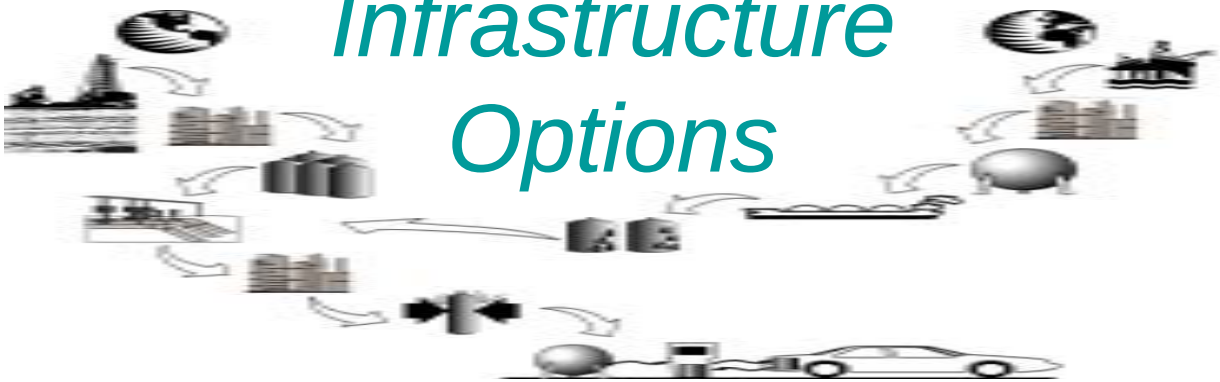
Cost of Some Hydrogen Fuel Infrastructure Options



Marianne Mintz
Stephen Folga
John Molburg
Jerry Gillette

Transportation Research Board
January 16, 2002

Argonne National Laboratory
Transportation Technology R&D Center

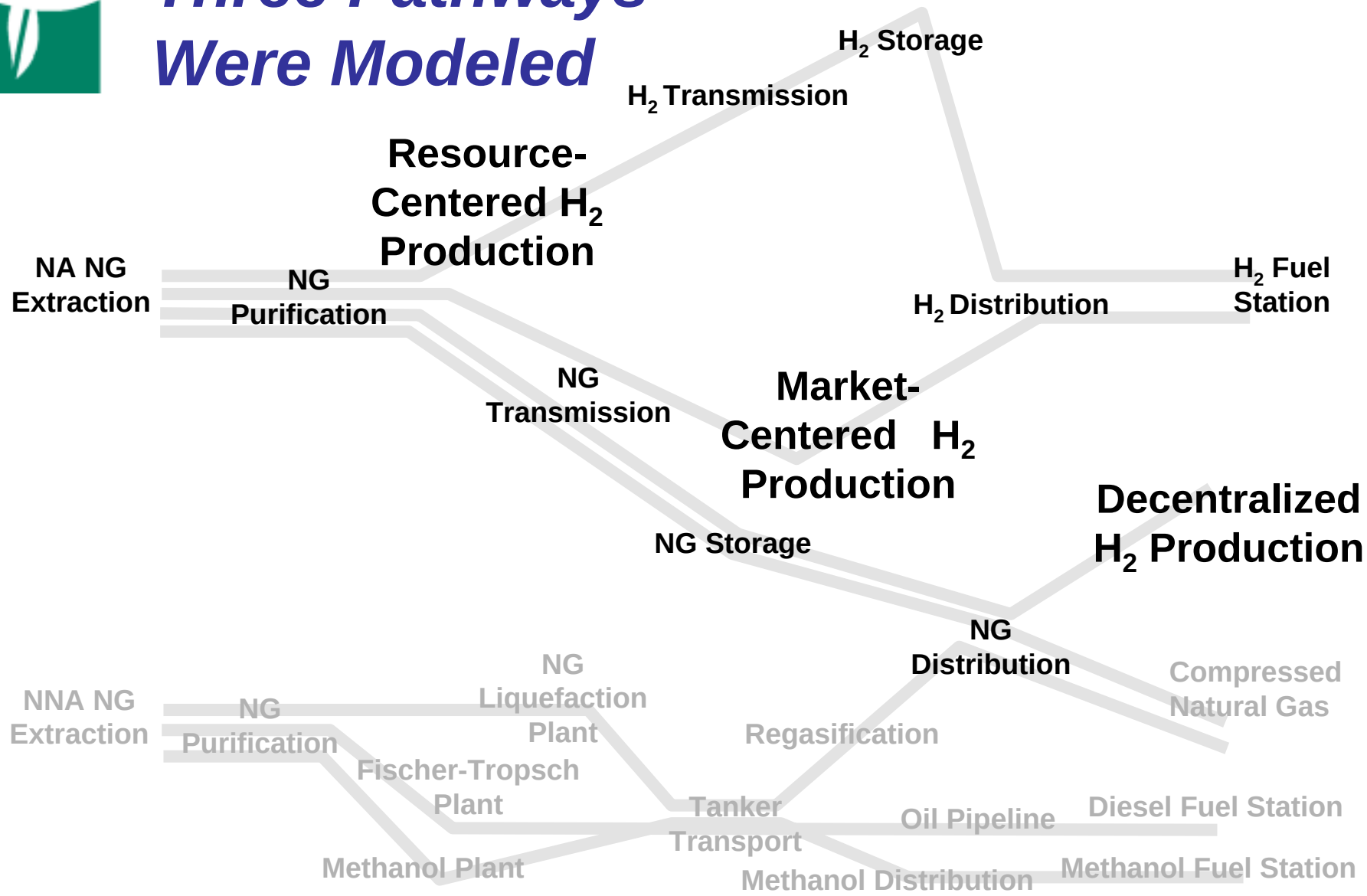
Focus of Presentation Is on:

- Cost modeling process
- Pathways
  - Components
  - Arrangement
  - Key assumptions
- Hydrogen delivery volumes
- Illustrative component cost analyses
- Results

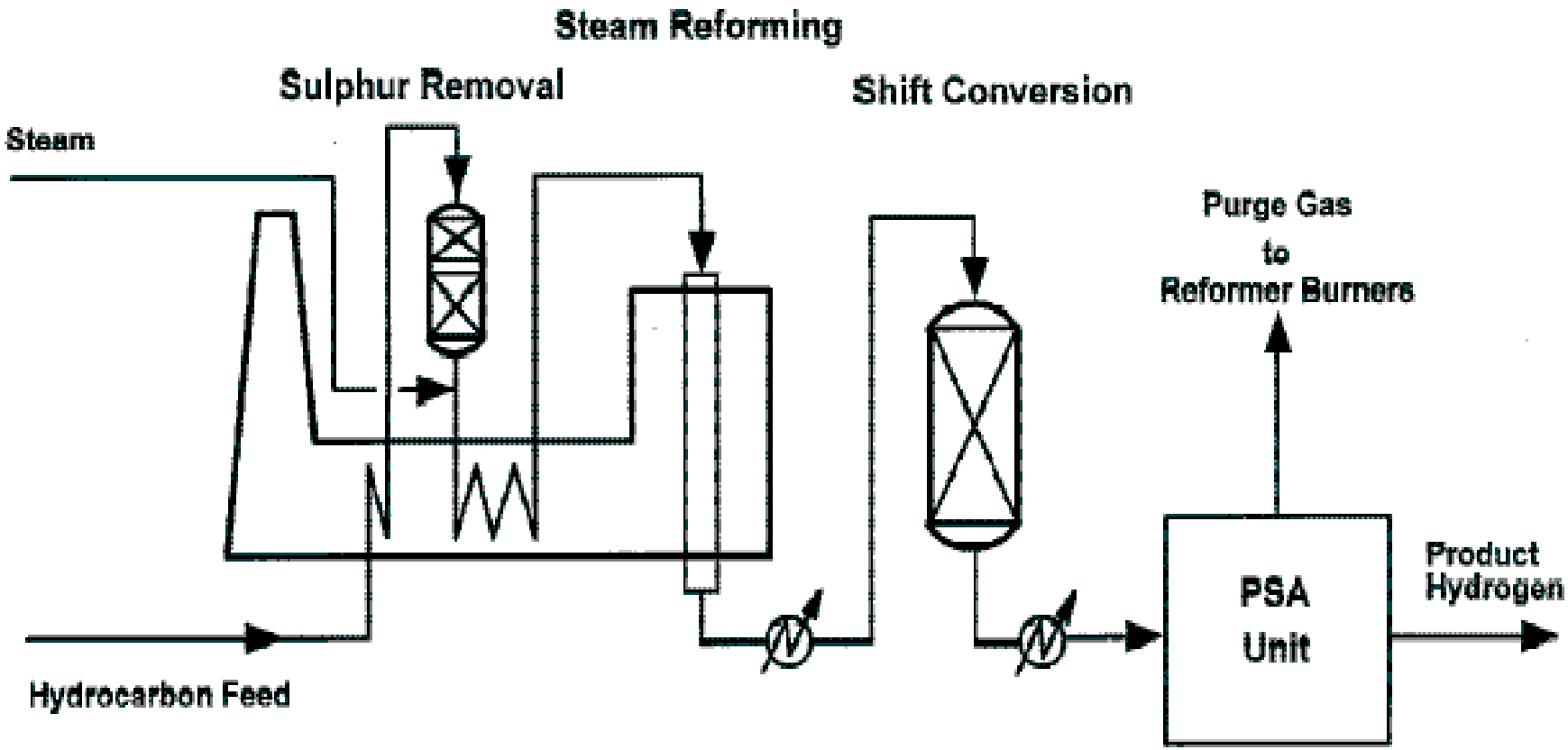
Cost Modeling Was Conducted Via a Five-Step Process

- Define paths
  - NG compression, storage and transport
  - Hydrogen production
  - H2 compression, storage and transport
  - Hydrogen dispensing
- Determine “tank-in” fuel requirement
  - HFCV market penetration & efficiency
- Size pathway components
- Estimate component costs
- Calculate pathway costs (NICC model)

Three Pathways Were Modeled

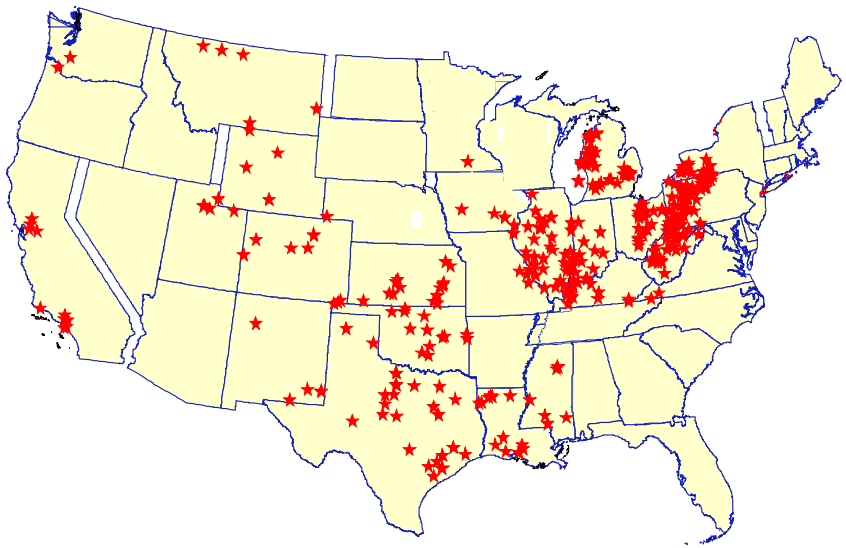


Steam Reforming Inputs Are Water and Hydrocarbon Feedstock; Outputs Are Hydrogen and Purge Gases



All Pathways Include Underground Storage

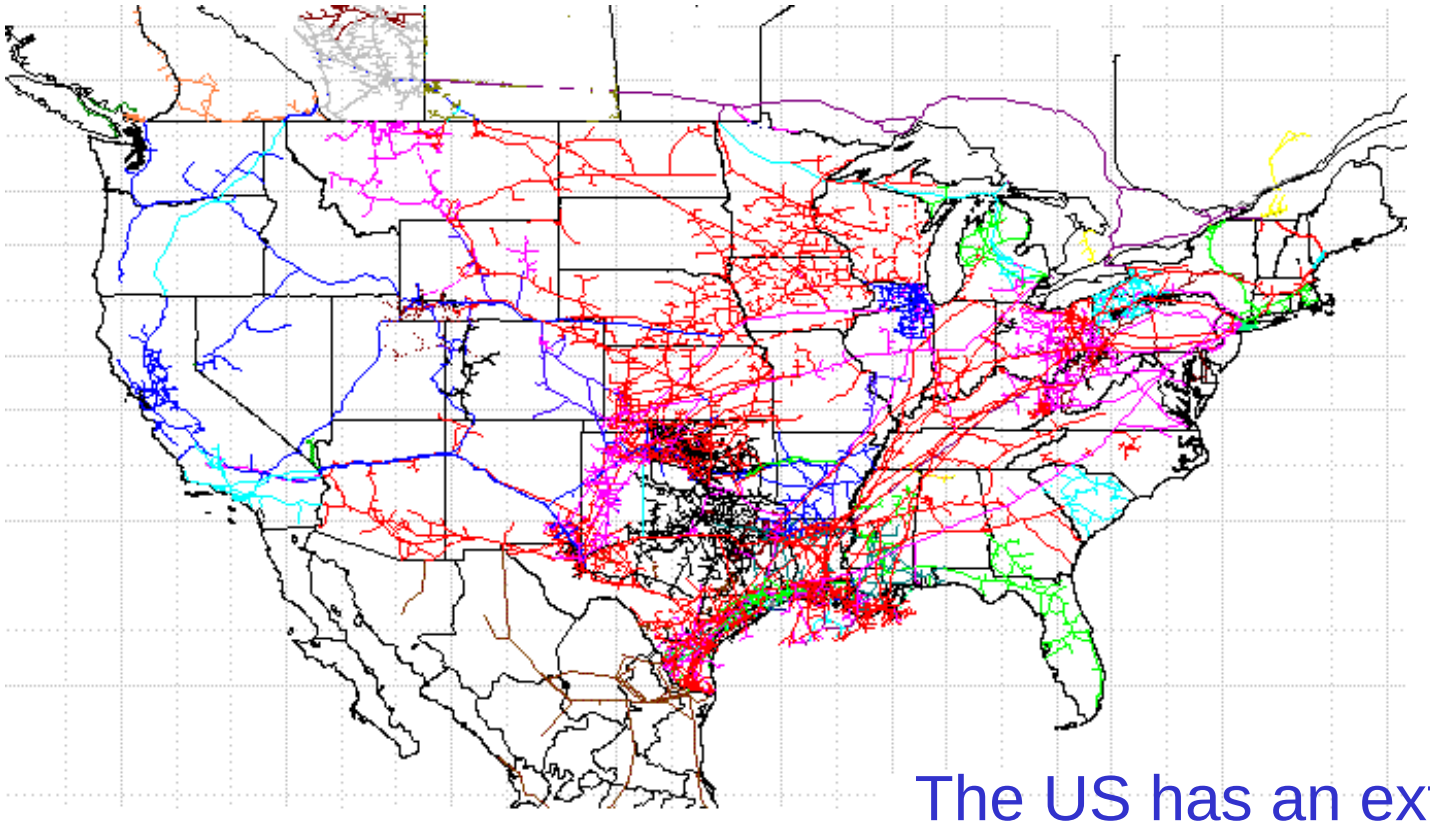
At the end of 1998 there were 410 underground natural gas storage sites in the U.S.



With 76 Bcf per day of Withdrawal Capability and 3,933 Bcf of Working Gas Capacity

www.eia.doe.gov Energy Information Administration

All Pathways Require Additions to the Existing Natural Gas Transmission Infrastructure

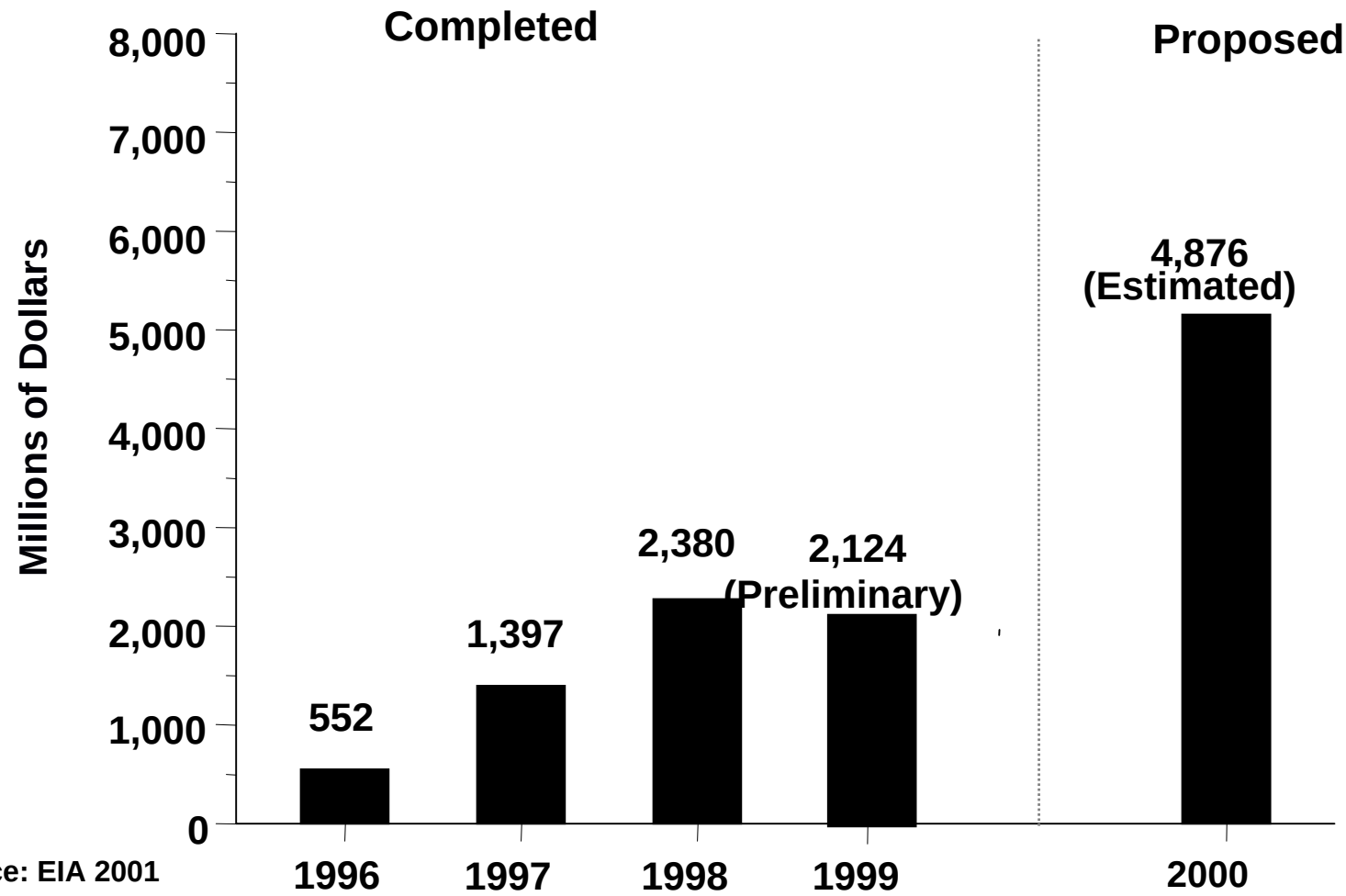


The US has an extensive in-place NG transmission infrastructure ……..

And a Track Record of Continually Expanding Transmission Capacity

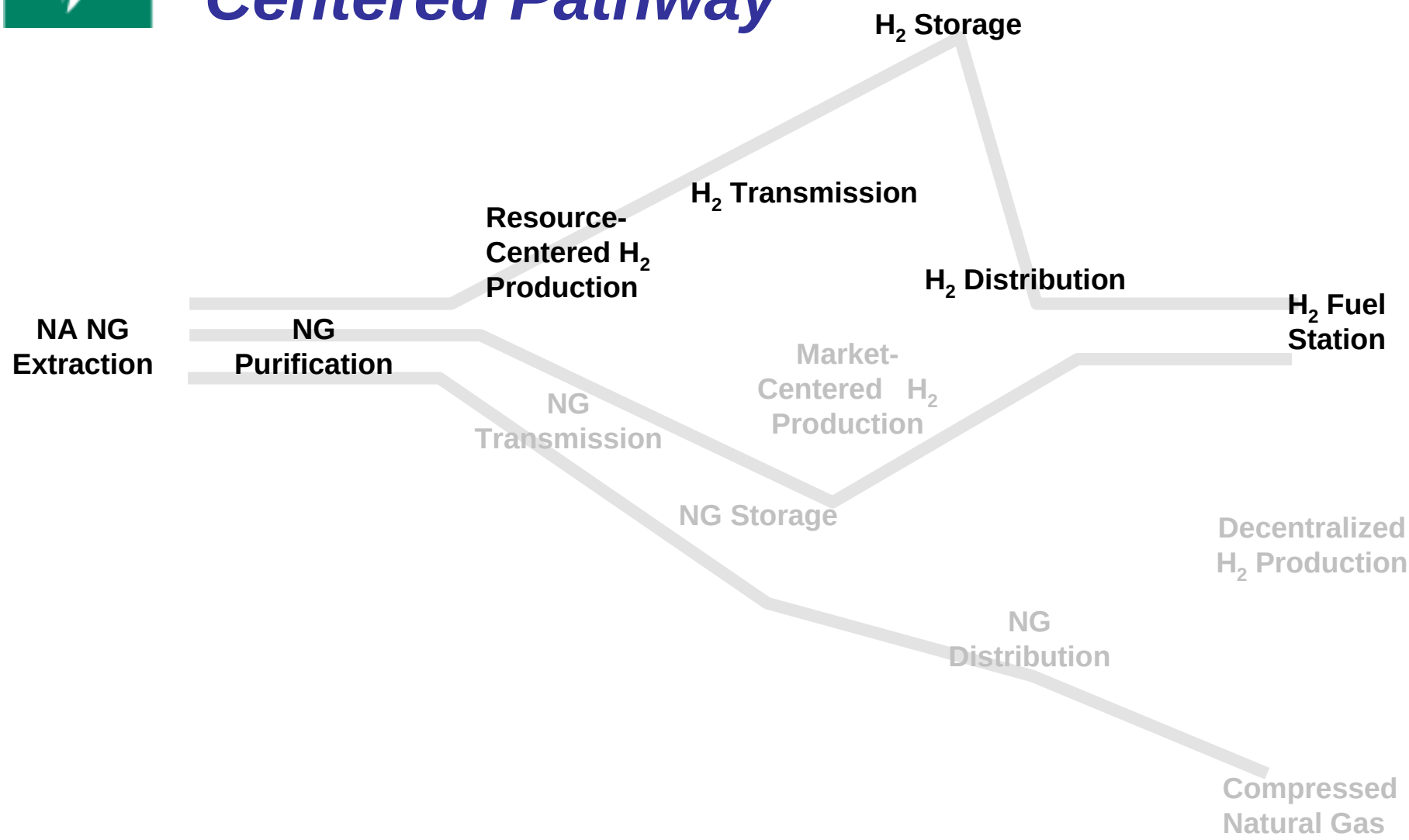
- New pipelines
- Additional compression
- Looping
- All of the above

According to EIA, Nearly $5 bln Was Spent on Pipeline Expansion in 2000

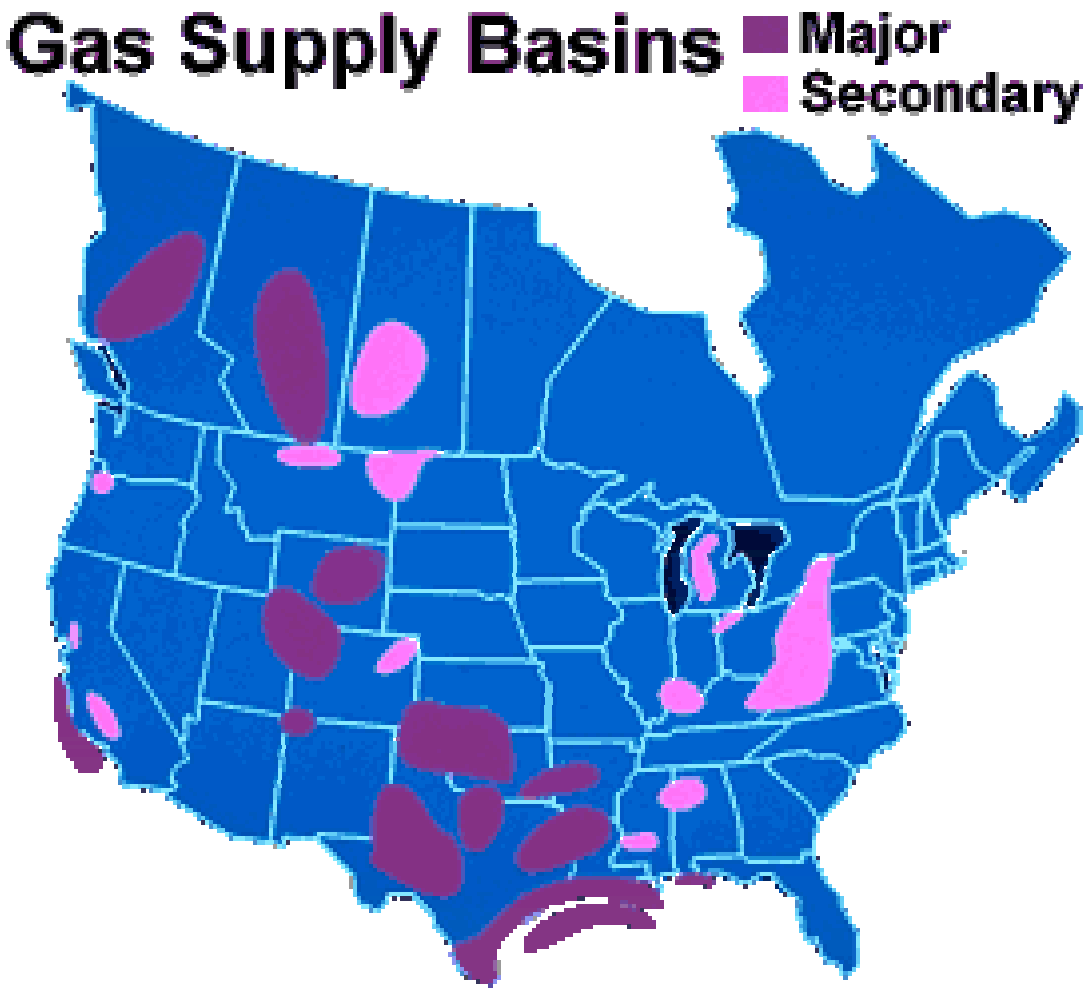


Source: EIA 2001

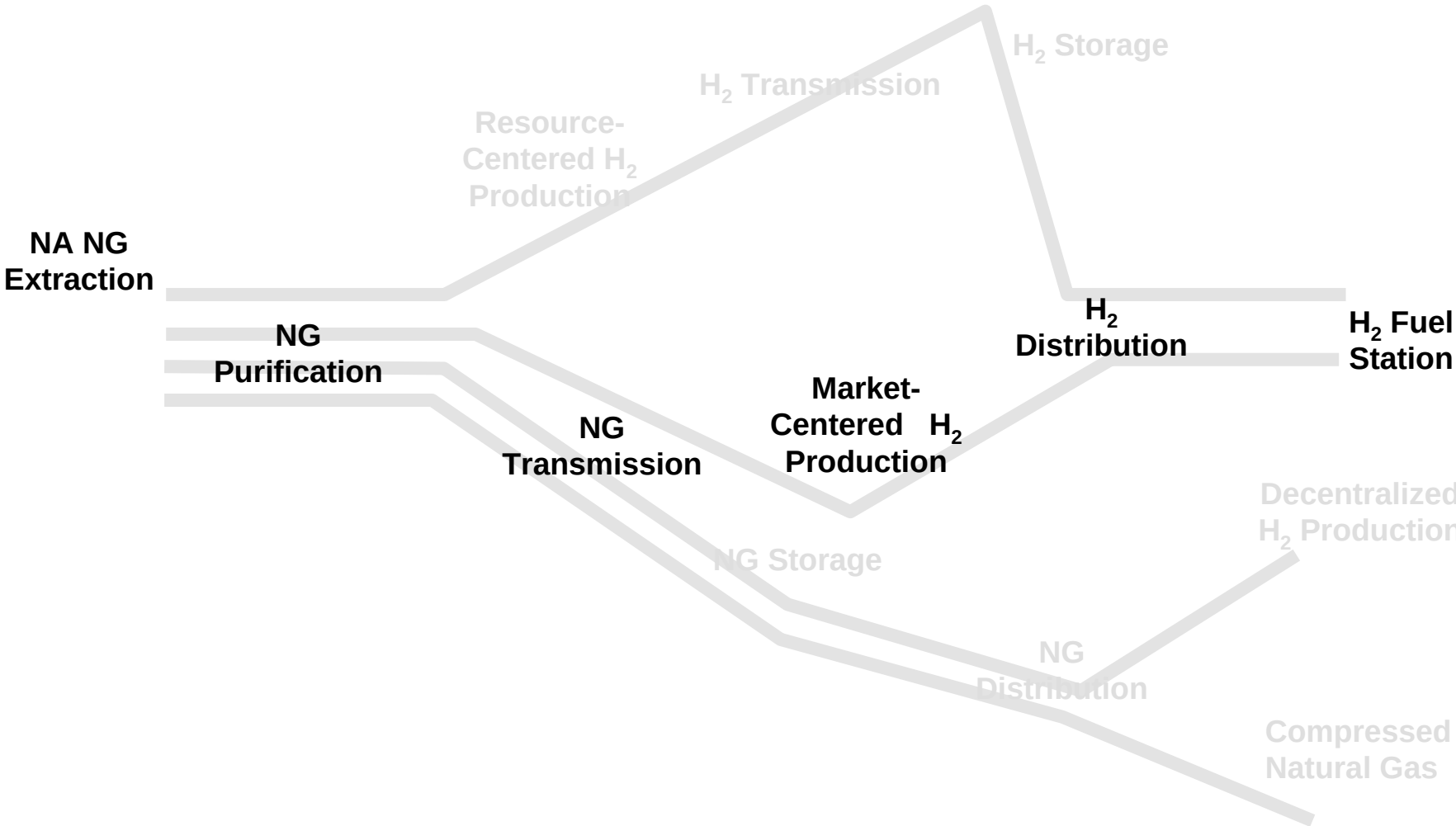
Components of the Resource-Centered Pathway



Hydrogen Production Is Near Natural Gas Supplies in the Resource-Centered Pathway



Components of the Market-Centered Pathway

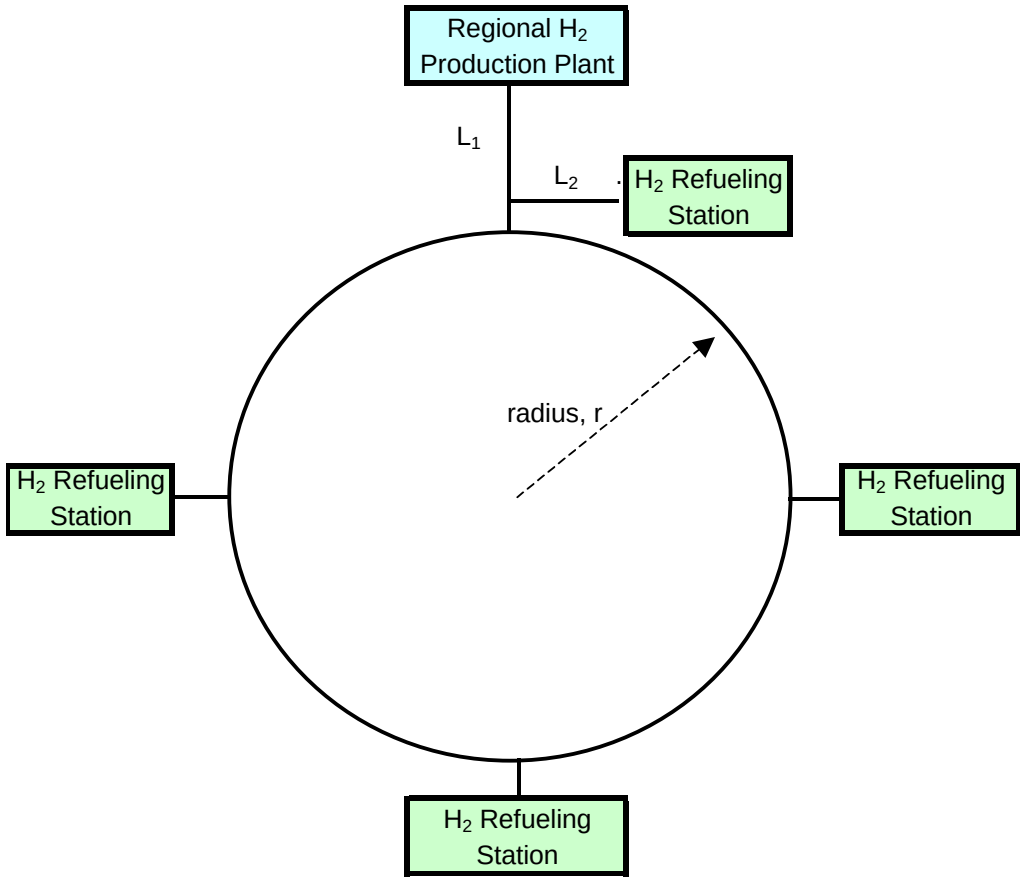


Market-Centered and Resource-Centered Paths Share H2 Distribution Assumptions

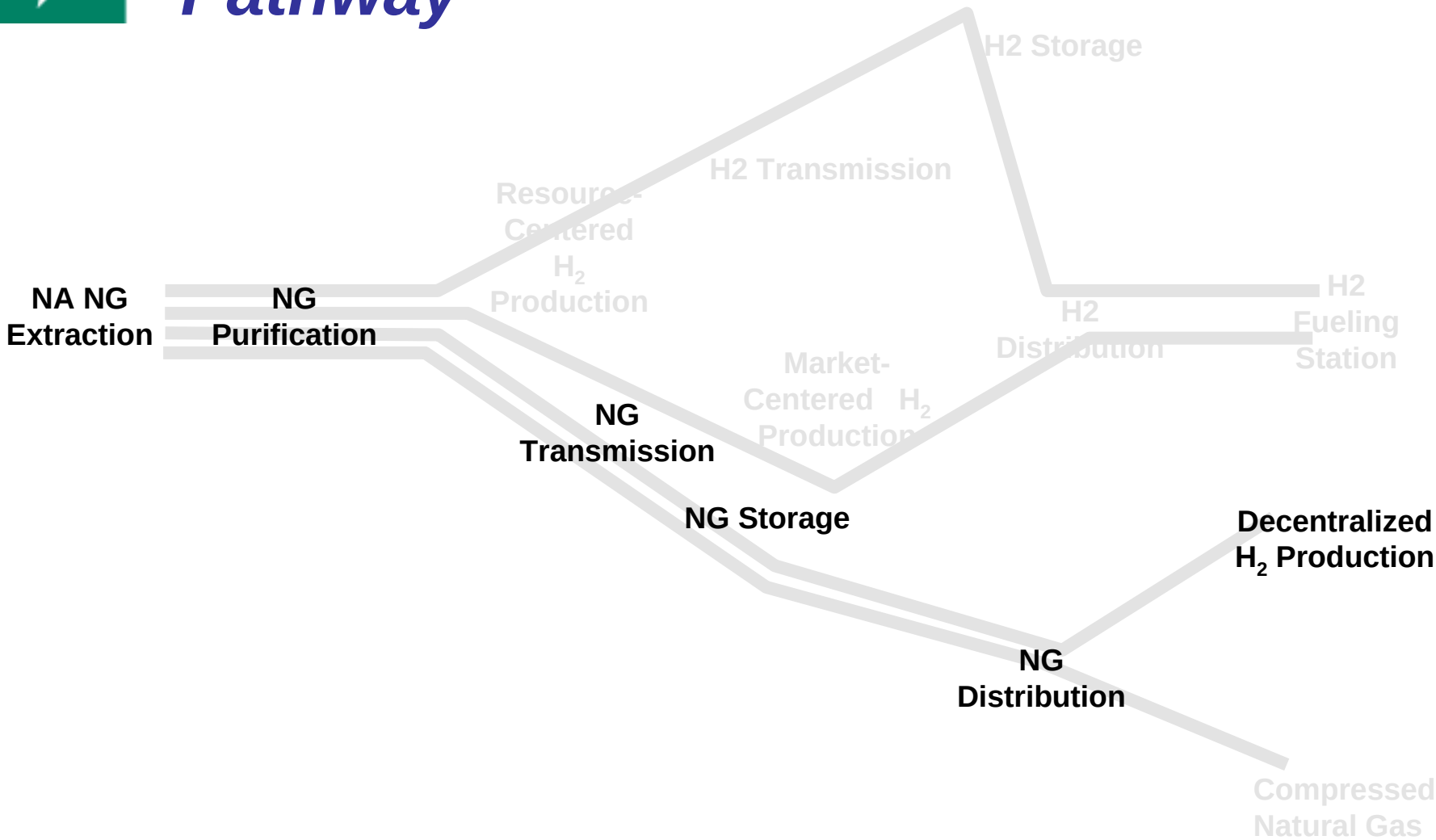
Component	Radius (mi)	Diameter (in)	Length (mi)
H_2 Pipeline Connecting Pipeline Ring with H_2 Production Plant	N/A	12	15
H_2 Pipeline Ring Encompassing Community	25	12	157
H_2 Pipeline Connecting H_2 Refueling Stations with H_2 Pipeline Ring	N/A	3	900 [a]

[a] Assumes 180 refueling stations, a service pipeline unit length of 15 miles, and 3 refueling stations per service pipeline.

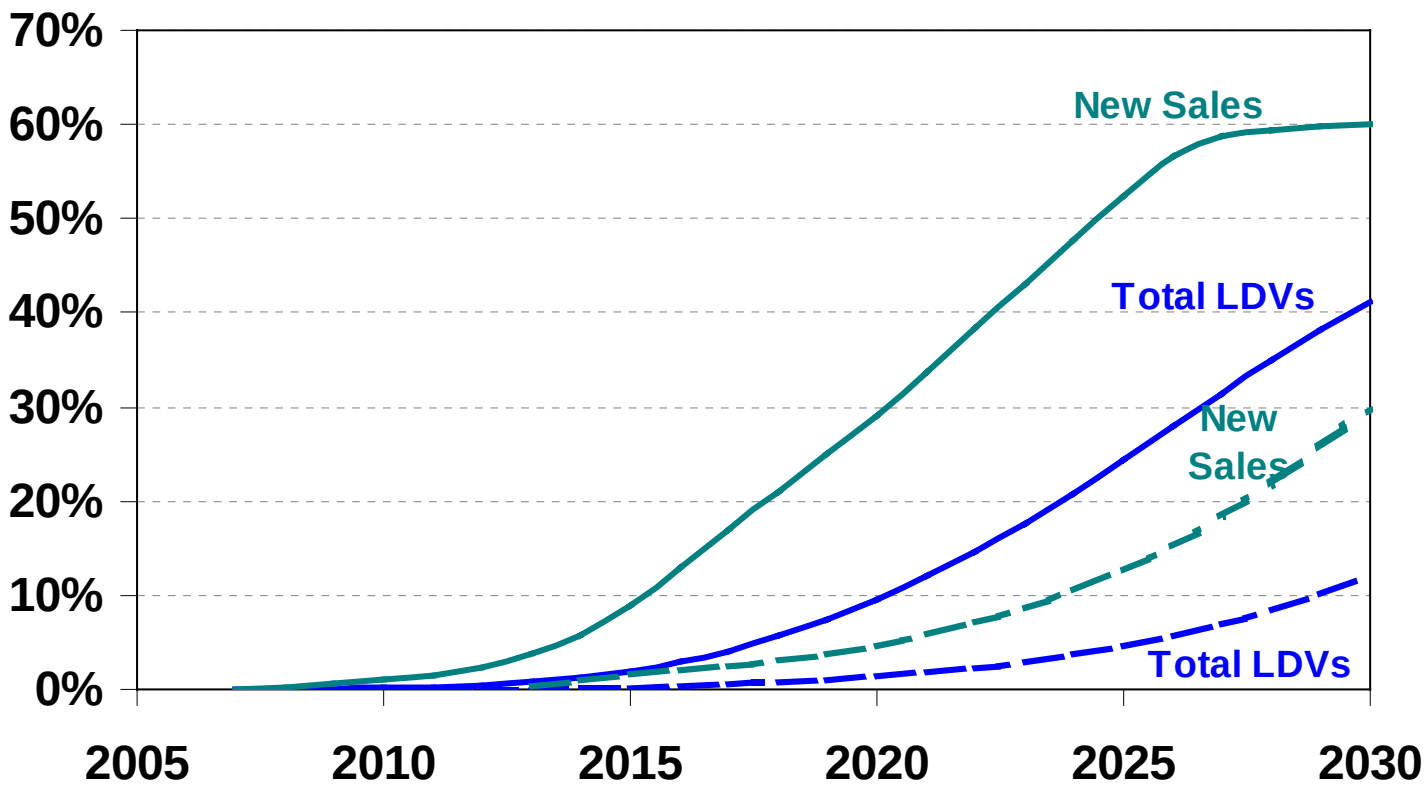
Conceptual Representation of Hydrogen Pipeline Loop Supporting Local H2 Delivery



Components of the Decentralized Pathway



Two Market Penetration Cases Were Modeled



Six Cumulative Delivery Volumes, Functions of HFCV MPGE & Market Penetration, Were Modeled

MPGE	30% Market Penetration	60% Market Penetration
60	6.9 bln GJ (6.6 Q)	High Penetration Low mpg 31.2 bln GJ (29.6 Q)
74	5.6 bln GJ (5.4 Q)	25.5 bln GJ (24.2 Q)
80	Low Penetration High mpg 5.2 bln GJ (4.9 Q)	23.4 bln GJ (22.2 Q)

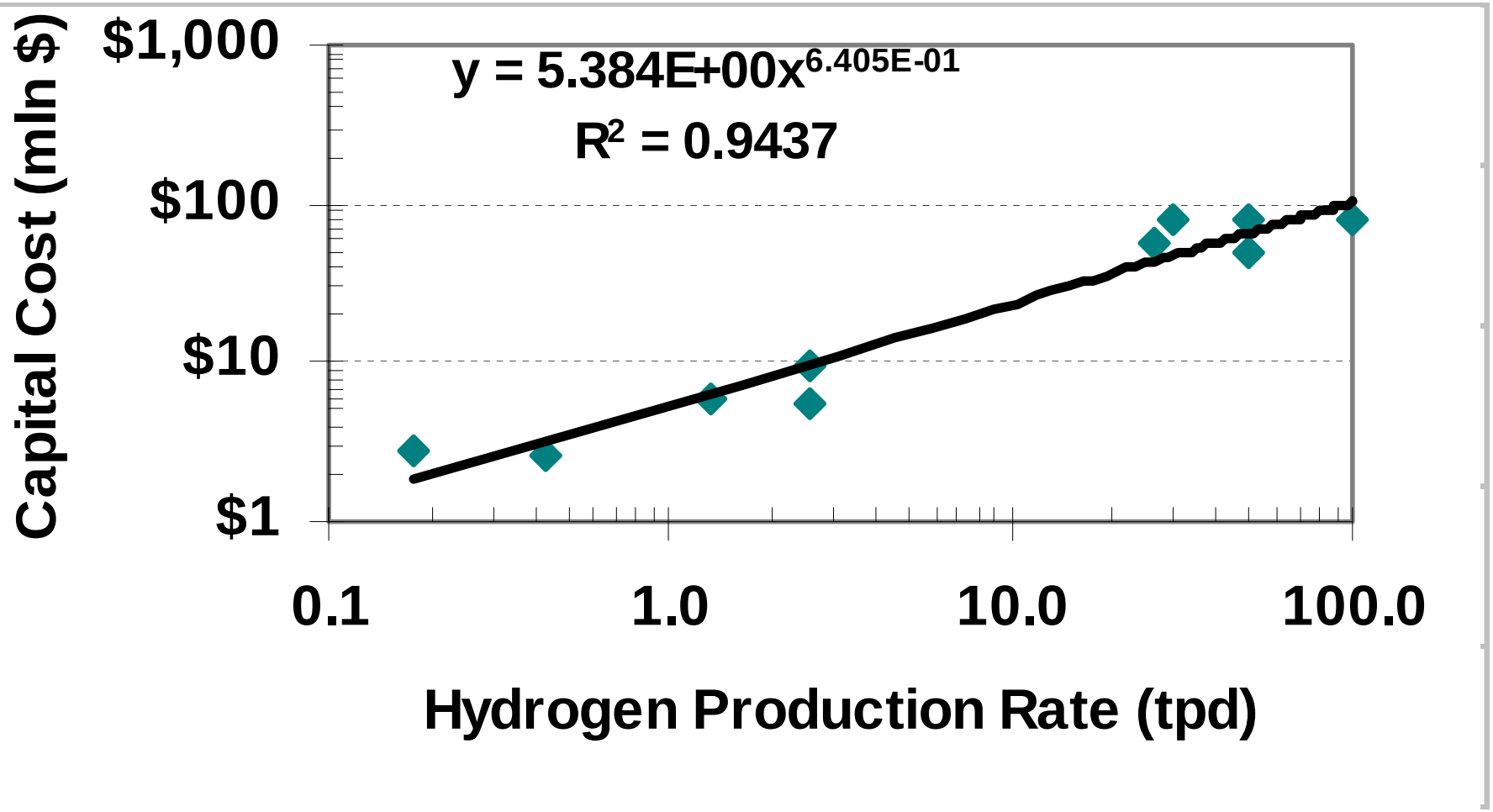
The US Accounts for 20% of Global Hydrogen Consumption , Approx. 1 Q (1999, tcf)

Captive Users	United States	Total World[1]
- NH_3 Producers	1.185	9.662
- Oil Refiners[2]	1.164	3.721
- MeOH Producers	0.303	1.428
- Other	0.128	0.489
Merchant Users	0.379	0.570
Total	3.160	15.872

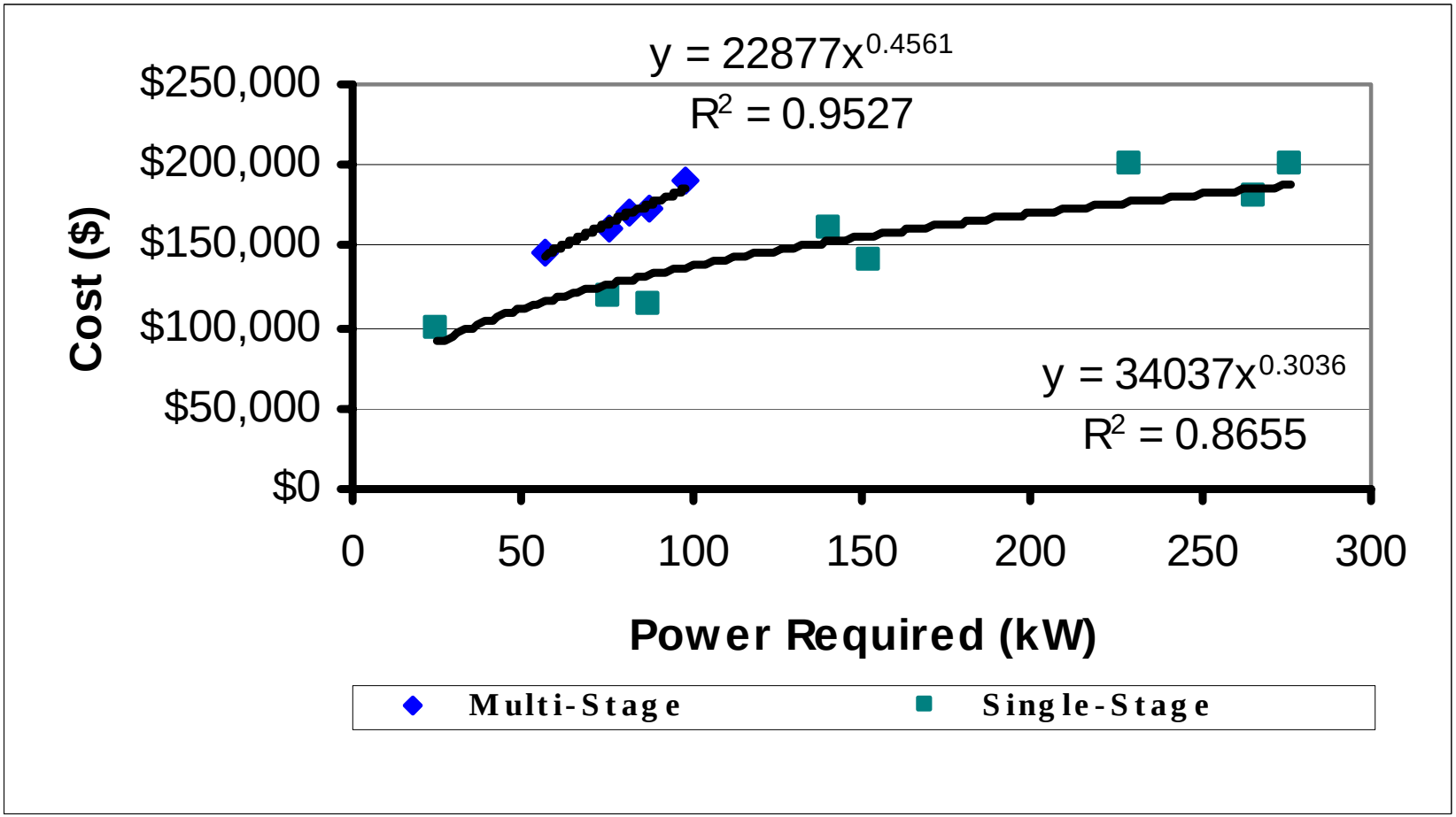
[1] Including US.
[2] Excluding byproduct hydrogen.

Source: SRI Chemical & Health Business Services 2001.

Current SMR Plants Have Large Economies of Scale



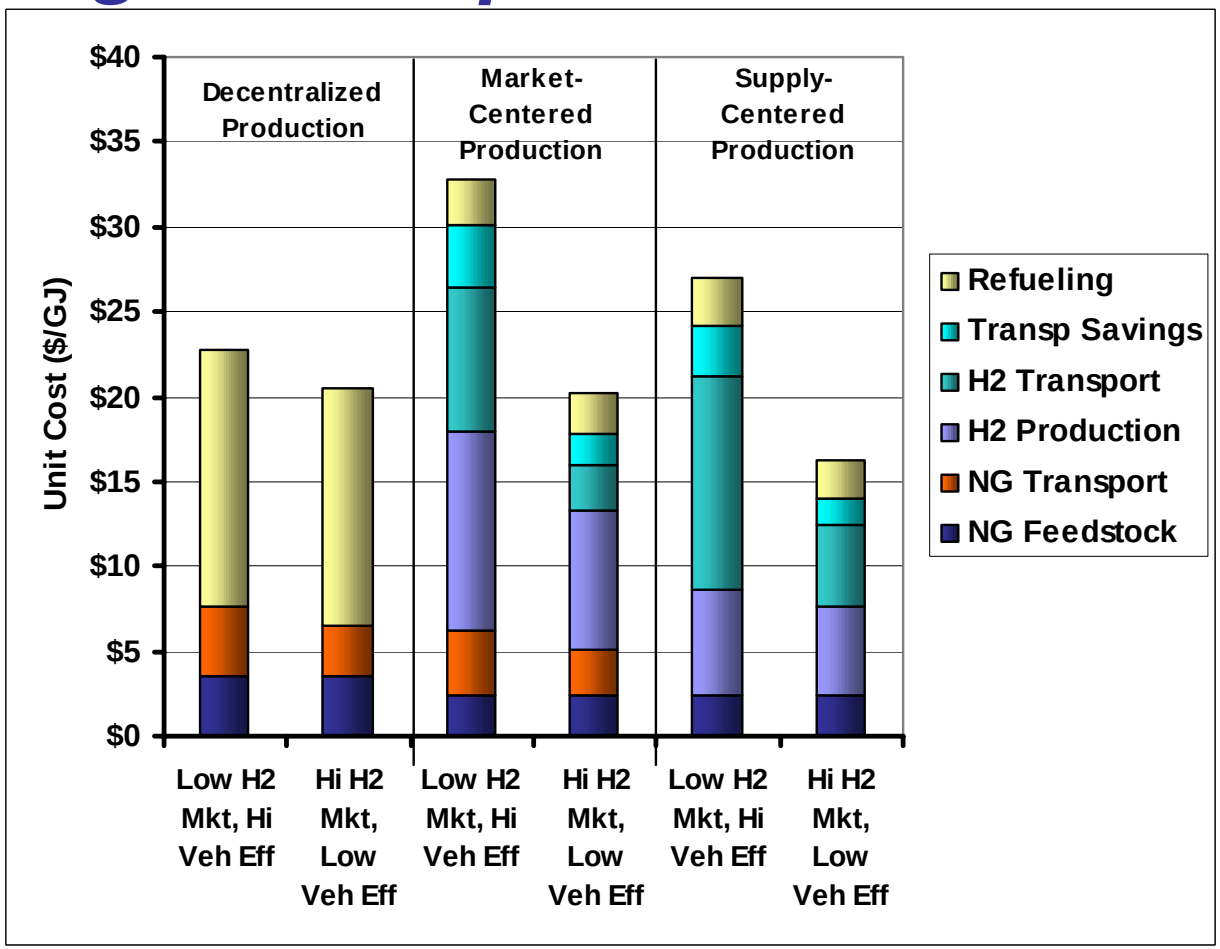
Compressor Costs Are a Function of Power



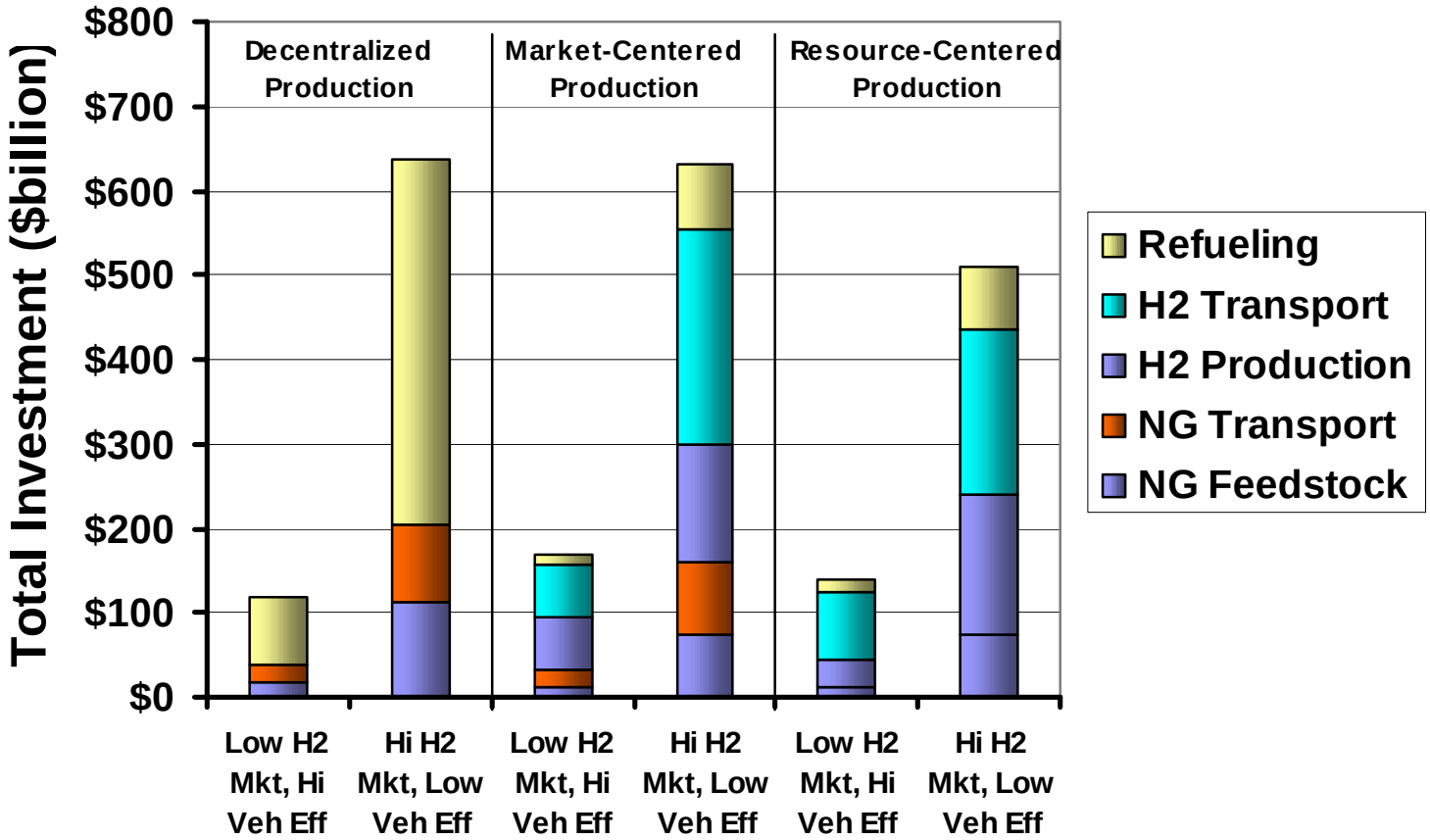
Unit Cost of NG & H2 Pipelines Vary with Pipe Diameter & Installation Technology

Diameter (inch)	Capital Cost of Natural Gas Pipeline ($/mi)	Capital Cost of H_2 Pipeline, Cut/Cover ($/mi)	Capital Cost of H_2 Pipeline, Trenchless ($/mi)
3	$200,000	$400,000	$300,000
9	$500,000	$900,000	$700,000
12	$600,000	$1,000,000	$900,000
14	$800,000	$1,400,000	$1,150,000

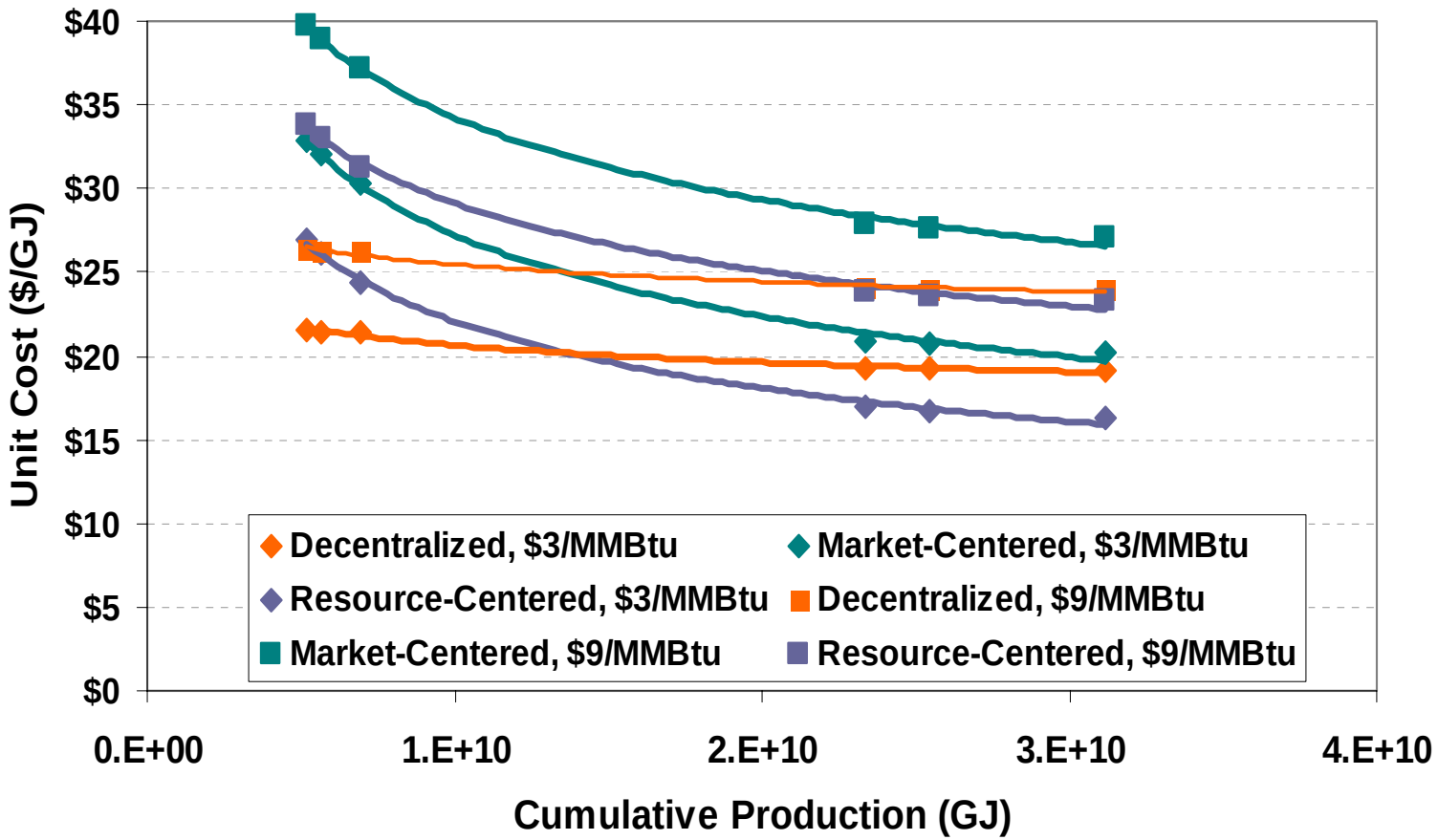
Least Cost Pathway Depends on H2 Volume; Reformers and Pipelines Are Largest Components



H2 Infrastructure to Fuel 100 Million+ FCVs Could Cost $500 Billion or More



H2 Unit Cost Varies by Pathway and Feedstock Price; Volume Matters for Centralized Pathways



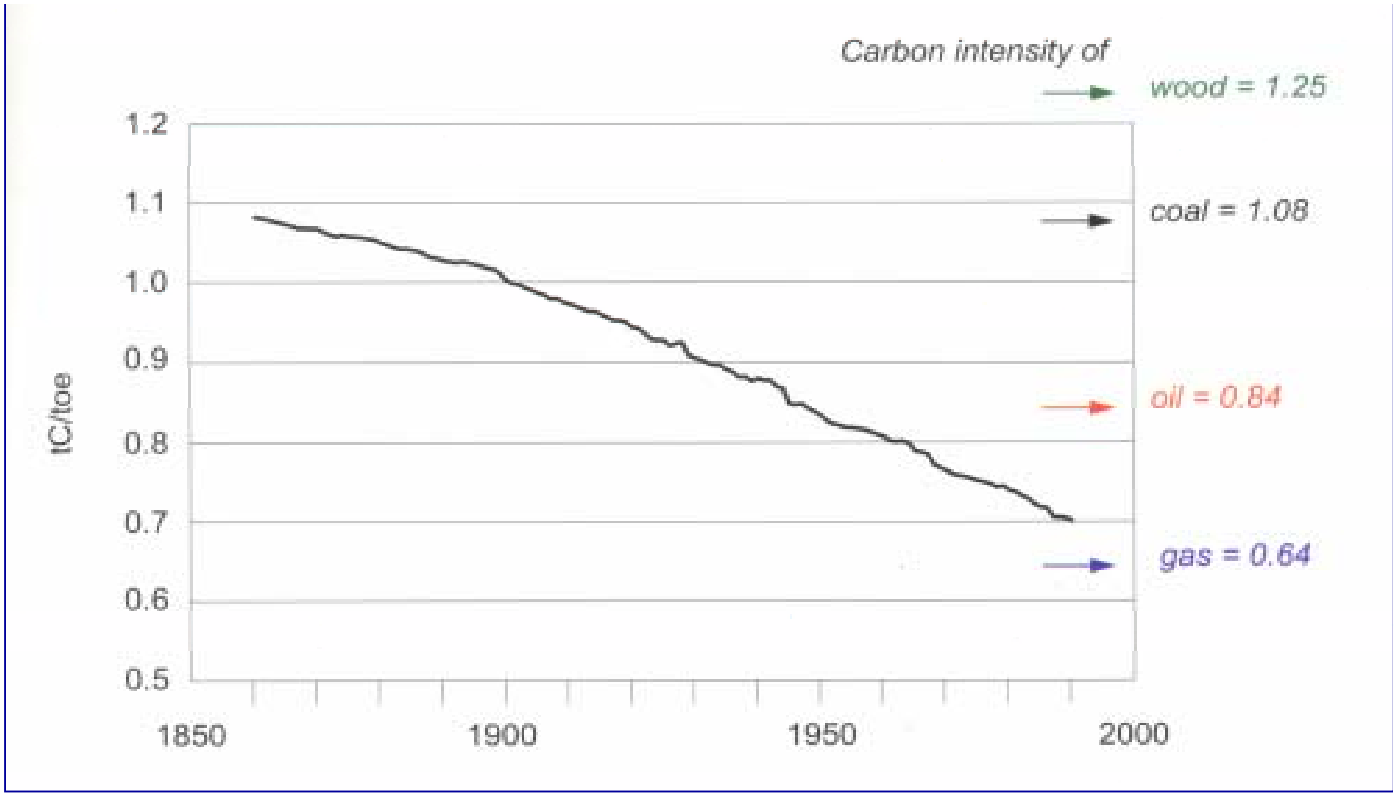
Some Conclusions:

- With current technologies, on a well-to-tank basis, hydrogen is likely to be at least twice as costly as gasoline.
- With current technologies, the hydrogen delivery infrastructure to serve 40% of the light duty fleet is likely to cost over $500 billion.
- For up to 7.5 bln GJ (7 Q) of cumulative hydrogen production, the decentralized path is lowest cost.
- For more than 13.6 bln GJ (13 Q), of cumulative production, the resource-centered path is lowest.

Conclusions (cont'd)

- With current technologies, scale economies are large for centralized options; small for decentralized
- Of the central production options, the resource-centered path is consistently lower cost (economies of scale).
- H2 transport and production are the largest cost components of all paths examined, hence appropriate focus for cost reduction.
- Pipeline costs may be overestimated in the literature due to improvements in excavation/installation technologies.

Carbon Intensity of World Primary Energy Has Been Declining Steadily



Marianne Mintz
mmintz@anl.gov