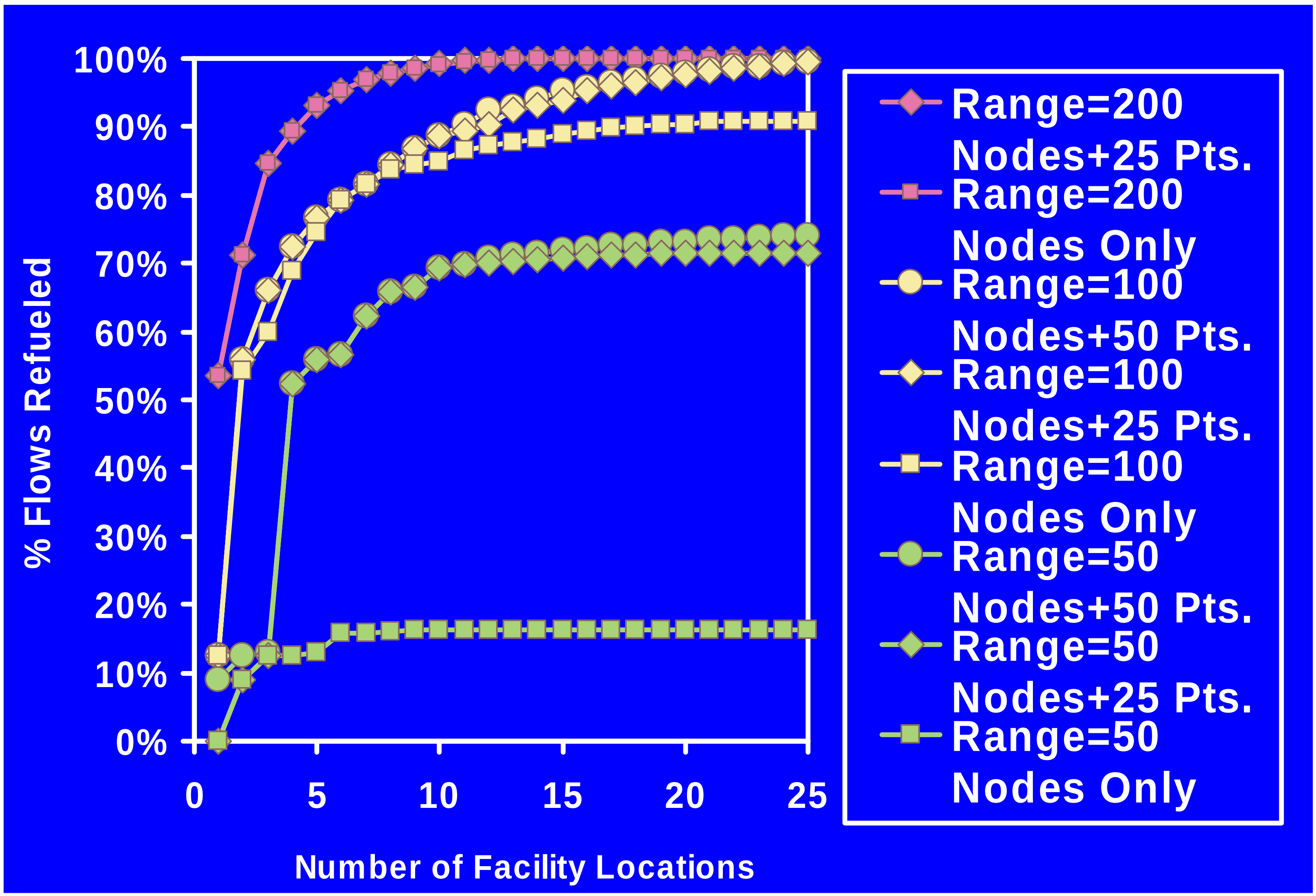
p=4, Range=50, Nodes+25 Minimax Pts



p=4, Range=100, Nodes+25 Minimax Pts

p=4, Range=200, Nodes Only

Tradeoff Curve: Refuelable Trips vs. Number of Facility Locations



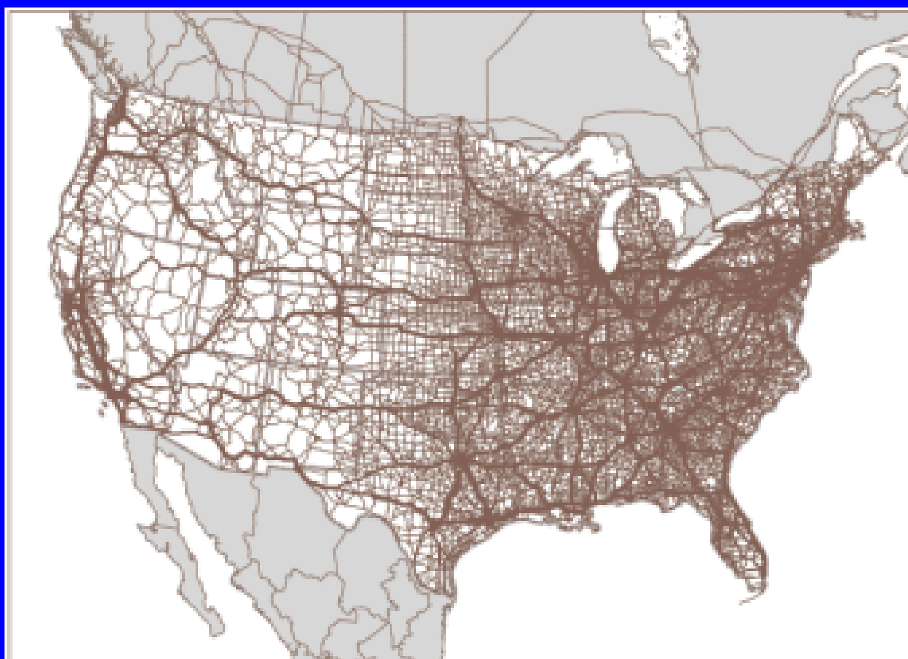
p=15, Range=100, Nodes+50 Pts

Current and Future Research

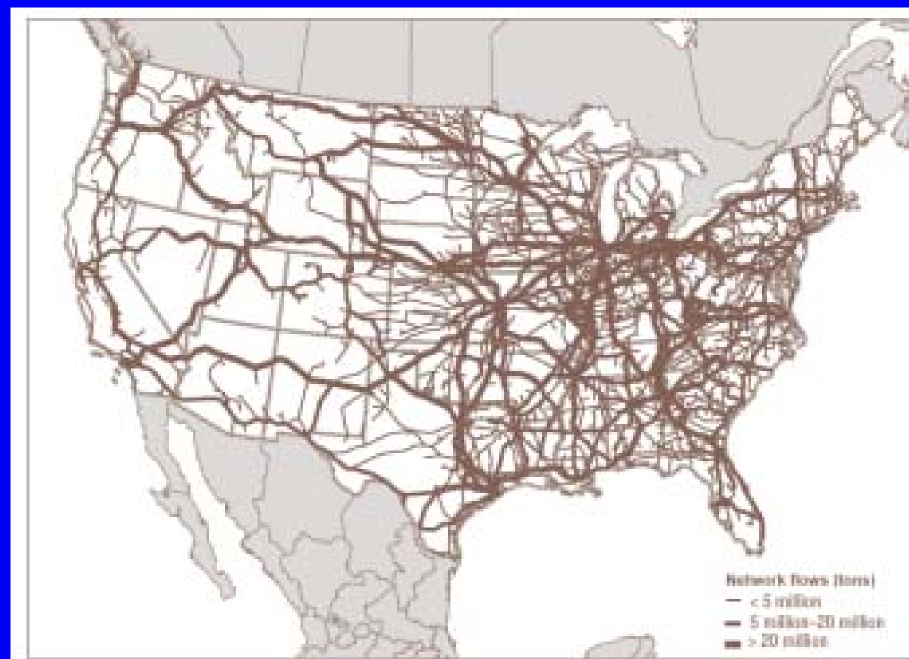
- Capacitated facilities
- Faster solution methods
- Hydrogen rental car fleet in Orlando (funded by Florida Hydrogen Initiative)
- Detouring off shortest paths

H_2 Refueling—Road vs. Rail: Detouring Less Likely for Rail

Road



Rail



Source: **2004 Transportation Statistics Annual Report, Figures 2-13, 2-14.**

H_2 Refueling—Road vs. Rail: Railroads Minimize Total Costs

http://www.uprr.com/aboutup/maps/sysmap/index.shtml

- Railroads own and operate vehicles and stations →
- Minimize total costs consisting of the sum of fixed and variable costs of H_2 supply, H_2 refueling, and train re-routing.

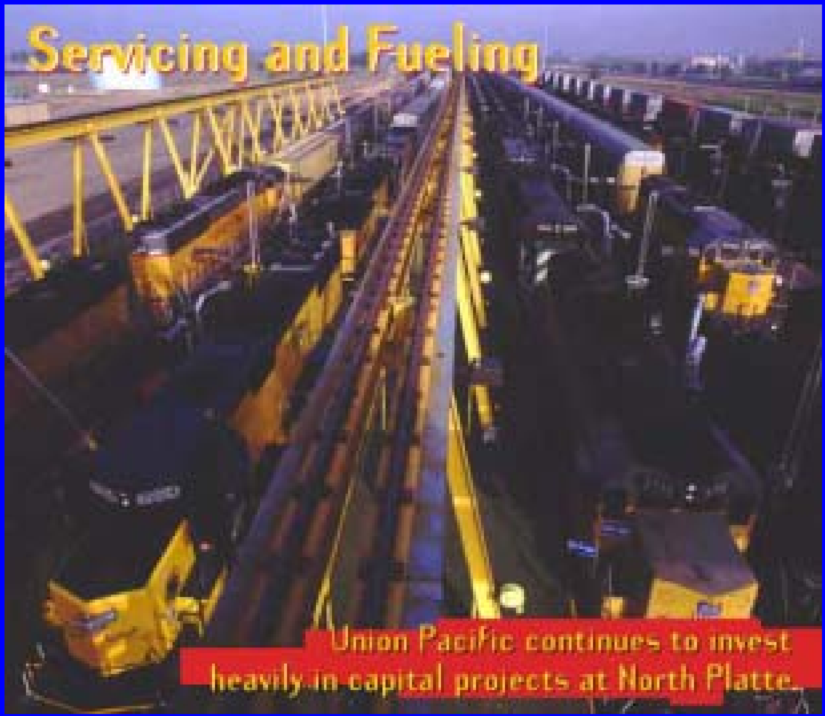
Remote Refueling by Tender Car Delivery, Instead of Re-routing Trains or Building More Stations

Source: http://www.snowcrest.net/photobob/ccnf30.html

H_2 Refueling—Road vs. Rail: Max Range (if any) Depends on Weight *and* Number of Hydrogen Tenders

***Source*: http://www.snowcrest.net/photobob/ccnf2.html**

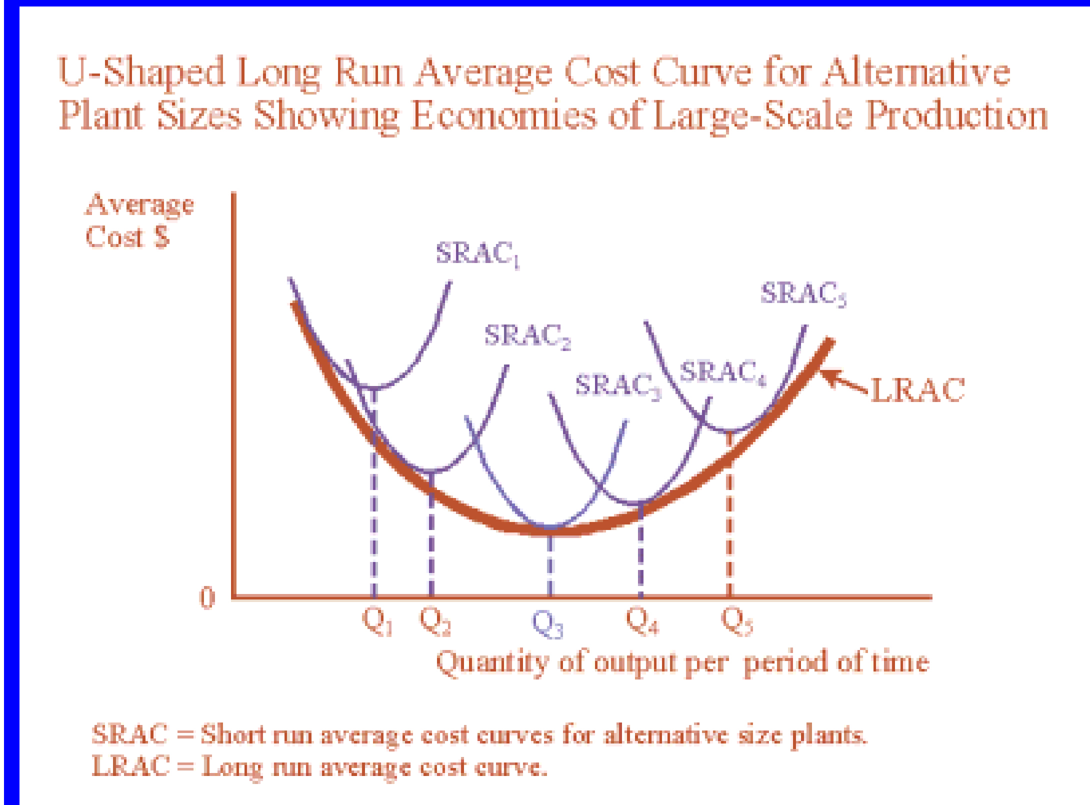
H_2 Refueling—Road vs. Rail: Economies of Scale in H_2 Generating Plants/Stations

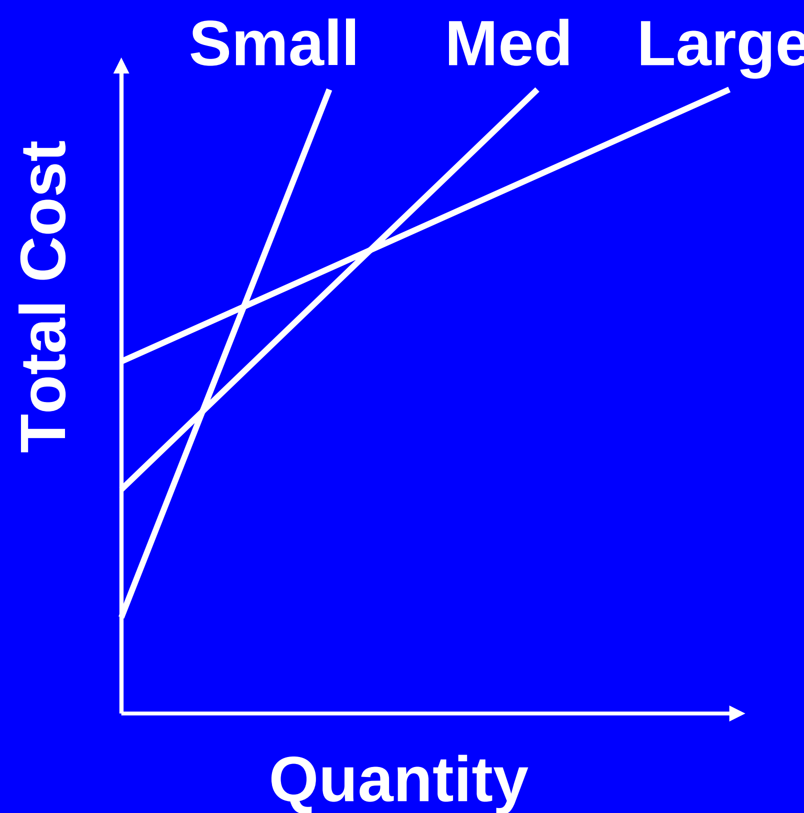


Source: **http://www.uprr.com/aboutup/history/bailey/byserv.shtml**

Source: **http://www.hynet.info/.**

H_2 Refueling—Road vs. Rail: Economies of Scale in H_2 Generating Plants/Stations





Source: Managing and Accounting Web

Conclusions

- Location of refueling facilities has been overlooked in the optimization literature.
- Flow-capturing model provides good basis.
- Vehicle range necessitates use of facility combinations.
- Must add some locations on links.

Conclusions for Modeling Rail Refueling

- Minimize total costs of transport and refueling
- Remote refueling
- Variable and extendable range
- Economies of scale

Acknowlegements

- **This research was funded by NSF (Decision Risk and Management Science Program).**
- **FRLM paper has been published in *Socioeconomic Planning Sciences*.**
- **Added-Node Dispersion paper submitted to *Geographical Analysis*.**
- **MIP models solved with Xpress-MP software.**