HYDROGEN TRUCKS: LONG HAUL’S FUTURE?

This report focuses on using hydrogen-based powertrains for heavy-duty Class 8 long-haul freight routes pulling van trailers. These powertrains include a range of fuel cell battery electric types and internal combustion engines (ICE) based on the diesel cycle. While there are certainly many other load types that are hauled long distances by Class 8 trucks, such as bulk carriers, fuel tankers, flat beds, etc., NACFE’s focus is on van freight. The information in this report may also be of value to those other uses.

In December 2019, the North American Council for Freight Efficiency (NACFE) compared a range of alternative fuel heavy-duty truck technologies including hydrogen in the report *Viable Class 7/8 Electric, Hybrid and Alternative Fuel Tractors*. In December 2020 NACFE issued the in-depth hydrogen report, *Making Sense of Heavy-Duty Hydrogen Fuel Cell Tractors*. These two reports are a solid foundation upon which this new hydrogen report is built.

Hydrogen is entering the marketplace as an energy source for zero-emission long-haul trucking. Two paths are emerging, fuel cell electric and new hydrogen internal combustion engines. Hydrogen is not optimum for all duty cycles. Hydrogen fuel cell tractors are, however, the only viable zero-emission solution currently proposed as a one-for-one replacement for diesel in the future of long-haul heavy-duty trucks.

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What NACFE Got Right And Wrong

NACFE’s 2020 *Making Sense of Heavy-Duty Hydrogen Fuel Cell Tractors* report had five major findings:

- Hydrogen fuel cell trucks are just starting to see real-world use and their adoption is being driven by regional or national considerations that are much bigger than what exists for trucking fleets.
- Battery electric trucks should be the baseline for hydrogen fuel cell electric vehicle (HFCEV) comparisons, rather than any internal combustion engine alternative.
- As for all alternatives, fleets should optimize the specifications of HFCEVs for the job they should perform while expecting that the trade cycles will lengthen.
- The future acceleration of HFCEVs is likely not about the vehicles or the fueling but more about the creation and distribution of the hydrogen itself.
- Finally, the potential for autonomous fuel cell trucks to operate 24 hours a day adds significant opportunity for making sense of capital and operational investment in hydrogen.

Those findings continue to be applicable in the rapidly evolving zero-emission commercial vehicle world.

NACFE also attempted to categorize the multiple paths to making hydrogen by generally accepted colors. What NACFE did not foresee was the extensive marketing effort to change the hydrogen color narrative from “how hydrogen is produced” to “how much carbon intensity” each method has.

NACFE forecasted trends in state and federal regulations that could hasten hydrogen adoption. The period 2021 to 2022 has seen significant acceleration of state and federal efforts.

The initial NACFE report correctly outlined that a hydrogen economy cannot be built solely on the shoulders of long-haul trucking, as there simply is not enough there to get the scale needed for cost reduction.

NACFE suggested that standardization will be critical to get volume cost reductions on designs of tanks, fuel systems, fuel cells, batteries, cables and connectors, etc. Individual OEMs will need to consider standardizing on generic system components with their competitors in order to increase demand and reduce unit costs.

There is not one design for a fuel cell powertrain; rather there is a complete spectrum based on choices for sizing both the fuel cell and battery electric system on board a vehicle to meet performance objectives.

NACFE did not forecast in the first report the development and deployment of hydrogen burning diesel-based engines.

What’s Changed?

The pace of innovation, investment, regulation and awareness of hydrogen as a heavy-duty truck fuel has increased since the December 2020 NACFE report. In parallel, the topic of zero-emission trucks (ZETs) in general has seen significant focus.

The 2021 to 2022 period has seen the oil industry significantly step-up publicizing and marketing their efforts to lower emissions. Companies like Shell and BP are actively promoting moves to hydrogen as the molecular fuel to replace gasoline, diesel and other fuels in a variety of industries and have publicly announced sustainability goals. The sea change in the oil industry to pursuing zero-emission markets is significant, reinforcing a path toward hydrogen as a fuel in trucks hauling freight. See Figure ES1.

Efforts like COP27, the Infrastructure Investment Jobs Act, the U.S. National Blueprint For Transportation Decarbonization, the Department of Energy’s Clean Hydrogen Strategy and Roadmap, the EPA Clean Truck Plan, The Multi-State Zero Emission Medium- and Heavy-Duty Truck Partnership have all been announced and are moving forward.

“Hydrogen technology is coming faster than we expected. We will be testing a truck this year.”

— Rob Reich, Executive Vice President, Chief Administrative Officer, Schneider
Heavy-Duty Vehicle Memorandum of Understanding, the Advanced Clean Truck Act, The Advanced Clean Fleets Rule, the Heavy-duty Low NOx Omnibus Rule, the Warehouse Indirect Source Rule, and the SEC Reporting Rule are also impacting the development of hydrogen as a fuel for medium- and heavy-duty trucks.

Additionally, awareness of the need for environmental justice has risen dramatically in the period since NACFE’s first hydrogen report was issued.

**Technology And Infrastructure Changes**

There have been developments in technology and infrastructure since the original release of *Making Sense of Heavy-Duty Hydrogen Fuel Cell Tractors*. The most significant is the development of hydrogen internal combustion engines, essentially adaptations of traditional diesel engines replacing diesel or natural gas combustion with hydrogen combustion.

A hydrogen internal combustion engine alternative presents a near-zero emissions vehicle that has the capability of going longer distances with shorter refueling times and weighing less than a battery electric vehicle specified to do the same job. The hydrogen ICE also preserves the conventional powertrain and will likely have a significantly lower initial cost than an equivalent fuel cell equipped vehicle.

However, the overall efficiency of the hydrogen ICE vehicle in terms of miles per kg of H₂ will likely be less than the HFCEV alternative. It should generally have better efficiency on an energy-equivalent basis compared to natural gas-powered engines. Of course, the hydrogen ICE alternative must overcome the challenges of fuel creation, cost, transportation and storage that any other hydrogen alternative has as is outlined in other parts of the full report. In addition, the challenges of servicing and maintaining hydrogen ICE vehicles also will be more involved than traditional diesels. See Figure ES2.

Significant funding is being allocated to hydrogen freight projects since the 2020 NACFE report. In 2022, the DOE announced $8 billion in funding for a hydrogen hub program with $7 billion earmarked to fund six to 10 regional clean hydrogen hubs.
The H2 ICE engine is a zero-carbon low-risk evolution for diesel truck operators. It is less of a leap than fuel cells.”

— Jim Nebergall, General Manager of Hydrogen Engines, Cummins
where hydrogen can be used as a power source. Terminal tractors tend to stay close to their home facilities so range and re-fueling are not an issue. A warehouse equipped for hydrogen forklifts might readily expand to having hydrogen terminal tractors and then evolve into hydrogen ICE and eventually long-haul hydrogen fuel cell tractors.

**The State of Hydrogen Today**

According to the DOE, today there are more than 50,000 hydrogen fueled forklifts, more than 80 hydrogen buses, and approximately 13,000 hydrogen cars. With the exception of forklifts, the vehicle deployments are in their infancy compared to market sizes. Also of note is that 55% of current production hydrogen usage is in refining oil and 35% is in producing ammonia and methanol. The hydrogen production infrastructure is primarily located, logically, near major coastal oil refining centers.

Converting the transportation industry to diesel alternatives has a steep hill to climb to supplant petroleum's dominance. The market dominance by petroleum companies hints at why hydrogen is attractive to the oil industry as a path forward to continue market prevalence as energy suppliers through products like gray, blue and green hydrogen.

The aggressive zero-emission vehicle goals being implemented at state and federal levels also will potentially reinforce that petroleum-based and natural gas-based hydrogen must be a part of the solution moving forward, due to the extensive economic impact and inertia of these industries, combined with the rapid need for hydrogen at scale. See Figure ES3.

There is a significant volume of information and misinformation on projected costs of hydrogen. Much of it focuses on predicting the cost of production, not the price. These two differ: cost is what the plant expends to actually make the fuel, price is what they charge for

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**FIGURE ES3**

**HYDROGEN PRODUCTION LOCATIONS IN THE US**

**Snapshot of Hydrogen and Fuel Cells in the U.S.**

- 10 million metric tons produced annually
- More than 1,600 miles of H₂ pipeline
- World's largest H₂ storage cavern

**Use of Hydrogen in the U.S. Today**

- 8% Other Metals (2%)
- 35% Ammonia & Methanol
- 55% Refining

**Examples of Hydrogen Production Locations**

**Examples of Deployments**

- >500MW Backup Power
- >50,000 Forklifts
- >620 MW PEM* Electrolyzers
- >80 Fuel Cell Buses
- ~50 H₂ Retail Stations
- >13,000 Fuel Cell Cars

*Proton exchange membrane
The expected cost to the producer inside the fence of the production facility is not necessarily representative of the retail price of the fuel at the gate of the plant, nor does it factor in transportation, storage, compression or dispensing of the hydrogen at the pump for the vehicle.

The DOE’s hydrogen program has targets for driving down the cost of hydrogen. Reducing costs on hydrogen fuel tanks for heavy-duty hydrogen trucks will be challenging in the real world.

Findings

Hydrogen may be the harbinger of a new green industrial revolution, or just the progression from one fossil fuel-based energy carrier to another with greater emphasis on reducing emissions. Either way, hydrogen will be a factor in future long-distance freight hauling in combination with battery electric vehicles for shorter range operations. See Figure ES4. NACFE’s first hydrogen report remains relevant and accurate. The changes since that report reinforce the following findings:

1. Hydrogen powered freight is required for a zero-emission freight future.
2. There is a significant amount of funding going toward establishing the basis for a hydrogen economy that includes long-haul freight transportation.
3. The cost of hydrogen production, transportation, storage and dispensing will not be cost competitive with diesel without significant assistance from tax credits and other subsidy mechanisms.
4. There is a significant amount of funding going toward establishing the basis for a hydrogen economy that includes long-haul freight transportation.
5. Hydrogen is closely tied to electricity. You can’t have hydrogen without significant amounts of electricity.
6. Hydrogen is a significant factor in federal, state and local planning and regulations for the zero-emission freight future.
7. Purpose-built hydrogen trucks optimized for specific duty cycles may not be valued well in the secondary market, leading to first owners keeping the vehicle until it is salvaged.
8. Hydrogen costs decrease as the scale of the

![Optimum Duty Cycle Sweet Spot](image-url)
hydrogen plants increase. Large production requires multiple industries to increase demand for hydrogen. Trucking alone is insufficient to reach demand scale needed to justify large hydrogen plants.

9. Hydrogen used for creating alternative fuels like renewable diesel will reduce net emissions but at the cost of delaying adoption of zero-emission alternatives.

10. All the answers do not need to be known on day one of hydrogen. Production supply and market demand will evolve in lock step over time. Innovators will find market opportunities where there is an oversupply of hydrogen, creating new market demand.

11. Hydrogen and electricity supply are inherently resilient as there are multiple methods of producing them, leading to competitive forces mitigating price and supply volatility.

Conclusions

Hydrogen is a complex topic. Hydrogen for use in freight transportation is just in its infancy. Trying to summarize the topic in a few closing statements is akin to describing a child’s potential impact on the world. NACFE presents four significant conclusions.

• Hydrogen and battery electric are not an “either/or” but an “and” for the zero-emission freight future. Battery electric vehicles will inherently be the most economical and efficient choice for shorter distance zero-emission duty cycles, and hydrogen will be the only viable economic choice for long-haul zero-emission duty cycles. Ultimately fleets in the market will make decisions on which technology succeeds for which duty cycles.

• Hydrogen fuel cell tractors are the only zero-emission solution for many duty cycles for heavy-duty tractors. Significant cost reduction across all cost elements is needed for these tractors to be cost effective. Supply chain companies from shippers, to carriers, to fuel suppliers and others along with government assistance, must share in higher costs for the benefits of zero emissions.

• Alternative fuels like RNG, renewable diesel, and hydrogen used in internal combustion engines will be required to support the transition in the next two decades to help make progress toward zero-emission goals, while in parallel ramping up the hydrogen and battery electric infrastructure and manufacturing base.

• Industry agreement is needed on whether hydrogen long-haul fuel cell tractors, and the transport of the hydrogen fuel itself, will be based on gaseous or liquid hydrogen. This is a core factor that can impact multiple infrastructure and manufacturing systems, and significantly impact market penetration and volume estimates for cost reduction potential.

“As we move to the zero-emissions freight future, in the long run, there are only two choices of power – battery electric and hydrogen fuel cell.”

— Rick Mihelic, Director of Emerging Technologies, NACFE
ABOUT NACFE
The North American Council for Freight Efficiency (NACFE) works to drive the development and adoption of efficiency enhancing, environmentally beneficial, and cost-effective technologies, services, and operational practices in the movement of goods across North America. NACFE provides independent, unbiased research, including Confidence Reports on available technologies and Guidance Reports on emerging ones, which highlight the benefits and consequences of each, and deliver decision-making tools for fleets, manufacturers, and others. NACFE partners with RMI on a variety of projects including the Run on Less demonstration series, electric trucks, emissions reductions, and low-carbon supply chains. Visit NACFE.org or follow us on Twitter @NACFE_Freight.

ABOUT RMI
RMI is an independent nonprofit founded in 1982 that transforms global energy systems through market-driven solutions to align with a 1.5°C future and secure a clean, prosperous, zero-carbon future for all. We work in the world's most critical geographies and engage businesses, policymakers, communities, and NGOs to identify and scale energy system interventions that will cut greenhouse gas emissions at least 50 percent by 2030. RMI has offices in Basalt and Boulder, Colorado; New York City; Oakland, California; Washington, D.C.; and Beijing. More information on RMI can be found at www.rmi.org or follow them on Twitter @RockyMtnInst.

GET INVOLVED
NACFE could use the assistance of fleets, manufacturers and other trucking industry stakeholders in improving freight efficiency. Become a part of this exciting opportunity.

Learn more at www.nacfe.org or contact Mike Roeth at mike.roeth@nacfe.org