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Hydrogen In Industry, Commercial Transport & Logistics

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New York | Boston | Austin |
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David Steven Jacoby

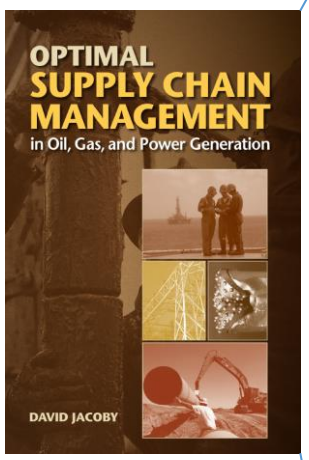
- 30 years of strategy and operations consulting
- Builds carbon-neutral supply chains
- CEO of Boston Strategies International
- Author of *Reinventing the Energy Value Chain* and 5 other books
- Global clientele, e.g., UPS, FedEx, Saudi Aramco, Iberdrola
- Senior Fellow at Boston University's Institute for Sustainable Energy.
- Adjunct Professor at NYU
- MBA (Wharton)

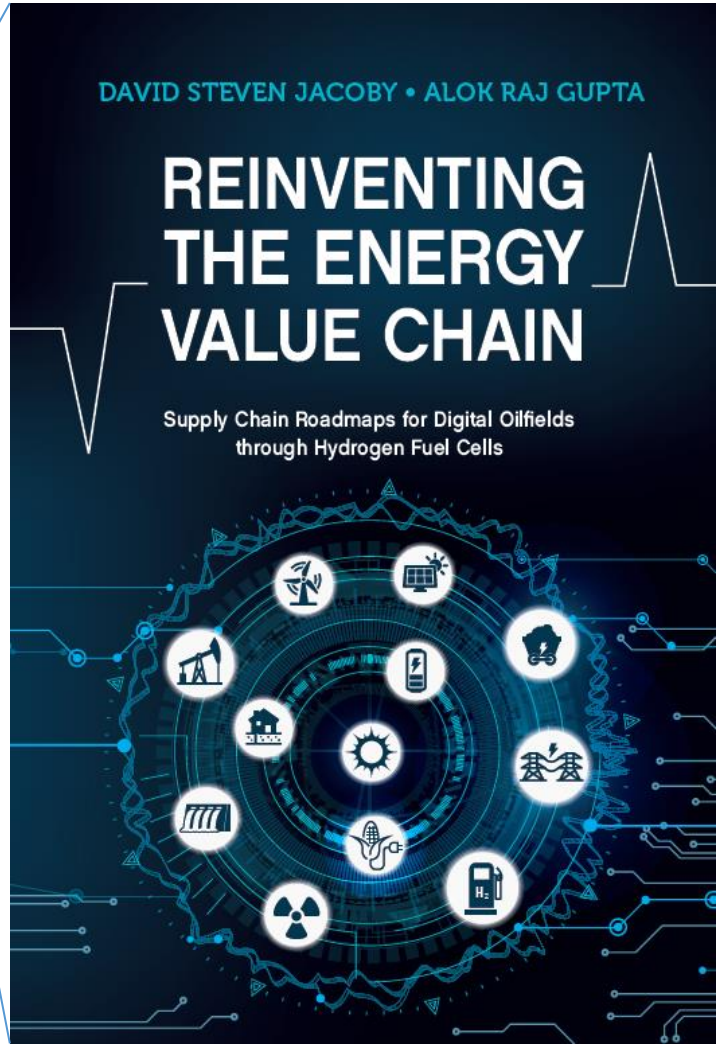
John A. Foote

- Former US Air Force Captain
- Ex Saudi Aramco
- Ex Applied Materials
- Cross-functional manufacturing executive
- Strategic supply chain leader
- Negotiates and manages multi-million dollar contracts
- Develops new manufacturing capabilities
- Implements B2B software solutions
- MBA, MS Tech (U. Texas)

From *Optimizing Supply Chain Management* to *Reinventing Value Chains*

- **Markets**
  - Hydrogen & Fuel Cells
  - Energy Storage
  - Wind
  - Solar
  - Biomass
  - Upstream Oil & Gas
  - Midstream Oil & Gas
  - Downstream Oil & Gas
  - Geothermal
  - Gas and Coal-Fired Power
  - Hydropower
  - Nuclear
- **Features**
  - Roadmaps for unlocking latent value in energy supply chains
  - Concepts and principles to guide energy investments
  - Techniques for optimizing supply chains and systems
  - Management techniques for capital project management
  - Management techniques for operations & maintenance
  - Risk mitigation strategies



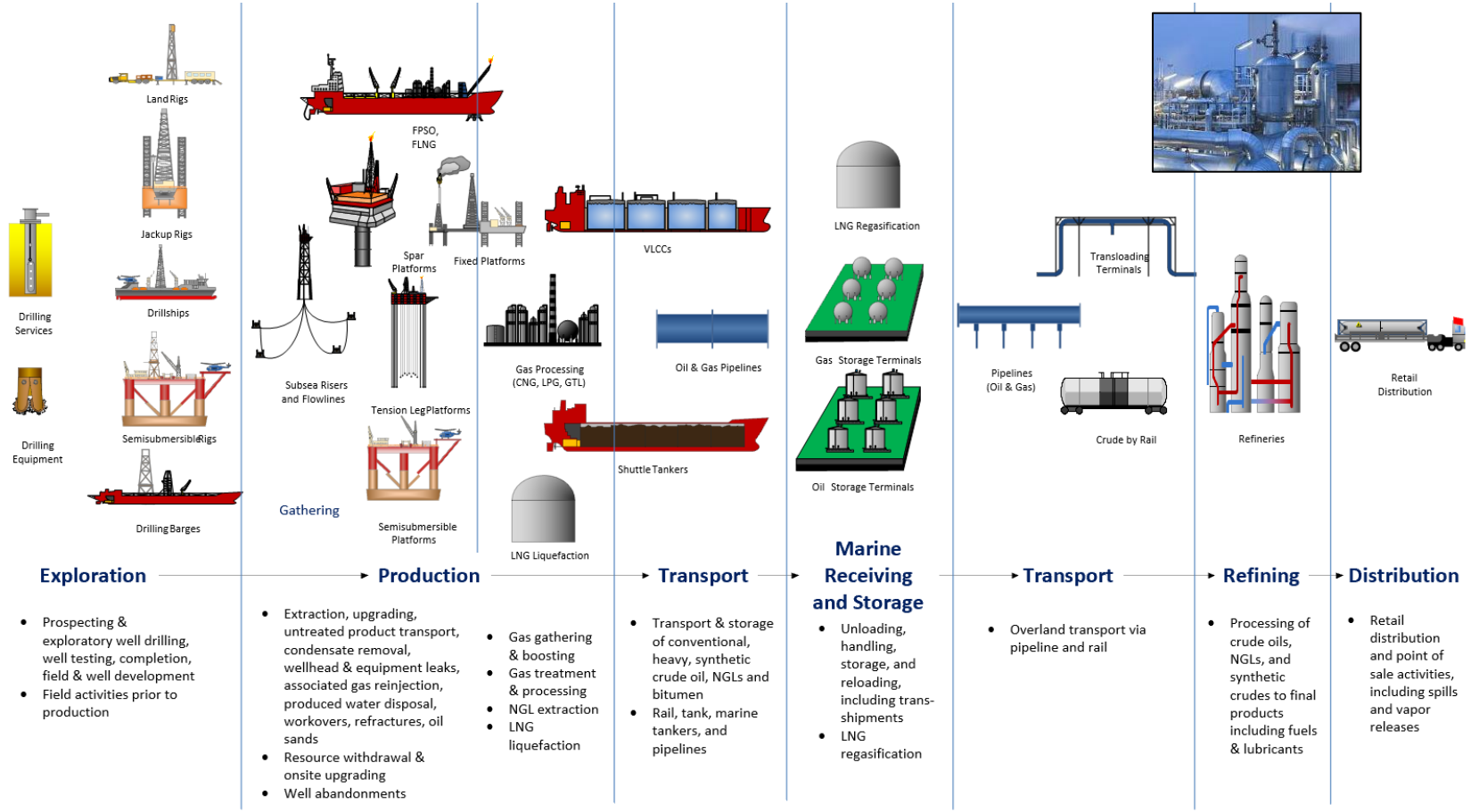


Today: Informational and Broad Intro, with a Close Look at Transport & Commercial Freight Applications

- Basics of Hydrogen
- Why the Hydrogen Buzz
- Hydrogen in Industry
- Hydrogen in Transport
- Hydrogen Economic Risks
- Is Hydrogen Right For You?

Gray H2 in the Natural Gas Chain

- Byproduct of gas production (methane and ammonia can be done quickly today)
- 55% used to make ammonia, 10% used to make methanol, 25% in refining

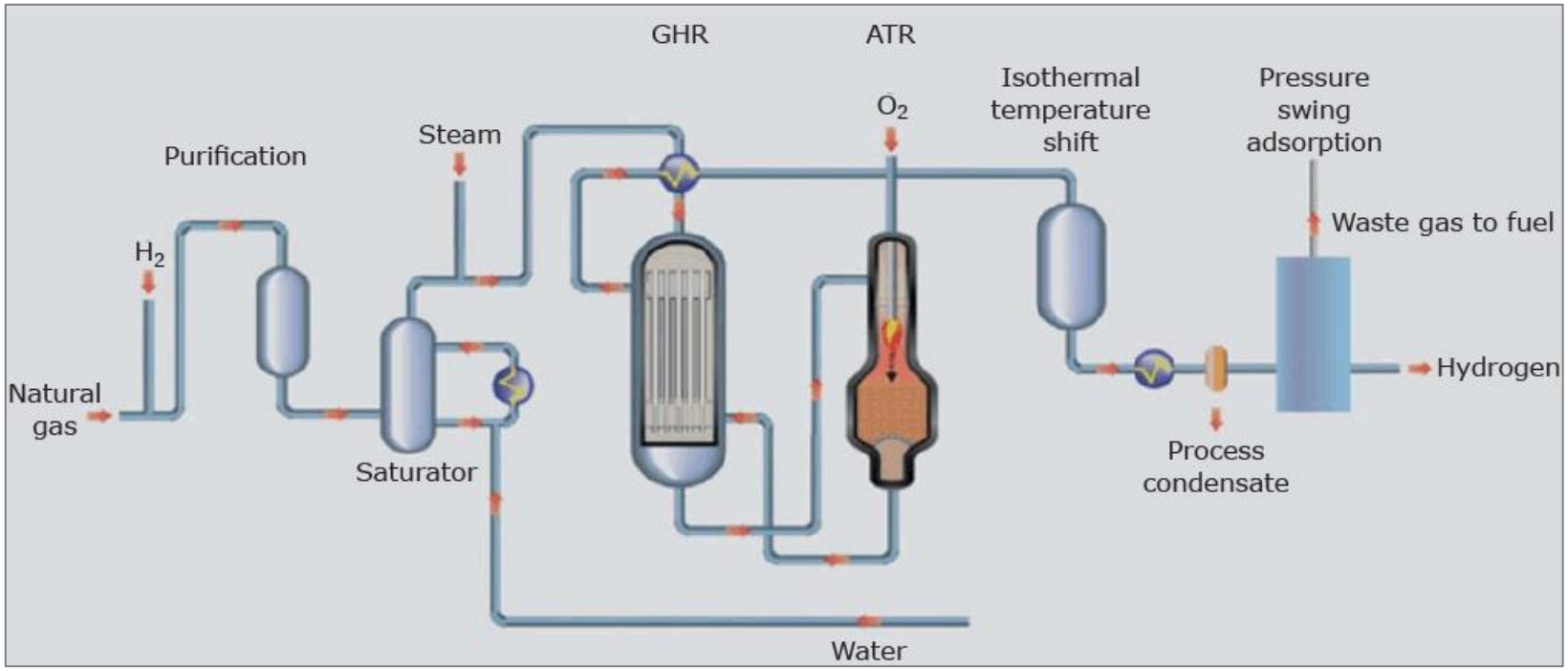


Source: [Reinventing the Energy Value Chain: Supply Chain Roadmaps for Digital Oilfields through Hydrogen Fuel Cells](#) (PennWell, 2021)

Natural Gas to H2 via Steam Methane Reforming

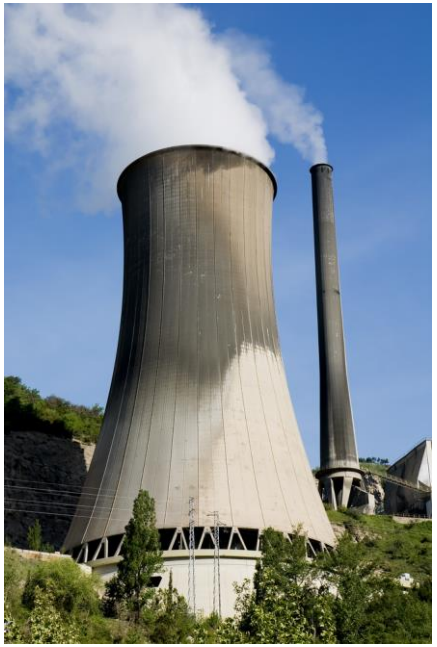
- Byproduct of gas production (methane and ammonia can be done quickly today)
- 55% used to make ammonia, 10% used to make methanol, 25% in refining

Steam Methane Reforming Process



Source: H2-CCS Network.
GHR: Gas-Heated Reforming
ATR: Autothermal Reforming

Green, Yellow, Pink, and Other Colors of Hydrogen

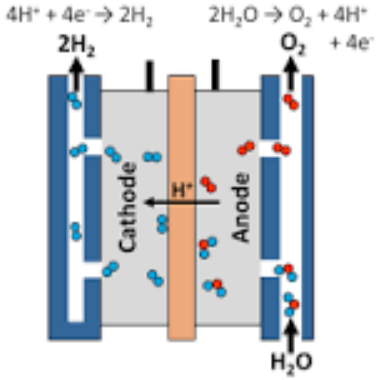


- Black-black coal, gasification
- Brown-lignite, gasification
- Green-electrolysis, solar/wind electricity, or steam thermolysis
- Yellow-grid electric, carbon loading depends on local grid mix
- Pink-electrolysis, nuclear power
- Turquoise-natural gas, pyrolysis
- Red-nuclear heat, thermolysis
- Purple-nuclear electricity and heat, electrolysis and thermolysis
- Orange-solar irradiance, photolysis

Why the Buzz About Hydrogen

- **Why the buzz**
  - <u>It's not carbon</u>
  - Many H2 production options
  - Many potential applications
  - Many storage & transport options
- **Safety**
  - High explosive reactivity
  - Accompanying gas risks
- **Economic Risks**
  - Today no large-scale hydrogen projects or retro-fit infrastructure projects
  - However, wind power @ 3 ¢ / kWh or less can allow H2 production at economic scale
  - Policy factors and regional differences

Electrolysis



Source: Energy.gov

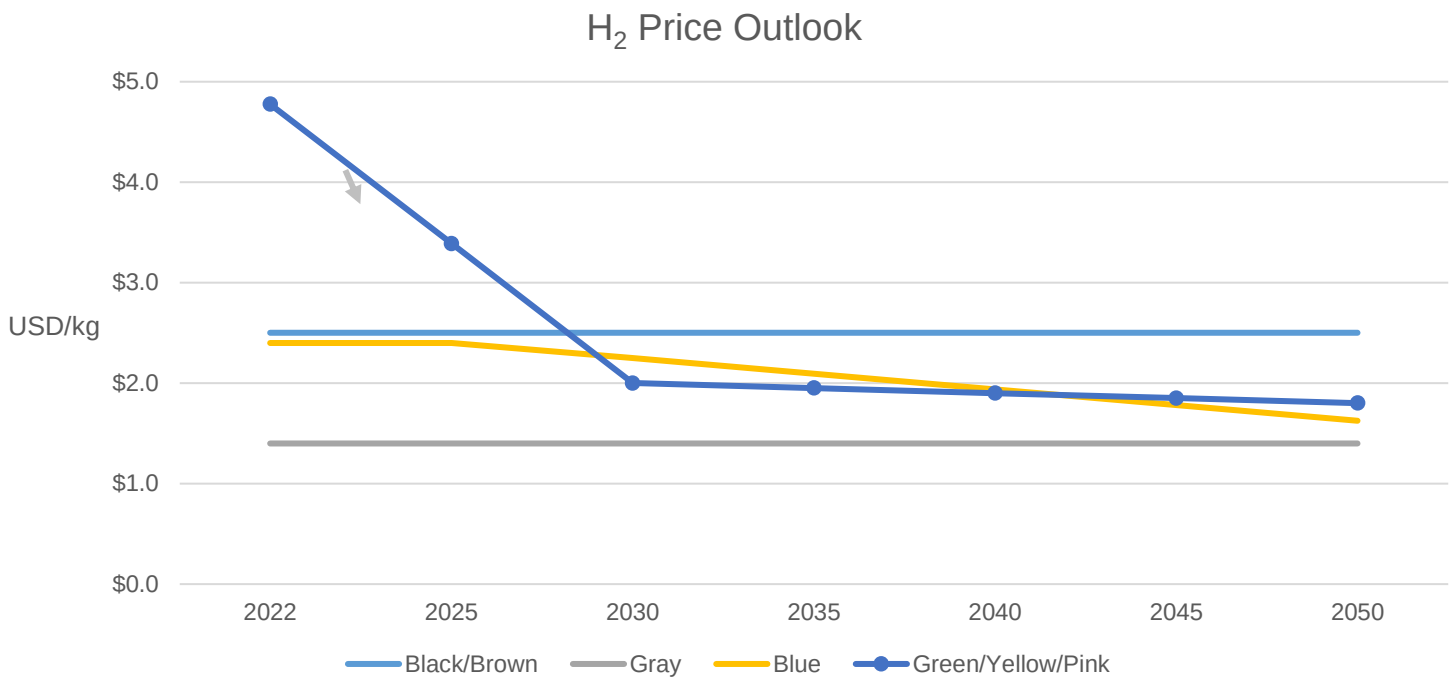
Sources and Uses

Production Method	Application
Steam methane reforming	Industrial
Green/wind	Transport
Green/solar	Power
Etc.	Etc.

Source: CNBC

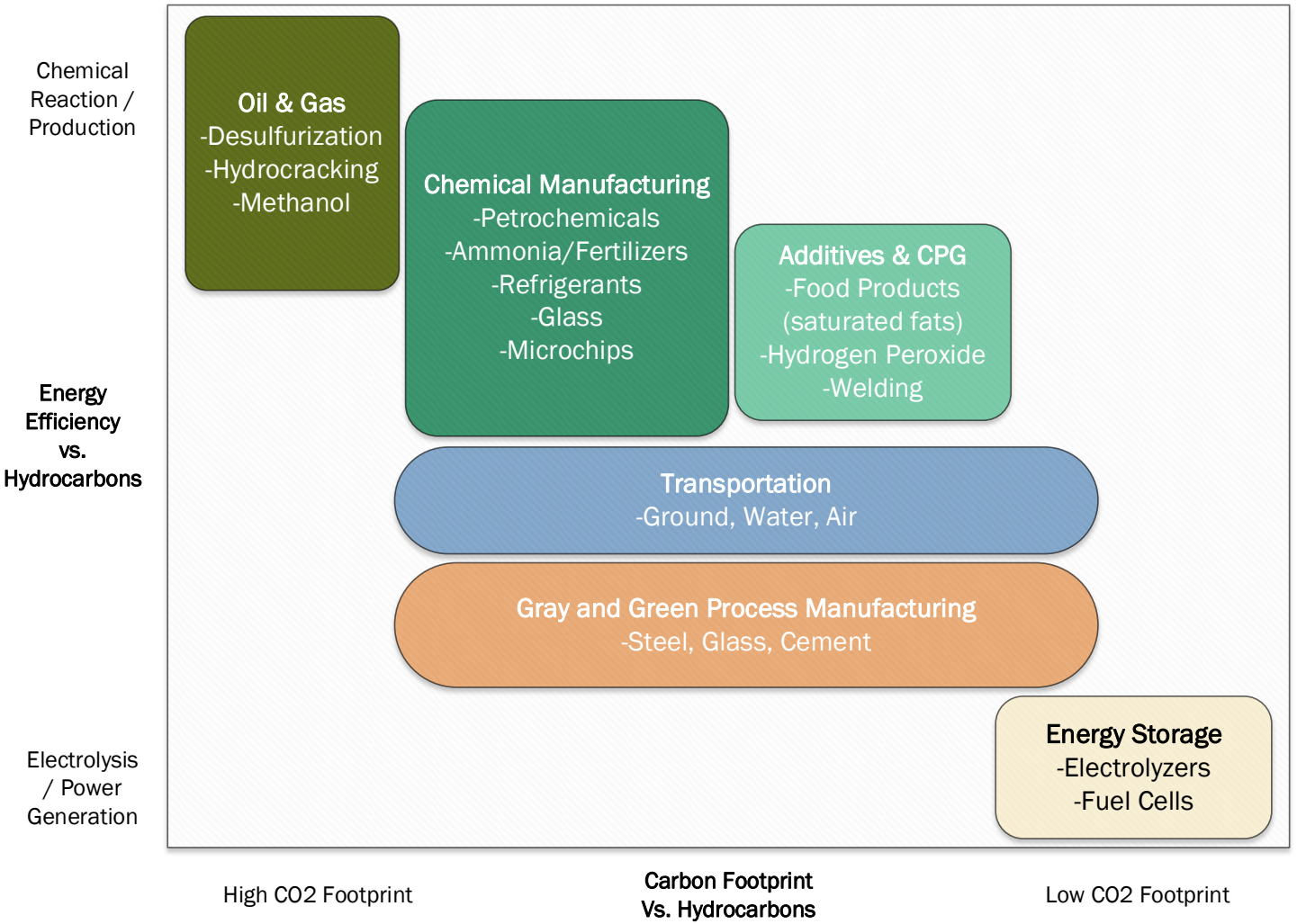
Efforts Underway to Cut Green H2 Costs by More than Half

- Massive per-kg cost decreases by 2030
- Green H2 will scale to nearly half of all production between 2030 and 2050
- Meeting 13% of global energy demands by 2050



Source: REVchain™ analysis. Some base data from Rystad, IRENA, USDOE, BNEF, et al.

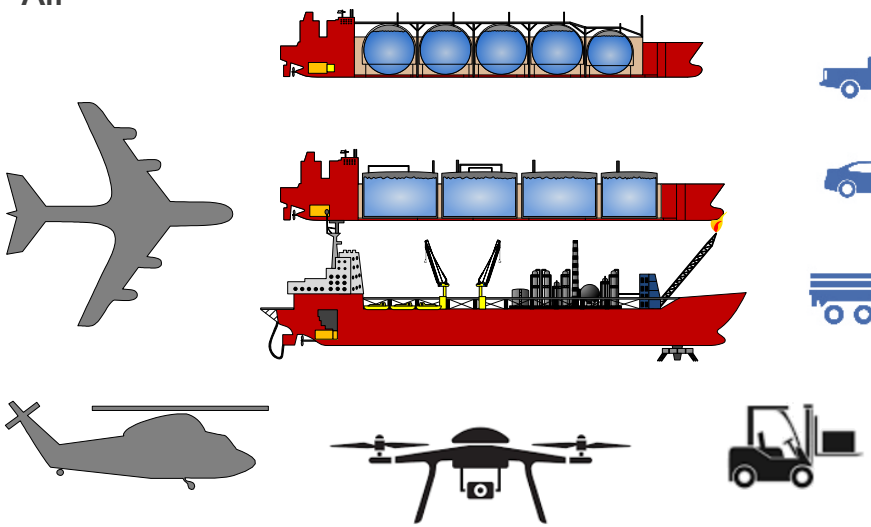
Hydrogen Adoption: Energy Efficiency vs. Lifecycle CO2 Footprint



Source: REVchain LLC

Hydrogen in Transport

- Material Handling Equipment
- Light Duty Trucks
- Heavy Duty Trucks
- Rail
- Ocean
- Air



Material Handling Equipment: Energy Density Requirements Will Favor H2

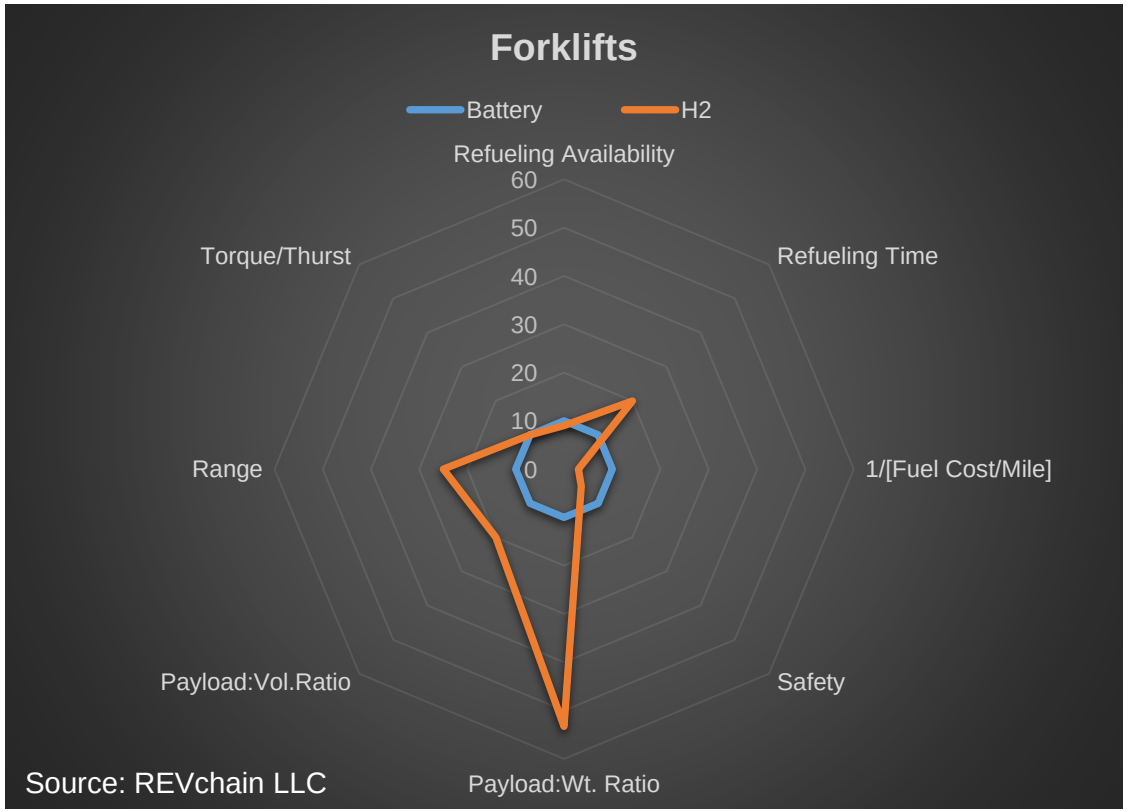
TODAY

- 35-40k fuel cell forklifts in US (2021)
- 95% proton exchange membrane fuel cells (PEMFC) (H2)
- 5% direct methanol fuel cells (DMFC)

OUTLOOK

- 300k in 2030
- H2 no recharging time vs. battery forklifts
- Walmart is expanding its fleet to 9500 H2 forklifts
- Amazon is ordering them.
- PlugPower offers to replace battery forklifts with H2 fuel cells

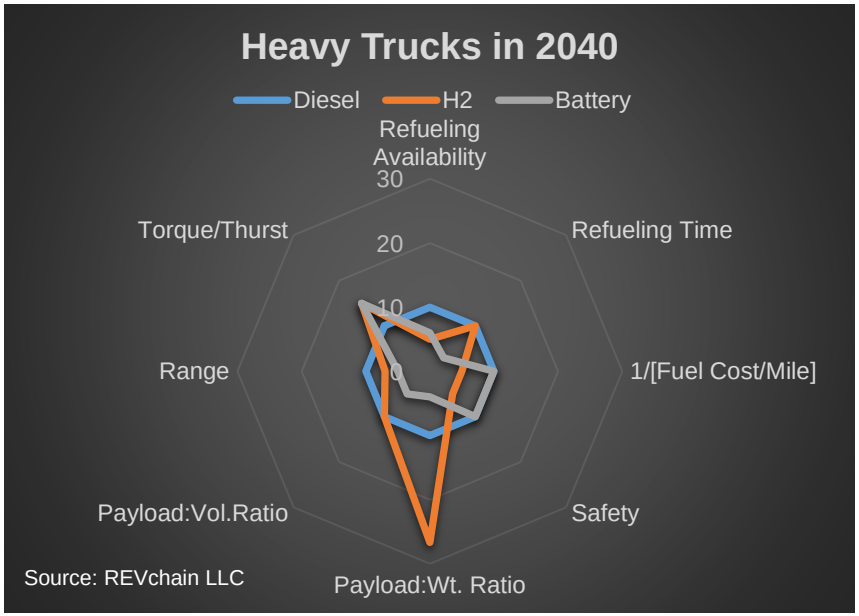
● Forklifts ● Cranes ● AGVs ● Transtainers ● Etc.

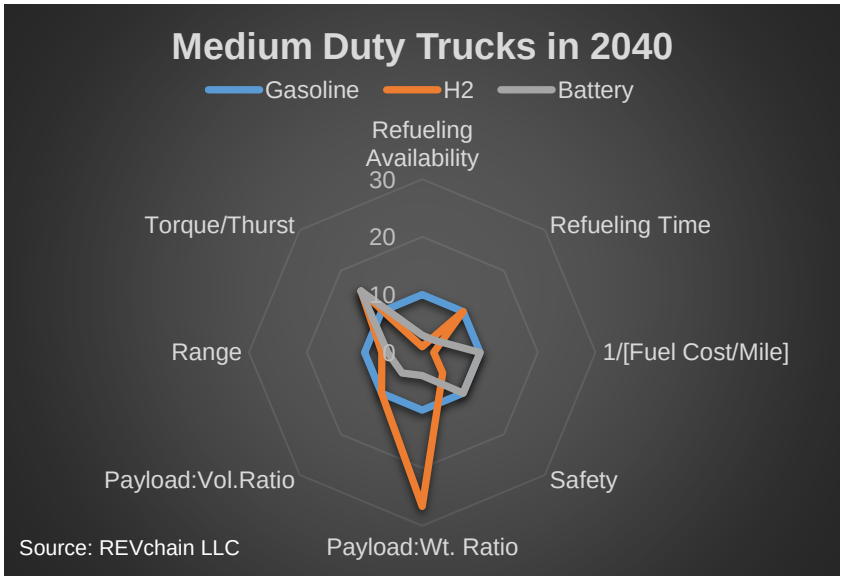


Trucks: Heavy Duty More Suitable Weight, Size, and Range for H2

TODAY
- 14k H2 passenger vehicles in the US
- CA building H2 refueling stations
- 54 retail stations opened in CA

OUTLOOK
- Batteries: small trucks, short range
- Hydrogen: heavy duty trucks due to weight & refueling
- Green H2 near coastal areas

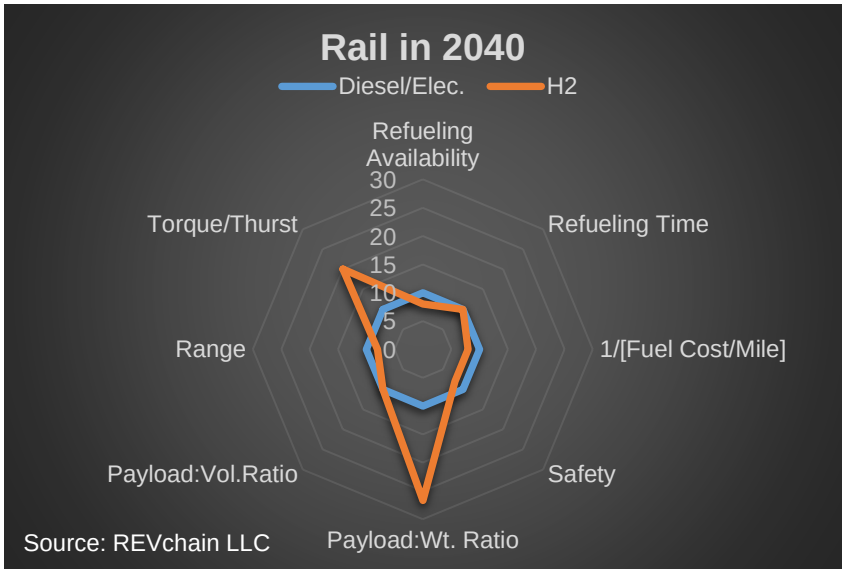


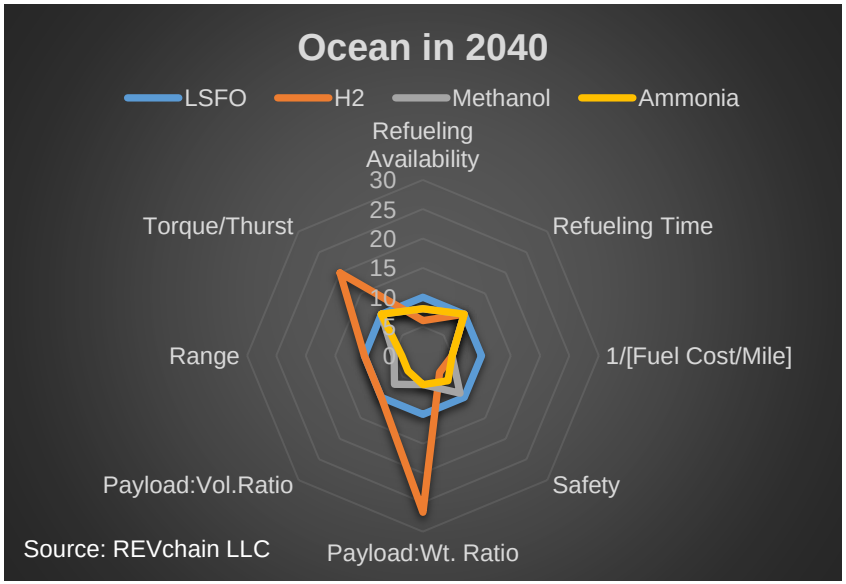


- Light Duty (Classes 1, 2)
- Medium Duty (Classes 3, 4, 5, 6)
- Heavy Duty (Classes 7, 8)

Source: REVchain LLC

Rail & Ocean are Promising Modes for Long-Term H2 Economics





RAIL

TODAY
- CP Experimental Hydrogen Locomotive
- BNSF demonstration project
- Caterpillar, Cummins research
- Chevron, energy company partnerships

OUTLOOK
- Cummins manufacturing in Germany
- Scale economies in R&D and production
- First-mover advantage

OCEAN

TODAY
- Modeling of transition fuels and time horizons
- Ethanol, methanol, hydrogen, ammonia and biodiesel

OUTLOOK
- Major propulsion system redesign
- 20-30 year commercialization cycle
- IMO: 40% less CO_2 by 2030
- IMO: 50% less CO_2 by 2050

The Use of H2 in Air Freight Presents Many Challenges

TODAY

- Basic research stage

OUTLOOK

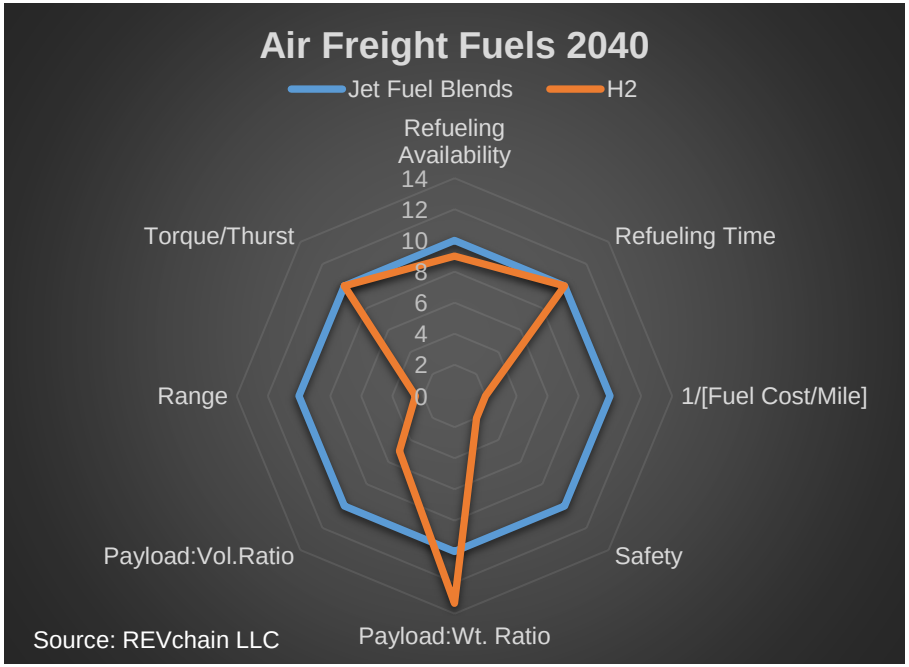
- Can't haul batteries due to weight

and

- Biofuels need to be grown on massive scale, won't happen. Won't replace JP4 and JP5 and AB (aviation) gas 115-125 octane.

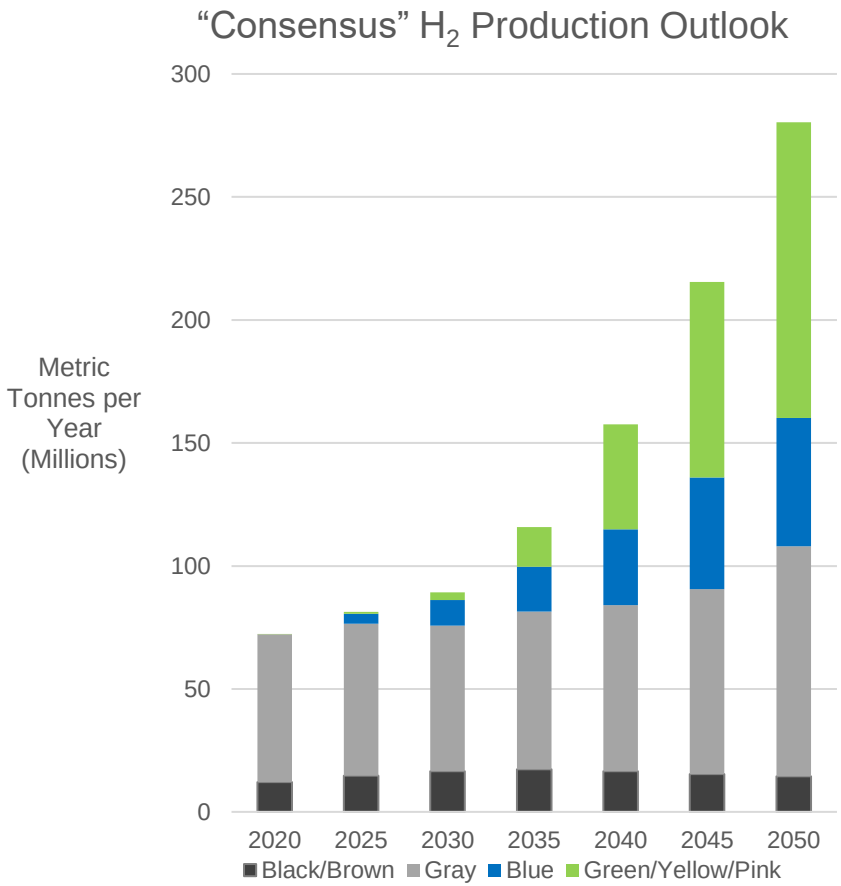
However:

- Space usage per BTU is low
  - Unless liquified as in space programs, but then safety issues
- Ammonia blends



Hydrogen Outlook: Factors

- **Policy & regulatory environment**
  - Bipartisan Infrastructure Law
  - European Union's regulations
- **Regional economic and political dynamics**
  - California
  - EU (offshore wind for green H2)
  - China
- **2050 Levelized Cost Outlook**
  - Methane reforming
  - Dedicated renewable electrolysis
  - Grid based electrolysis



Source: REVchain™ analysis of data from DNV.

Is Hydrogen Right for You?

REVchain™ Capabilities

Forecasting

- Industry/ Application-Specific Technology News & Information
- Market Sizes, Costs & Prices (Baselines)
- Carbon Footprint Boundaries
- Carbon Footprint Calculator

Scenario Building

- Everything in Revchain Analytics
- Cost & Price Forecasts
- Parametric Prices & Forecasts and Scaling Factors
- Market Intelligence by Subsegment
- Carbon Scenario Builder
- Target Validation
- Carbon Footprint Baseline & Target Certification

Project Management

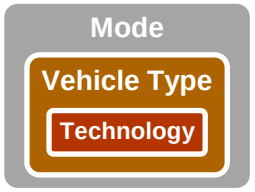
- Everything in Revchain Analytics+
- Carbon Footprint Baseline & Target Certification
- Strategic (Level 1) Fit Assessment
- Tactical (Level 2) Fit Assessment
- Channel Selection
- Key Success Factors
- SWOT & Gap Analysis
- Financial Evaluation (Revenue, Cost, Capex, & ROI)
- Dedicated Consultants
- On-Call Scientists
- Experienced Executives

IDEAL FOR:
- Concept screening
- Evaluating new markets
- Deciding whether to do a feasibility study

IDEAL FOR:
- Selecting technologies
- Deciding whether to authorize a pre-FEED study
- Deciding on projects that are contingent on how much carbon can be eliminated

IDEAL FOR:
- Deciding on Financial Investment Decision

Commercial Transport Data Matrix



REVchain™ Analytics

Modes

- Air Transport (Freight/Pasgr)
- Airport Operations
- Ground Freight
- Ocean Shipping
- Rail
- Port Operations
- Warehousing

Vehicle Types

- Aircrafts (wide body, narrow body and feeder aircraft)
- Cargo Vans (Classes 1,2,3)
- Delivery Robots
- Drones - Freight
- Drones - Parcel Delivery
- Forklifts
- Heavy Duty Trucks (Classes 7, 8)
- Medium Duty Trucks (Classes 4,5, 6)
- Locomotives
- Tug Boats
- Containerships (Panamax, Post - Panamax, Neo-Panamax and Ultra Large Container Vessels)
- Oil Tankers (Product tanker, Panamax, Aframax, Suezmax, VLCC and ULCC)
- Airport Tractors
- Airport Auxiliary Power Unit
- Airport Tugs
- Bulk Cargo Ships
- Automated Guided Vehicles
- Cranes
- Transtainers
- Tug Boats
- Oil Tankers (Product tanker, Panamax, Aframax, Suezmax, VLCC and ULCC)

Power Technologies

Fuel Cells - Proton-Exchange Membranes Fuel Cells
Fuel Cells - Phosphoric Acid Fuel Cells
Fuel Cells - Alkaline Fuel Cells
Fuel Cells - Molten Carbonate Fuel Cells
Fuel Cells - Solid Oxide Fuel Cells
Batteries - Lithium-Ion Batteries
Batteries - Flow Batteries
Hybrids - Self-Charging
Hybrids - Plug-In
Charging - Level 1 (Slow Speed)
Charging - Level 2 (Medium Speed)
Charging - Level 3 (High Speed)
Hydrogen Refueling - H30
Hydrogen Refueling - H70
Biofuels - Ethanol
Biofuels - Methanol
Biofuels - Ammonia
Biofuels - Biodiesel
Biojetfuel - Oil-to-Jet
Biojetfuel - Alchohol-to-Jet
Biojetfuel - Sugar-to-Jet
Biojetfuel - Gas-to-Jet
Hydrocarbons - CNG
Hydrocarbons - LNG
Hydrocarbons - LPG
Hydrocarbons - 0.1% Low Sulpher Fuel Oil
Hydrocarbons - 0.5% Low Sulpher Fuel Oil
Hydrocarbons - 1.0% Low Sulpher Fuel Oil
Hydrogen

* Example scope of analysis: Biodiesel for use in Class 8 Trucks for Ground Freight

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