An Overview of Hydrogen Trucking Technology and Technoeconomic Factors

HEC Workshop on Decarbonizing long-haul trucking in Eastern Canada

April 25, 2023

Presentation Overview

- Change Energy
- Technology: Vehicles
- Technology: Refuelling
- Technoeconomic Assessment
- SWOT
- Recommendations for Decision-Makers

CH2NGE Change Energy

- Engineering firm with a 32 year history specializing in compressed and liquefied gaseous fuel systems solutions
- We assess, design, and implement fuel systems that yield the desired **economic, environmental**, and **social** outcomes.
- Experience:
  - International
  - > 150 gaseous vehicle refuelling and bulk fuel filling and decanting stations (CNG, H2)
  - Life-Cycle Techno-Socioeconomic modelling of stations, fleets, and regional infrastructure.
  - 30 years in the development of Codes, Standards, and Regulations

- Services:
  - Detail design of: Infrastructure, Refuelling Stations, Virtual Pipeline (Bulk Transport System), and Facilities
  - Safety Assessment
    - Development of Regulations, Codes and Standards.
  - Business case analysis
    - Corporate fleets
    - Municipalities
    - Economic Regions (Infrastructure)
  - Assessment of Markets and Applications
  - Development of end use applications
  - Training

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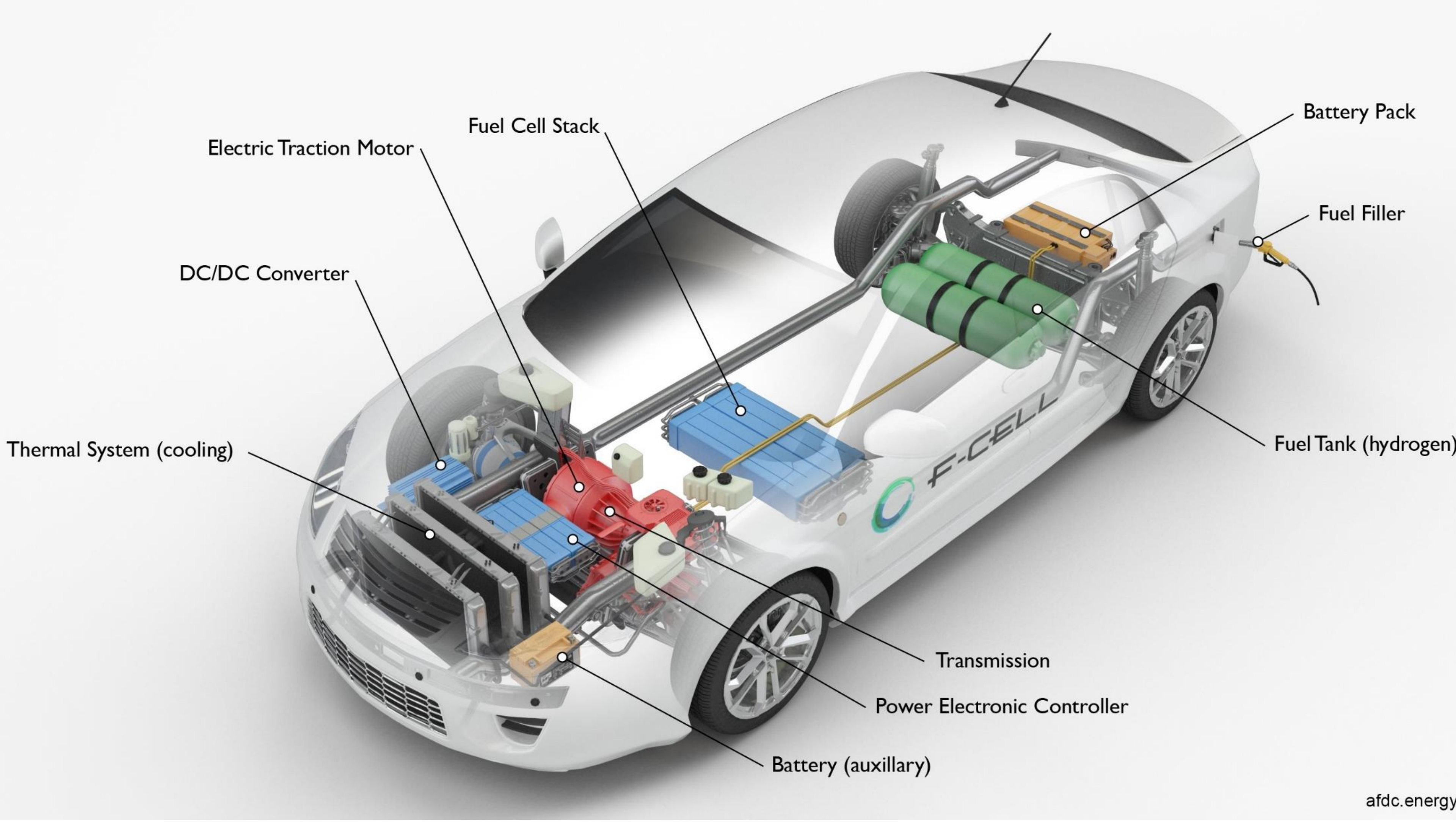
Technology: Vehicles

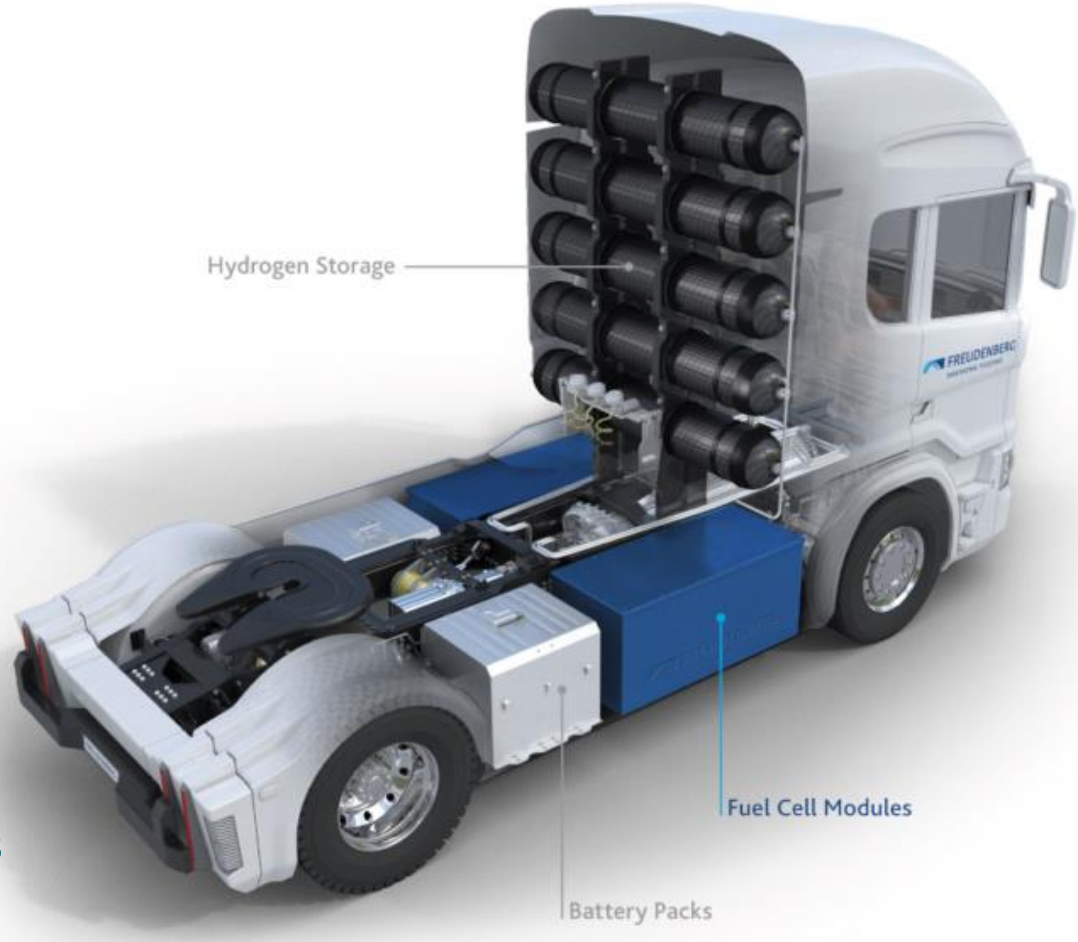


Pros and Cons Medium/Heavy-Duty Vehicles

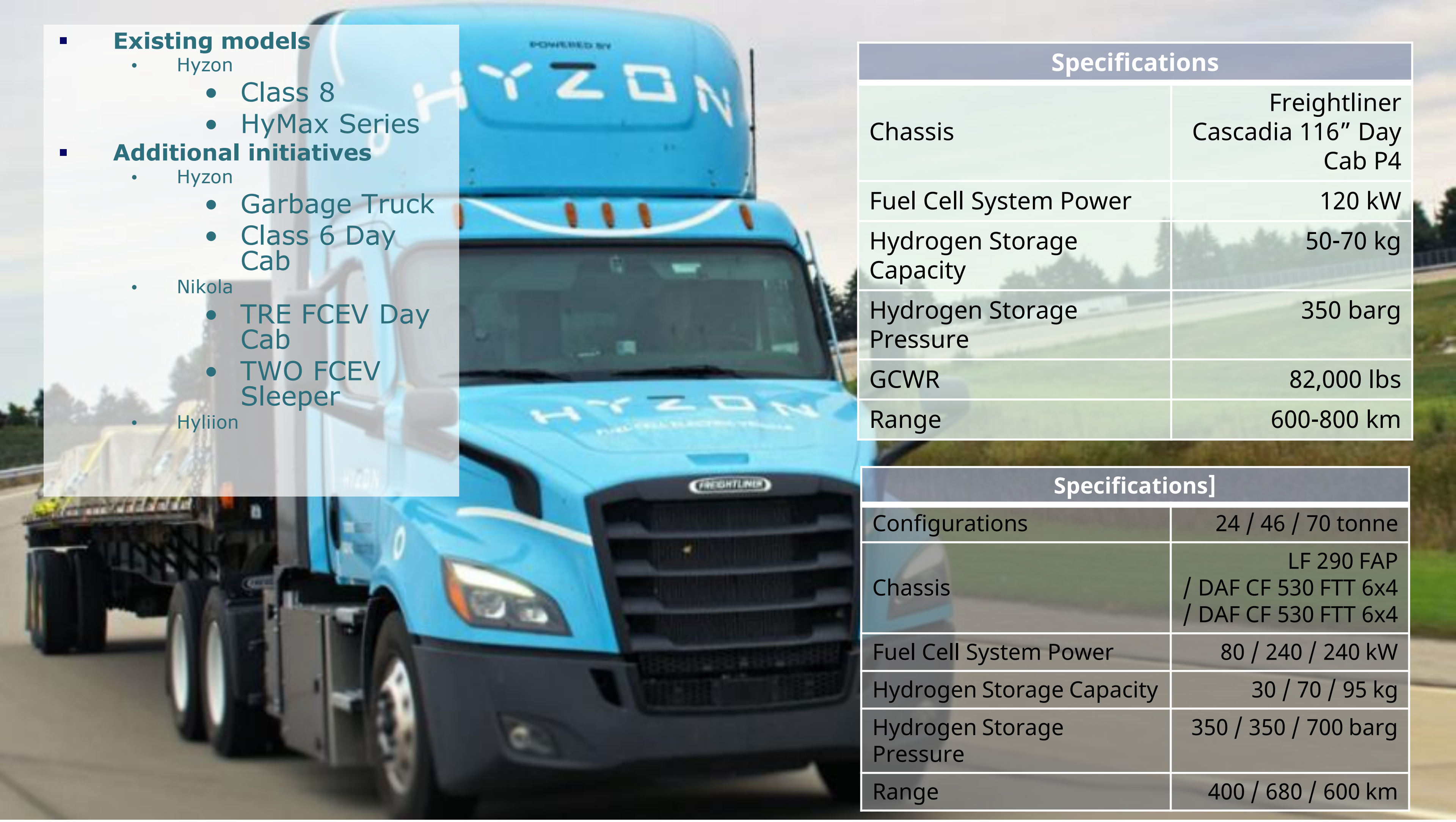
- **Advantages**
  - Potential for greater EV driving range
  - Quicker refuelling than BEV
  - Efficiency (vs diesel)
  - Emissions reductions
  - Noise reduction
  - Lighter weight energy storage
  - Permits large payloads

- **Disadvantages**
  - Cost (technology dependent)
  - Fuel Cost
  - Lack of refuelling facilities
  - Range (vs diesel)
  - Efficiency (vs BEV)
  - H_2 Supply chain

- **No Easy Answers:** The Net Benefit is Case-by-Case and depends on the Value drivers of the investor or end-user.



Heavy-Duty Vehicles



- **Existing models**
  - Hyzon
    - Class 8
    - HyMax Series
- **Additional initiatives**
  - Hyzon
    - Garbage Truck
    - Class 6 Day Cab
  - Nikola
    - TRE FCEV Day Cab
    - TWO FCEV Sleeper
  - Hyliion

Specifications	
Chassis	Freightliner Cascadia 116” Day Cab P4
Fuel Cell System Power	120 kW
Hydrogen Storage Capacity	50-70 kg
Hydrogen Storage Pressure	350 barg
GCWR	82,000 lbs
Range	600-800 km

Specifications]	
Configurations	24 / 46 / 70 tonne
Chassis	LF 290 FAP / DAF CF 530 FTT 6x4 / DAF CF 530 FTT 6x4
Fuel Cell System Power	80 / 240 / 240 kW
Hydrogen Storage Capacity	30 / 70 / 95 kg
Hydrogen Storage Pressure	350 / 350 / 700 barg
Range	400 / 680 / 600 km

Vehicle Retrofits and ICEs

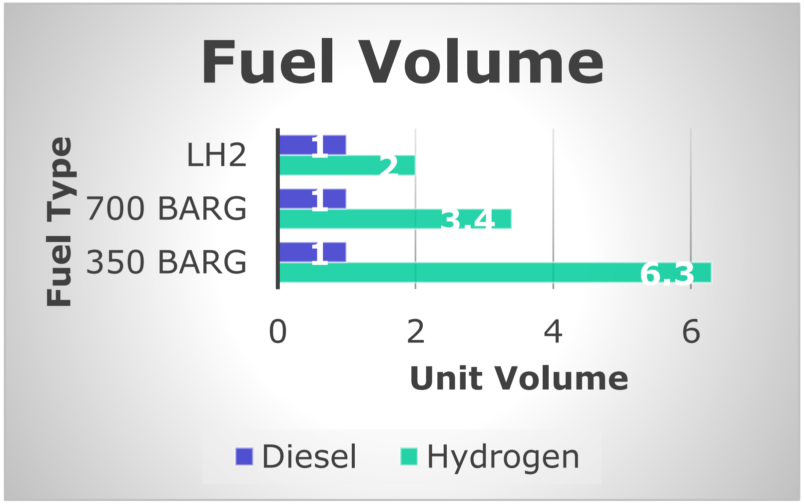
Issue	Pros	Cons
Acceptance	The EU and China recognize Hydrogen Internal Combustion Engines as Zero Emission Vehicles (ZEV).	Not yet universal.
Fuel	Use of relatively inexpensive low-carbon hydrogen.	Complexity at refuelling facilities.
Cost	ICE Engine is significantly less expensive than FC.	ICE Uses more fuel than FC (40% vs 50% eff.).
Availability	BMW, Ford, and Aston Martin have developed 100% HICE engines in the past, not a technical issue.	Just entering commercial availability in limited markets.
Blending vs 100% H_2	• Blending allows for full diesel power performance • Blending eliminates range anxiety • 100% H2 is required for true ZEV	

- **ULEMCo**
  - Introduced a dual fuel system retrofitted onto an existing Grundon Waste Management truck, allowing the vehicle to run on diesel or hydrogen
- **Hydra Energy**
  - Delivered the first of 12 hydrogen-converted semi-trucks to Lodgewood Enterprises
  - Up to 40% diesel displacement by energy. In a 1,000 km trip burns ~40 kilos of hydrogen (134 litres of diesel displaced).
  - Integrating machine learning, expect 50% diesel displacement

Technology: Refuelling

Hydrogen Storage

- Hydrogen onboard a vehicle is typically stored at either:
  - 350 barg – **6.3 times** diesel volume
  - 700 barg – **3.4 times** diesel volume
- Liquefied Hydrogen results in a better volume reduction about 3 times better than CH2 - still need ~ **2 times** diesel volume.
  - Making LH2 generally more suitable for heavy duty and long haul '24/7' vehicles



There are three main types of fill:
Slow: Preferred if the vehicles return to base and are parked outdoors for more than 6 hours. Multiple vehicles filling simultaneously.
Fast (Cascade): Preferred if vehicles tend to fill intermittently and in groups of 5 or less, spaced an hour or more apart. Fill times of 5 minutes for LDC, and10 – 15 minutes for HDV are typical.
Fast (Buffer): Preferred if vehicles are fuelled in back-to-back succession.

Standard Equipment: Gaseous fill

- Hydrogen Source
- Deoxo Dryer
- Compressor
- Filters
- Storage
- Chiller
- Safety systems

Advantages of slow fill
- Well understood fill cycle – able to optimize capital expenditure
- Heat of compression dissipation over time can achieve a true full fill

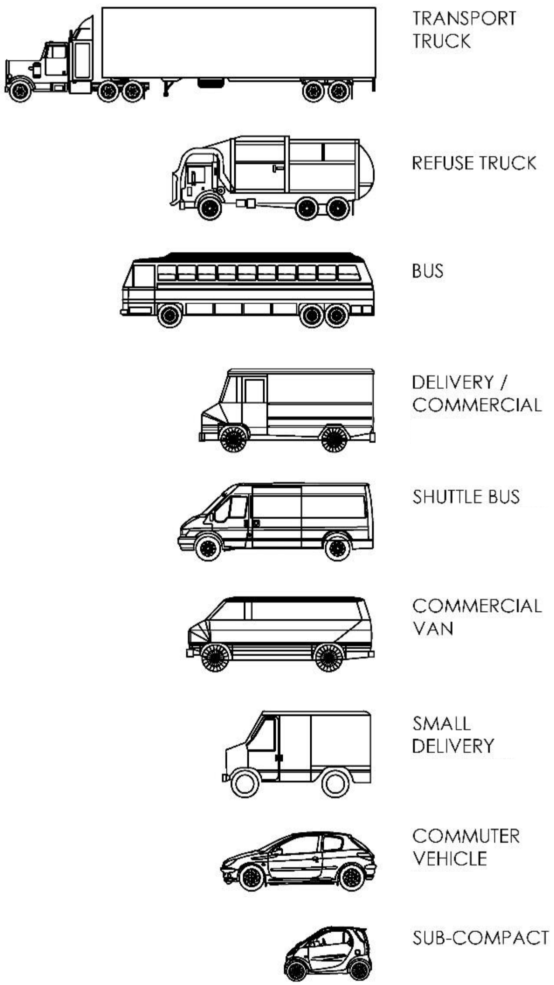
- Dispenser Options:
  - Multiple hose (and dispensing pressures)
  - Metered/unmetered
  - Target pressure
  - Flow rate control
  - Cardlock
  - Captured vent

Benefits of LH2

- **Range and storage:**
  - LH2 hold **3** X times the energy in the same volume at 350 barg (1.5 X at 700 bar)
- **Pressure:** LH2 systems operate at much lower pressures than CH2
- **Cost**: Station costs can be less than CH2 in a high volume, large fleet scenario
- **Weight:** LH2 tends to utilize lighter tanks than CH2
- **Applications**:
  - Heavy duty transportation fleets
  - High horsepower stationary equipment
  - Potential for marine and rail applications

- On-site storage tank
- Vaporization system
- Control panel
- Vent or capture unit
- Pump
- Dispenser
- More extensive equipemnt compound and safety systems

Value Drivers



Choosing the best solution for a particular fleet depends on:

- Specific application, range and duty cycle
- Availability of technology (acceptable performance with required vehicle platform)
- Local fuel supply infrastructure
- Capital and operating costs
- End user values and objectives (cost, GHG emissions/climate change, energy security, air pollution/health, jobs, etc)

Supply Chain Issues

- Most common first question of potential adopters
  - Commonly known that most supplies of large scale industrial H_2 come from other hydrocarbons – due to application
  - However, renewable Hydrogen from Electrolysis, Bio-sources, other emerging technologies
  - Production capacity in face of improving technology
- Next most common questions:
  - Is it safe?
  - What drives the business case/value proposition?
  - It is reliable? Will it always be there when we need it?
- Regional Considerations:
  - Best local production technology (raw materials)
  - Distribution vs On-site production
  - Regulatory landscape
  - Integration and relationship with other infrastructures (e.g.; fuelling, service, skill set demography)
  - Local market vs wide ranging

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Typical Inputs for AFV TEA Modelling

Capital & Related Factors	Operating Costs
Vehicle cost premium (residual values)	Total fuel consumed annually
Station cost: equipment, approvals, engineering, construction, commissioning, etc.	Fuelling operation costs: Vehicle efficiency, refuelling frequency, operating days, and time for and time of refuelling
Facilities modification costs	Incremental insurance costs
Cost of money	Station and vehicle maintenance costs
Economic life of station	Training (operators, mechanics)
Economic life of vehicles	
Timing of Expenditures: • Vehicle Acquisition • Station phased construction	Cost of fuel. Including delivery or production feedstocks, regulatory carbon-reduction impacts
Land acquisition and site work	Retail margin for public Corridor stations
Hydroge supply methodology (delivered vs on-site)	Taxes
Availability of electricity	Cost of electricity (forecast)
	Inflation/deflation rates

Other

GHG-Impact Factors
Grid energy mix (nuclear, hydroelectric, gas/coal-fired, wind, solar)
Carbon content of fuel per unit of energy released (as it applies)
Time-of-day grid use
Operational efficiency
Proximity of energy source

Opportunity Revenues and Costs
Sales to third parties and emerging markets
Cost of commerce – business systems
Cost of commerce – delivery
Job Creation
Fuel Export
Quantified benefits – performance, real estate, air quality, market appeal

SWOT Topics and Recommendations

- Must consider both “Market Ready” and “Emerging” technologies
  - Rapid technology improvement can actually hinder market adoption
- Rigorously identify and define goals (cost, emissions, jobs) and their KPIs
  - These MUST be built into any <u>complete</u> Technoeconomic assessment
- Recognize that Government funding skews the playing field – often engendering wrong (unsustainable) markets
- Funding strategies must evolve
  - technology development, demonstrations, market development, none.
- Proactively address market barriers such as: Safety/Regulations, end-user familiarity& understanding
- Avoid “Siloing”
  - Hydrogen adoption and infrastructure development must be viewed within the larger energy system.

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Thank you

For more information, please contact:

Ry Smith
Change Energy
Phone: 905-822-1539
Email: rsmith@changeenergy.ca
www.changeenergy.ca
www.dmatechnical.com

Profit, Planet, People

Technoeconomic Assessment

Fuel Value Index

An example of Change Energy's commitment to commercial success in alternative fuels, the **Fuel Value Index (FVI)** comprises a proprietary model used to objectively evaluate the business case for individual applications. Using a triple bottom-line approach that reflects the importance a client may uniquely place on economic, social and environmental outcomes, the viable fuel-technology combinations are thoroughly assessed to produce a comparative index of the relative value of each alternative.

The FVI model is calibrated to real-world data on supply chain and infrastructure costs, job creation and lifecycle emissions. Much of the database content is acquired directly through Change Energy's project experience, maximizing the fidelity of the modelling. The outputs reveal to public and commercial fleet managers, as well as to policymakers, the optimal value-creating investment opportunities in alternative fuels.

A consequence of the FVI is that the same vehicle may be served by different alternative fuels depending on how it is used. For example, a plug-in rechargeable car may yield optimal value in personal use, while the hydrogen-powered variant is better for use in 24-hour taxi service.

Image: highvlocity.eu/hydrogen-taxis-for-london-roads

Example of London Hydrogen Taxi Fleet Vehicle