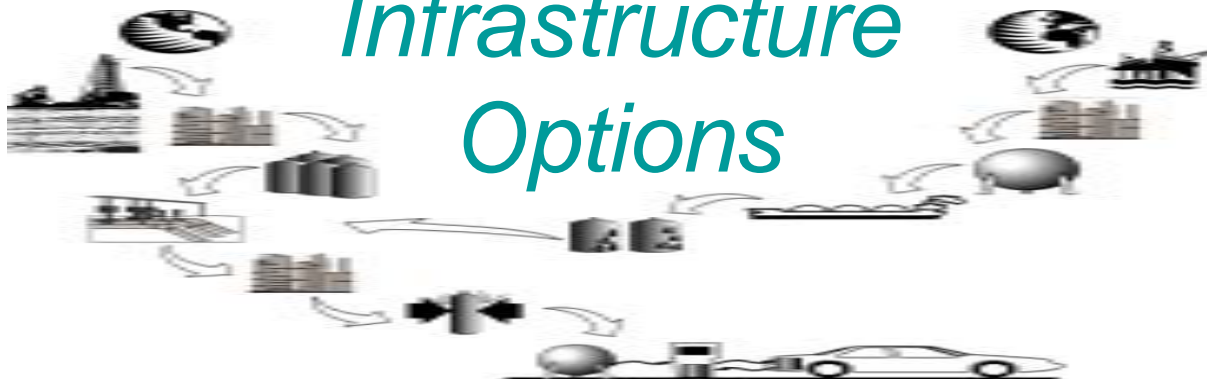




# *Cost of Some Hydrogen Fuel Infrastructure Options*



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Transportation Research Board  
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## ***Focus of Presentation Is on:***

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

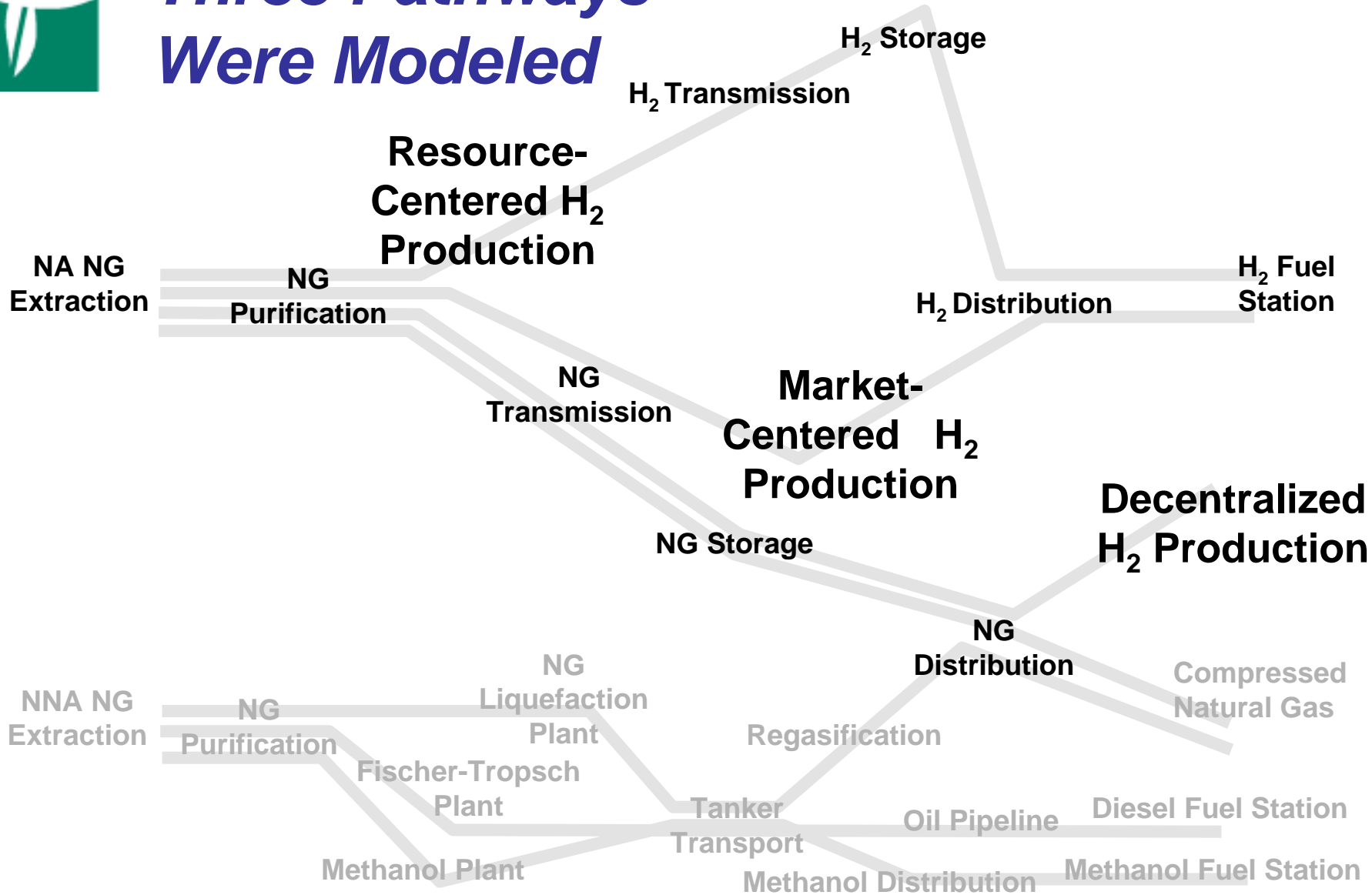


# ***Cost Modeling Was Conducted Via a Five-Step Process***

- 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)

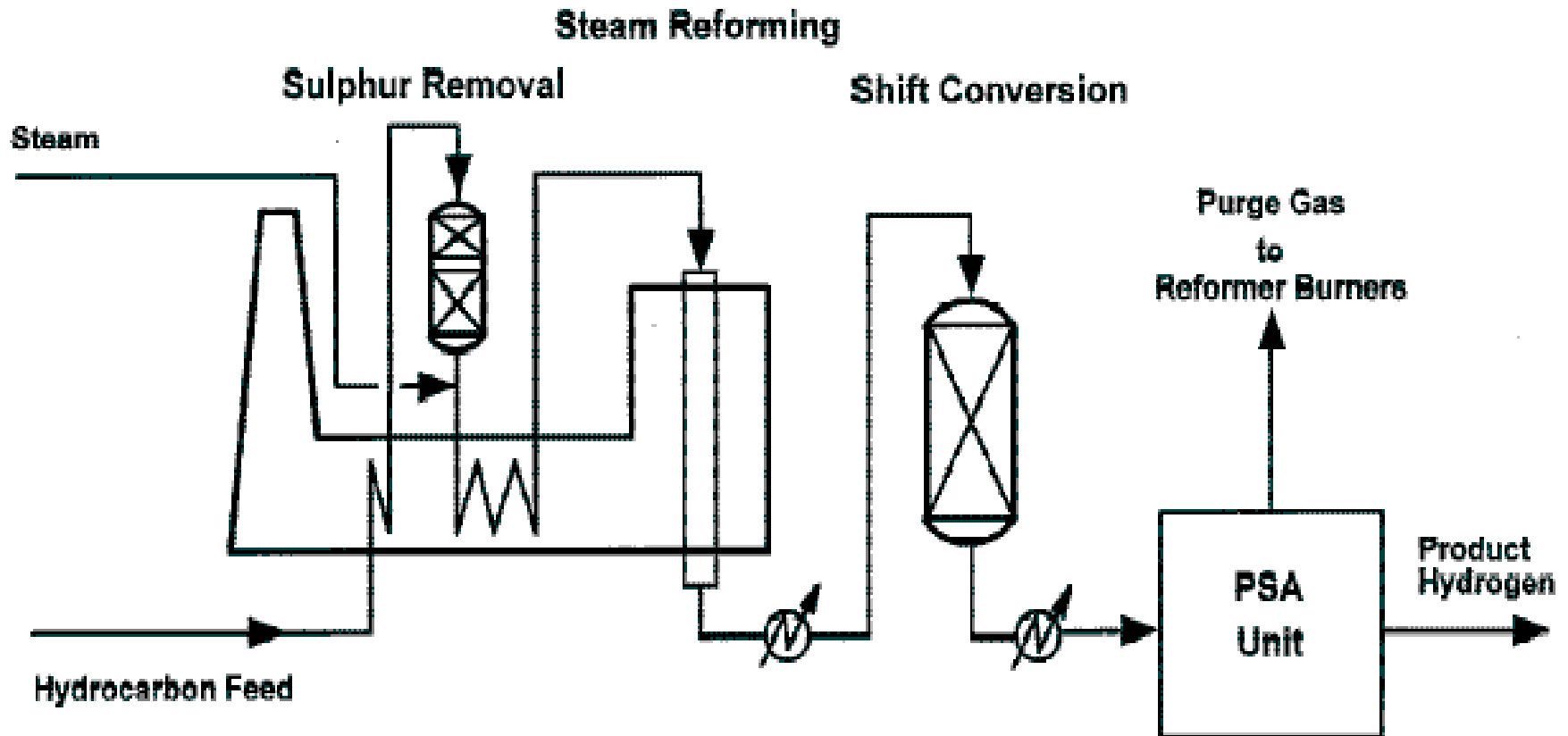


# Three Pathways Were Modeled





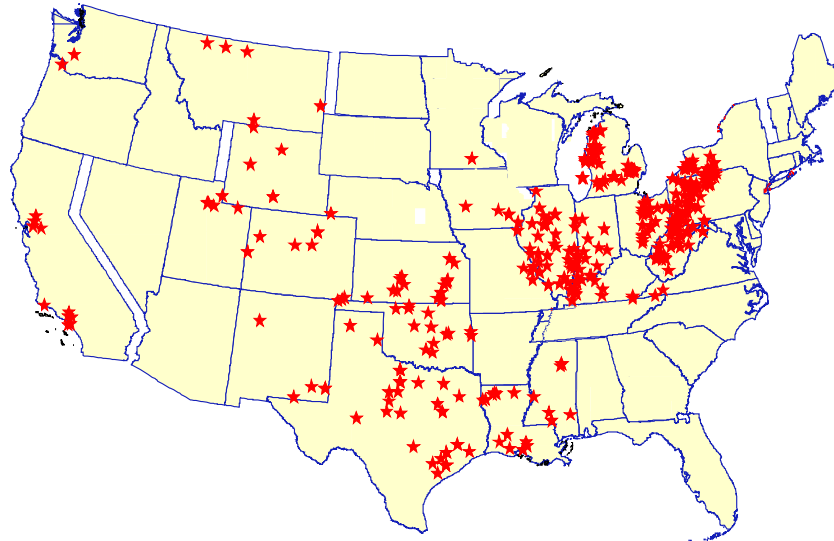
# *Steam Reforming Inputs Are Water and Hydrocarbon Feedstock; Outputs Are Hydrogen and Purge Gases*





# *All Pathways Include Underground Storage*

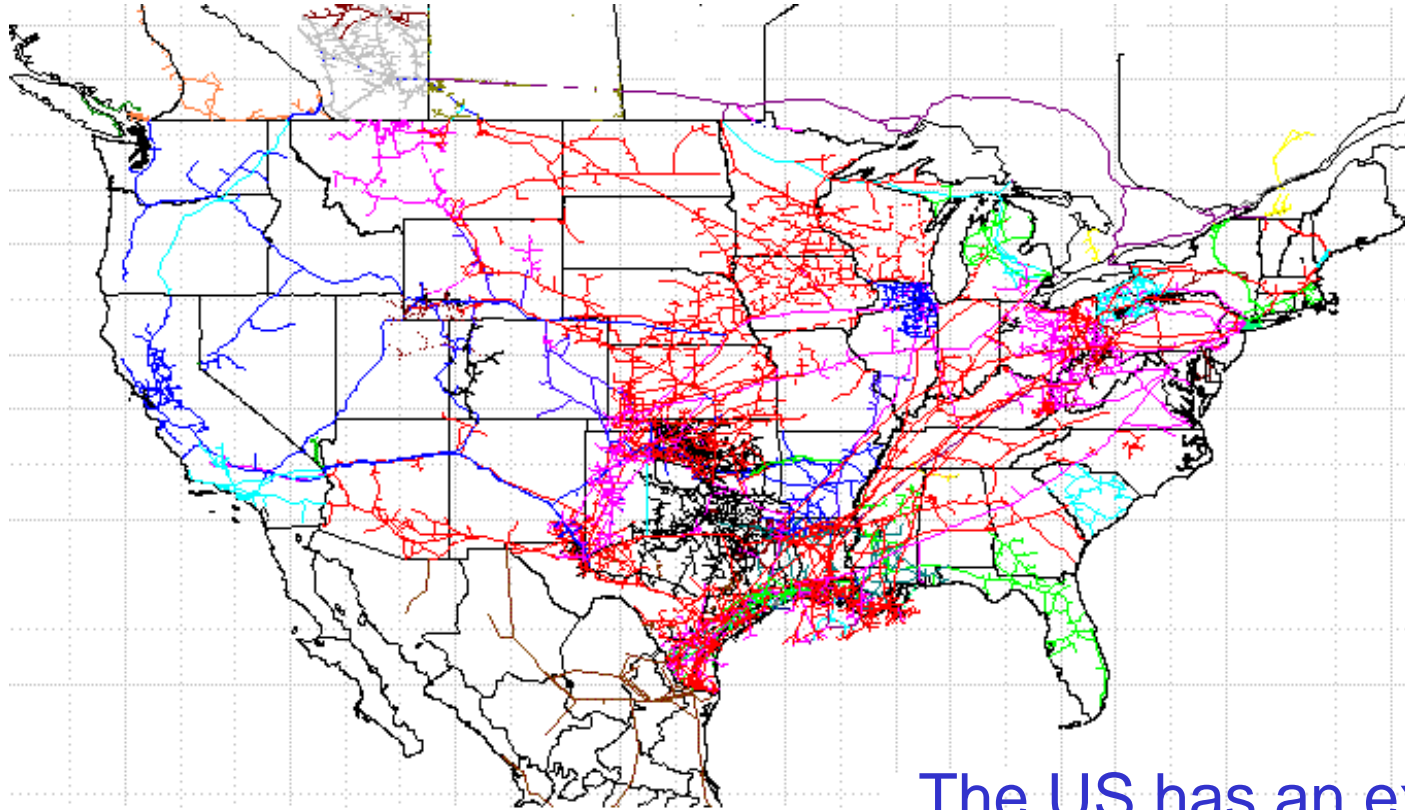
**At the end of 1998 there were 410 underground natural gas storage sites in the U.S.**



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



# *All Pathways Require Additions to the Existing Natural Gas Transmission Infrastructure*



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



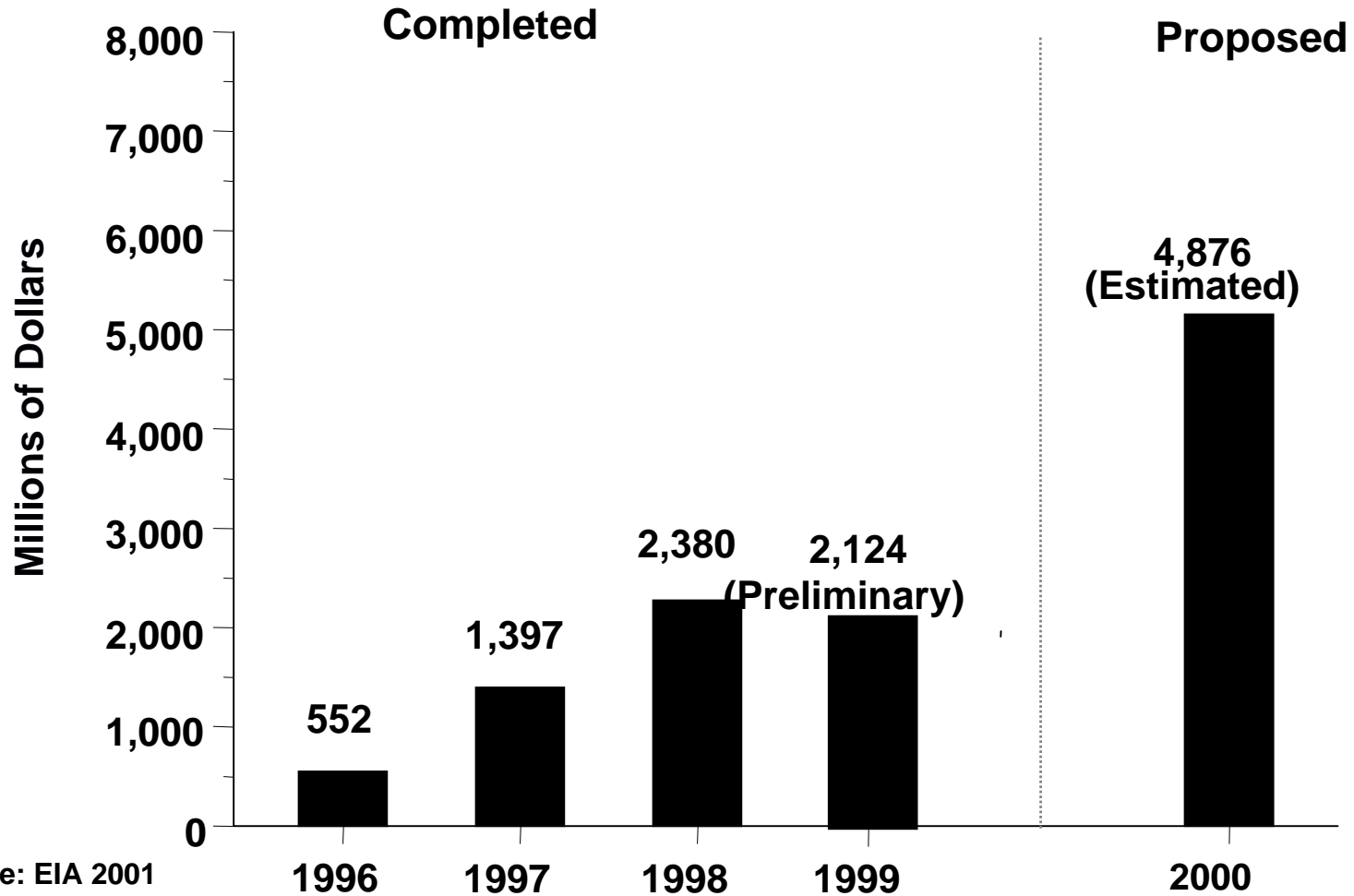
# ***And a Track Record of Continually Expanding Transmission Capacity***

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





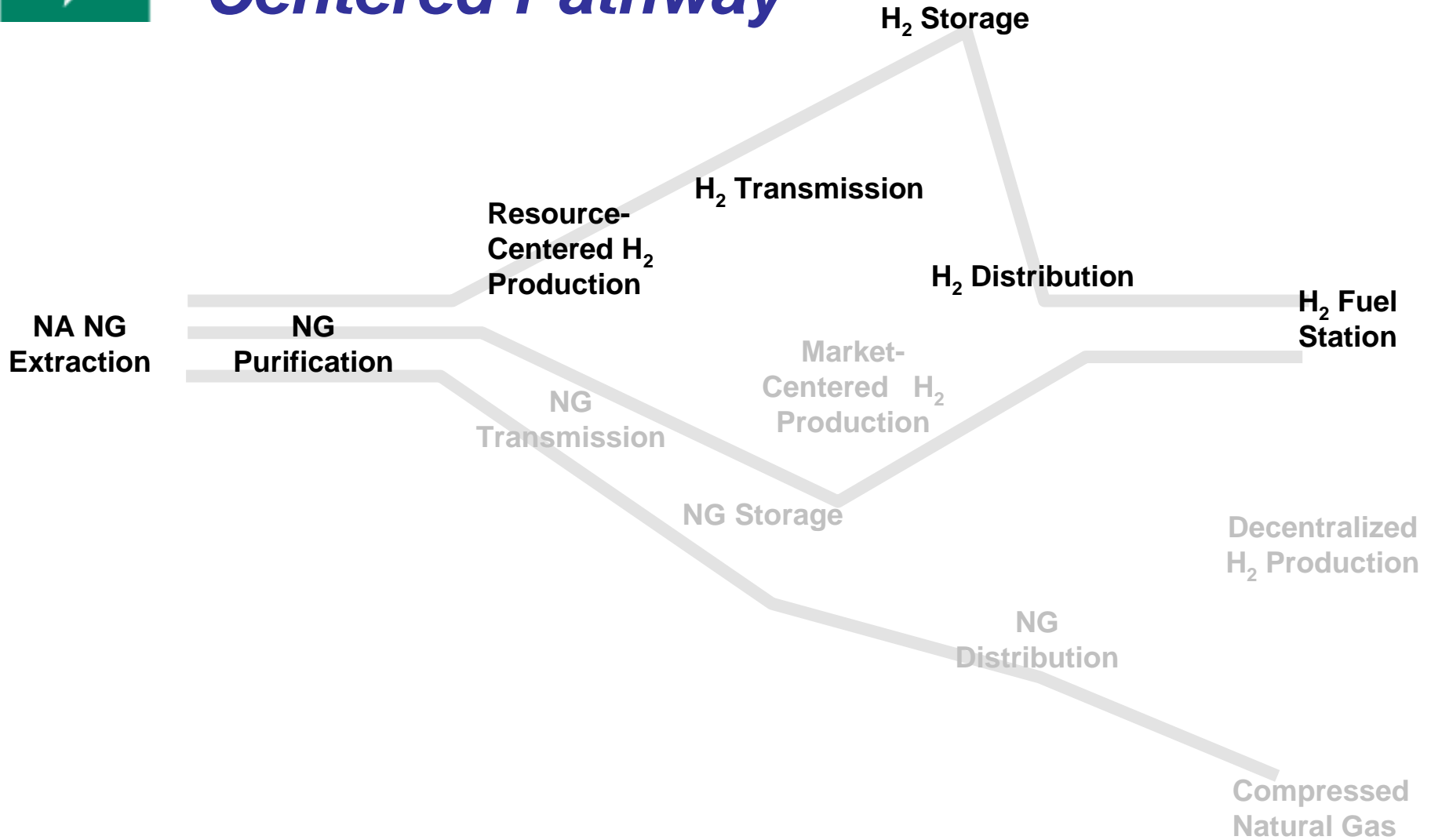
# According to EIA, Nearly \$5 bln Was Spent on Pipeline Expansion in 2000



Source: EIA 2001



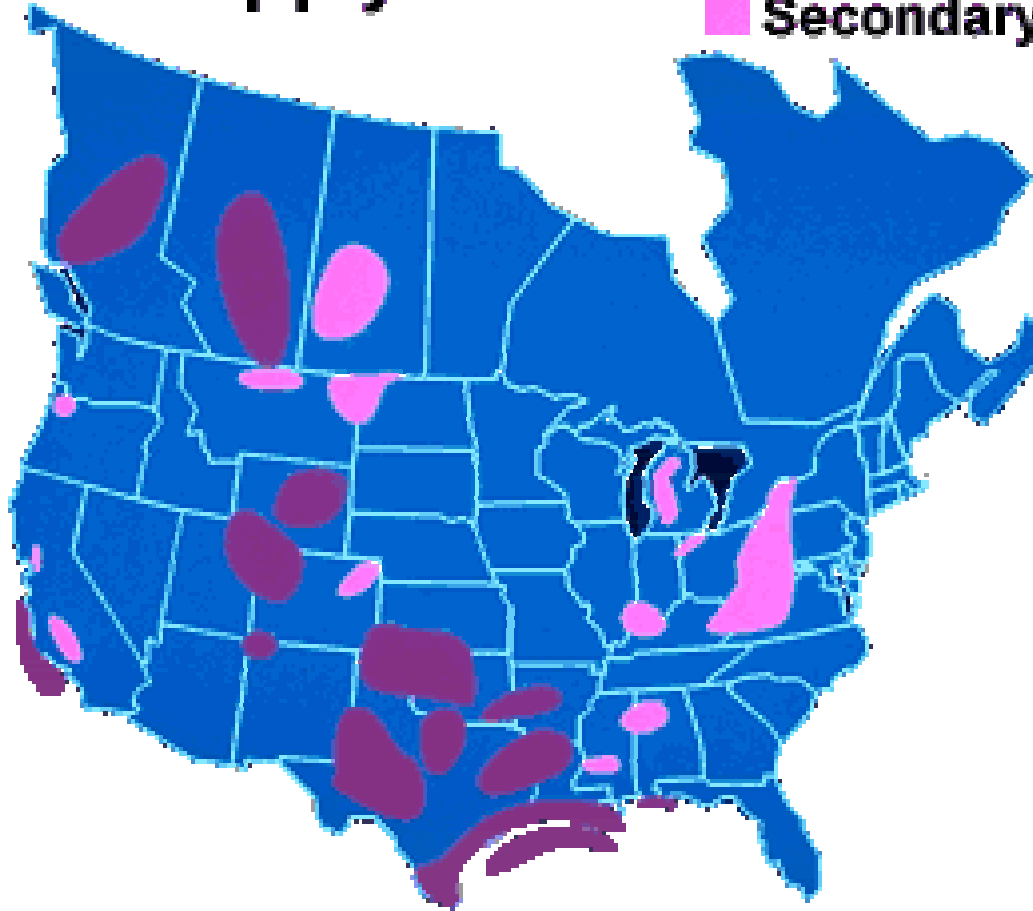
# Components of the Resource-Centered Pathway





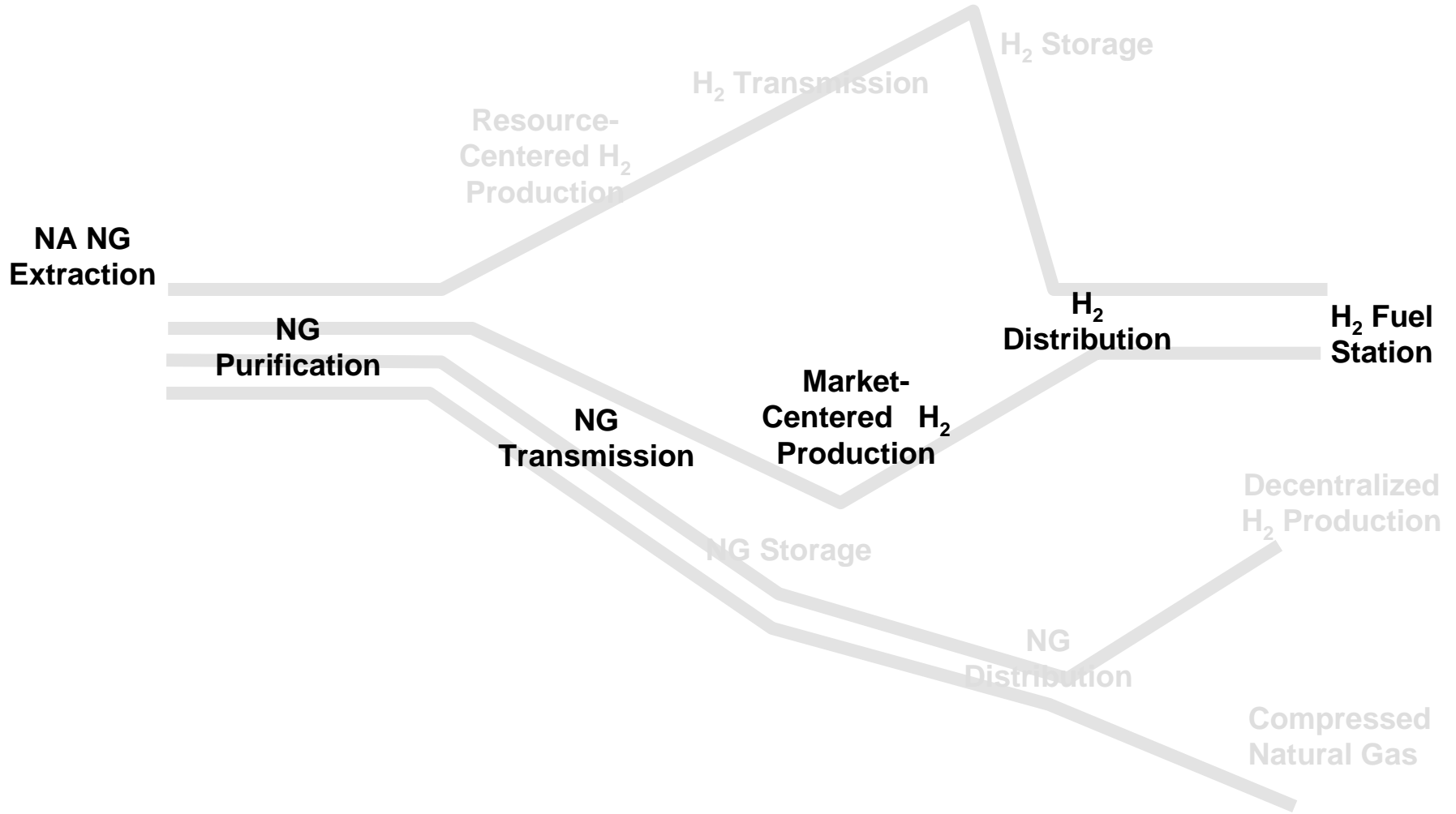
# *Hydrogen Production Is Near Natural Gas Supplies in the Resource-Centered Pathway*

**Gas Supply Basins** ■ Major ■ Secondary





# Components of the Market-Centered Pathway





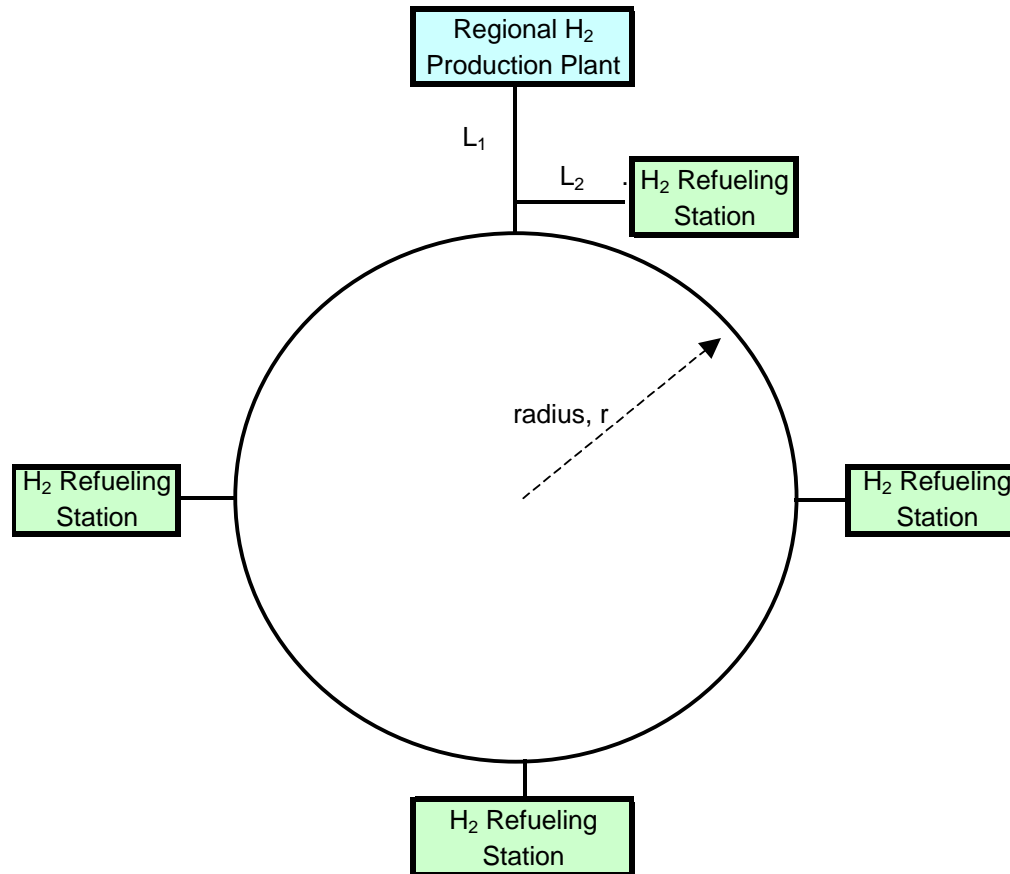
# ***Market-Centered and Resource-Centered Paths Share H<sub>2</sub> Distribution Assumptions***

<b>Component</b>	<b>Radius (mi)</b>	<b>Diameter (in)</b>	<b>Length (mi)</b>
<b>H<sub>2</sub> Pipeline Connecting Pipeline Ring with H<sub>2</sub> Production Plant</b>	<b>N/A</b>	<b>12</b>	<b>15</b>
<b>H<sub>2</sub> Pipeline Ring Encompassing Community</b>	<b>25</b>	<b>12</b>	<b>157</b>
<b>H<sub>2</sub> Pipeline Connecting H<sub>2</sub> Refueling Stations with H<sub>2</sub> Pipeline Ring</b>	<b>N/A</b>	<b>3</b>	<b>900<sup>a</sup></b>

<sup>a</sup> Assumes 180 refueling stations, a service pipeline unit length of 15 miles, and 3 refueling stations per service pipeline.

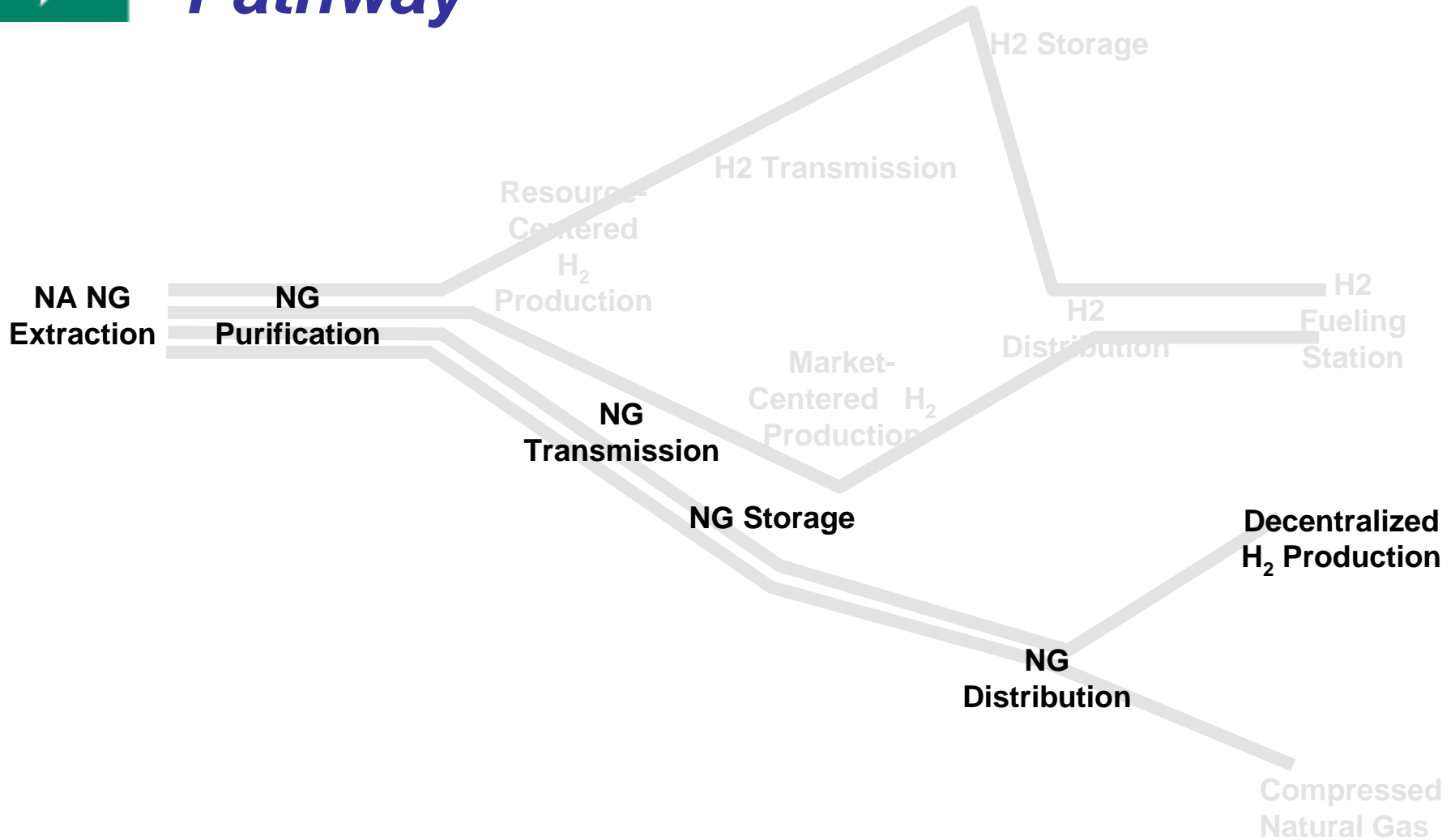


# *Conceptual Representation of Hydrogen Pipeline Loop Supporting Local H<sub>2</sub> Delivery*



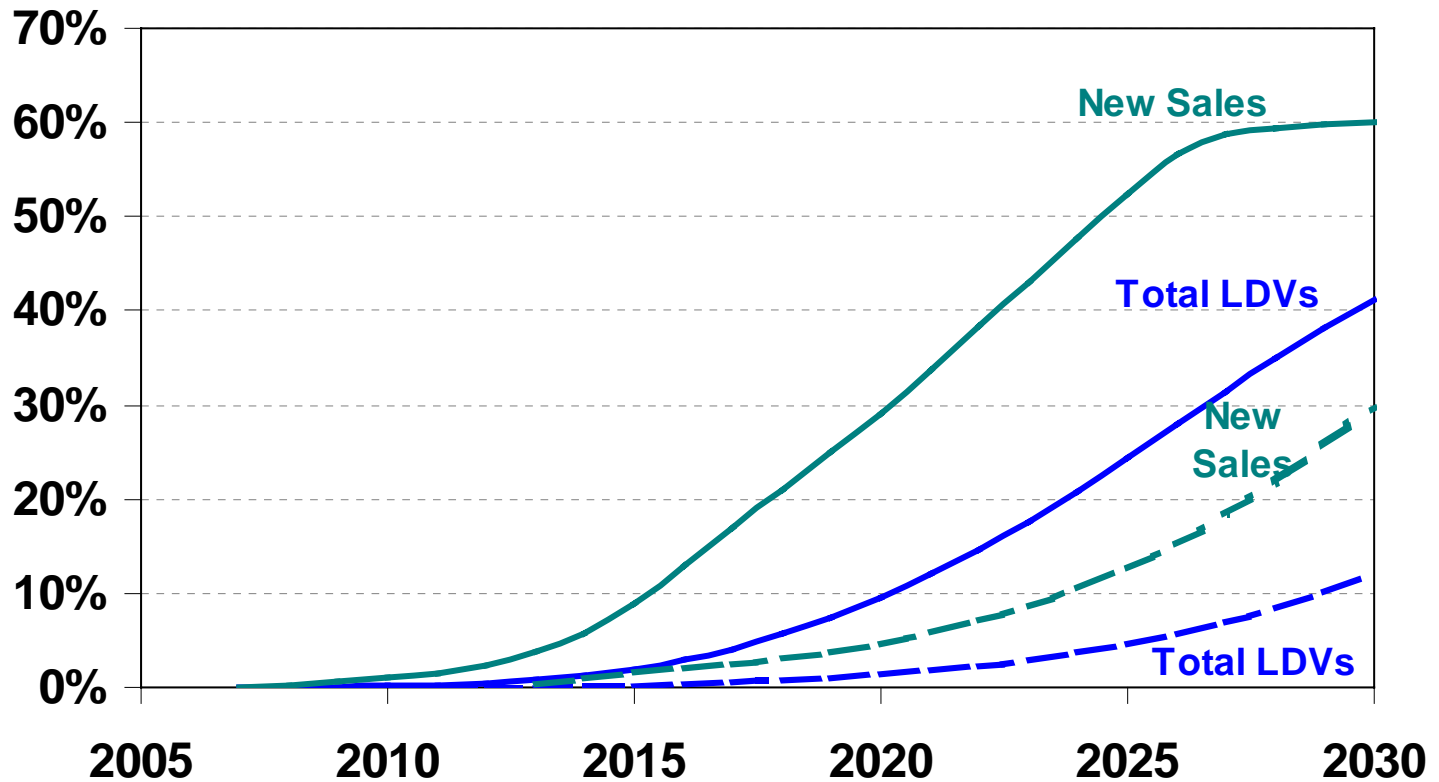


# Components of the Decentralized Pathway





# 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 <sup>1</sup>
- NH <sub>3</sub> Producers	1.185	9.662
- Oil Refiners <sup>2</sup>	1.164	3.721
- MeOH Producers	0.303	1.428
- Other	0.128	0.489
Merchant Users	0.379	0.570
<b>Total</b>	<b>3.160</b>	<b>15.872</b>

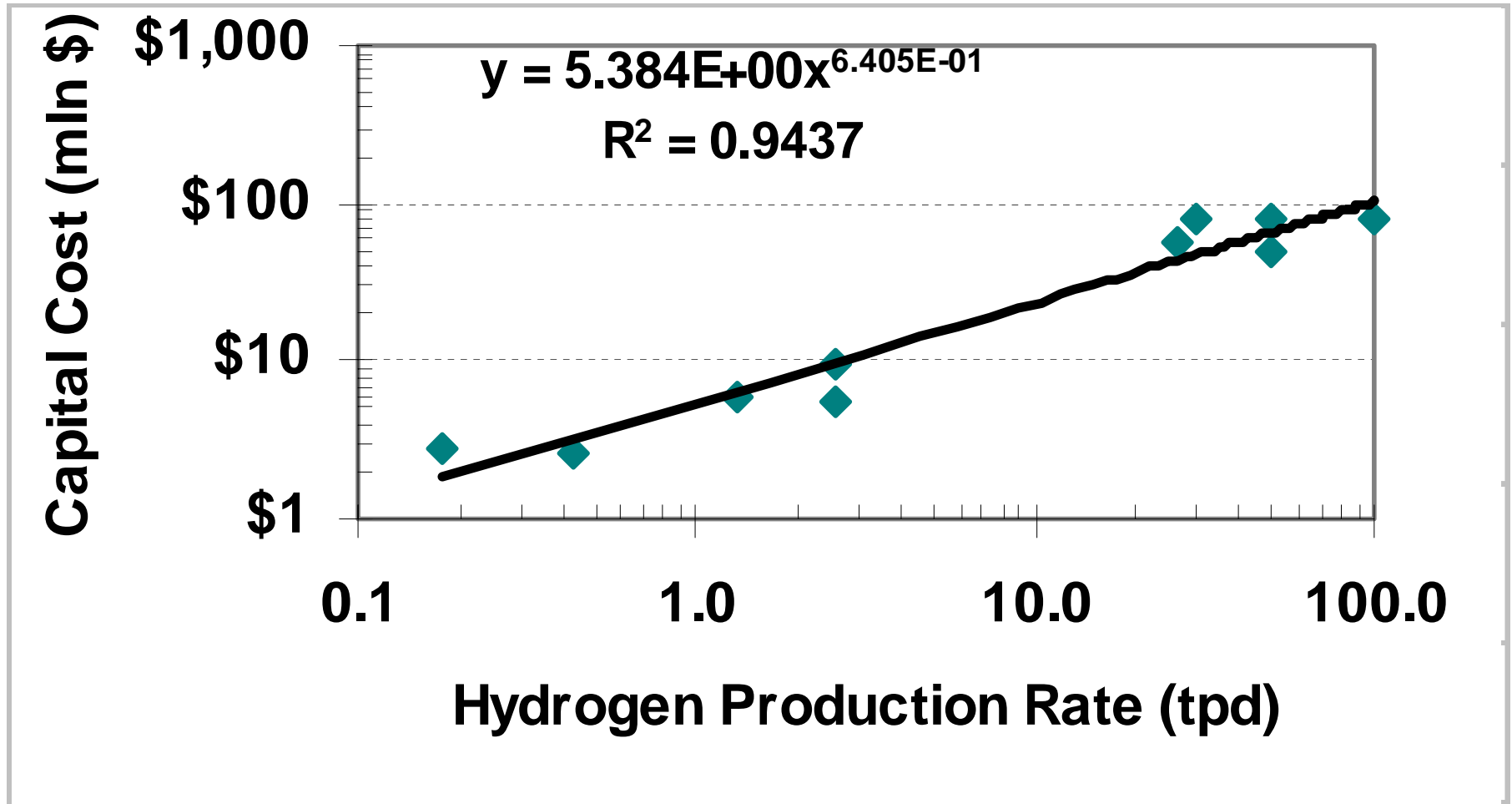
<sup>1</sup> Including US.

<sup>2</sup> Excluding byproduct hydrogen.

Source: SRI Chemical & Health Business Services 2001.

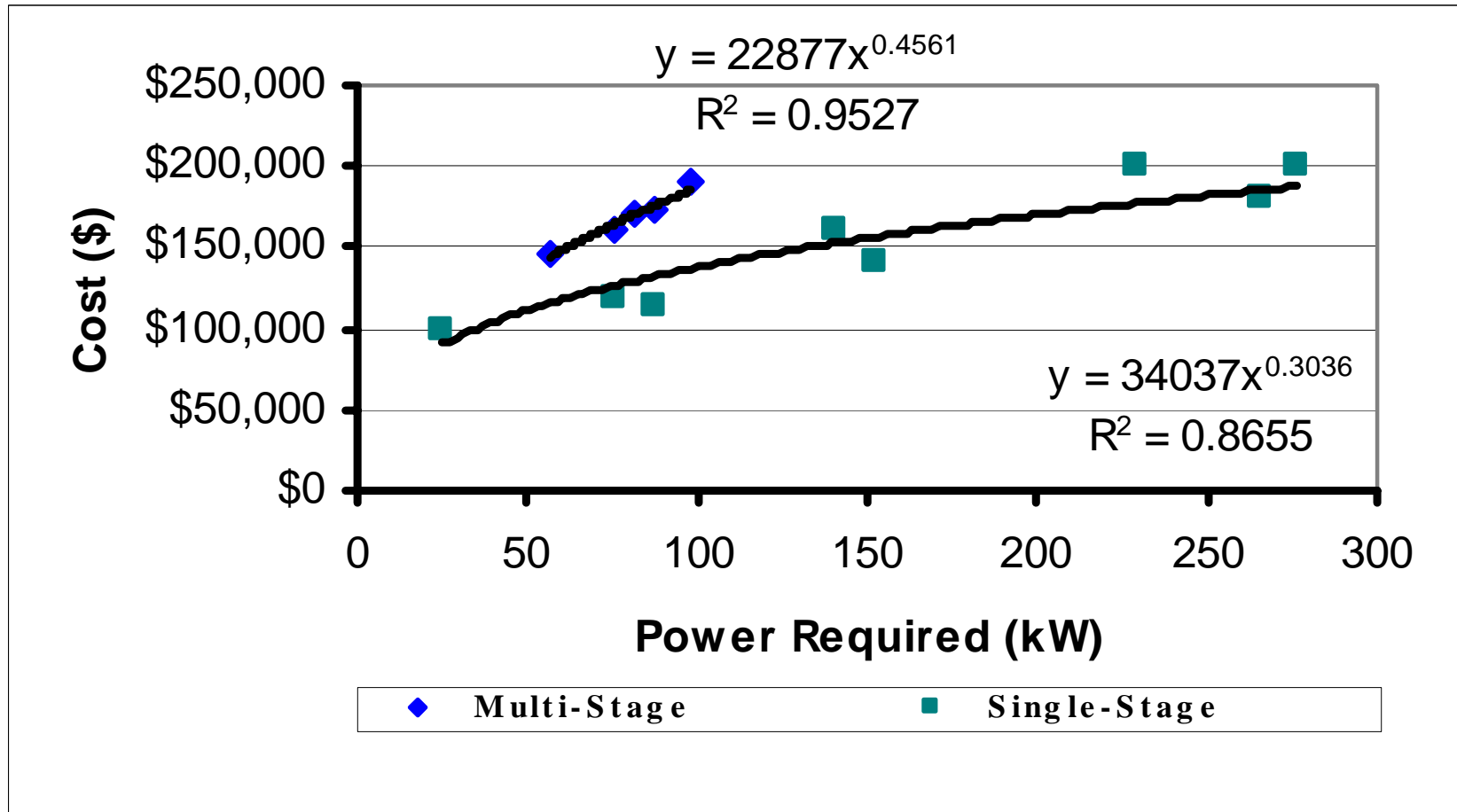


# Current SMR Plants Have Large Economies of Scale





# Compressor Costs Are a Function of Power



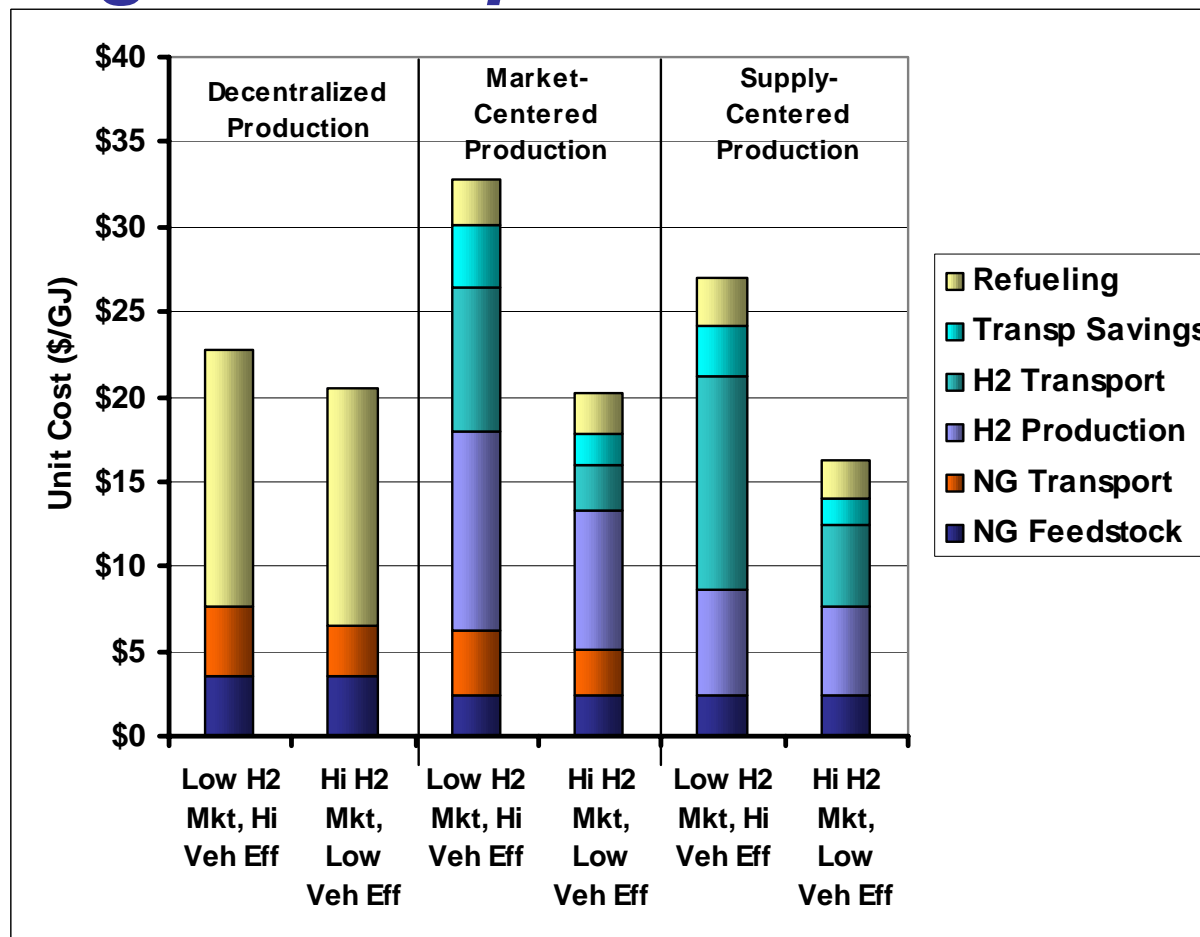


# ***Unit Cost of NG & H<sub>2</sub> Pipelines Vary with Pipe Diameter & Installation Technology***

<b>Diameter (inch)</b>	<b>Capital Cost of Natural Gas Pipeline (\$/mi)</b>	<b>Capital Cost of H<sub>2</sub> Pipeline, Cut/Cover (\$/mi)</b>	<b>Capital Cost of H<sub>2</sub> Pipeline, Trenchless (\$/mi)</b>
<b>3</b>	<b>\$200,000</b>	<b>\$400,000</b>	<b>\$300,000</b>
<b>9</b>	<b>\$500,000</b>	<b>\$900,000</b>	<b>\$700,000</b>
<b>12</b>	<b>\$600,000</b>	<b>\$1,000,000</b>	<b>\$900,000</b>
<b>14</b>	<b>\$800,000</b>	<b>\$1,400,000</b>	<b>\$1,150,000</b>

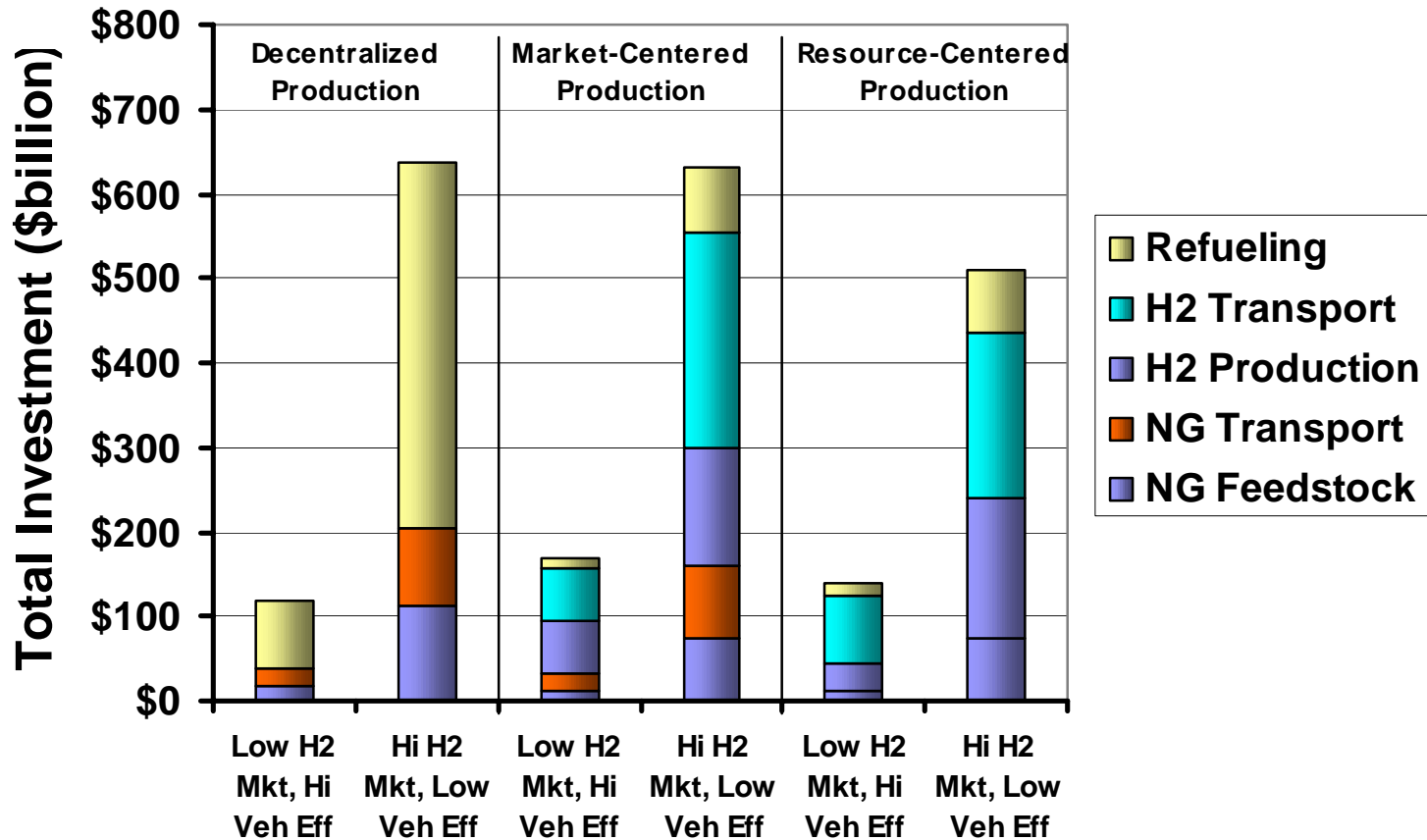


# Least Cost Pathway Depends on H2 Volume; Reformers and Pipelines Are Largest Components



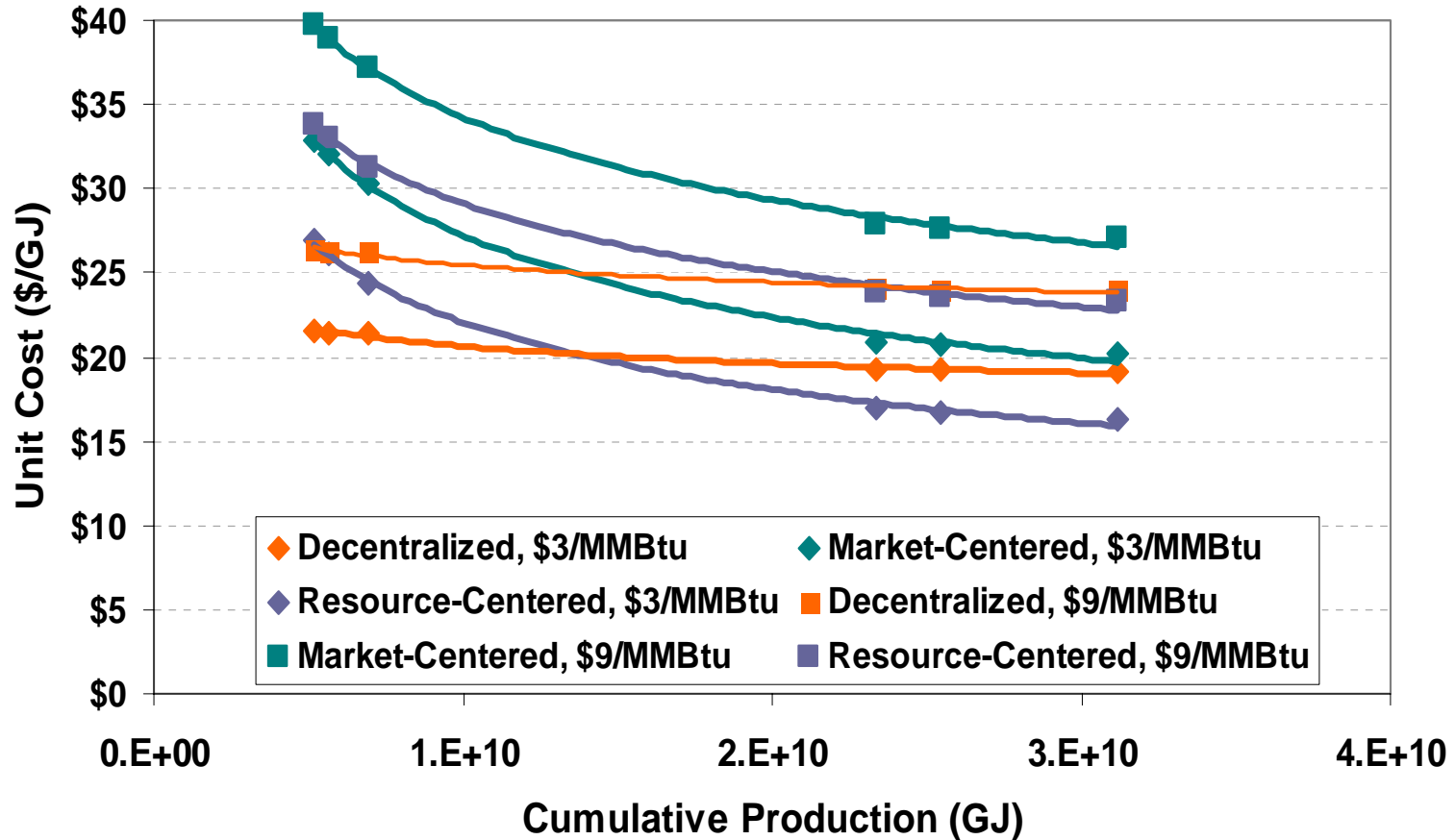


# H2 Infrastructure to Fuel 100 Million+ FCVs Could Cost \$500 Billion or More





# *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.

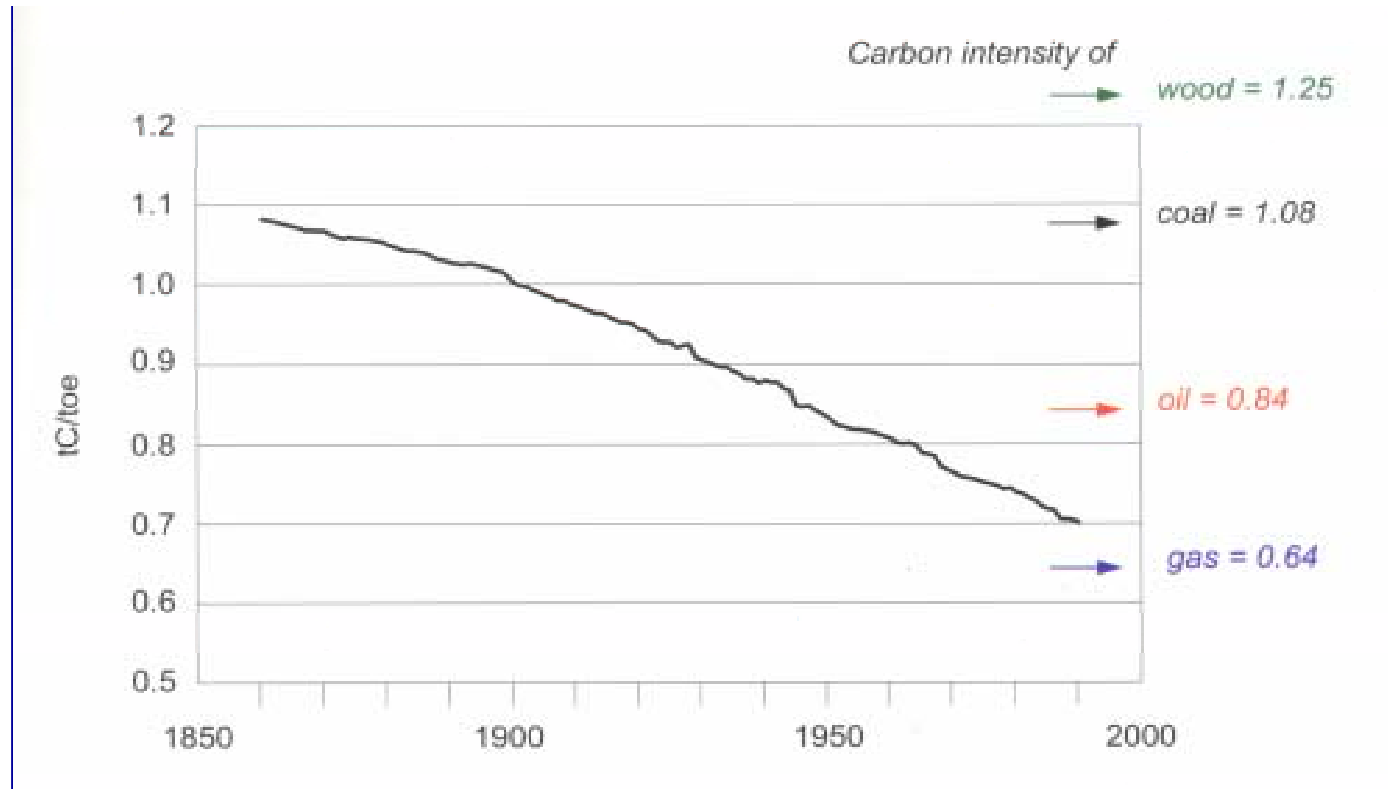


## ***Conclusions (cont'd)***

- 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





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