Ammonia as carbon free fuel for internal CombusTion engIne driVen AgriculTural vEhicle (ACTIVATE)

Work Package 4
Deliverable Report

Karolina Petela (SUT)
karolina.petela@polsl.pl

Mateusz Proniewicz (SUT)
matproniewicz@gmail.com

Topic: D4.3

Report on economic impact indicators of the technology

30.10.2022

1 Ammonia cost

Another perspective on the ACTIVATEngine technology could be elaborated using the economic indicators. The shape of the assessment generally aims at comparing the costs for diesel tractor as a reference case (which is the same approach as in case of the LCA) and compare it to ammonia fuelled tractor. The Total Cost of Ownership (TCO) is defined as the sum of the costs for: acquisiton of the vehicle, exploitation and end of life. The first part is the estimation of the cost of ammonia production which depends on its source.

The general equation 1 presents the approach to estimating the costs for ammonia produced from natural gas (steam methane reforming):

$$TC = FC + VC + CCSC = FC + A \cdot NG_C + B + CCSC \tag{1}$$

where: TC - total cost, FC - fixed cost, VC - variable cost, CCSC - cost for carbon capture and storage, A,B - coefficients for empirical function describing the variable costs depending on the price of natural gas based on the [1]. All the costs are expressed in USD/tNH3.

The idea is that the price of natural gas is the most important variable determining the final cost for ammonia, all other costs are approximated and they are contained within the empirical coefficients. It is assumed that CCSC is a fixed cost expressed per tonne of NH3 (for the case of grey ammonia the value of CCSC equals 0). The values for fixed costs are estimated based on the [2], the coefficients for variable costs are based on [1].

The approach to estimation of cost for green ammonia is presented in the equation 2, which is essentially the same as in case of the equation 1.

$$TC = FC + VC = FC + A \cdot EL_C + B \tag{2}$$

The difference is that the cost depends on the price of electrical energy. The fixed cost depends on the type of electrolyser, based on low and high cost for electrolyser (455 and 894 USD / tNH3), from [1], an average value of 674.5 USD/kWe has been used for further calculation (electrolyser capex). The empirical values of coefficients of A and B are taken again from the [1].

Collating all of these prices using USD/MJ (LHV) allows for obtaining the figure 2. SMR (steam methane reforming) as low regards to the 3 $/MMBtu, high regards the 10 $/MMBtu. Diesel low regards the 75 USD/bbl, high regards the 150 USD/bbl. All of the values refer to the spot price. From the graph, it is seen that the cost of electrolysis would need to reach below 18.1 USD/MWh to compete with diesel at 75 USD/bbl which seems extremely unlikely. However, since the cost of diesel has been recently growing, the cost of electrolysis below 46 USD/MWh for diesel at 150 USD/bbl could be possible thus making the ammonia economically competetive.

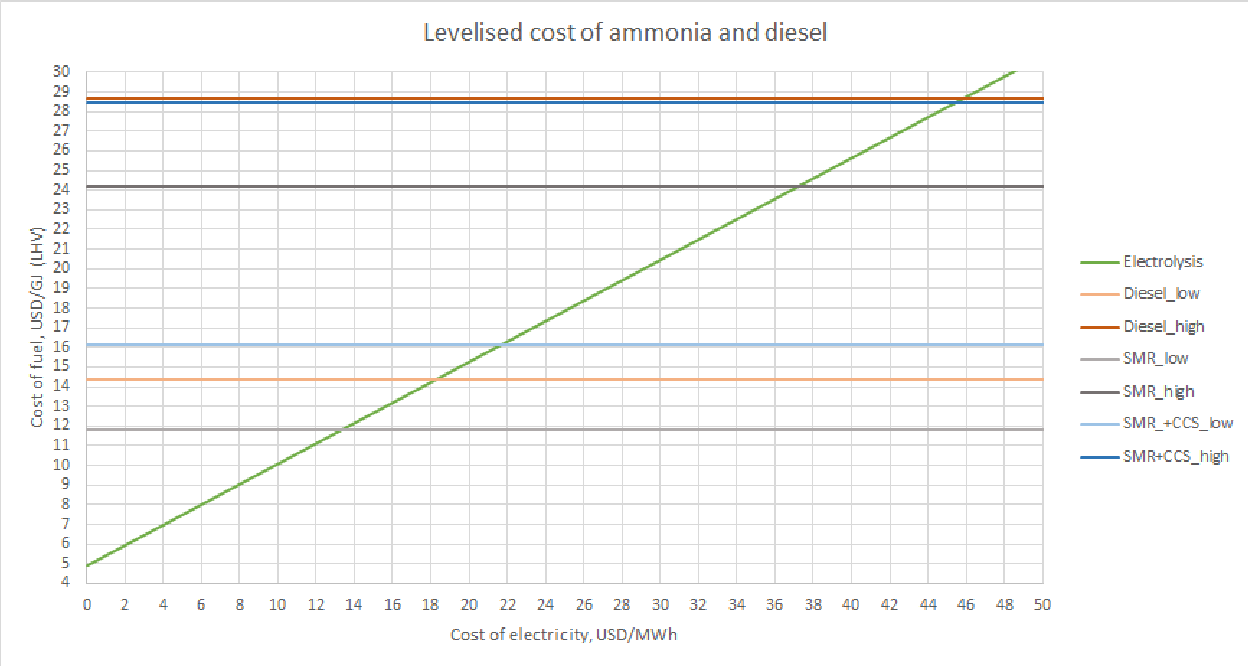

Figure 1: Break-point cost of fuels comparison.

2 Case study of a tractor

Table 1 presents the assumptions of the case study of economic assessment of the tractor. It uses the cost of acquistion of the tractor based on the market data, other parameters have been selected arbitrarily. Modernization cost is a cumulative term including the costs for: ammonia tank, fuel line, controllers, assembly and the SCR. The price for the ammonia tank has been taken from the market data, SCR from the literature [3] (extrapolating the data for 1l engine), the rest takes value of the LPG adaption system to the passenger vehicle (the approach consulted with the WP2). The detailed value for port injection system has not been obtained based on the WP2 due to lack of the data as the engine has been installed on a test rig, installing the real case on a demonstrator vehicle will allow for estimation of realistic value.

Incorporating the assumptions from 1 into the assessment considering different fuelling systems allows for calculation of TCO, presented in table 2. The operation phase has been calculated using the requirements for the fuels based on the experimental data (however it does not include the costs for orchard activities such as exploitation of additional equipment as is placed outside the scope of this assessment). The price for the end of life has been taken from the [4] as a part of the acquisition cost (20%).

Table 1: Assumptions for the economic case study.

Economic data	Value	Unit
Timeframe	10	year
Acquisition cost (net)	2230	USD
Retail/spot price ratio	30.00%	
Tax (on vehice)	23.00%	
Financing acquisition		
Credit (rest - equity)	50.00%	
Timeframe for credit	5	years
Credit interest rate	8.00%	
Cost increments		
Annual diesel cost increment	1.50%	
Annual ammonia cost decrement	-1.00%	
Modernization costs	2754.9	USD
Ammonia tank	416.9	USD
SCR	578	USD
Other costs (fuel line, controllers, assembly, common rail)	1760	USD

The following considerations regarding the price of fuels have been used (all of the values regard the July 2022):

1. Diesel price is taken from [5] as an average from New York Harbour, U.S. Golf Coast and Los Angeles from statistical data (spot price) and is equal to 3.65 USD/gallon.
2. Biodiesel price is taken from [6] the report and is equal to 5.34 USD/gallon (retail price, recalculated to spot price using the ratio as in 1).
3. Natural gas price is taken from the statistics [7] for Henry Hub and equals to 7.28 USD / Million Btu.
4. Electricity price is taken from the [8] and it is equal to 94.3 USD/MWh.

The summary of TCO comparison is presented graphically in the figure 2. The highest value of the TCO is obtained for green ammonia and diesel, the lowest for the pure diesel.

Table 2: Economic case study results.

	NG cost, USD/ MMBtu	Electricity cost, USD/ MWh	Price of pilot fuel, USD/l	Price of ammonia, USD/l	Operation phase cost, USD	Acquistion cost (inc. credit), USD	EoL (part of acq. cost), USD	Total Cost of Ownership, USD
Pure diesel	-	-	0.96	-	1060.19	3072.05	614.41	4746.65
Pure biodiesel	-	-	0.99	-	1229.92	3072.05	614.41	4916.38
Grey ammonia + biodiesel	7.28	-	0.99	0.25	921.30	6157.54	1231.51	8310.35
Blue ammonia + biodiesel	7.28	-	0.99	0.30	982.93	6157.54	1231.51	8371.97
Green ammonia + biodiesel	-	94.30	0.99	0.68	1414.27	6157.54	1231.51	8803.32
Grey ammonia + diesel	7.28	-	0.96	0.25	906.43	6157.54	1231.51	8295.47
Blue ammonia + diesel	7.28	-	0.96	0.30	968.06	6157.54	1231.51	8357.10
Green ammonia + diesel	-	94.30	0.96	0.68	1399.40	6157.54	1231.51	8788.45

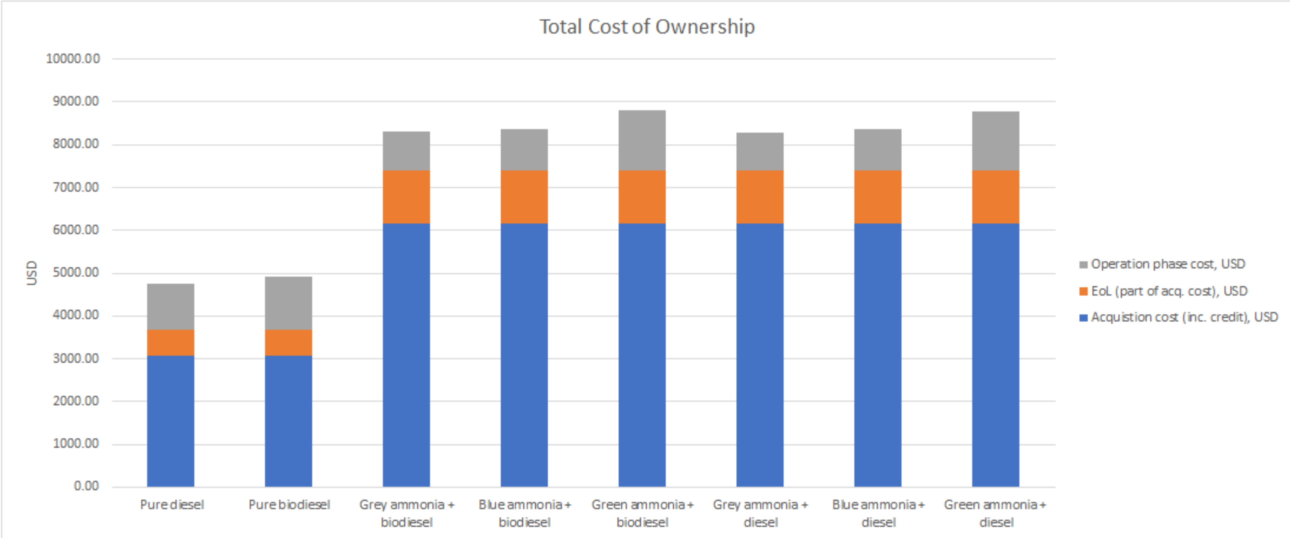

Figure 2: Economic results.

3 Conclusions

The lowest price for diesel tractor is naturally due to maturity of the technology and availability of the fuel, however the increasing price of diesel with the parallel decrease price of alternative sources of energy (such as ammonia) could make it competitive, as explained in the section 1, if the price of renewable electricity reaches below 46 USD/MWh. The results presented in the table 2 and figure 2 refer to the particular case study using statistical data from the U.S. for the period July 2022. The purpose of the case study was to illustrate that current prices still favor the conventional solutions and therefore improvements in terms of modernization of the engine are needed for the vehicle to be competitive. Still, relatively small differences in terms of the operation phases indicate the ammonia to be a promising solution from the profitability point of view. The assessment regards the port injection technology, the WP5 will verify these assumptions in terms of direct injection.

References

[1] Future of hydrogen. *Seizing today's opportunities, Report prepared by the IEA for the G20, Japan.*, page 107, 2019.

[2] B. Shiozawa. The cost of co2-free ammonia. *Ammonia Energy Association*, 2020. [Online; accessed 19-September-2022]. URL: https://www.ammoniaenergy.org/articles/the-cost-of-co2-free-ammonia/.

[3] Sarah Chambliss Francisco Posada and Kate Blumberg. Cost of emission reduction technologies for heavy-duty diesel vehicles. *The Internation Council of Clean Transportation*, page 7, 2016.

[4] J. Ally and T. Pryor. Life cycle costing of diesel, natural gas, hybrid and hydrogen fuel cell bus systems: An Australian case study. *Energy Policy*, 94:285–294, 2016. URL: http://dx.doi.org/10.1016/j.enpol.2016.03.039.

[5] Petroleum and other liquids. *U.S. Energy Information Administration.* [Online; accessed 19-September-2022]. URL: https://www.eia.gov/dnav/pet/pet_pri_spt_s1_m.htm.

[6] Clean cities alternative price fuel report. *U.S. Department of Energy.* [Online; accessed 19-September-2022]. URL: https://afdc.energy.gov/files/u/publication/alternative_fuel_price_report_july_2022.pdf.

[7] Natural gas. *U.S. Energy Information Administration.* [Online; accessed 19-September-2022]. URL: https://www.eia.gov/dnav/ng/ng_pri_fut_s1_m.htm.

[8] Electric power monthly. *U.S. Energy Information Administration.* [Online; accessed 19-September-2022]. URL: https://www.eia.gov/electricity/monthly/epm_table_grapher.php?t=epmt_5_6_a.