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ENERGY INSIGHTS

A Clean Future for Heavy Duty Vehicle Powertrains is Within Reach

A myriad of new powertrain technologies are competing to usurp diesel as the heavy duty vehicle powertrain of choice. Of these, FTI Intelligence finds that the economic case for battery electric and hydrogen fuel cell powertrains in the US market will be favorable faster than previously expected. Our results indicate that we stand on the precipice of revolution in the road freight sector, with heavy investment across the value chain required, particularly in model availability, charging and fueling.

Battery electric and hydrogen fuel cell are likely to become the dominant powertrain technologies in class 8 vehicles.

2026

There may be a business case for fleet operators to switch to electric class 8 vehicles in 2026.

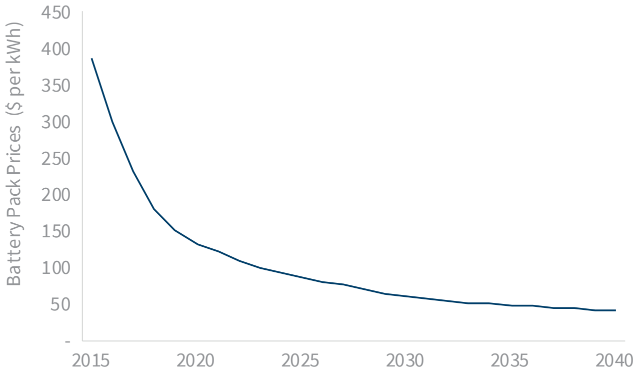
When buying a class 8 heavy duty vehicle (HDV), the key purchasing criteria used to be only the total cost of ownership (TCO) of the vehicle. The TCO was an effective metric for evaluating legacy technology which demonstrated little variation in revenue generating potential. These days, however, we stand on the precipice of seismic change in all transportation sectors as the need to decarbonize grows more urgent by the day. A myriad of powertrain technologies are competing to usurp diesel as the HDV powertrain of choice; to evaluate these technologies we should no longer consider just the TCO but should consider it alongside the revenue generating potential and emissions reduction potential of the new technologies.

In this paper we will explore the key factors behind the adoption of new powertrain technologies and develop a timeline for their adoption. Our analysis indicates that battery electric and hydrogen vehicles will become the most favorable powertrain technologies within the decade. To support uptake within this timescale, heavy investment will be required across the value chain, particularly in model availability, charging and refueling.

Total Cost of Ownership Analysis

While there are now other factors to consider when purchasing an HDV, the TCO remains a key metric and demonstrates significant variation among future powertrain technologies. In particular, while the TCO of legacy HDVs is expected to rise in the future, the TCO of HDVs utilizing new powertrain technologies is expected to drop rapidly as these technologies mature. Key drivers include economies of scale, the cost of fuel, battery cost and fuel cell cost. Battery pack costs have decreased by around 60% over the last five years and are forecast to continue to drop steadily.

FIGURE 1 – HISTORICAL AND FORECAST BATTERY PACK PRICES



Source: FTI Consulting analysis

FTI Intelligence has analyzed the TCO of class 8 HDVs in the US market for two use cases, short haul delivery and long haul multi-day trips. Short haul delivery is defined as point to point distribution, using a day cab tractor, with an average trip length of less than 300 miles, and a typical annual distance of 50,000 miles. Long haul delivery is defined as multi-day trips using a sleeper cab, and with a typical annual distance of 100,000 miles. The two use cases are analyzed over an ownership period of 10 years, using a discount rate of 3%.

Five key powertrain technologies have been analyzed: diesel, liquefied natural gas (LNG), compressed natural gas (CNG), battery electric and hydrogen fuel cell. Ethanol, biodiesel, renewable diesel and propane fuels have been excluded from the analysis due to low expected market share or compatibility with legacy powertrains. For each powertrain technology the TCO is calculated for every purchase year from 2020 to 2040. As the TCO of new technologies drops, the crossover points between new and legacy technologies illuminate the expected timeline of adoption.

The analysis uses FTI Intelligence estimates of purchase price forecasts based on component prices and manufacturing costs. At every point these estimates are benchmarked to commercially available values. Full battery replacement is assumed for battery electric HDVs after five years, and the replaced batteries are assumed to have a residual value of 10% for second life applications. Fuel price forecasts are derived from the US Energy Information Agency's Annual Energy Outlook 2020 Reference Case and the US Department of Energy's Alternative Fuels Database. Electricity charging costs assume fast charging infrastructure, at a power of 350kW, and associated grid upgrades. Electricity and hydrogen price forecasts assume the cost of infrastructure and delivery remains constant over time, while a profit margin of 10% is used.

As is the case for any new technology, the policy landscape will play a key role in enabling early adoption. To maintain the generality of our results across the US, we based our analysis on federal regulations only. An exception to this rule is that we chose to model the action of California's Low Carbon Fuel Standard (LCFS) on diesel price as a separate scenario in our short haul TCO, to demonstrate the effect on intra state haulage. This separate scenario also illuminates the potential effect on TCO if President-elect Biden chooses to impose a countrywide LCFS to replace the Renewable Fuel Standard (RFS). In addition, our analysis assumes that the Alternative Fuel Excise Tax Credits (AFTC) are extended by Congress indefinitely.

Our modeling is summarized in Figures 2 & 3. The TCO of diesel vehicles is seen to rise steadily with increasing fuel costs while the TCO of CNG and LNG vehicles remains steady over time due to flat fuel price forecasts. CNG achieves a consistently lower TCO than LNG due to lower unit fuel costs; LNG incurs additional compression and distribution costs. In contrast to the flat or rising profiles of diesel, CNG, and LNG, hydrogen fuel cell and battery electric vehicles display a significant drop in TCO over time, due to decreasing purchase price and fuel costs. When compared to legacy diesel powertrains, hydrogen fuel cell and battery electric appear to be competitive sooner for long haul use rather than short haul use; this is due to fuel costs playing a larger role in the TCO of long haul vehicles and illustrates the necessity of interpreting TCO results alongside other considerations, such as range and recharging or refueling downtime, for new powertrain technologies.

FIGURE 2 – TCO FOR LONG HAUL CLASS 8 VEHICLES IN THE US

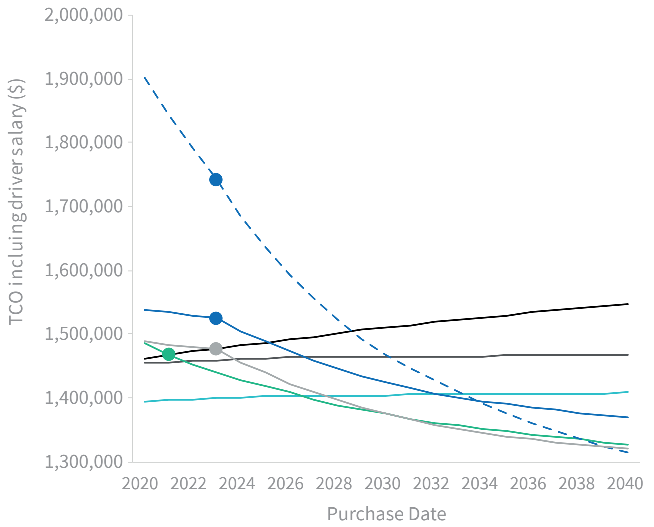
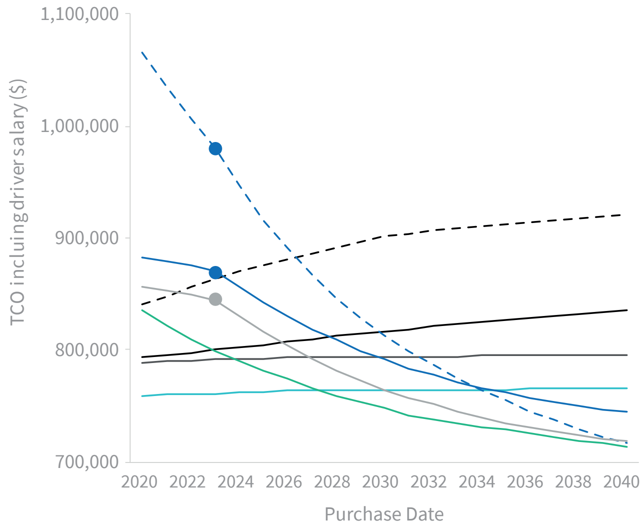


FIGURE 3 – TCO FOR SHORT HAUL CLASS 8 VEHICLES IN THE US



Notes: The TCO of RNG is equal to that of fossil CNG and the TCO of L-RNG is equal to that of fossil LNG in the US due to the action of the RFS
Source: Proprietary FTI Consulting TCO Model

For battery electric class 8 vehicles, our analysis shows cost parity with diesel being reached during 2021 for long haul and 2023 for short haul. Furthermore, it shows that battery electric vehicles are already at cost parity with diesel for short haul use in California. Thus, we expect to see first movers adopting battery electric vehicles in California imminently. Over time, the TCO of battery electric vehicles continues to decline, overtaking CNG to become the lowest TCO technology during 2026 for long haul and 2027 for short haul use. It is then surpassed by grey hydrogen for long haul in 2031 and by green hydrogen in 2038 but remains the lowest TCO technology for short haul over the period analyzed.

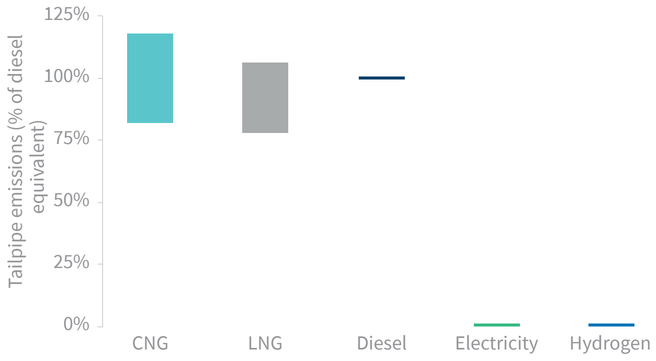
For CNG class 8 vehicles, our analysis shows a significant current cost advantage over diesel and the lowest TCO overall in the short term. CNG's TCO dominance is eventually broken by both battery electric and hydrogen fuel cell vehicles. The period over which CNG class 8 vehicles maintain their TCO advantage is, however, strongly dependent on AFTC support. In the case where Congress does not extend AFTC support for CNG, battery electric vehicles will reach TCO parity with CNG vehicles during 2022 for long haul and 2024 for short haul use.

Vehicles using grey hydrogen are expected to be cost competitive with diesel by 2023 for long haul and 2026 for short haul use. Benefiting from anticipated cost reductions in fuel cell and vehicle manufacturing scaling, grey hydrogen is expected to be cost competitive with battery electric by 2030 for long haul use only. For fuel cell vehicles using clean (i.e. green or blue) hydrogen to compete with battery electric vehicles, an accompanying and significant reduction in the delivered cost of clean hydrogen is required. Given the early stage of the clean hydrogen economy, there is significant uncertainty over when the required production cost decrease will occur in the US – but it will largely depend on hydrogen demand growth from a broad range of potential end-users (e.g. industry, power and building heat), and not just transport applications. FTI Intelligence currently anticipates that green hydrogen fuel cell vehicles will become competitive with both grey hydrogen and battery electric vehicles by 2040, but there is clear potential for this to be advanced or delayed. All types of hydrogen are beneficiaries of AFTC support and so are subject to a similar degree of policy risk as CNG. Finally, fuel cell vehicles have key advantages in range and refueling downtime for the long haul use case, factors which are not captured in the TCO.

Emissions intensity of powertrain technologies

When considering the emissions intensity of powertrain technologies, two approaches may be taken: comparison of the tailpipe emissions and comparison of the lifecycle emissions. Electricity and hydrogen are the only fuels that achieve zero tailpipe emissions; this is important not just for CO2 emissions but also for NOx and particulate emissions.

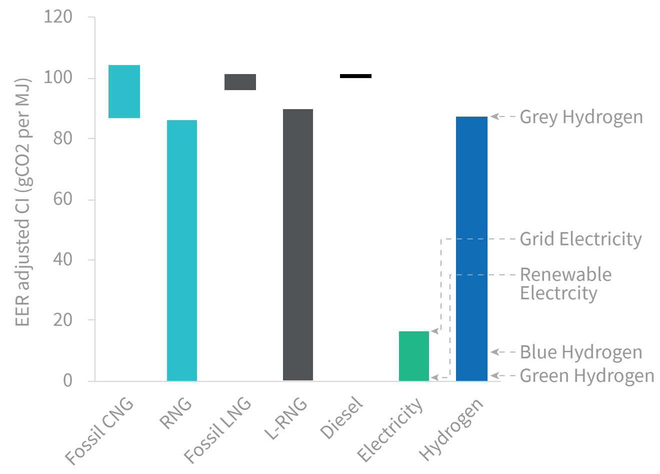
FIGURE 4 – TAILPIPE CO_2 EMISSIONS FOR ALTERNATIVE FUELS



Source: FTI Consulting; Office for Low Emission Vehicles

Secondly, we must consider the lifetime emissions of the fuels. Fossil CNG, fossil LNG and grey hydrogen offer only a limited reduction in lifecycle emissions when compared to diesel. None of these fuels are therefore likely to be favored by fleet operators in the future. Grid electricity and blue hydrogen achieve significant lifecycle savings when compared to fossil derived fuels, while renewable electricity and green hydrogen offer near zero lifetime emissions.

FIGURE 5 – LIFECYCLE CO_2 EMISSIONS FOR ALTERNATIVE FUELS



Notes: LCFS certified energy economy ratio (EER) adjusted carbon intensities (CI); only EER adjusted CI values greater than or equal to zero are displayed; Liquefied renewable natural gas (L-RNG) is often referred to as Bio-LNG
Source: California Air Resources Board

Significant lifecycle emission savings are possible when renewable natural gas (RNG) made from biogenic feedstock is used as a fuel, in compressed or liquid form. The degree to which RNG reduces lifecycle emissions is, however, sensitive to the feedstock and the method of the lifecycle assessment used. Highly negative lifetime values are possible for pathways that are credited with avoiding methane emissions but are indirect beneficiaries of other industries with relaxed emissions controls. In the future, such industries are likely to face their own pressure to decarbonize and thus avoidance credits are likely to be removed from lifecycle analyses; in contrast to the US approach, EU lifecycle assessments for biofuels often already exclude such avoidance credits. Nevertheless, certain feedstocks allow RNG to achieve very low lifecycle emissions without reliance on methane emissions avoidance.

In summary, it is clear that electricity, blue hydrogen, green hydrogen and RNG offer the greatest potential emissions reductions, and thus are likely to be favored by fleet operators when the economics are competitive.

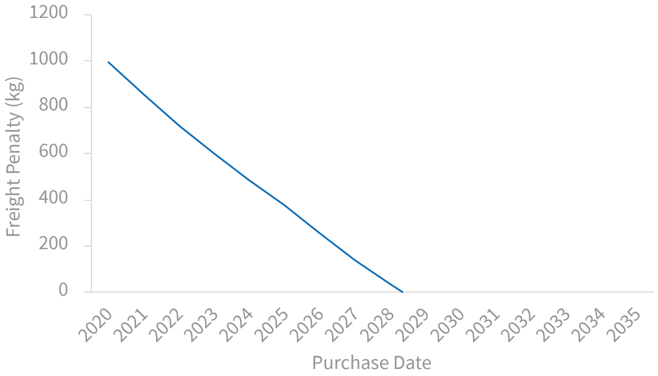
Freight Penalty

As well as considering the TCO and emissions reduction potential of new powertrain technologies, we must consider whether HDVs with new powertrain technologies offer the same revenue generating potential as legacy HDVs. The maximum gross weight of a class 8 vehicle is controlled by federal regulation and cannot exceed 40,823 kgs. If new powertrain technologies are heavier than those they replace, the vehicle will have to carry less freight to remain below this limit and so revenue generating potential will be diminished. To compensate, in the Consolidated Appropriations Act, 2019, an allowance was made for natural gas and battery electric class 8 vehicles to exceed the gross vehicle weight limitation in the US by 907 kgs. A similar measure was passed in Europe as part of the EU's Weights & Dimensions Directive 2019 allowing zero (tailpipe) emission class 8 vehicles an additional allowance of 2,000 kgs.

There has been much consternation over the weight of batteries required for long haul HDVs. However, the weight of the drivetrain as a whole must be considered, not just the weight of new components. FTI Intelligence analysis of the drivetrain shows that the freight penalty incurred for long haul vehicles, with 1000kWh batteries, is only 997kgs in 2020 in the US, due to weight savings across the drivetrain and the allowance.

For context, the freight penalty of a having a common steel cab over an aluminum cab in a class 8 vehicle is approximately 1,500 kgs, and so the freight penalty of a long haul battery electric vehicle is within bounds the industry already encounters. Using an average freight revenue of 0.02 cents per kg-mile the freight penalty for the long haul use case corresponds to an annual loss in revenue of $20,700. This value is strongly dependent on the load state of the vehicle and the value of the freight. FTI Intelligence predicts that the freight penalty for long haul battery electric class 8 vehicles will decrease in an almost linear fashion over the decade as the energy density of batteries improves, reaching zero before 2029.

FIGURE 6 – FREIGHT PENALTY FOR LONG HAUL CLASS 8 VEHICLES IN THE US



Source: FTI Consulting analysis

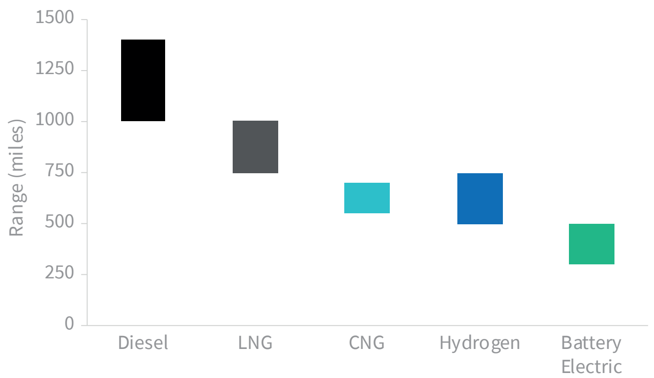
For short haul battery electric vehicles, with 620kWh batteries, and LNG and CNG vehicles, it was found that there was no freight penalty in 2020. Hydrogen fuel cell vehicles were not included in the freight penalty modeling, as there is a higher level of uncertainty in prediction of component weights, and the gross weight allowance in the US does not extend to fuel cell vehicles.

Recharging or Refueling Downtime

The revenue generating potential of an HDV is also dependent on the downtime required for charging or refueling. Downtime is in turn dependent not only on the powertrain technology, but on vehicle range, use case and charging or refueling infrastructure.

Short haul point to point delivery does not usually require en route charging or refueling as the average trip length is less than the range of a battery electric class 8 day cab, which has the lowest range of the powertrain technologies analyzed. Around 70% of class 8 trips fit this description. Short haul vehicles thus may be recharged or refueled at depots, either during loading or overnight, and so new powertrain technologies are not expected to result in increased downtime.

FIGURE 7 – RANGE OF CLASS 8 VEHICLES BY POWERTRAIN TECHNOLOGY



Source: FTI Consulting analysis

Long haul, multi day trips (30% of class 8 trips) sometimes require trucks to travel up to 800 miles a day. On these trips, drivers are legally required to take a minimum break of 30 minutes for every eight cumulative hours of driving (approximately equal to 500 miles). On such trips, all vehicles will stop to refuel. Diesel and LNG vehicles may be able to make the trip in range but have to stop for driver breaks and will use these opportunities to refuel, and thus carry less fuel weight. Refueling times for diesel, LNG, CNG, and hydrogen are broadly similar at around 10 minutes, well below the mandated 30 minute break. On the other hand, battery electric class 8 vehicles will not be able to charge in less than 30 minutes in the short term. To do so would require a 2MW charger. In our TCO analysis we have used infrastructure costs equivalent to 350kW chargers (which is close to the upper range of fast charger powers currently available) in our electricity prices. A 350kW charger allows a long range class 8 vehicle to charge in less than three hours, during sleeping breaks, but not during a short 30 minute truck stop. Long haul battery electric vehicles will therefore incur increased downtime.

Due to these downtime considerations battery electric HDVs will prefer depot charging where possible, and uptake is likely to occur faster for the short haul use case where this is possible. As we have assumed 350kW fast charging in our electricity prices, our TCO results for short haul vehicles do not require depot charging to occur overnight; overnight charging would, however, further reduce the TCO as electricity costs are lower during the night, and the CAPEX required for a lower power charger would be reduced.

In light of the additional downtime incurred during en route battery charging, hydrogen fuel cell vehicles are likely to be preferable for long haul use. It should, however, be remembered that the long haul use case only represents 30% of class 8 trips in the US.

Implications for Uptake

For the short haul use case, currently representing 70% of the class 8 market, we expect fleet operators to favor battery electric powertrains in future purchase decisions, with the TCO and emissions benefits available outweighing the freight penalty incurred. We expect to see immediate uptake in California, followed by uptake across the rest of the US as TCO parity with diesel is reached in 2023. By 2027, we expect to see battery electric vehicles accounting for a significant share of short haul class 8 vehicles sold.

For the long haul use case, currently representing 30% of the class 8 market, uptake of battery electric vehicles is dependent on the development of MW scale charging infrastructure that has the potential to reduce charging downtime. If MW scale charging is widely deployed we expect to see uptake of battery electric vehicles in the second half of the decade; in the absence of widespread roll out of such infrastructure, we expect to see only modest uptake, with CNG & RNG replacing diesel in the short term and hydrogen uptake gaining momentum in the 2030s. We do not see a long term future for grey hydrogen due to its limited emissions reduction potential, instead we expect that any usage of grey hydrogen as a fuel will be transitory and will eventually be replaced by blue or green hydrogen.

TABLE 1 – COMMERCIAL IMPLICATIONS FOR RELEVANT STAKEHOLDER GROUPS

STAKEHOLDER	IMPLICATIONS
OEMs	— Battery electric and hydrogen fuel cell trucks will become credible alternatives this decade and should be manufacturer priorities; with an advantageous TCO, demand should be strong — OEMs should build robust supply chains positioned to capture the value or cost reduction potential in new powertrains; this will be critical in developing a competitive offering — Building initial market share may require a collaborative proposition with both refueling/charging service providers and end customers to alleviate concerns over lack of access to refueling or recharging infrastructure
Suppliers	— The HDV powertrain supply chain will be subject to disruption within the decade, powertrain manufacturers should accelerate efforts to diversify their offerings to potentially include CNG powertrains, fuel cells, batteries and electric drive trains — Current tier 1 and tier 2 HDV powertrains suppliers will face decreasing demand for diesel powertrain components — There will be an opportunity for new tier 1 and tier 2 suppliers to gain markets share in the supply of new drivetrain technology components; existing EV suppliers are likely to be in a good position to take advantage of this opportunity and should begin discussions with HDV OEMs
Fleets	— Fleet operators already have cost competitive alternative power train options to consider (RNG/CNG/LNG) — If fleet operators transition their fleets to new powertrain technologies over a significant period of time or operate a range of use cases, they will have to be prepared to operate a mixed fuel and powertrain fleet, this will require careful planning across all operations and new vehicle management systems — Successful integration of new powertrains will be dependent on which refueling, or recharging infrastructure solutions are best suited to the fleet operator's specific operational requirements — As battery electric vehicles are adopted for short haul point to point delivery, fleet operators will have to expand their operations to enable depot recharging — An advantageous TCO will drive the adoption of new powertrain technologies faster than was previously expected; to access the steep reduction in TCO expected operators will be likely to renew their fleets at an accelerated rate
Energy, Utilities & Refueling and Recharging Infrastructure	— En route refueling station business models will be disrupted; the short haul segment of the market may forego the use of en route refueling or recharging entirely and depot charge, limiting the size of the market — Companies that provide recharging services or infrastructure should target the larger short haul segment of the market, and will have to offer these services on site for fleet customers, as battery electric fleets will favor depot charging — To address the remaining long haul market segment en route refueling stations will have to adapt to the prevalent technologies, and are likely to need to offer CNG & RNG, hydrogen or electric charging instead of diesel — For battery electric vehicles to capture the long haul market, the power of fast chargers must be increased, and such chargers plentifully deployed along major freight routes; charger manufacturers should make MW scale chargers an R&D focus area — Utilities will have to manage additional EV charging demand both in aggregate and geospatially as chargers will introduce high load to the grid in new areas; transmission and distribution upgrades and strict power quality measures will be needed

While CNG offers the lowest current TCO, has no revenue penalty and is widely available for both use cases, FTI Intelligence sees CNG's dependence on AFTC support as a significant policy risk. This uncertainty should be resolved in the early days of the Biden administration. An extension of support by Congress would lead to strong uptake in this decade for both use cases, while the lapse of support would accelerate the change to battery electric vehicles. A conceivable middle ground could be continued support for specified RNG blends only. FTI Intelligence expects that CNG powertrain vehicles will increasingly use RNG fuel over fossil CNG in the future, due to the superior emissions reduction potential.

Lessons from CNG uptake

When considering the potential uptake of new powertrain technologies, it is valuable to consider the lessons available from the limited uptake of CNG powertrains. FTI Intelligence estimates that CNG vehicles make up no more than 2% to 3% of class 8 vehicle sales in the US despite having had a significant TCO advantage since 2018. This can be attributed to a number of factors that include infrastructure availability, lack of accurate TCO knowledge, model availability and the inherent conservatism of the industry. These factors will continue to delay the uptake of new powertrain technologies.

To overcome these factors a multifaceted approach is required. FTI Intelligence is publishing this spark note to add to the body of TCO information available. To ensure sufficient model and infrastructure availability for new technology uptake, heavy investment is needed by original equipment manufacturers (OEMs) and charging and fueling infrastructure providers. A non-exhaustive list of the commercial implications of new powertrain uptake for selected stakeholders is included in Table 1.

Conclusion

A myriad of new powertrain technologies are competing to usurp diesel as the heavy duty vehicle powertrain of choice. Of these, FTI Intelligence finds that the economic case for battery electric and hydrogen fuel cell powertrain technologies will be most favorable in the long term and will drive uptake within the decade. Our results indicate that we stand on the precipice of revolution in the road freight sector, with disruptive commercial implications across the value chain.

A follow on of this analysis will be published for the European truck market in the first quarter of 2021.

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