Some Technical Challenges in Large Scale Hydrogen Production and Use

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Drivers for Future Energy Carrier Choice

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

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If Hydrogen Then ....

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**

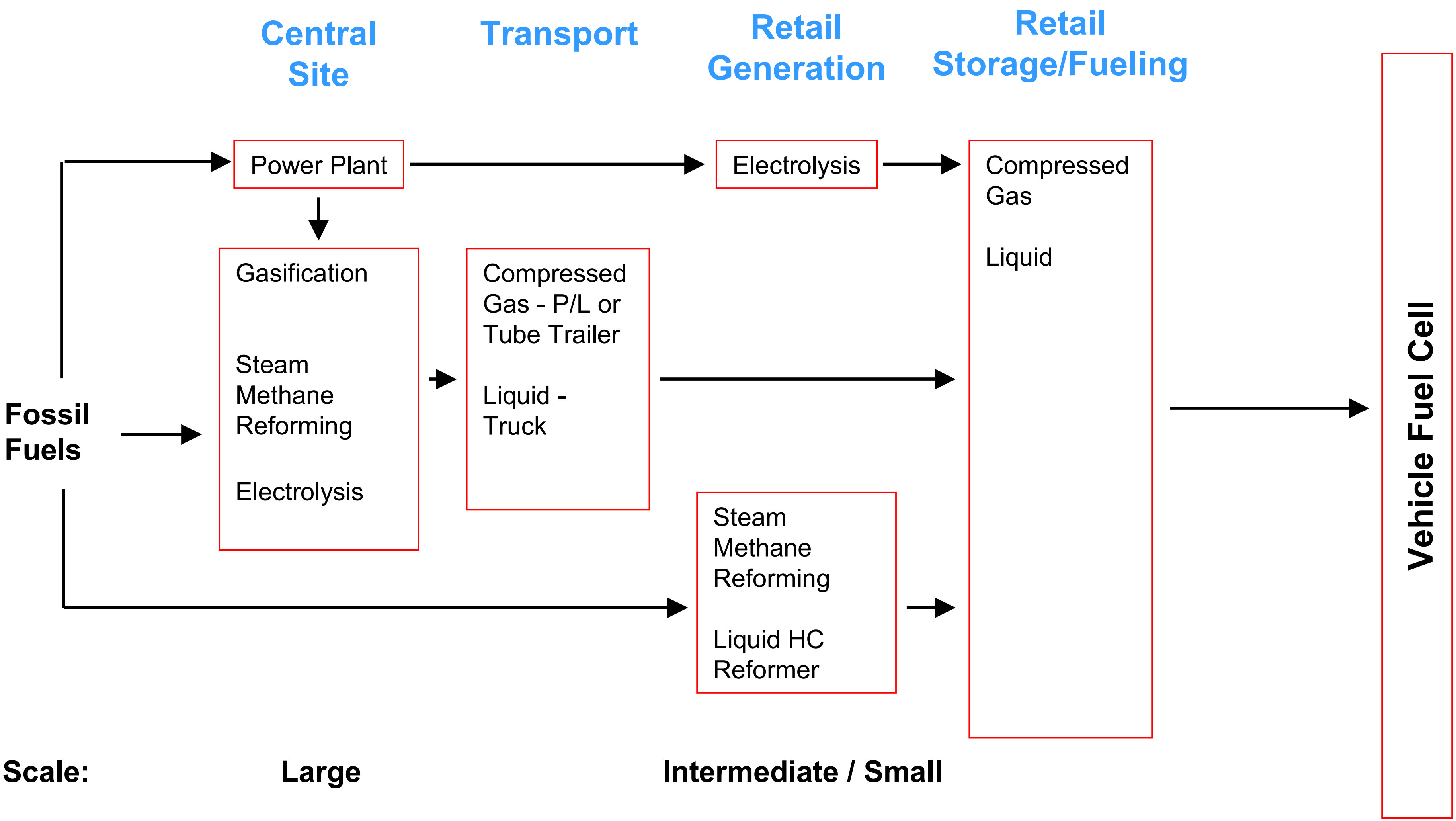
Driver 3

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

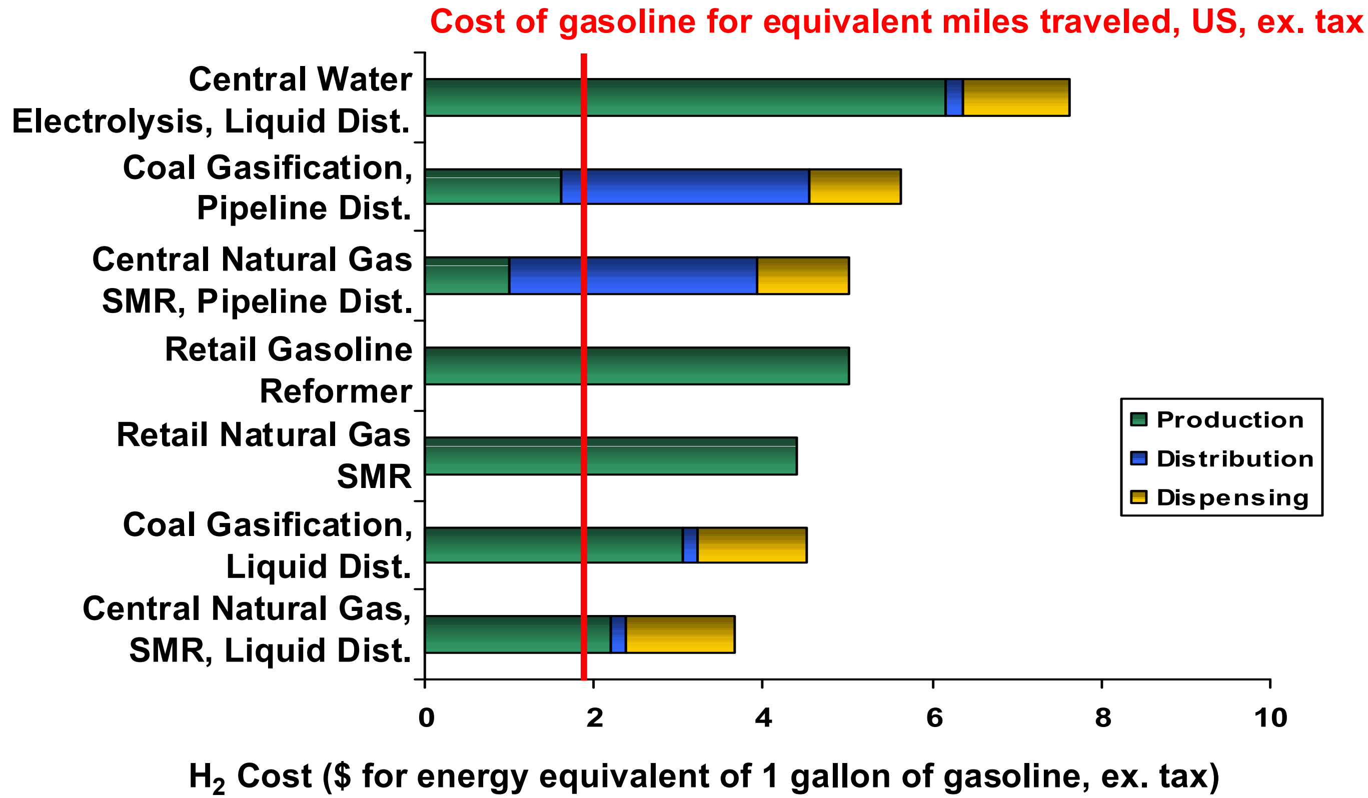
Driver 4

- **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

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Source: SFA Pacific

Production Challenges and Implications

- **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_2 distribution now an infrastructure factor**

Scaleability,Combined Electricity / Hydrogen Generation Expand Options

Distribution Challenges

- **High pressure tube trailers are suitable for small volumes only - current technology requires ~130 kg steel per kg of H_2 transported**
  - **~19 tube trailers needed to supply energy of 1 gasoline tank truck**

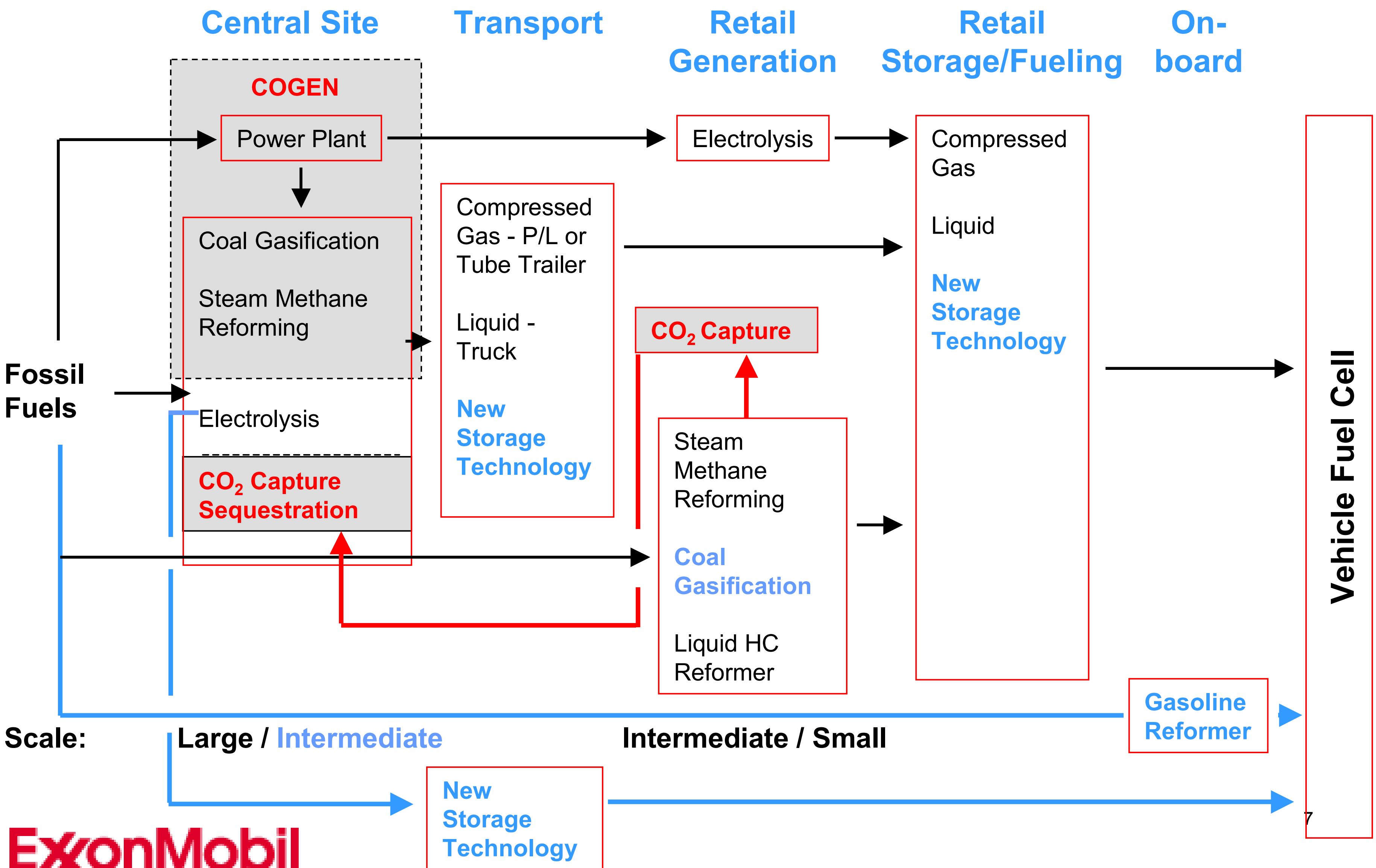
- **Cryogenic tankers are an economical way to transport large quantities of hydrogen over long distances but liquefaction is energy intensive**
  - **Energy per load comparable to gasoline tank truck**
  - **Electricity needed to liquefy sufficient hydrogen to satisfy California demand is nearly equivalent 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, Scaleable 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_3OH)
Nitrogen-Based Carriers	max. 20%	Chemical process varies from compound	Toxicity (e.g. NH_3)

Used by Permission G.Parks, ConocoPhillips

Meets DoE 2010 target

Meets DoE 2015 target

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

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Carbon Capture

- Assumption is for Capture as Supercritical CO_2
- Hydrogen Equivalent to 60 kg H_2[1] Produces ~ 1 MeT of CO_2
- Estimated Costs for Capture Including Separation, Dehydration and Compression are $ 33 - 72 / MeT CO_2[2]
  - Equivalent to $ 0.55 - 1.20 / kg H_2
- Tank Truck Capacity 4-6 MeT / Load
  - Equivalent to 48 - 72 fills @ 5 kg H_2 / 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

Production

- Higher Efficiency Conversion Processes for Coal
  - New primary reactor concepts
  - Greater scaleability: 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_2
- Scaleable Capture Technology Critical to Combining Efficient / Affordable Production and Delivery of Hydrogen in the Transportation Sector