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Hydrogen Production and Delivery Analysis in U.S. Markets: Cost, Energy and Greenhouse Gas Emissions

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Outline of Presentation

- H2A Methodology
- Centralized Hydrogen Production
  - Technologies
  - Illustrative results for a range of production rates (50-650 tonne/day)
  - Conclusions
- Hydrogen Delivery
  - Pathways
  - Illustrative results for a range of market demands (50,000-5 million population, 15-75% penetration)
  - Conclusions
- Energy Consumption and Greenhouse Gas (GHG) Emissions

H2A Delivery and Production Models Share a Common Heritage and Features

- Similar layout and color-coding conventions
- “First principles” approach
- Programmed as series of Microsoft EXCEL spreadsheets with embedded macros
- Run with either H2A-supplied defaults or user inputs
- Discounted cash flow analysis to estimate levelized cost of hydrogen and breakdown of cost into capital, fixed O&M and fuel/energy costs
- Common financial assumptions and fuel properties
- Posted on USDOE website (www.hydrogen.energy.gov) with Users Guide
- Technical support provided by USDOE EERE help desk
- Developed with industry input and review to validate assumptions and approach

Hydrogen Delivery Scenario Analysis Model (HDSAM 1.0) Has Several Enhancements

- User-friendly interface (GUI) to quickly and easily define scenarios of interest
- Interface automatically links and sizes components into pathways with capacity sufficient to satisfy scenario demand
- Default scale factors for most components in pathways
- Energy and greenhouse gas (GHG) emissions estimates using rates derived from GREET model
- Resulting structure permits efficient examination of new technologies, alternative delivery pathways and packaging options

Both models provide "snap shot" of levelized cost of hydrogen resulting from input assumptions. Not transition models

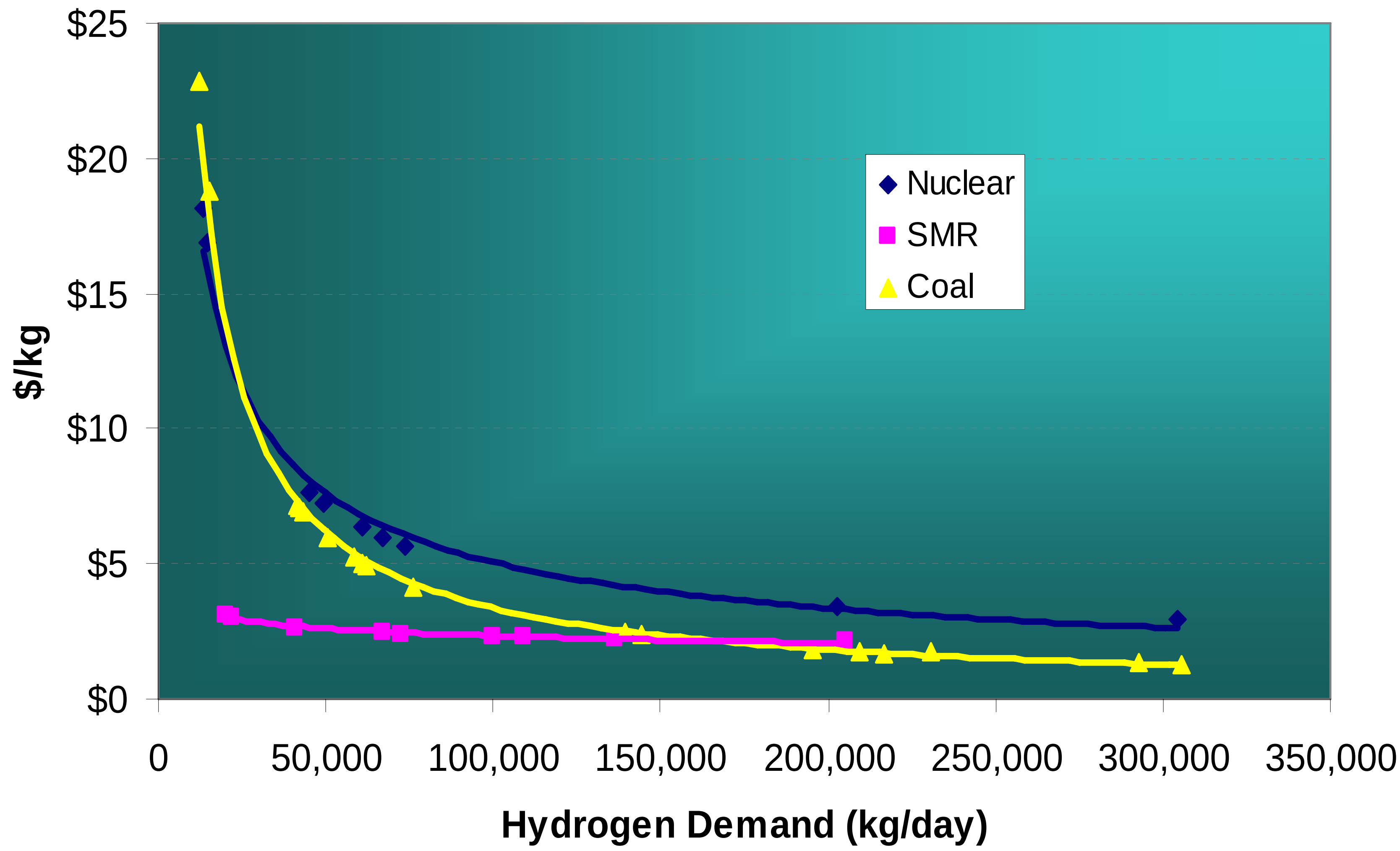
For This Analysis, the H2A Production Model Was Run for Three Technologies

- SMR: Natural gas process based on Steam Methane Reforming (SMR) with water-gas shift and pressure swing adsorption
- Coal: Coal gasification with shift conversion and pressure swing adsorption
- Nuclear: High-Temperature-Gas Reactor providing heat to Sulfur-Iodine (S-I) water-splitting process

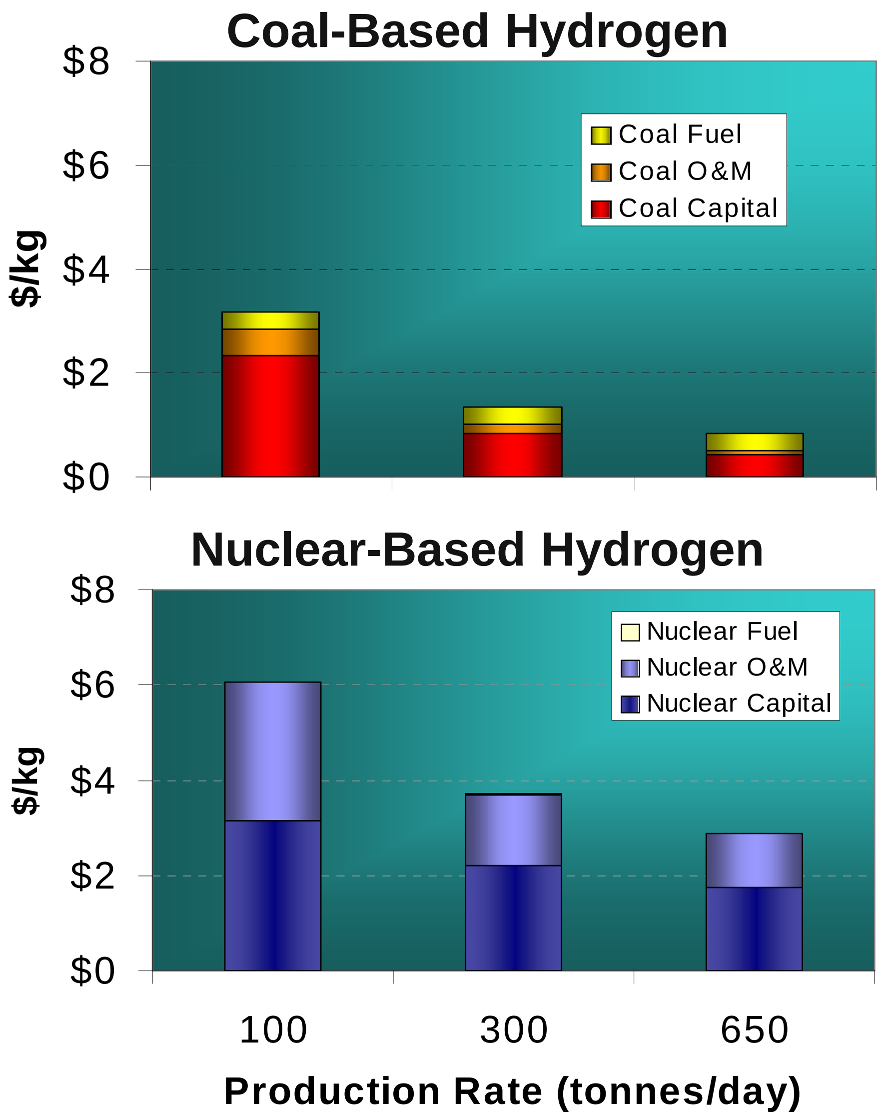
Runs Differed from "Standard" H2A Production Model Configuration

- Scale factors were input to model hydrogen production rates from 50 to 650 tonnes/day for all production technologies.
- The effect of carbon taxes on coal-based hydrogen production cost was calculated offline. Taxes of $25 to $100 per tonne CO2 were modeled.
- The effect of carbon capture and sequestration (CCS) was also calculated offline, assuming 85% capture rate.
- Coal-based hydrogen production costs were estimated as the lower of levelized cost + CO2 tax **OR** levelized cost + CCS for 85% captured + CO2 tax for 15% released

Results Show Nuclear and Coal-Based H2 Production Costs Are Strongly Dependent on Production Rate (Scale)

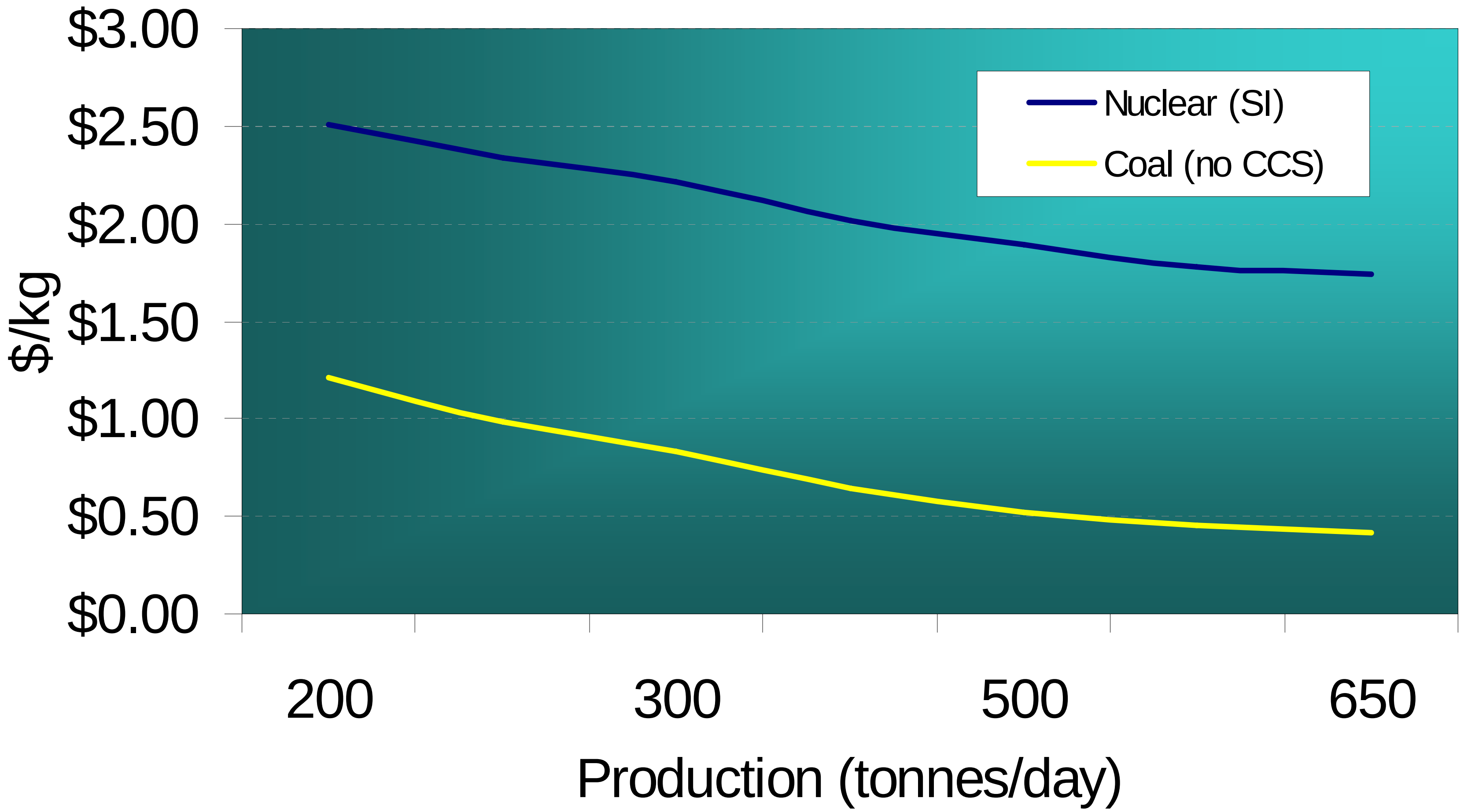


Capital Accounts for Most of Production Cost; Depending on Technology, O&M and Fuel Costs Can Be Substantial

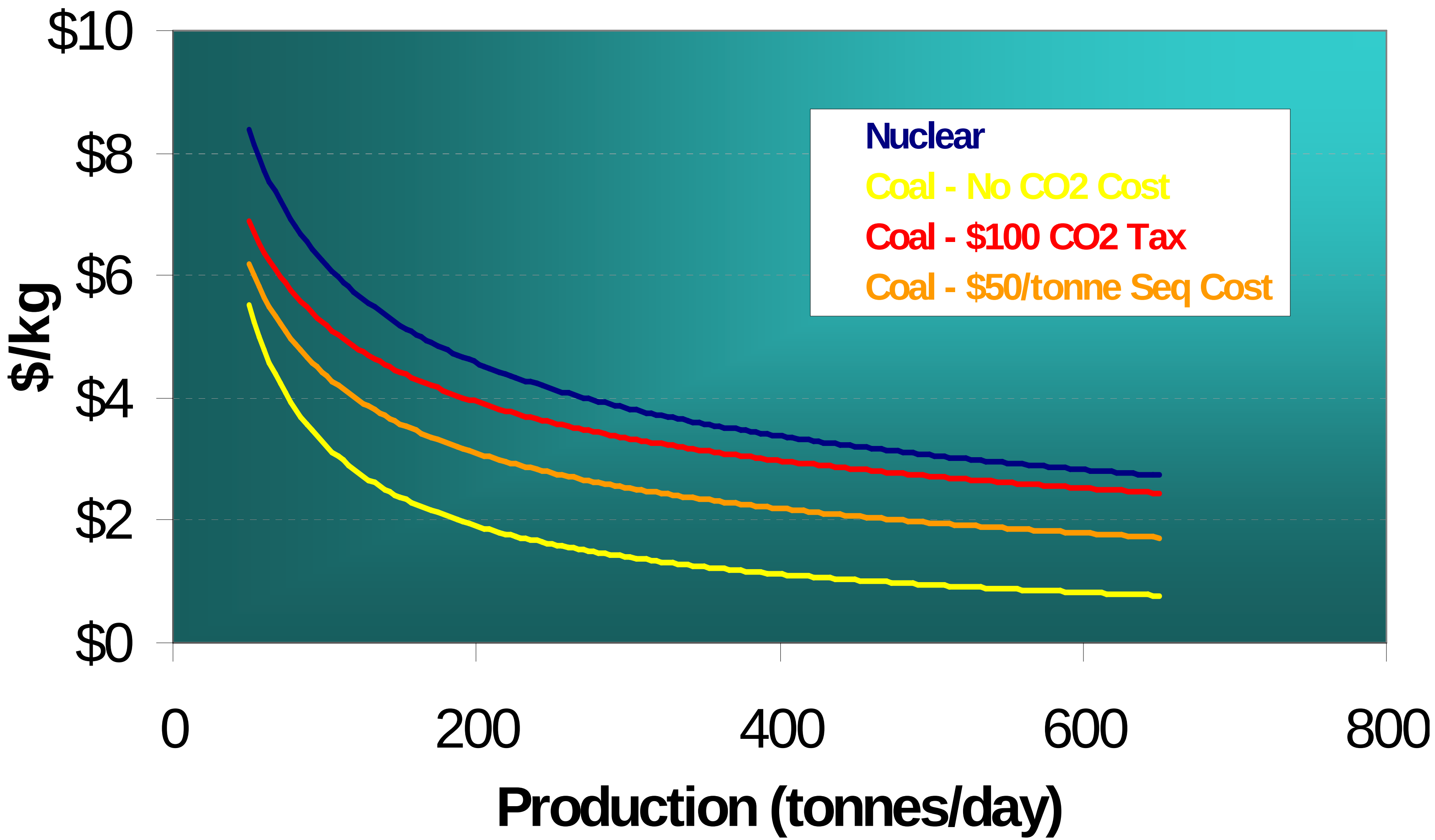


- Model results show operating and maintenance account for a much bigger share of production cost for hydrogen from nuclear than from coal.
- Much of the difference is due to labor assumptions.
- Using H2A default assumptions for coal and uranium prices and process efficiencies, fuel accounts for $0.33 of the unit cost of hydrogen produced from coal versus $0.01/kg of the cost from nuclear processes.

Capital Cost to Produce Coal-Based H2 Is ~$1.25/kg Less than Nuclear; With Feedstock, Differential Drops to ~$0.90/kg



Production Costs for Coal-Based Hydrogen Approach Nuclear with Carbon Tax and CCS Assumptions*



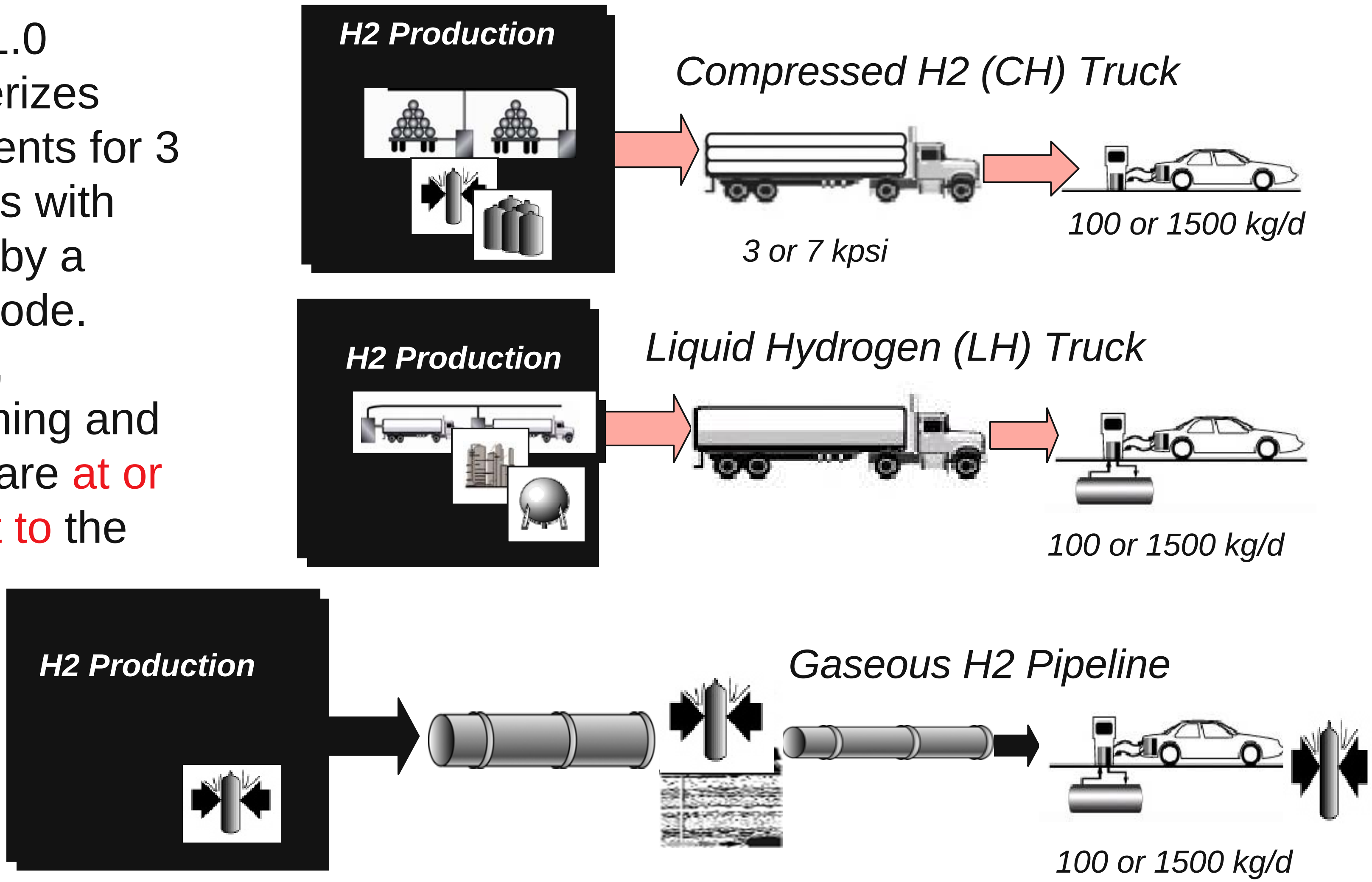
$100/tonne CO2 ~$27/tonne carbon

Production Cost Conclusions:

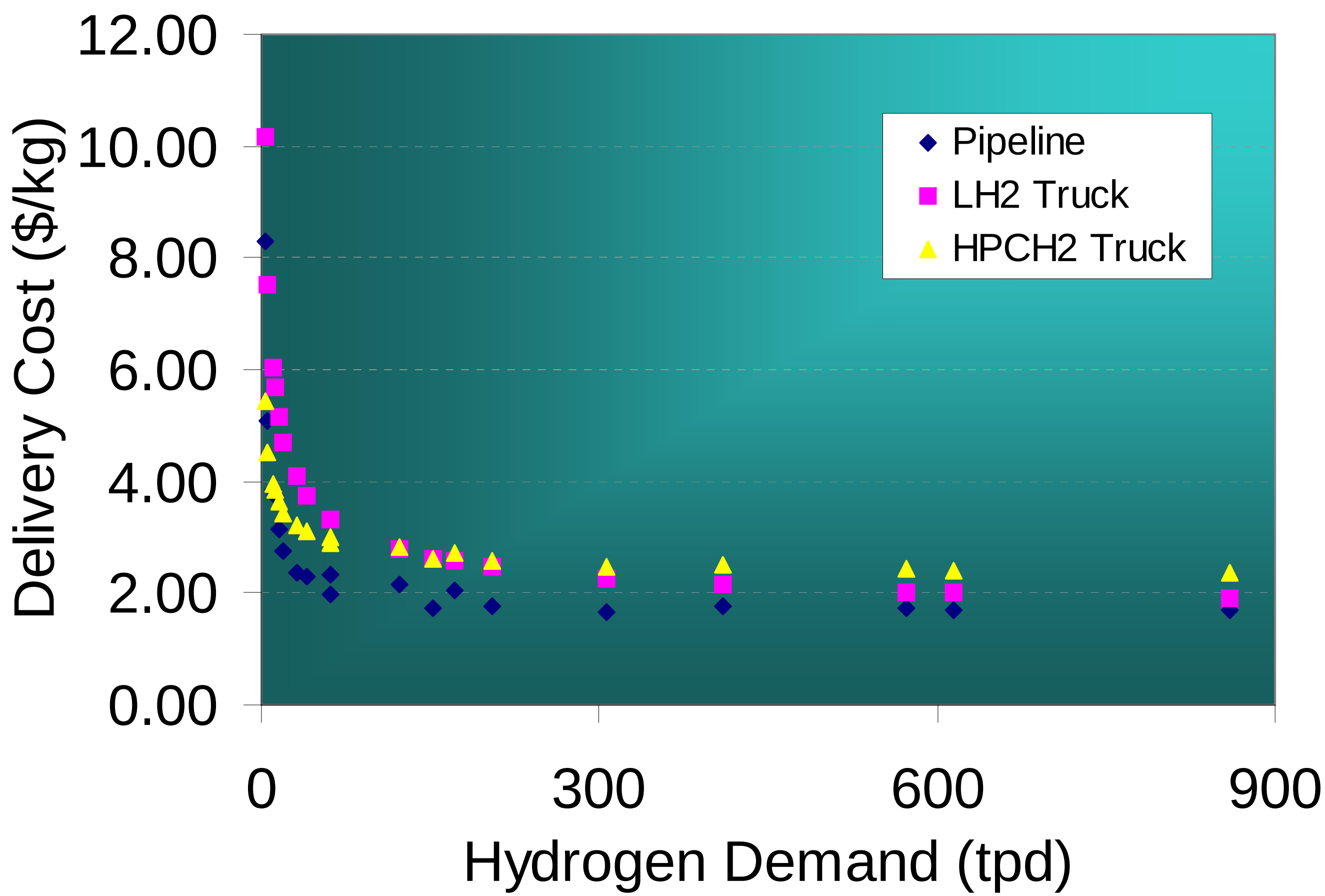
- SMR is the least-cost production option at current natural gas prices and for initial hydrogen vehicle penetration rates. At high production rates, SMR may not be the least-cost option.
- Unlike coal and nuclear technologies, the cost of natural gas feedstock is the largest contributor to SMR production cost.
- Coal- and nuclear-based hydrogen production have significant penalties at small production rates (and benefits at large rates).
- Nuclear production of hydrogen is likely to have large economies of scale. But because fixed O&M costs are uncertain, the magnitude of these effects may be understated.
- Given H2A default assumptions for fuel prices, process efficiencies and labor costs, nuclear-based hydrogen is likely to be more expensive to produce than coal-based hydrogen. Carbon taxes and caps can narrow the gap.

H2A Delivery Model Estimates Cost for 3 Pathways

Version1.0 characterizes components for 3 pathways with delivery by a single mode. Loading, conditioning and storage are at or adjacent to the plant



Results for this Analysis Show Delivery Cost Is Very Sensitive to Mode and Market Size

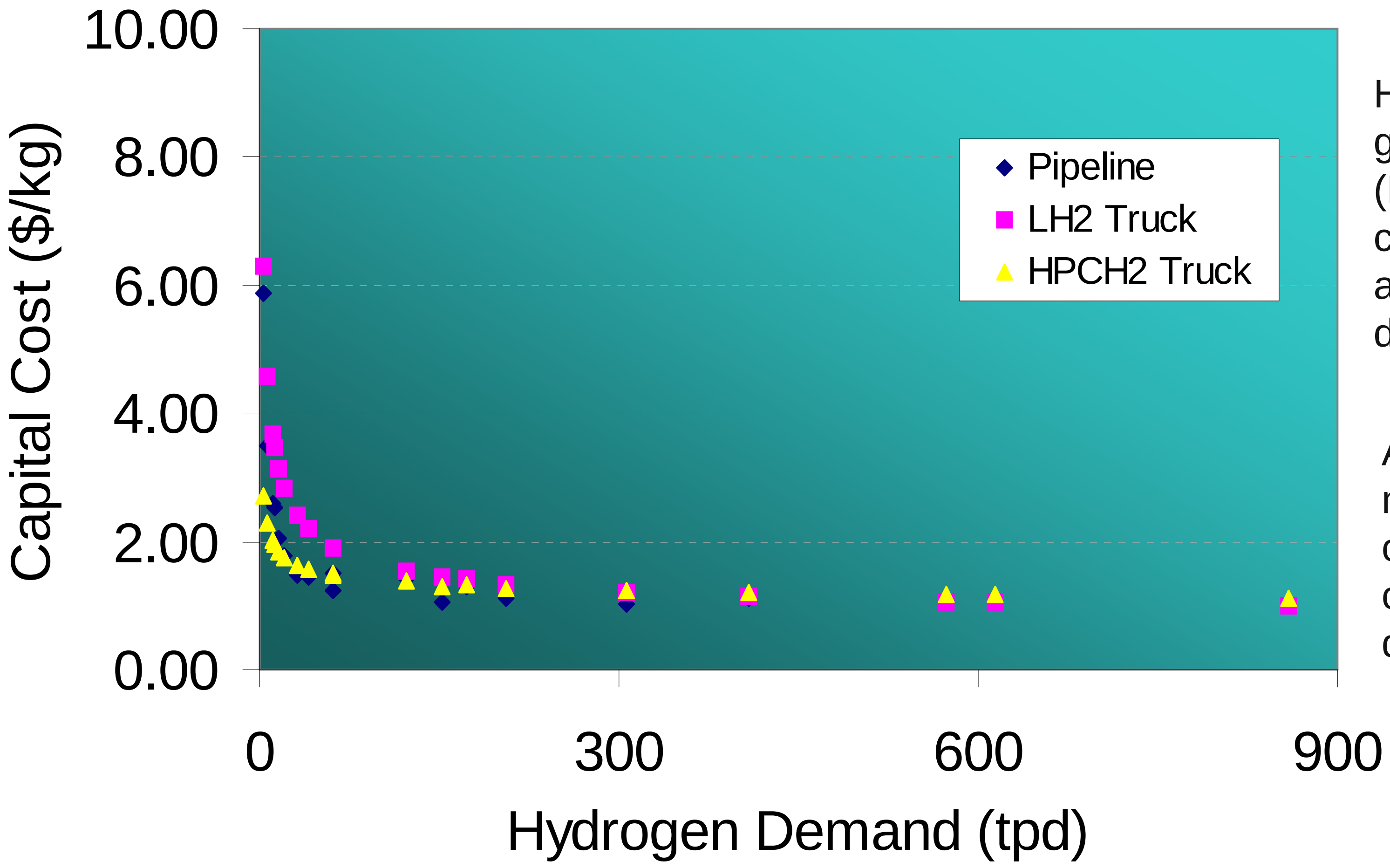


Cost for delivery drops rapidly with increasing market size, up to about 100 tonnes/day

Scale matters for pipeline and liquid truck (LH2) delivery, less so for compressed gas truck

High pressure gaseous truck (HPCH2) may be attractive for smaller markets

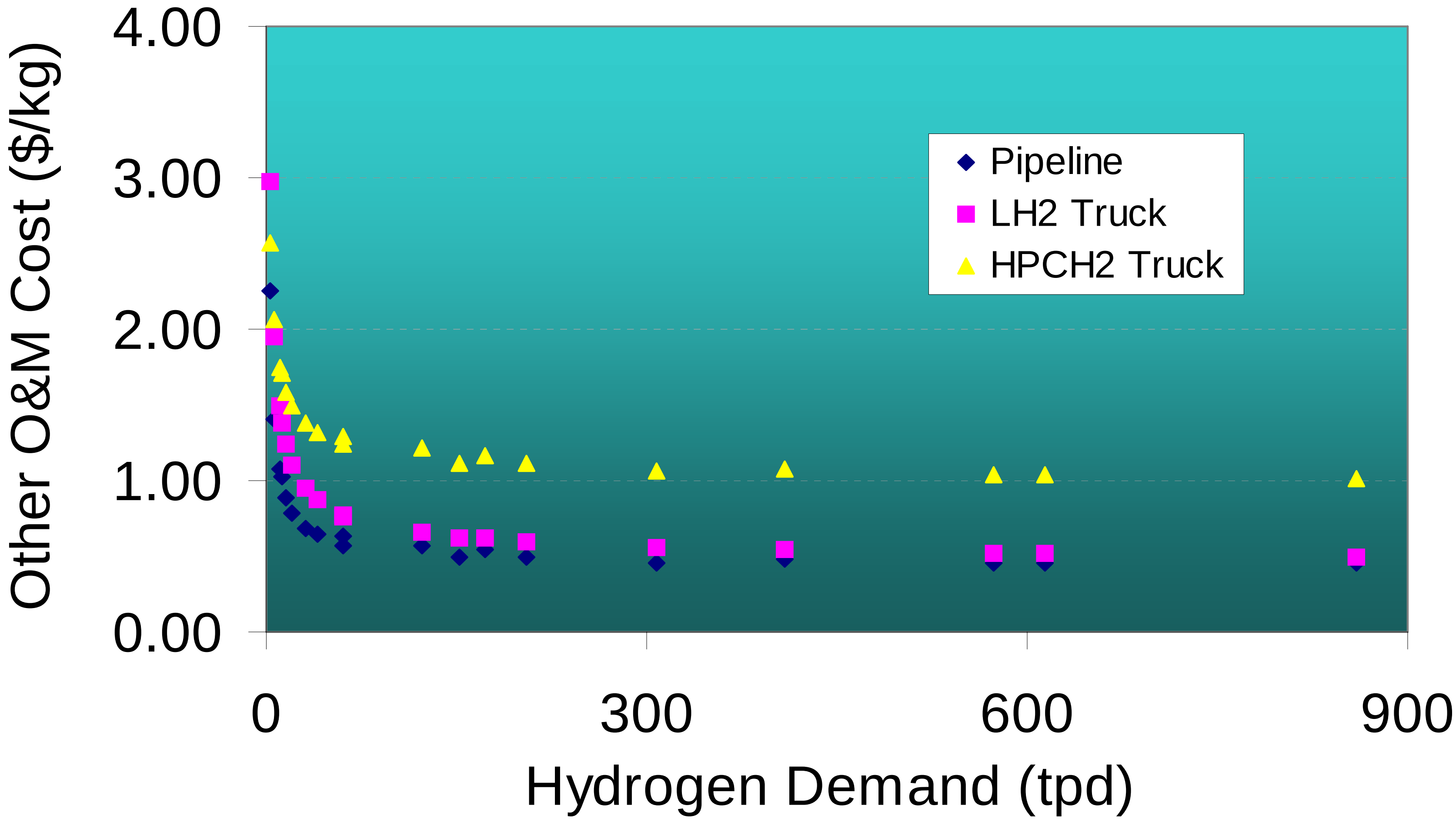
And Delivery Is Capital Intensive



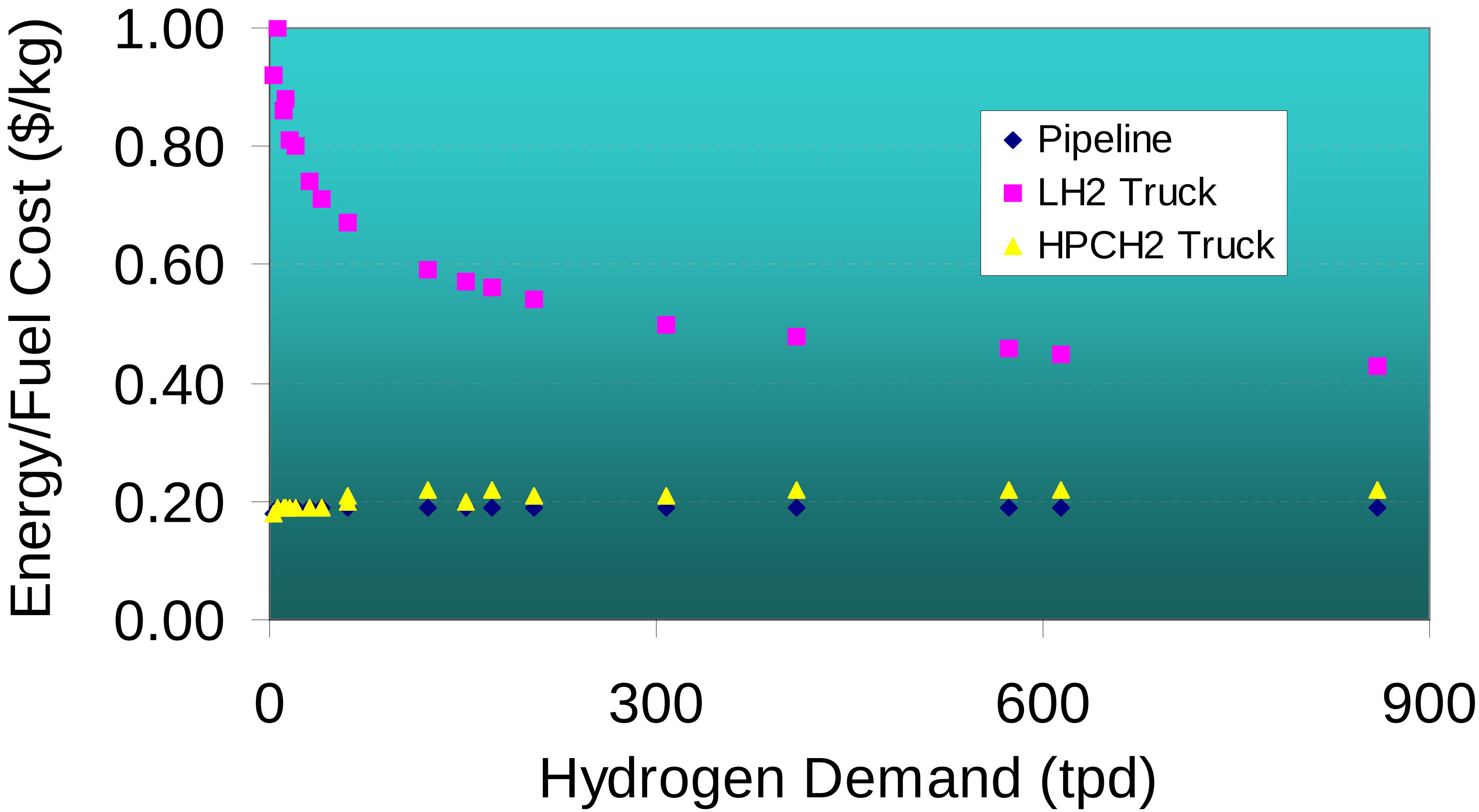
High pressure gas truck (HPCH2) is less capital intensive at very low demand

All delivery modes have comparable costs at higher demand

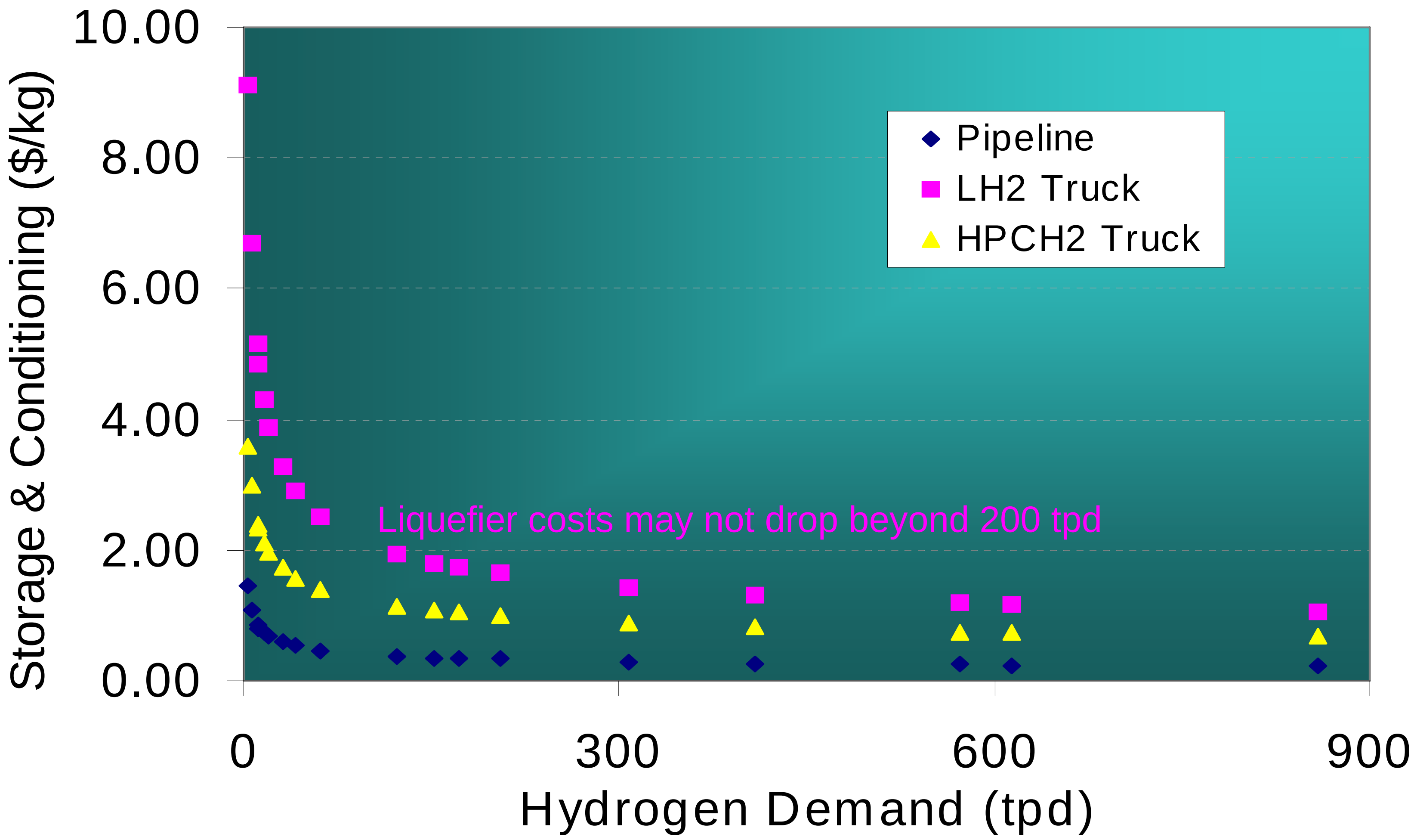
Non-Fuel Operating & Maintenance Costs Decline Less with Market Size, Especially for Labor-Intensive, Truck Modes



Energy Is a Much Smaller Cost for All Delivery Modes, Especially Pipelines and Gaseous Trucks



Examined by Individual Component, Storage & Conditioning Represent the Bulk of Delivery Cost



Delivery Cost Conclusions:

- For smaller urban markets, compressed gas delivery appears most economic, although cost inputs for high-pressure gas trucks are uncertain.
- For larger urban markets, pipeline delivery is least costly.
- Distance from hydrogen production plant to city gate may change relative costs (all results shown assume 100 km).
- Pipeline costs may be reduced with system “rationalization”, primarily reductions in service pipeline mileage.
- Liquefier and pipeline capital costs are a hurdle, particularly at small market sizes

Energy and Greenhouse Gas Observations:

- Energy use (per kg of H2) declines slightly with increasing production or delivery rate for most components (unless energy efficiency varies appreciably with scale, e.g., liquefaction).
- Energy use is a strong function of production technology and delivery mode.
- GHG emissions reflect the energy efficiency and carbon content of each component in a production-delivery pathway.
- Coal and natural gas production pathways have high energy consumption and significant GHG emissions (in the absence of carbon caps, taxes or sequestration).
- Nuclear pathway is most favorable from energy use and GHG emissions perspective.
- GH2 Truck and Pipeline delivery have much lower energy use and GHG emissions than LH2 Truck delivery.
- For LH2 Truck delivery, the liquefier accounts for most of the energy and GHG emissions.

H2A is the product of the combined effort of individuals from:
Argonne National Laboratory (ANL)
National Renewable Energy Laboratory (NREL)
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Technology Insights, Inc.
TIAX, Inc.
Parsons, Inc.
Nexant, Inc.

Thank You All!

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