

# ***Some Technical Challenges in Large Scale Hydrogen Production and Use***

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# ***Drivers for Future Energy Carrier Choice***

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- 1.) Meet Growing Energy Demands in All Regions and in Major Sectors: Power and Transportation**
- 2.) Broaden Range of Primary Sources Including Coal, Wind and Nuclear**
- 3.) Increase Efficiency of Source - Carrier Chain - Well to Wheels**
- 4.) Increase “Fitness for Purpose” in End Use Recognizing Regional Differences**

# ***If Hydrogen Then ....***

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## **Driver 1**

- **Light Duty Transportation is Key**

## **Driver 2**

- **Coal is Prospective Source for US, China, India**
- **Natural Gas is Only a Short Term Option**

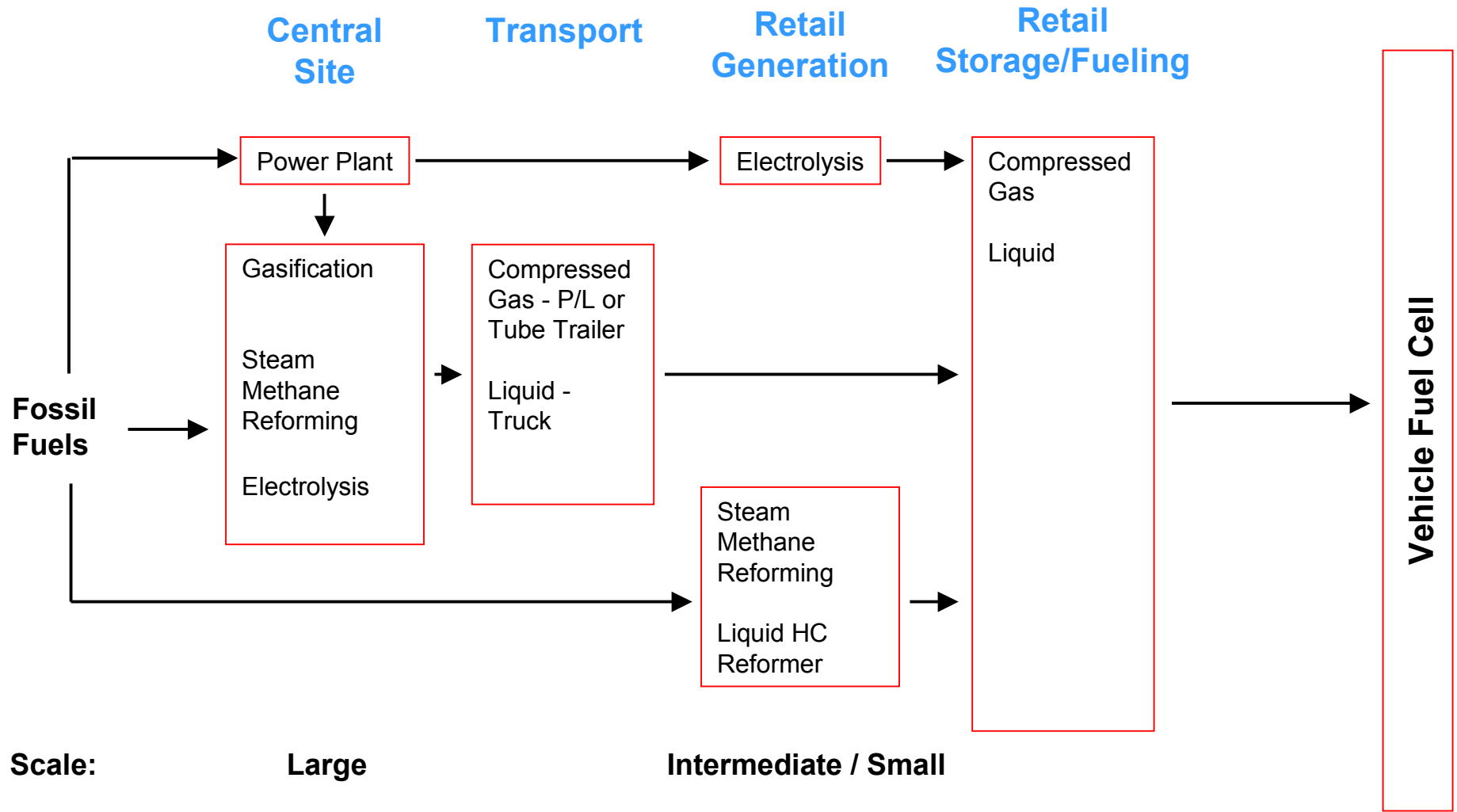
## **Driver 3**

- **Breakthroughs are Needed in:**
  - **Production, distribution, storage efficiency, and sequestration**
  - **Capital and operating cost**

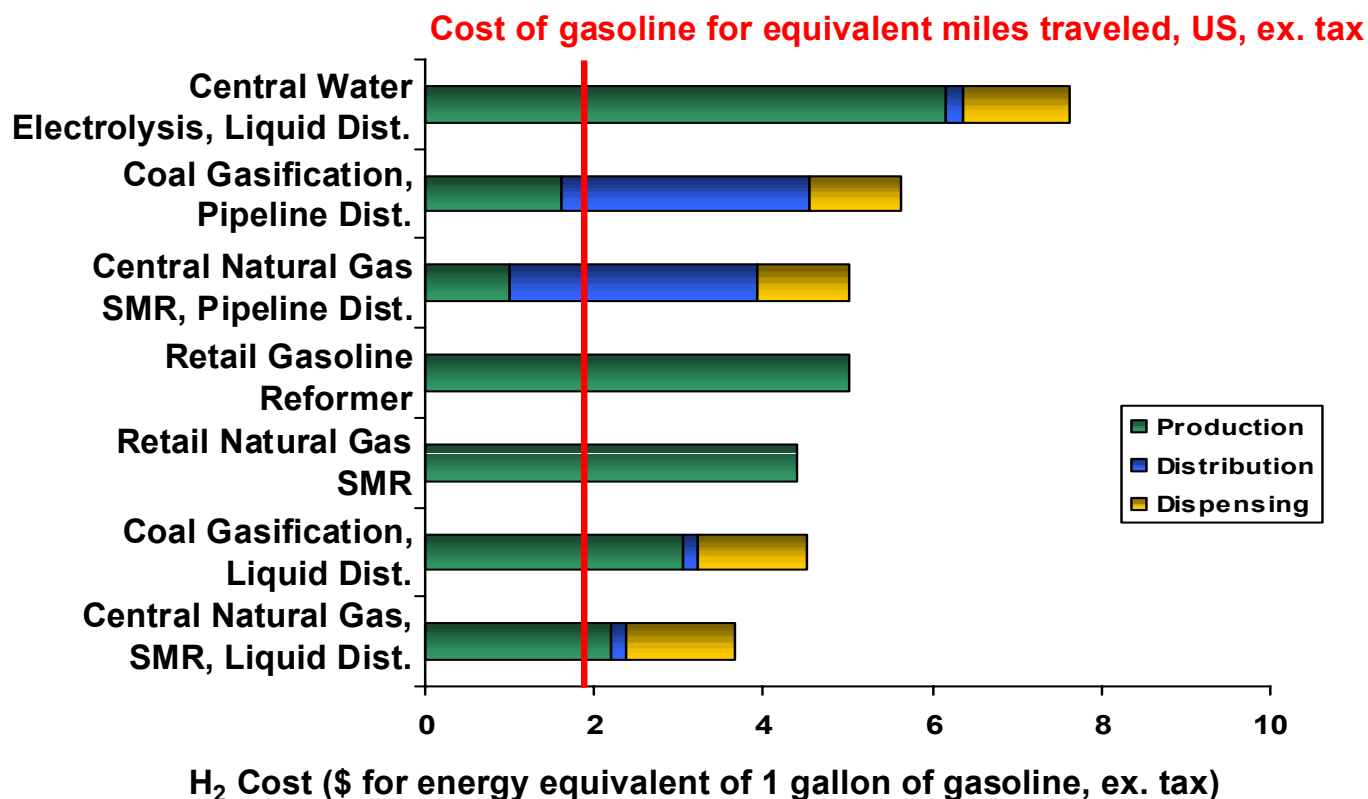
## **Driver 4**

- **Scaleability of Technologies a Critical Criterion**
- **Cogeneration Strategies will be Favored**

# Hydrogen Production and Delivery Options



# Hydrogen Production / Delivery Costs



- Gas and Coal are Lowest Cost Central Plant Options
  - Distribution costs for pipeline are high - liquid lower, but issues of scaleability
- All Options Require New / Improved Technology to be Competitive

# ***Production Challenges and Implications***

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- **Transportation Energy Demand Varies Substantially Seasonally / Daily**
  - Processes whose dynamics / scale result in best fit to demand
  - Energy efficient storage could have a major impact
- **Capacity Utilization Critical to Cost Efficiency**
  - Scaleable / modular production systems
  - Combined electricity / hydrogen generation
- **Carbon Capture and Sequestration Needed for Fossil Fuel Based Options**
  - Scaleable / modular capture systems
  - CO<sub>2</sub> distribution now an infrastructure factor

***Scaleability, Combined Electricity / Hydrogen Generation Expand Options***

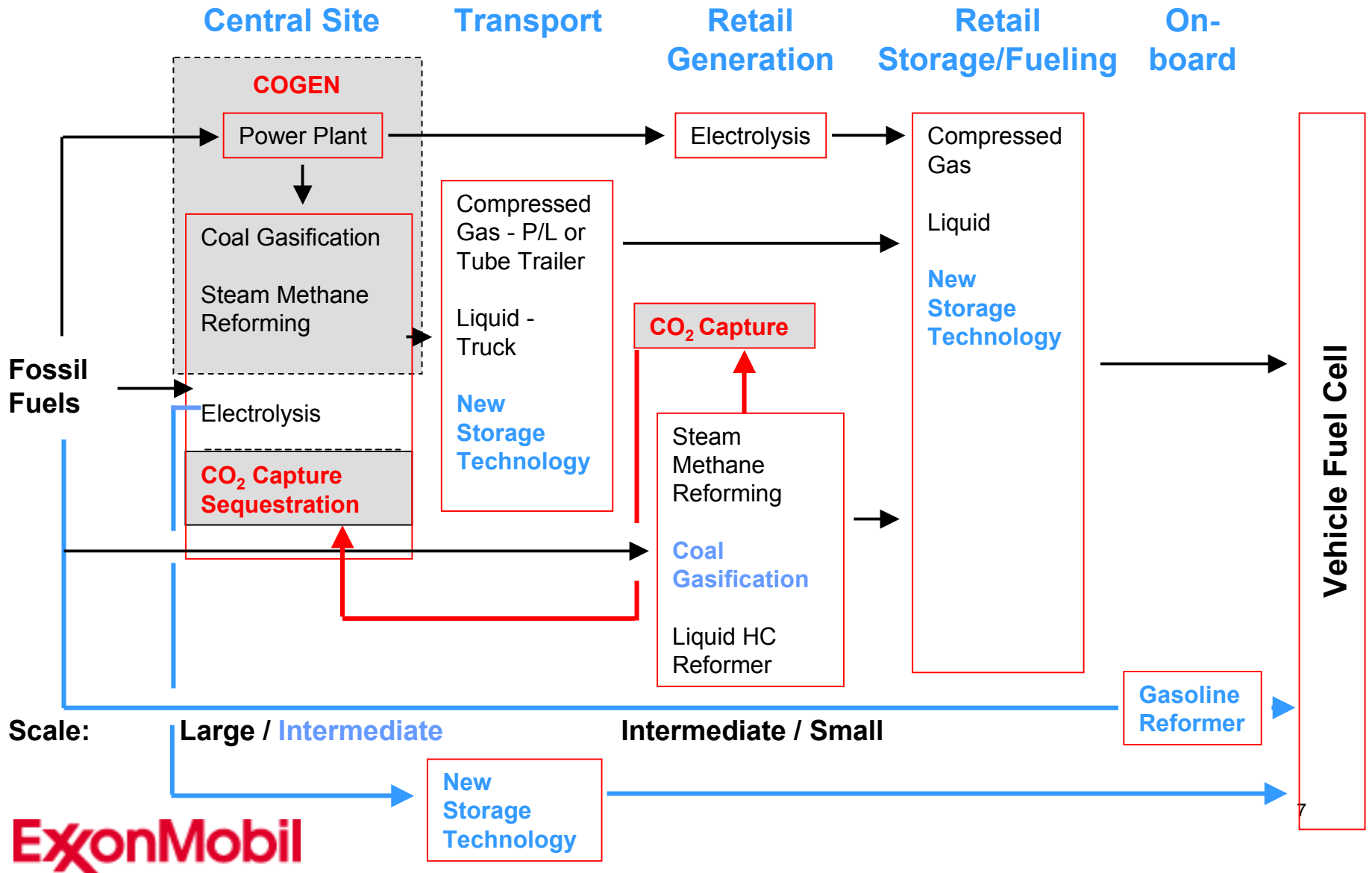
# ***Distribution Challenges***

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- **High pressure tube trailers are suitable for small volumes only - current technology requires ~130 kg steel per kg of H<sub>2</sub> transported**
  - **~19 tube trailers needed to supply energy of 1 gasoline tank truck**
- **Cryogenic tankers are an economical way to transport large quantities of hydrogen over long distances but liquefaction is energy intensive**
  - **Energy per load comparable to gasoline tank truck**
  - **Electricity needed to liquefy sufficient hydrogen to satisfy California demand is nearly equivalent to all of California's residential electricity use**
- **Hydrogen pipelines are expensive and energy inefficient beyond short distances**
  - **Arterial design of pipelines is expensive**
- **Natural gas systems are incompatible with hydrogen**
  - **Embrittlement of steel, migration into plastics, pressures, metering, safety systems all require unique designs**

***Efficient, Scalable Storage a Critical Enabler for All Production Options***

# Altering the Paradigm



# Current Status: Low Pressure Storage Options

	Specific Gravimetric Density* (weight %)	Desorption Temperature (K)	Remarks
Carbon Nanotubes	7-8%	77K ?	Physical process still under investigation
Low Temperature Adsorption	max. 5%	80-120K	Storage at cryogenic temperatures
Complex Hydrides	max. 10%	350 – 390K	High T & Thermal Management
Hydrogen Storage Alloys	3-5%	?	High T & Thermal Management
Hydrocarbon Carriers	max. 8.3%	Reforming process at high temperatures	Toxicity (CH <sub>3</sub> OH)
Nitrogen-Based Carriers	max. 20%	Chemical process varies from compound	Toxicity (e.g. NH <sub>3</sub> )

Used by Permission G.Parks, ConocoPhillips

Meets DoE 2010 target

Meets DoE 2015 target

- No Systems Currently Meet DOE Targets - Still Limited By:
  - Energy losses in adsorption / desorption
  - Costs
  - Toxicity

# Carbon Capture

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- Assumption is for Capture as Supercritical CO<sub>2</sub>
- Hydrogen Equivalent to 60 kg H<sub>2</sub><sup>1</sup> Produces ~ 1 MeT of CO<sub>2</sub>
- Estimated Costs for Capture Including Separation, Dehydration and Compression are \$ 33 - 72 / MeT CO<sub>2</sub><sup>2</sup>
  - Equivalent to \$ 0.55 - 1.20 / kg H<sub>2</sub>
- Tank Truck Capacity 4-6 MeT / Load
  - Equivalent to 48 - 72 fills @ 5 kg H<sub>2</sub> / fill
  - ~ 70 vehicles / day
- Issues Include Compressor Costs, Materials of Construction, Energy Efficiency, Scaleability and Intermediate Storage

1.) Assuming Gasoline Reforming @ 65% Efficiency and Utilities

2.) L. Smith, N. Gupta, B. Sass, T. Bubenik, C. Byrer, and P. Bergman. 2002. "Engineering and Economic Assessment of Carbon Dioxide Sequestration in Saline Formations." *Journal of Energy & Environmental Research*, Volume 2 (5-22).

# ***Implications for GCEP***

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## ***Production***

- **Higher Efficiency Conversion Processes for Coal**
  - **New primary reactor concepts**
  - **Greater scalability: conversion, oxygen enrichment, hydrogen separation**
- **Cogeneration and / or Higher Dynamic Range Processes**
- **Effort on Wind and Nuclear Options Also Needed**

## ***Storage***

- **Scaleable Low Energy Loss Storage - DOE Energy Density Targets About Right**
- **Someone Should be Looking at Battery Systems**

## ***Carbon Capture / Sequestration***

- **Lower Cost, More Efficient Carbon Capture Based on Supercritical CO<sub>2</sub>**
- **Scaleable Capture Technology Critical to Combining Efficient / Affordable Production and Delivery of Hydrogen in the Transportation Sector**