ENVIRONMENTAL FOOTPRINT OF THE HEAVY-GOODS VEHICLES OF THE FUTURE

Nikola Manev[1*], Dame Dimitrovski[1], Zoran Markov[1], Viktor Iliev[1]

[1*]Mechanical Engineering Faculty – Skopje, Ruger Boshkovik nmb.18, North Macedonia;

[*]E-mail: manev.nikola@yahoo.com;

ABSTRACT

Motor vehicles running on internal combustion engines are the world's foremost method of transport well into the 21st century. Their major economic and social benefits have long overweighed the ethical concerns of the environmental effects of transport such as, global warming and air pollution, and a subsequent reduction in air quality and quality of life. As a result, there have been major efforts by the automotive industry to "go green" by implementing regulations that support the use of more fuel-efficient vehicles, vehicles using alternative fuels, hybrids or fully electric vehicles (EVs). Consequently, this brought for a significant drop in the demand for light passenger, diesel vehicles compared to the years before. In fact, while in 2017, diesels accounted for 44% of new cars sales, this number dropped to 29,9% for the first quarter of 2020. All the while, the total number of vehicles that run on alternative fuels, hybrid-electric vehicles (HEVs) and electrically chargeable vehicles has been in a constant rise, from 5,7% in 2017, 7,5% in 2018, and 10,6% in 2019, to 17,8% for the first quarter of 2020. This tendency however, does not apply to heavy goods vehicles (lorries and road tractors) as sales of diesel HGVs account for 97.9 % percent of the total market share. That being said, the goal of this paper is to identify the main directions of development for future HGVs powerplants and their reliance on a particular fuel type and more importantly assessing the environmental footprint of such solutions.

Key words: HGVs, future, alternative fuels, environment, footprint, impact

INTRODUCTION

Environmental Effects of Road Freight Transport

The growing transport sector has defined the lives of our societies since most everyday activities revolve on the basis of a well-developed transport infrastructure. As a result, transport is one of key elements that set the tone for a country's economic and social prosperity. At the same time, these economic and social benefits have long overweighed the concerns brought on by the environmental effects of transport. Conventional fossil fuels, while literally fueling societies' progress, have been one of the major causes of air pollution and global warming, and have led to a significant reduction in air quality and quality of life. (Michalek et al., 2011; Tessum et al., 2014)

With its heavy reliance on oil products (more than half of the global oil demand), transport is a key contributor to climate change and emits about 22% of the global total CO2 emissions. Transport activity can be split into two broad categories, one being passenger movements and the other being the movement of goods and services. In the case of movement of goods, road freight vehicles are a central pillar of global economic activity and constitute a key segment of global oil demand, responsible for about 7% of the total global CO2 emissions. Teter et al. (2017) In addition, road traffic is a major source of air pollution due to emissions of a range of pollutants but most notably carbon monoxide, nitrogen oxides and particulate matter which have been proven to lead to respiratory system diseases. (AQEG 2019; Hooftman, 2018; Fedotov et al., 2014) Diesel engines traditionally have the highest emission rates of these pollutants (Boulter, 2005; Petrovic, 2008) but they also dominate heavy-duty applications because of their greater fuel efficiency and torque output which makes them able to haul bigger loads. This signifies that air pollution and the general negative impact to the environment have been exacerbated by the presence of road freight vehicles, otherwise known as heavy-goods vehicles (HGVs).

Current Trends in Alternative Fuels and Powertrains (AFPs)

Diesel technology progressed with the introduction of turbochargers and common rail fuel management systems, which along a trade of for smaller quantity of CO2 (GHG) emissions led to the number of new diesel registrations of light passenger vehicles in Europe to rise from 15% in 1990 to 52% in 2015. However, studies proved that diesel is worse for the climate than petrol, in addition to being the largest contributor to air pollution. Consequently, there have been major efforts by the automotive industry to "go green" by implementing regulations that support the use of more fuel-efficient vehicles, vehicles using alternative fuels, hybrids or fully electric vehicles. As a result, the demand for light passenger, diesel vehicles in the EU, in 2020 saw a serious decline compared to the same period, years before. ACEA (2020) In fact, while in 2017, diesels accounted for 44% of new cars sales, this number dropped to 29,9% for the first quarter of 2020. All the while, the total number of vehicles that run on alternative fuels, hybrid-electric vehicles and electrically chargeable vehicles has been in a constant rise, from 5,7% in 2017 to 17,8% in the beginning of 2020. This tendency however, does not apply to HGVs as sales of diesel trucks in Europe in 2020 accounted for 97.9 % percent of the total market share.

Containing more energy potential than petrol, diesel engines are more efficient, robust and have greater longevity in demanding applications which makes them the natural choice for heavy-duty purposes. This is why a fast transition to a different fuel type or powertrain, is highly unlikely. But, with the current dependence on oil being burdensome, both economically and environmentally, and air pollution leading to a range of health concerns, this accelerated the development of the following alternative fuels: Liquefied petroleum gas (LPG), Liquefied natural gas (LNG), Compressed natural gas (CNG) and Biofuels (BIO); and electrified powertrains: (Battery electric vehicles (BEV), Catenary electric vehicles (CAT), Plug-in hybrid electric vehicles (PHEV) and Fuel cell electric vehicles (FCEV).

Aim of this Paper

The aim of the paper is to identify the main directions of development for future HGV AFPs, review the current emission rates of HGVs and compare them with the environmental footprint of the proposed solutions of the future. Aside from presenting the current number of alternative HGVs, this paper discusses the opportunities and barriers to their development and the present research initiatives related to the development of alternative fuels and electromobility. Finally, it evaluates the use of each AFP to ensure that the current preferences and the directions taken by HGV manufacturers would effectively lead to a decreased environmental footprint in the future.

MATERIALS AND METHODS

Materials

Research on AFPs in HGVs is an emerging field in the mobility sector (Hein et al., 2007) since the current findings are not clear in identifying their pros and cons, and how they might lead to a reduction in GHG emissions and air pollution, or opposite, act to further increase the magnitude of these environmental challenges. In order to identify suitable research sources on the topic of AFPs and their application in HGVs, we conducted a comprehensive search of publications, primarily relying on online data from renown scientific databases, in addition to a range of feasibility studies. We used three criteria for the content crosscheck and selection: the papers/studies need to cover the relevant HGV sizes, include quantitative data on the contribution of each AFP to global warming and air pollution, and they need to be published no earlier than 2010. These criteria allowed us to identify multiple papers/studies per each of the abovementioned AFVs and provided a suitable and reliable basis in our comparative analysis and evaluation.

Out of the 32 titles we used at the core of this paper, the relatively low number of peer-reviewed, relevant scientific papers (12 and 1 master thesis) already indicates the early research stage of this topic and the lack of research in some developed countries (e.g. France and Japan) and in most developing markets such as Africa, India, the Middle East and Latin America. On the other hand, the higher number of studies (19) in comparison, speaks volumes of the fact that the major transport and political bodies, as well as the HGV manufacturers are taking the matter of AFPs seriously enough to research and invest in these options.

Methods

Having identified the critical literature to the topic of AFPs in HGVs, this paper proceeds to conduct a comparative analysis and an evaluation of the LPG, LNG, CNG, BIO, BEV, CAT, PHEV and FCEV technologies. To ensure a good understanding of the potential of each technology, we developed a grading system that is based on: technology maturity, production costs, operating costs, GHG emissions reduction benefit (split into well-to-tank, tank-to-wheel and well-to-wheel GHG emissions) and air pollution reduction benefit. We should note, that all the data used to grade each of the technologies included their most favorable reviews in emissions, air pollution reduction potential, existing infrastructure and of course operating and production costs.

Technology Maturity

Battery technology (BEVs) holds great promise for passenger cars and light vehicles, but the outlook for long-haul HGVs is that full battery electrification is not realistic in the near future, while fleets are more likely to become partially electrified through PHEV technology. (EC, 2015; Lajevardia, 2019) Technologies such as CAT have the potential to complement heavy-duty freight trucks, but the overhead contact lines that exist are only prototypes or early commercial versions from a handful of suppliers worldwide. (ERTRAC, 2014; Scania, 2012).

Table 1. Grading AFPs on the criteria of Technology Maturity

Alternative fuel or Powertrain	Research Phase (1)	Technology is available, but not in HGVs (2)	Prototypes in HGVs (3)	Technology has made edntry into HGVs market (4)	Significant HGV market presence (5	Total
BEV				4		4
PHEV				4		4
CAT			3			3
FCEV		2				2
CNG					5	5
LNG					5	5
LPG				4		4
BIO				4		4

The FCEV technology commercialization process has begun within some specific market segments; (passenger cars, buses and materials-handling vehicles) and as such is mature, safe and ready for deployment in road freight transport. However, the levels of cost competitiveness and performance required for large-scale deployment have not yet been achieved, neither for the vehicles nor for the refueling stations. Atkins (2015) Today, there are but a handful of prototype fuel cell demonstrator trucks purpose built as proof of concept vehicles and guide production designs. NACFE (2020)

CNG vehicles are more common and have a longer history of use, but LNG is more popular in heavy-duty applications. USDE (2013) Nevertheless, according to Teter et al. (2017), HGVs fueled by CNG or LNG accounted for about one per cent of the total stock of HGVs in 2015. Looking ahead, the role of gas fueled HGVs is likely to grow in importance as they represent a more prospective market for natural gas-based systems then cars. Le Favre (2019) The technology is very mature and a range of EURO VI/6 cars, vans, buses and trucks exists. When it comes to LPG, the combination of diesel and LPG (dual fuel technology) has enjoyed some success with heavy duty vehicles. LPG can be used for road transport in trucks for all range of distances, and while it lacks the numbers in HGV sales, currently is the most widely used alternative fuel, with approximately 9 million LPG vehicles (in total) running in the EU. Infrastructure is well developed with a significant number of filling stations already present. EC (2013) Biofuels, are an existing technology, however current engine technologies can only accommodate a relatively low biofuel content so consumption in road freight is most commonly in blended forms from B5 to B20, providing a high degree of compatibility with existing vehicle fleets and fueling infrastructure. Higher blends, such as B50 or pure biodiesel (B100), can be used but require modifications to freight vehicles. With 31 billion liters of biodiesel produced in 2015, and 100 billion liters of ethanol in 2016 (although currently limited to LCVs) these are the two most commercialized biofuel options for heavy-duty transport and infrastructure is significantly developed. (Kampman et al. 2013; Du et al. 2018).

Production Costs

Total production costs for a diesel rigid lorry in 2020 have been reported at an average of 49 500 Euro and 82 250 Euro for a diesel road tractor. These costs are expected to increase over time due to tightening exhaust after-treatment regulations and the integration of new technology. Current battery prices are the main cost driving factor in BEVs resulting in an approximate production value of 100 975 Euro for a lorry BEV, and 118 540 Euro for a road tractor.

Table 2. Grading HGV AFPs on Production and Operating Costs

Alternative fuel or Powertrain	Significantly higher than conventional (diesel) HGVs (1)		Slightly higher than diesel HGVs (2)		Same as diesel HGVs (3)		Slightly lower than diesel HGVs (4)		Significantly lower than diesel HGVs (5)		Total
	P	O	P	O	P	O	P	O	P	O	
BEV			2							5	7
PHEV			2			3					5
CAT	1	1									2
FCEV	1	1									2
CNG			2					4			6
LNG			2	2							4
LPG			2					4			6
BIO			2			3					5

At present, FCEVs costs are high due to the limited production, with the production costs of a FCEV lorry on average being 79 294 Euro, and 176 005 Euro for a FCEV road tractor. den Boer et al. (2013) ICE diesel/PHEV hybrids production costs, at present are found to be roughly 20-25 % larger than those of conventional diesel HGVs,

however prices depend on the market. Teter et al. (2017) Finally, based on existing configurations CAT HGV road tractors are looking at production costs of approximately 133 348 Euro (we are lacking data on lorries). It is estimated that due to a rise in production, innovations in production technology and a reduction in the use of precious metals, battery and electric motors costs will decrease, and therefore the general costs of electric based powertrains are likely to decrease as well. Özdemir (2012)
On the other hand, regarding vehicles driven by alternative fuels, TTR (2011) has claimed that the production costs for dedicated gas (LNG, CNG and BIO) and dual fuel vehicles cost more than their diesel equivalents largely due to the lower production volume and the requirement of additional equipment. Costs range from 17 000 to 40 000 Euro more, depending on the size of vehicle. However, more recent data shows that the production costs for LNG and CNG fueled HGVs have approximately similar value being only slightly more expensive than conventionally used diesel ICEs. (T&E 2018, Langshaw et al., 2020) In addition, according to WLPGA (2018) the conversion costs of a diesel ICE to LPG are about 10 % higher, than the diesel HGV itself.

Operating Costs
According to (Teter et al. 2017; EC 2015) BEVs have a higher purchase price than diesel ICEs (mainly due to high battery cost) but a lower fuel cost (due to greater efficiency and no use of oil) and a lower maintenance cost (e.g. due to fewer moving parts, absence of catalyst and other emission control systems). Additionally, studies have shown that drive trains using direct electricity (CAT trucks) can already achieve costs similar to efficient diesel trucks in long-distance road haulage, (Plötz et al., 2018; Mareev & Sauer, 2018) however the present lack of CAT infrastructure significantly bumps up the costs, making this one of the least budget friendly options. (Connolly, 2017; ECF, 2018) Overall, the higher capital expenditure would be offset by lower operating costs. Significantly higher overall costs, are also associated with the use of FCEV trucks (Plötz et al. 2018; Den Boer et al. 2013). On Europe's transportation scene, PHEV trucks show almost no difference in lifetime operational expenses over diesel ICEs. Teter et al. (2017)
Significant cost savings can be achieved from switching diesel trucks to LPG trucks. Considering three lifetime costs - maintenance, operation and fuel, the total lifetime undiscounted cost of a diesel truck comes to $299,266 while the cost for an LPG truck comes to $270,700. This yields a cost saving of $28,566. WLPGA (2018) Moreover, even with the current infrastructure (in Europe) and the limited presence of LNG and CNG refueling stations, CNG HGVs offer lower operational costs, while LNG HGVs offer slightly higher operational costs than diesel ICEs, which is mainly due to the lower cost of natural gas in comparison to diesel fuel. Teter et al. (2017) The operation cost of the biofuel vehicles is not significantly different from diesel vehicles, plus the fuels that to a large extent are able to use current infrastructure (ethanol, biodiesel, etc.) have almost similar costs to conventional fuels. EC (2015)

Ghg Emissions Reduction Benefit

Tank-To-Wheel Emissions – Ttw (Tailpipe Emissions)
Tailpipe emissions (TTW) from diesel amount to 120 gCO_2/km (or any other GHG, CO_2 equivalents). In comparison, depending on electricity production and the decarbonization pace of the power sector, according to JEC (2014), the 2010 EU28 power generation mix gives well-to-tank (WTT) GHG emissions of 78 gCO_2/km for BEVs. The overall well-to-wheel (WTW) emissions for BEVs are the same as the WTT emissions, which is to show that BEVs do not account for any TTW emissions. The TTW emissions for an average PHEV (diesel hybrids) are 68 gCO_2/km, however the amount will vary depending on the way electricity is produced. In FCEVs, only electricity, water and heat are produced as a result of the hydrogen to electricity conversion process, thus, the CO_2 tailpipe emissions are also zero.
The Thinkstep (2017) analysis of HGV emissions and a more recent study from the Sustainable Gas Institute at Imperial College (SGI, Piers et al 2019) agree that GHG emissions from natural gas fueled trucks (both CNG and LNG) could be around 15 per cent lower than those of diesel trucks if looking at the total WTW emissions, but with regard to TTW emissions, EC (2015) have reported a value of 132 gCO_2/km. LPG mixes readily with the air in the engine and exhibits generally superior combustion properties to liquid fuels, but the energy specific GHG emissions are still higher than conventional diesel (JEC, 2014) with TTW emissions at 142 gCO_2/km. On account of biofuels,

JEC (2014) has assessed GHG emissions for biofuels produced from different biobased feedstocks to include 125 gCO_2/km for biodiesel and 146 gCO_2/km for ethanol, with different blends having similar emission rates.

Well-To-Wheel Emissions – Wtw (Lifecycle Emissions)

Tailpipe emissions from diesel amount to 120 gCO_2/km with an additional 25 gCO_2/km from well-to-tank emissions (sum of fuel and electricity). Therefore, the total well-to-wheel emissions would account to 145 gCO_2/km of GHG (CO2 equivalents) emissions. According to JEC (2014), the 2010 EU28 power generation mix gives GHG WTT emissions of 78 gCO_2/km for BEV and obviously, the WTW emissions for BEVs are the same as the WTT emissions. The WTT GHG emissions for diesel PHEV are 36 gCO_2/km on average, but this depends on the power used. When TTW emissions are included, the total WTW GHG emissions for PHEV (diesel hybrids) are 105 gCO_2/km. In FCEVs, GHG emissions depend on the production pathway followed for the production of the hydrogen, which currently is predominantly produced by steam reforming of methane. In this process, around 10 kg of CO_2 per kg of H2 is produced (WTT), which corresponds to 62 gCO_2/km. It is worth noting that if electricity is used in the hydrogen production process (electrolysis), an EU mix of electricity would correspond to WTT emissions of 125 gCO_2/km. However, since FCEV tailpipe emissions are zero, WTW emissions are equal to WTT emissions. CEPA (2015)

The use of CNG as fuel will be a significant contributor to reducing GHG emissions, but only if it is blended with biomethane. Ricardo E&E (2016) It is evident that the origin of the natural gas and the supply pathway are critical to the overall WTW GHG balance. Biomethane based on manure implies negative WTW GHG emissions, whereas using energy crops for biomethane production have a low carbon footprint due to their high production yields and can save 70% in emissions compared with conventional diesel. Summaries of the GHG WTW emissions for regular CNG show 163 gCO_2/km (30 gCO_2/km WTT), and range from -158 to 99 gCO_2/km for biomethane (-290 to -33 gCO_2/km WTT). The negative GHG emissions for some biomethane paths are due to the de-gasification processes that take place during production. Considering Euro VI CNG and LNG fueled HDVs, the homologation data indicates a lower GHG emission of up to 10% (e.g. as reported by IVECO, Daimler, and Scania). In regards to LPG, EC (2015) reports a value of 160 gCO_2/km WTW emissions (17 gCO_2/km WTT). According to JEC (2014) the fossil energy and GHG savings of conventionally produced biofuels such as ethanol and biodiesel are critically dependent on the manufacturing processes and the use of co-products. With that said, biodiesel WTW emissions range from 44-103 gCO_2/km (-101 to -22 gCO_2/km WTT), while ethanol emissions range from 19-176 gCO_2/km (-127 to 30 gCO_2/km WTT).

Table 3. WTT, TTW and WTW emissions in HGVs per AFP

Alternative Fuel/ Powertrain	WTT gCO2/km	WTT % compared to diesel ICE	TTW gCO2/km	TTW % compared to diesel ICE	WTW gCO2/km	WTW % compared to diesel ICE
Diesel ICE	25	/	120	/	145	/
BEV	78	212%	0	-100%	78	-46%
PHEV	36	44%	68	-44%	105	-28%
CAT	n/a	n/a	n/a	n/a	n/a	n/a
FCEV	62	148%	0	-100%	62 to 125	-36%
CNG	-290 to 99	-482%	132	10%	-158 to 163	-97%
LNG	-290 to 99	-482%	132	10%	-158 to 163	-97%
LPG	17	-32%	142	18%	160	10%
BIO	-127 to 30	-294%	125 to 146	13%	19-176	-33%

Table 4. Grading HGV AFPs on GHG reduction benefit

Alternative fuel or Powertrain	Worst (No) GHG reduction benefit (1)			Small (<10%) GHG reduction benefit (2)			Medium (10-30%) GHG reduction benefit (3)			High (30-50%) GHG reduction benefit (4)			Best (>50%) GHG reduction benefit (5)			Total
	WTT	TTW	WTW	WTT	TTW	WTW	WTT	TTW	WTW	WTT	TTW	WTW	WTT	TTW	WTW	
BEV	1											4		5		10
PHEV	1								3		4					8
CAT	1								3		4					8
FCEV	1											4		5		10
CNG		1											5		5	11
LNG		1											5		5	11
LPG		1	1							4						6
BIO		1										4	5			10

Air Pollution Benefit (CO, NOx, Pm)

Air pollution is a major public health problem, and the transport sector is an important contributor, given its high reliance on the combustion of petroleum-derived fuels. For example, the transport sector contributed to more than half of global energy-related emissions of nitrogen oxides (NOx), 12% of Sulphur dioxide (SO2), and 7% of total fine particulate matter (PM2.5) in 2015. EC (2015) Electric vehicles can contribute to air quality improvement, especially in urban areas since they produce neither NOx emissions nor particles (PM) while running in electric drive mode. The same goes for FCEVs, as only electricity, water and heat are produced from the hydrogen to electricity conversion process. CEPA (2015) CAT hybrids emit far lower levels of local pollutants than conventional trucks, and even less than conventional (diesel) PHEVs. (Hill, 2019; Singh, 2016).

Table 6. Grading HGV AFPs on Air pollution reduction benefit

Alternative fuel or Powertrain	Worst (No) Air Pollution reduction benefit (1)	Small Air Pollution reduction benefit (2)	Medium Air Pollution reduction benefit (3)	High Air Pollution reduction benefi (4)	Best Air Pollution Reduction benefit (5)	Total
BEV					5	5
PHEV			3			3
CAT				4		4
FCEV					5	5
CNG					5	5
LNG					5	5
LPG					5	5
BIO	1					1

The local air quality benefits from switching to natural gas are clear – switching from diesel to CNG in urban fleets directly reduces emissions of hydrocarbons, carbon monoxide, nitrogen oxides and particulate matter emissions. Robinson et al (2017) Natural gas is a clean-burning fuel and offers a number of advantages to users. The use of CNG, LNG and biomethane has low pollutant emission levels (mainly NOx), almost zero SOx emissions, and no particulate matter (PM) emissions close to zero, which means that natural gas and biomethane do not pose any problem to air quality. Le Favre (2014) Also, due to its simple chemical composition and gaseous combustion, LPG mixes readily with the air in the engine and exhibits combustion properties generally superior to liquid fuels. It burns with nearly no particle emissions and hydrocarbon and carbon monoxide emission are lower than diesel. Through the combustion LPG also emits much less NOx than diesel. In addition, propane is nontoxic, so it isn't harmful to soil or water when spilled or leaked. Peters et al. (2021) Finally, liquid biofuels are not very different from petroleum fuels in terms of air pollution, meaning they have a similar impact to diesel vehicles.

RESULTS

After analyzing the potential on each of the selected AFPs and having summed up the grade points per each of the grading categories (technology maturity, production costs, operating costs, GHG emissions reduction benefit and Air pollution reduction benefit), CNG HGVs ranked highest among the AFPs with 27 grade points. Only 1 point behind are BEV HGVs and 2 points being is the LNG technology, which makes these 3 AFP technologies the most reliable and environmentally friendly solutions that are likely to be the future of HGVs.
On the other hand, CAT and FCEV HGVs ranked lowest among the AFPs. The foremost reason behind their low score lies with the complexity of the technologies, the fact that they are still in their early phases of development, the lack of appropriate infrastructure that would support their expansion among the HGV fleets and the subsequent high production costs. PHEV, LPG and BIO are all technologies that have existed for some time now, however besides having a sufficiently developed supporting infrastructure and having a presence on the market, none of these technologies has managed to make a greater impact with HGVs, which includes reducing their environmental impact.

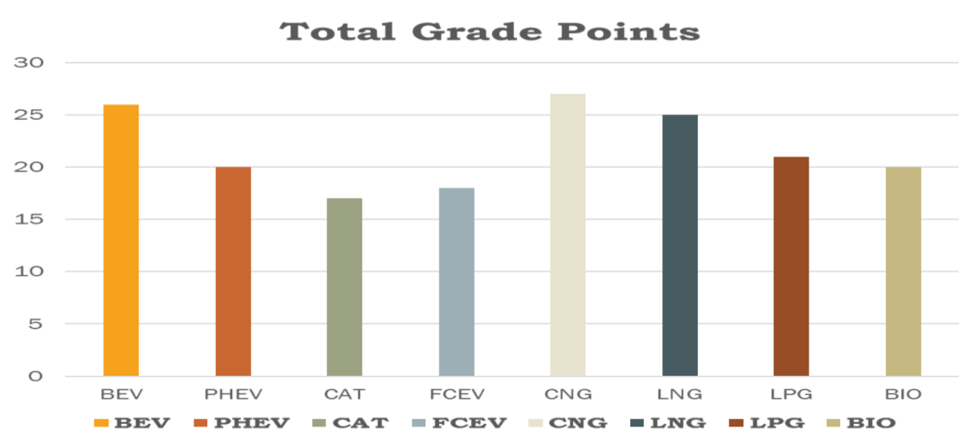

Figure 1. Total grade points per each HGV AFP

CONCLUSION

HGVs alone are responsible for a substantial chunk of the total global energy-related CO2 emissions and have traditionally high emission rates of CO, NOx and PM which are one of the foremost causes of air pollution, which paired with a burdensome dependence on oil and fossil fuels has undoubtedly put forth in motion the accelerated development and implementation of multiple different AFPs in HGVs. A fast transition to a different fuel type or powertrain in HGVs is highly unlikely since diesel's robustness and efficiency, as well as a greater power output makes it the natural choice for road freight transport. Although research on AFPs in HGVs is an emerging field in

the mobility sector, scientists, engineers and HGV manufacturers have been working hard to produce AFPs with a smaller environmental footprint than diesel. We made it our aim to identify the main directions of development for future HGV AFPs, and upon reviewing the current emission rates of HGVs and comparing them with the environmental footprint of the 8 proposed solutions, concluded that all present factors indicate that natural gas driven HGVs and BEVs hold the highest potential in expanding on the HGV market of the future.
With that said, this paper still leaves a lot of room for further research in life-cycle emissions, non-exhaust emissions and waste management. Life cycle emissions for BEV HGVs, which were graded as the second most potent solution of the future of freight transport, are rarely thought of, mainly arise from the manufacturing cycle of these vehicles and the production of electricity, and account for a variety of harmful pollutants, and a significant environmental impact in their own right. Notter et al. (2015) Since their batteries make up the largest portion of the vehicle's mass, manufacturers need to lighten the rest of the vehicle Notter et al., (2010) by using aluminum and carbon-fiber-reinforced polymers that often require a lot of energy to produce. The batteries' themselves are rarely recycled (during 2017 only 5% of lithium-ion batteries were recycled in the EU) Gardiner (2017), and if disposed improperly, they can release toxic chemicals. Based on a variety of sources early prototype battery-electric trucks are about 3.5 to 5 tones heavier than diesel trucks which makes for a lot higher amount of non-exhaust emissions as a result of tire and brake wear. Park (2020).

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