Hydrogen Roadmap
Future of Vehicle Transportation – Part 1
Q420 Fuel Comparisons

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W|EPC Key Takeaways

Alternative Fuel Analysis…Will History Repeat Itself?

- In 1992 & 2005, the Department of Energy (DOE) created & amended the Energy Policy Act (EPA) that addressed fuel research and tax benefits for vehicle manufacturing.
- Battery Electric Vehicles (BEV), Hydrogen (H2), Hybrids, Biofuels, Ethanol and Methanol were analyzed in 2005, but vehicle manufacturers supported *gasoline hybrid vehicles* due to technology and production constraints.
- Since then, fuel cell technology and global, federal, & state emission guidelines have accelerated innovation and **the market is now actively deciding transportation alternatives**.

Small Vehicle Applications

- BEV have taken a leading role in the small vehicle category with minimal competition from Hydrogen.
- Hydrogen's price, lack of infrastructure, and safety concerns highlight the risk associated with new fuel applications; however, Methanol may have an opportunity to fill this role.
- *The Roland Gumpert Nathalie markets an impressive range and methanol costs are comparative to BEV, but the $450k price tag limits it's applications until manufacturing scales up to reduce cost.*

Mid-Sized Vehicles and Truck Applications

- *Fuel energy density becomes a larger role as the size of a vehicle increases.*
- Fuel storage capacity, energy density, and vehicle efficiency play a large role in the range and cost for a vehicle.
  - Chevy Silverado 1500: 1000 miles & ~$0.11/mile
  - Tesla/Rivian: 400-500 miles & $0.05/mile
  - *Nikola Badger (on hold): 600 miles & ~$0.20/mile*
- Charge/Filling time could be the deciding factor if long distances or heavy haul is required (Hydrogen & Diesel ~10min vs. Multiple Hours for BEV)

Semi-Truck Range Is A Gating Issue For Future Fuels

- New Semi-Truck concepts are ranging from shorter applications (<300 miles) to the long-haul market (>600 mile/day).
- Daimler eCascadia seems to make sense for shorter applications and Hyliion's Compressed Natural Gas (CNG) hybrid semi will likely apply well to long haul trades, if the marketing is as good as advertised.
- *Hydrogen will be limited by fuel price and infrastructure but by using Methanol as an energy dense carrier for Hydrogen in the vehicle may allow for equivalent distance at ~1/6 the cost.*

W|EPC Rankings – Fuels vs Fuel Cells From Current Available Tech & Pricing

Power System	Vehicle Range	Energy Efficiency	Safety	Emissions		Implementation Cost			Average Score
				TTW[4]	WTW[5]	Feedstock	Gas Station	Vehicle Production	
Methanol FC [1]	4	3	4	4	4	4	4	2	***3.6***
Diesel	5	2	4	1	2	5	5	5	***3.6***
Biofuels (FAME) [3]	4	1	5	4	5	3	2	4	***3.5***
BEV [2]	2	5	3	5	2	4	2	4	***3.4***
CNG Hybrid [1]	5	2	2	3	5	5	2	3	***3.4***
Hydrogen FC [1]	3	3	2	5	2	3	1	3	***2.8***
Ethanol FC	2	1	3	2	5	4	4	1	***2.8***
Ammonia FC [1]	2	2	1	3	3	4	3	1	***2.4***

1 – Assumes from Natural Gas
2 – Assumes from USA electric grid
3 – Assumes Blended with Diesel
4 – Tank-to-wheel
5 – Well-to-wheel

Score rankings: 5=Best & 1=Worst

Methanol Provides A Safe And Low-Cost Opportunity For Hydrogen Vehicles.

Source: Company & Regulatory Filings, W|EPC Analysis

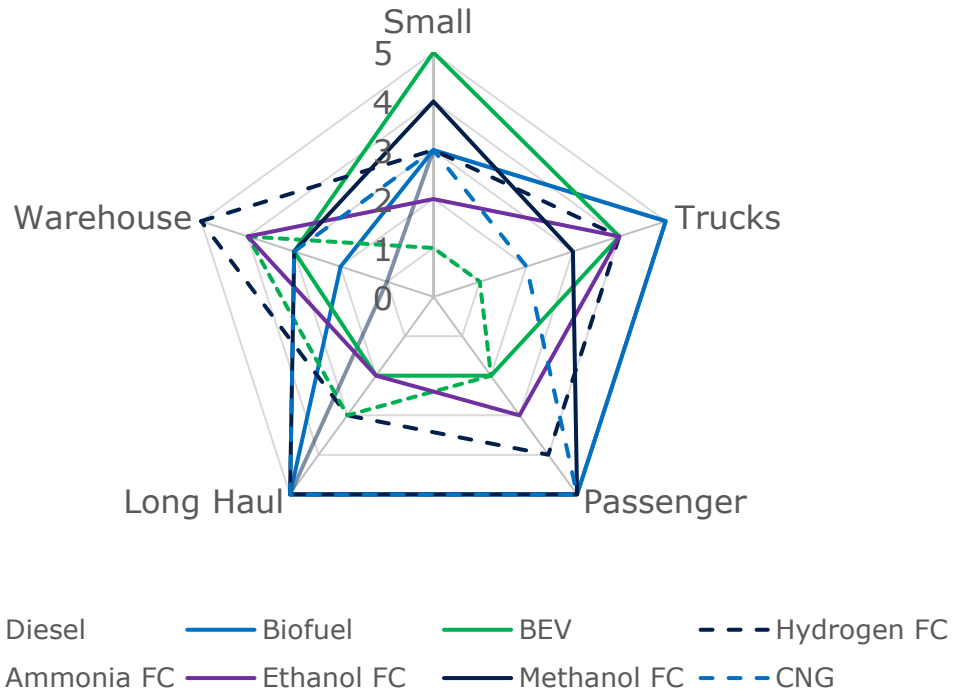
Alternative Fuels - Applications

Ranking Fuels By Vehicle Type

Overview

- **Our Focus:** Hydrogen is now competing with BEV and traditional fuels in economics, emissions, and investments.
- **Why It Matters:** With emission guidelines phasing out diesel, a new fuel/engine type will be necessary for vehicle manufacturers.
- **The Impact**: Hydrogen can provide at least *2x* the mileage per fill as an electric vehicle and takes minutes to fill vs hours.
- **Key Thoughts & Takeaways**: Ammonia and Methanol Fuel Cells are being investigated for on-board vehicle use. These will take up half the space as a Hydrogen FC and provide 2-4 times the range over a Hydrogen heavy or long-haul vehicle.

Fuel Rankings for Vehicle Type



Score rankings: 5=Best & 1=Worst

* Biofuels represent an assumed blend with Diesel to meet emission mandates

Fuel Cells Are Better Positioned Than Batteries For Large Vehicle Applications.

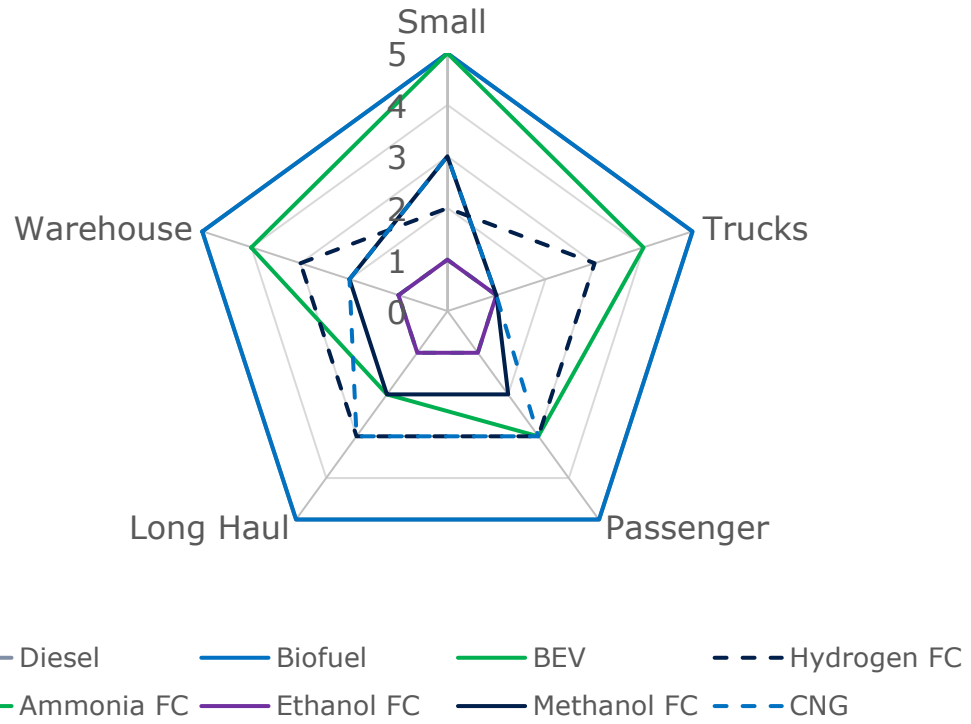
Source: Company & Regulatory Filings, W|EPC Analysis

Varying Alternative Fuel Availability By Vehicle Type

Overview

- **Our Focus:** New technology is being considered by vehicle manufacturers to compete with existing Diesel and Gasoline fuels.
- **Why It Matters:** The transition to the new technology is slow as manufacturers are waiting to see if supporting infrastructure develops.
- **The Impact**: Early adopters of Hydrogen vehicles are finding it difficult to find the gas stations or maintenance capable of handling their vehicles.
- **Key Thoughts & Takeaways**: 5 vehicle types are competing across the transportation sector and each could be a viable option. Auto manufacturers will need to analyze options for sale vs lease and weight future environmental mandates. *There is unlikely to be a single cross-sector winner however, we expect significant battery/fuel-cell penetration across most vehicle verticals.*

Comparing Vehicle Availability



Score rankings: 5=Best & 1=Worst

* Biofuels is an assumed blend with Diesel to meet emission mandates

As Highlighted Above, There Remain Significant Gaps In Availability Across Fuel Types.

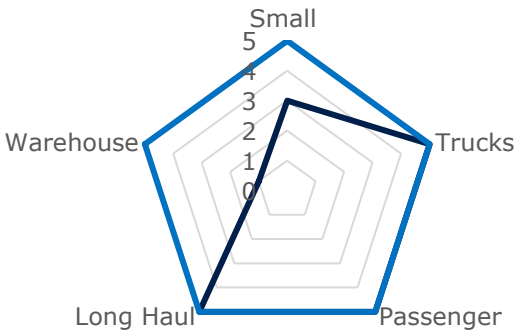
Source: Company & Regulatory Filings, W|EPC Analysis

Comparing Alternative Fuel Availability Across Vehicle Segments

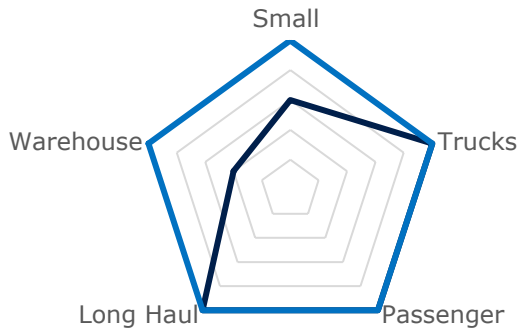
Ranking Availability

Score rankings: 5=Best & 1=Worst

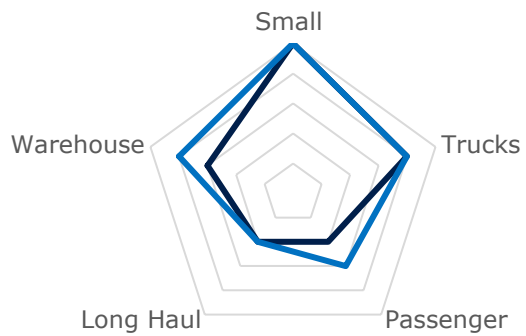
Diesel



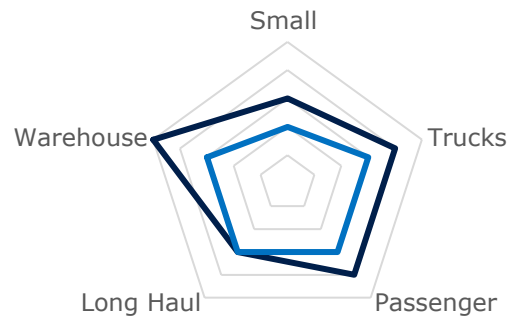
Biofuels



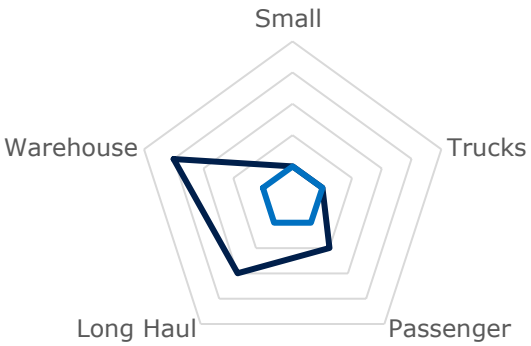
BEV



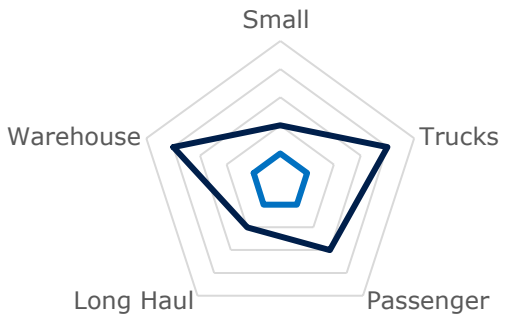
Hydrogen FC



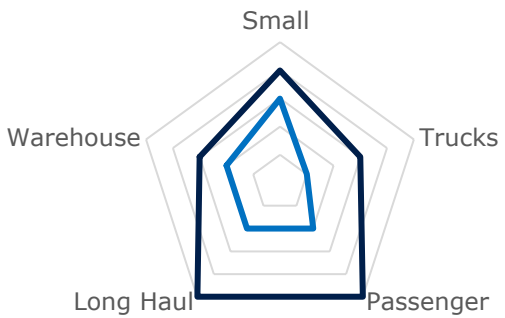
Ammonia FC



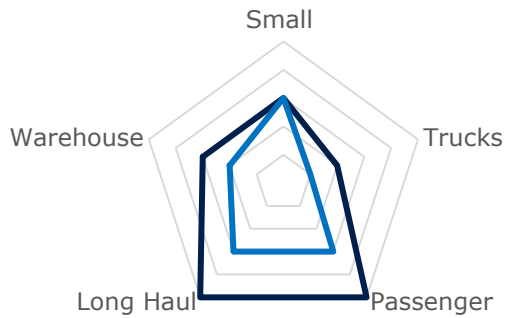
Ethanol FC



Methanol FC



CNG Hybrid



Alternative Fuels Availability Still Lags Considerably Relative To Diesel.

Source: Company & Regulatory Filings, W|EPC Analysis

Vehicle Transportation – Fuel Comps

Energy Density & Vehicle Range

Overview

- **Our Focus:** Car Manufacturers (i.e. Toyota, GM, Hyundai, etc.) are re-tooling their facilities to build out the next generation of low emission vehicles but haven't chosen a fuel.
- **Why It Matters:** Vehicles need to be environmentally friendly & perform equal or better than existing products.
- **The Impact:** Energy density is a key factor in selecting a fuel to maintain/improve existing range for vehicles.
- **Key Thoughts & Takeaways**: We looked at 4 different fuel cell types for onboard applications; Methanol, Ammonia, and Ethanol provide a significant advantage (compared to Hydrogen & Electric) when used in a fuel cell application while ***also*** bringing environmental benefits.

Comparison for Small Vehicle Engines (mi)

Product	Miles/Unit	Vehicle Capacity	Range/Tank	Relative Range to BEV
Methanol FC	43+[2]	12gal[1]	510	73%
Ammonia FC	37.1[4]	12gal[1]	446	49%
Hydrogen FC	65[3]	6.33kg	380	27%
Diesel	30.6	12gal	367	22%
Biofuels (FAME)	26.4	12gal	317	6%
BEV	3.3	90kWh	300	0%
CNG ICE	22[5]	12gal[5]	264	-12%
Ethanol FC	20.0[6]	12gal[1]	240	-21%

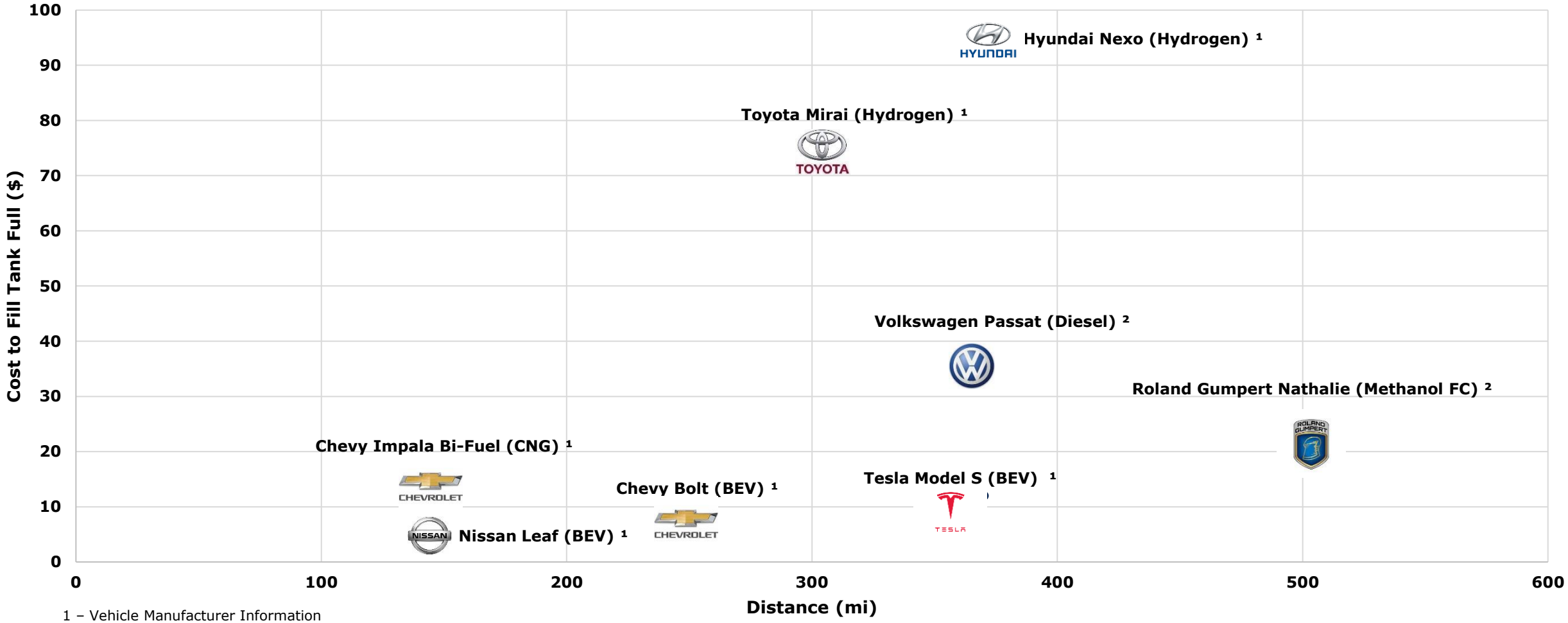
1 - This represents the fuel tank that supplies the Hydrogen tank
2 - Roland Gumpert Nathalie eco mode 43.3 miles/gallon
3 - Hyundai's NEXO Fuel Cell Vehicle
4 – W|EPC conceptual estimates using energy density and Methanol Fuel Cell calculations
5 – Chevy Impala 2015 Bi-Fuel CNG Vehicle
6 – Nissan e-Biofuel Ethanol SOFC

Energy Storage That Provides The Best Miles Per Gallon

Hydrogen Carriers (H2, Ammonia, Methanol) Provides Significantly More Range Than Electric Vehicles.

Source: Company & Regulatory Filings, W|EPC Analysis

Energy Density & Vehicle Range – Small Vehicles

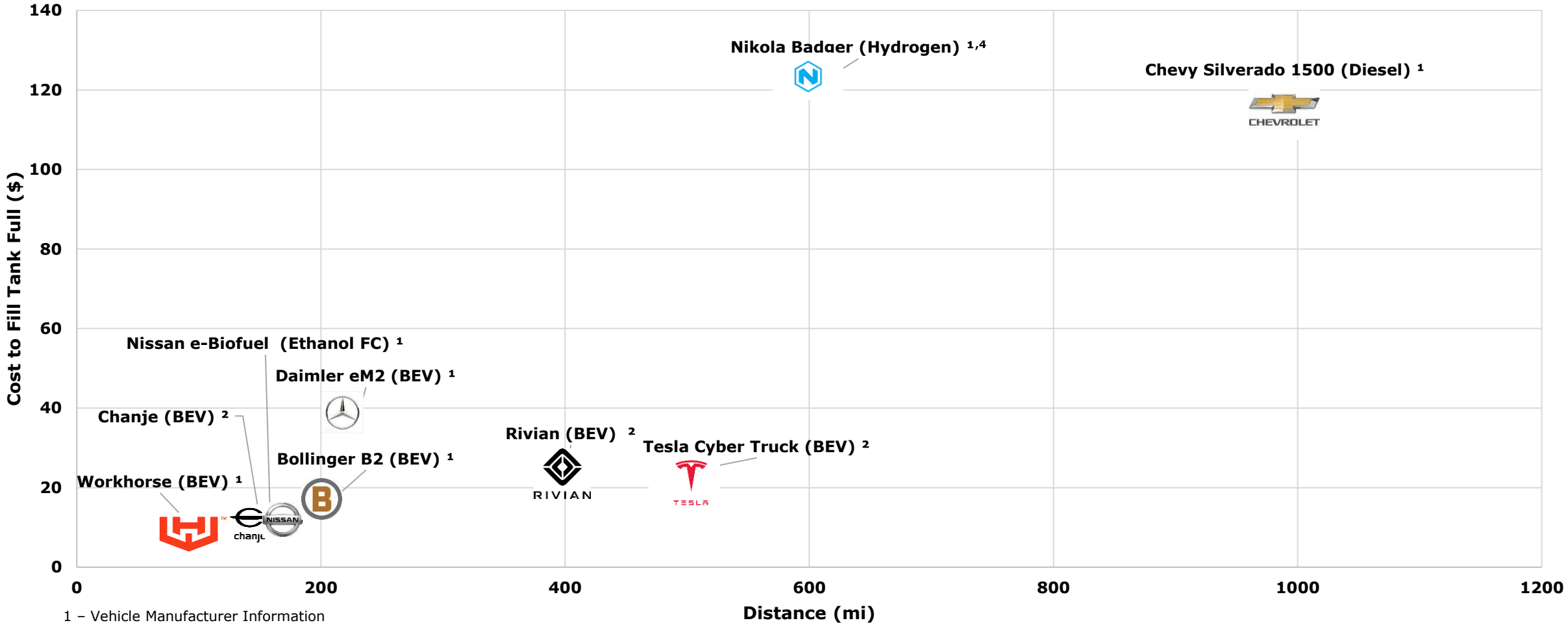


1 – Vehicle Manufacturer Information
2 – 3rd Party Information
3 – W|EPC Estimate

Major Hydrogen Brands Currently Trade Significant Cost At The Pump For Extended Range.

Source: Company & Regulatory Filings, W|EPC Analysis

Energy Density & Vehicle Range – Mid-Sized Vehicles & Trucks



1 – Vehicle Manufacturer Information
2 – 3rd Party Information
3 – W|EPC Estimate
4 – Production and related range data may be in question

Hydrogen's $15/kg Price Will Need To Be Reduced To Be Competitive.

Source: Company & Regulatory Filings, W|EPC Analysis

Vehicle Technology Considerations – Long Haul Vehicles

Overview

- **Our Focus:** The long-haul heavy duty trucking industry is looking to incorporate environmental mandates into their future vehicles.
- **Why It Matters:** With many options available, these companies are looking at range, cost, and reliability as main drivers.
- **The Impact**: Hydrogen fuel cells and on-board reforming seem to have a range/fill time advantage vs electric, but the cost to fill could outweigh the stopping time.
- **Key Thoughts & Takeaways**: Battery energy storage degradation could be as high as 30% over the first 150k miles depending on temperature, driving conditions, battery discharge and number of chargings. *Replacing a Long-Haul battery is estimated to cost ~$100k.*

Long Haul Vehicle Comparisons (600mi Range)

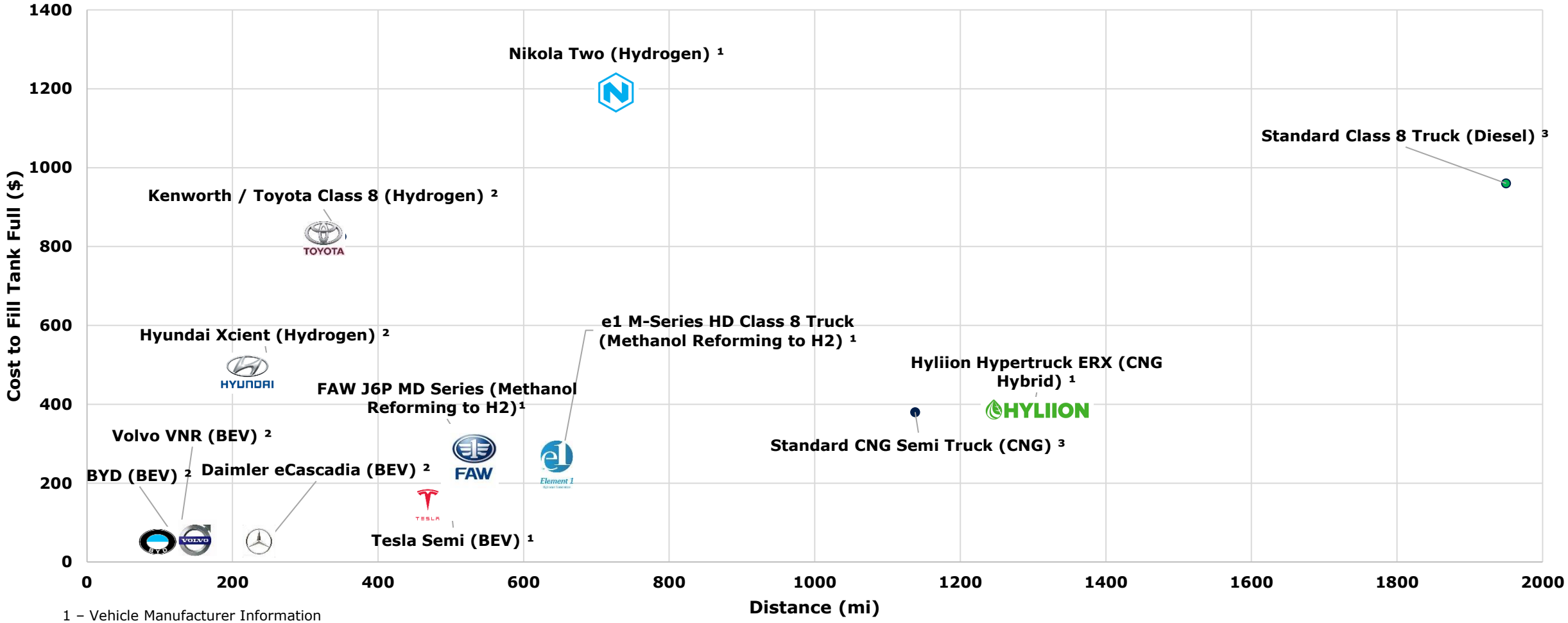
Vehicle Power System	Tank Size	$/Unit	Cost to Fill ($)	Relative To Diesel
BEV	1200kWh[1]	0.12	144	-55%
CNG	81gal[6]	2[6]	162	-49%
Methanol FC	277gal[4]	1.3	250	-21%
Diesel	102gal	3.15	320	0%
Ammonia FC	323gal[5]	1.1	355	11%
Biofuels (FAME)	118gal	4	472	47%
Ethanol FC	600gal[5]	1.5	900	181%
Hydrogen FC	100kg[3]	15[3]	1500	368%

1 – Current size is 1000kWh from Tesla for a 500mi Long Haul Semi
2 - Based on Model S Warranty. Battery capacity degradation is assumed to be as high as 30% over the first 150k miles.
3 – Nikola estimates and California Hydrogen Prices
4 – Element 1 Conceptual Design For Heavy Duty Class 8 Trucks with a water/methanol mixture. FAW has a MD Vehicle in operations using Element 1 technology.
5 – W|EPC estimated
6 – Hyliion Hypertruck ERX reports 7.4 mpg from their hybrid semi with a range of 1300 miles. Pricing from DOE.

Renewable Fuels *Cost To Fill* Are Still ~69% (On Average) More Expensive Relative To Diesel.

Source: Company & Regulatory Filings, W|EPC Analysis

Energy Density & Estimated Vehicle Range – Semi Trucks



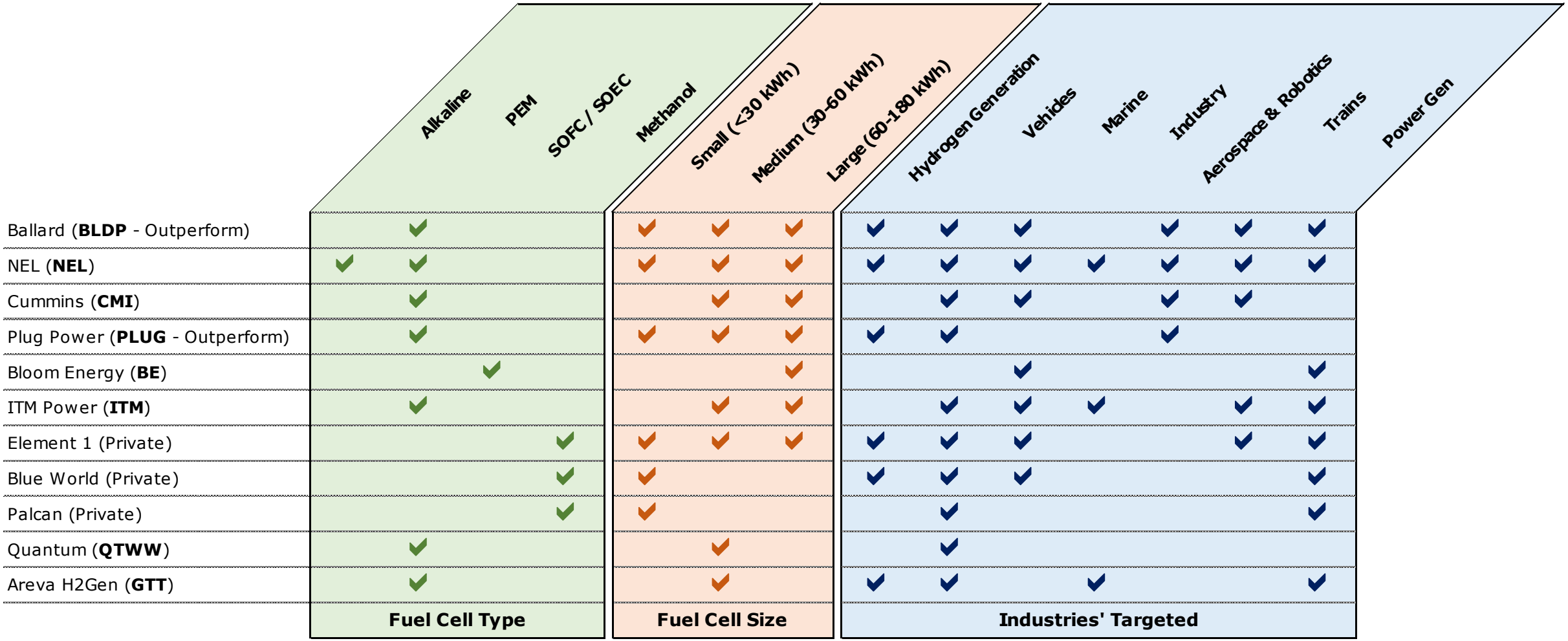
1 – Vehicle Manufacturer Information
2 – 3rd Party Information
3 – W|EPC Estimate

As Vehicle Loads Become Heavier, Energy Density Increasingly Impacts Range.

Source: Company & Regulatory Filings, W|EPC Analysis

Fuel Cell Technology Leaders and Applications

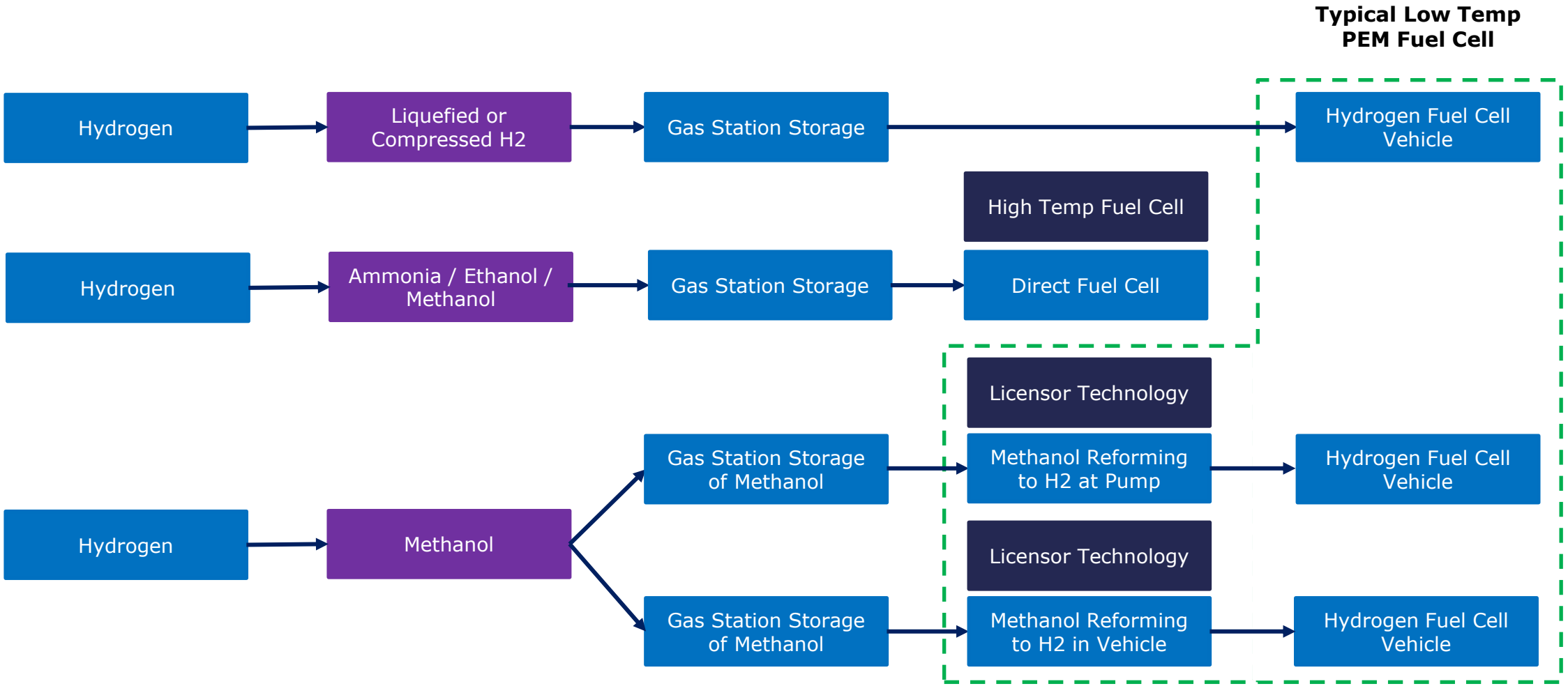
Fuel Cell Companies & Applications



The Hydrogen Fuel Cell Market Is Consolidating And Experiencing A Large Shift In Capabilities.

Source: Company & Regulatory Filings, W|EPC Analysis

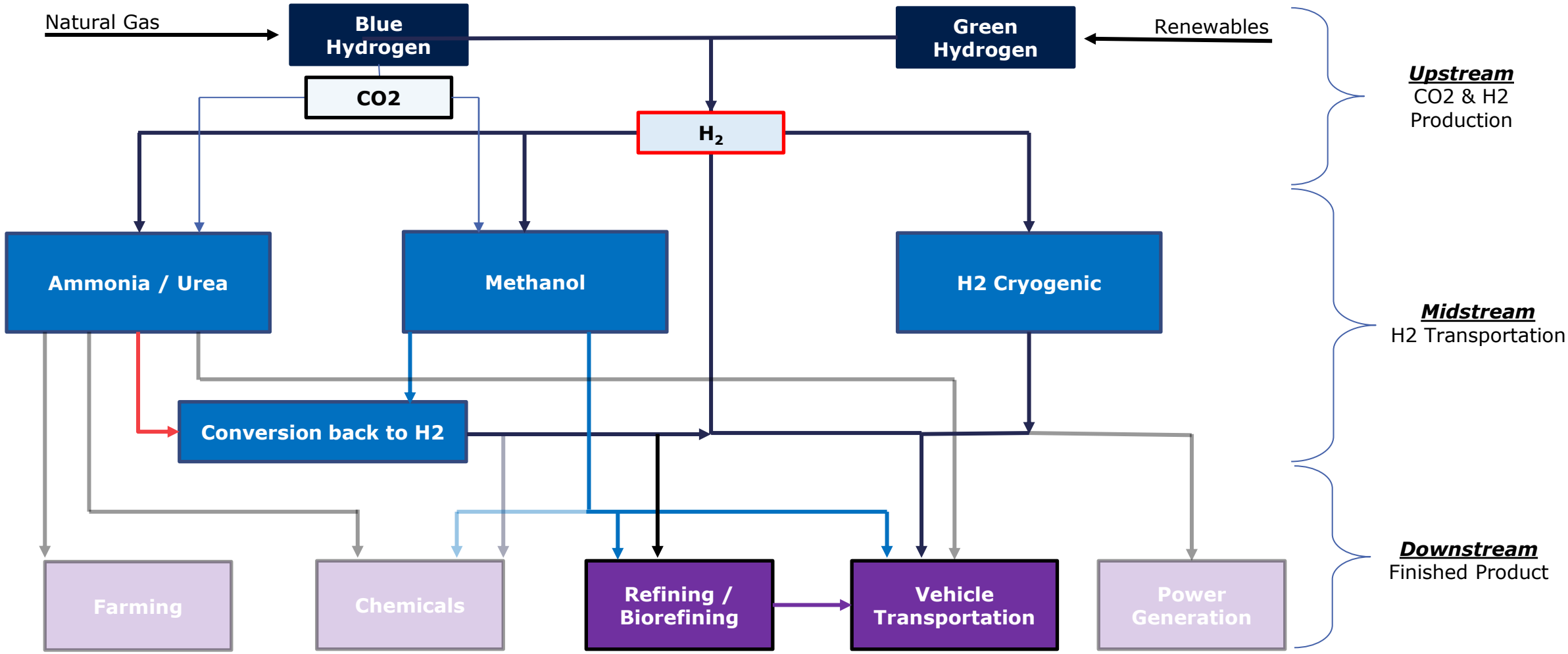
Conversion Back to Hydrogen



Low Temperature PEM Fuel Cells Will Have Multiple Fuel Applications. (Ballard, Plug, Etc.)

Source: Company & Regulatory Filings, Methanol Institute, W|EPC Analysis

Upstream, Midstream And Downstream Markets Of Hydrogen



Ammonia And Methanol Support A Hydrogen Economy After Conversion.

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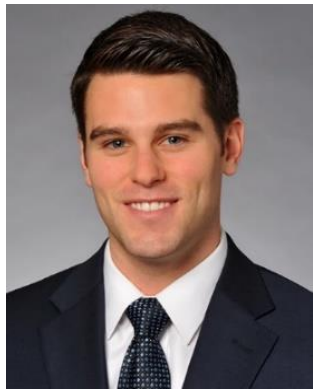

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