Specific report for discussion paper "Developing a modern renewable fuel standard for gasoline in Ontario"

Ammonia (NH_3) as a Potential Transportation Solution for Ontario

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INTRODUCTION

Ammonia as a Carbon-Free Fuel for Use in the Transportation Sector

The action plan lays out the specific commitments Ontario is making to meet its 15% overall greenhouse gas emissions reduction target by 2020. Emissions from total passenger transportation (cars, trucks, bus, rail and domestic aviation) have grown almost 15% since 1990, to 36 million tonnes of CO_2e, approximately 66% of Ontario's 2014 transportation emissions. This growth was driven by an increase in vehicle-kilometres travelled as well as a shift in the composition of the fleet from cars to sport-utility vehicles, pick-ups and minivans where the specific contributions of the vehicle types are shown in Fig 1.

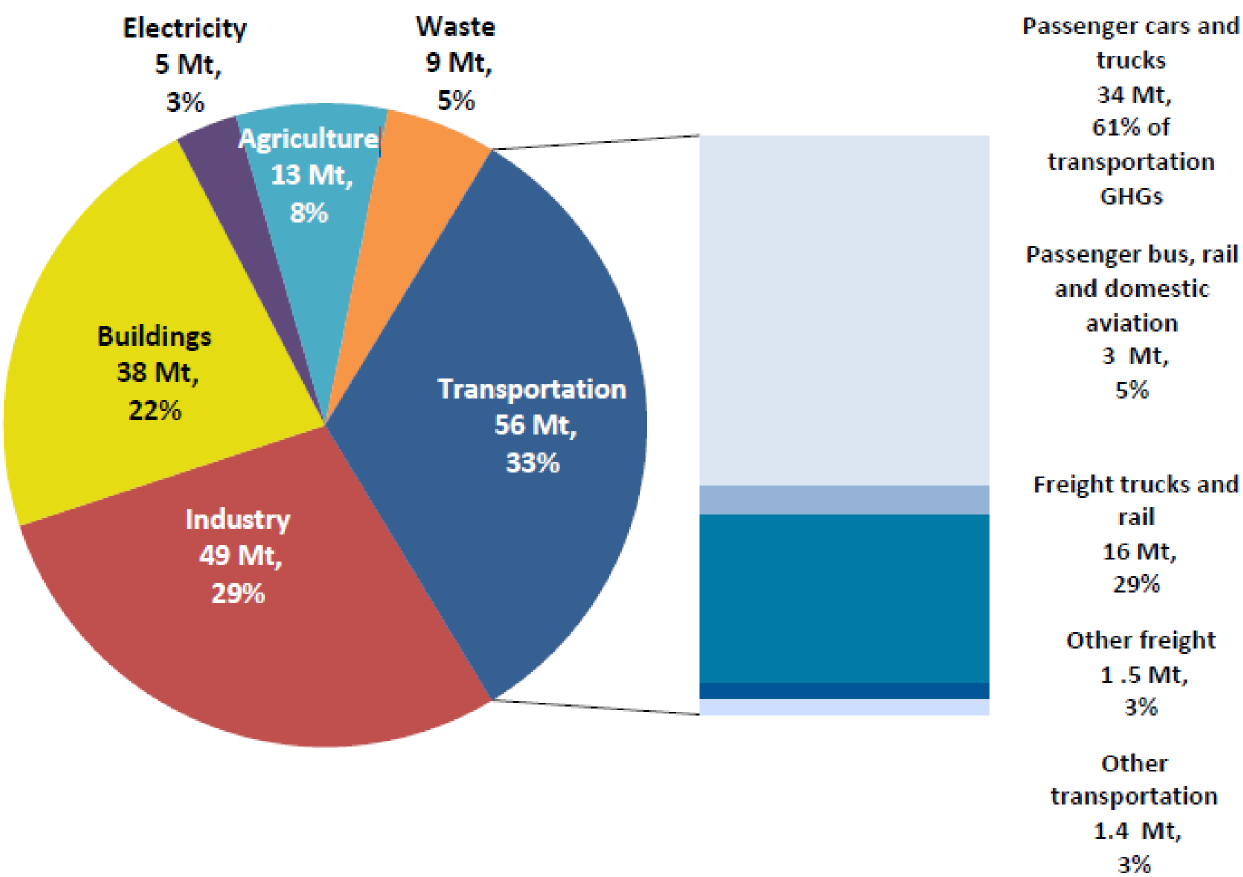

Fig. 1. Ontario's greenhouse gas emissions in 2014 (data from Ref. 1).

Here, it is important to note that under Environment and Climate Change Canada's economic sector categorization, most off-road transportation emissions are allocated to their host economic sectors and consequently are not included under transportation in Fig. 1. For example, emissions from diesel combustion in farm equipment are categorized under Agriculture. Therefore, in reality GHG emissions caused by the transportation vehicles are higher than 33% in Ontario.

Additionally, emissions from total freight transportation (trucks, rail and other) have increased more drastically over the period, rising 85% since 1990, to almost 18 million tonnes of CO_2e (approximately one third of Ontario's current transportation emissions). This was driven by a significant increase in the use of diesel-fuelled heavy-duty trucks, with additional kilometres travelled offsetting improvements in efficiency [1].

This brief report tries to address the following points:

1. Targets and blending requirements:
   a. Ontario's has existing content requirements for ethanol in gasoline. What minimum level of ethanol blending and GHG performance would help support the objectives of the RFS?
   b. Given Ontario's GHG reduction targets for 2030 and 2050, what factors should be considered in setting RFS targets post-2020?
2. Flexibility mechanisms:
   a. Should activities to lower the carbon intensity of other conventional transportation fuels be eligible for compliance purposes?
   b. Should investments in low-carbon transportation projects also be eligible for compliance purposes? If yes, what types of projects?
3. Assessing lifecycle emissions
   a. Should an RFS consider impacts from indirect land-use changes (ILUC),7 even though science in this area continues to evolve? If so, how?
4. Transparency:
   a. What measures can be taken to increase transparency and support business decision making under an RFS (e.g. an information registry, bulletins, guidance material)?
5. Others:
   a. What other considerations should be included in the discussion?

AMMONIA FACTS

Ammonia is one of the largest synthesized industrial chemical in the world having over 200 million tonne per production per year.

Ammonia (NH_3):

- consists of one nitrogen atom from air separation and three hydrogen atoms from any conventional or renewable resources.
- is the second largest synthesized industrial chemical in the world.
- is a significant hydrogen carrier and transportation fuel that does not contain any carbon atoms and has a high hydrogen ratio.
- contains about 48% more hydrogen by volume than liquefied hydrogen.
- does not emit direct greenhouse gas emission during utilization
- can be used as solid and/or liquid for many purposes.
- can be stored and transported under relatively lower pressures.
- can be produced from various type of resources ranging from oil sands to renewables.
- is a suitable fuel to be transferred using steel pipelines with minor modifications which are currently used for natural gas and oil.
- can be used in all types of combustion engines, gas turbines, burners as a sustainable fuel with only small modifications and directly in fuel cells which is a very important advantage compared to other type of fuels.
- brings a non-centralized power generation via fuel cells, stationary generators, furnaces/boilers and enables smart grid applications.
- can be used as a refrigerant for cooling in the car.

WHAT ARE THE USES OF AMMONIA?

Ammonia is considered a possible working fluid for thermodynamic cycles, working for refrigeration, heating, power or any mixture of those can be coupled with internal combustion engines, and using exhaust gasses to drive automotive absorption refrigeration system.

Ammonia has been recognized and employed as a leading refrigerant in the industrial sector due to its outstanding thermal properties, zero ozone depletion and global warming potential (GWP). Ammonia has the highest refrigerating effect per unit mass compared to all the refrigerants being used including the halocarbons. The remarkable advantages of ammonia over R-134a could be lower overall operating costs of ammonia systems, the flexibility in meeting complex and several refrigeration needs, and lower initial costs for numerous applications. Ammonia has better heat transfer properties than most of chemical refrigerants and consequently allow for the use of equipment with a smaller heat transfer area. Thereby plant construction cost will be lower. But as these properties also benefit the thermodynamic efficiency in the system, it also reduces the operating costs of the system. In many countries the cost of ammonia per mass is considerably lower than the cost of HFCs. This kind of advantage is even multiplied by the fact that ammonia has a lower density in liquid phase. Modern ammonia systems are fully contained closed-loop systems with fully integrated controls, which regulate pressures throughout the system. Ammonia is used as refrigerant highly in the refrigeration structures of food industry like dairies, ice creams plants, frozen food production plants, cold storage warehouses, processors of fish, poultry and meat and a number of other uses.

It is also stimulating to note that NH_3 is a reduction agent for the NOx typically current in combustion releases. The reaction of NOx with ammonia over catalysts produces only steam and nitrogen. An average car needs only approximately 30 ml of NH_3 per 100 km to neutralize any NOx emissions. If the vehicles run with NH_3 as fuel, this amount is unimportant with respect to the fuel tank volume.

Ammonia is used as fertilizer in the agriculture. It is also converted into urea by reacting with CO_2. The majority of growth in ammonia usage is expected to be for industrial uses and the production of fertilizer products.

It is also worth to examine the option to cool the engine with ammonia that can act as a refrigerant while it is heated to the temperature at which it is fed to the power producer (ICE or fuel cell). Optionally, the cooling outcome of ammonia, i.e., its high latent heat of evaporation, may be used to harvest some air conditioning onboard.

IS AMMONIA REALLY A FUEL?

Ammonia as a sustainable fuel can be used in all types of combustion engines, gas turbines, and burners with only small modifications and directly in fuel cells. Ammonia was initially used as a fuel for buses in Belgium in 1940s [2]. Many studies have already been performed and many applications have been implemented so far. A prototype unit for combustion which enabled liquid kerosene and gaseous ammonia to be fed, and ammonia was combusted in a gas-turbine unit. Further studies have been performed by various researchers which have proven the practicality of using ammonia as fuel [3-10]. Numerical studies of combustion characteristics of ammonia as a renewable fuel have been conducted. Ammonia can also be used a fuel blending option for current gasoline and diesel engines. Combustion and emissions characteristics of compression-ignition engine using dual ammonia-diesel fuel have been performed. Performance enhancement of ammonia-fueled engine by using dissociation catalyst has been studied. These are just a few examples to show the current progress in the ammonia utilization options in transportation applications.

IS AMMONIA A SUITABLE FOR TRANSPORTATION SECTOR?

The storage and delivery infrastructure of ammonia is similar to liquefied petroleum gas (LPG) process. Under medium pressures (5-15 bar), both of the substances are in liquid form which brings the significant advantage because of storage benefits. Today, vehicles running with propane are mostly accepted and used by the public since their on-board storage is possible and it is a good example for ammonia fueled vehicle opportunities since the storage and risk characteristics of both substances are similar to each other. An ammonia pipeline from the Gulf of Mexico to Minnesota and with divisions to Ohio and Texas has served the ammonia industry for many years. It indicates that there is a working ammonia pipeline transportation which can be spread overall the world. The potential of ammonia usage in many applications will be dependent on the availability of ammonia in the cities. Ammonia is a suitable substance to be transferred using steel pipelines with minor modifications which are currently used for natural gas and oil. In this way, the problem of availability of ammonia can be eliminated.

HOW CAN AMMONIA BE USED IN TRANSPORTATION?

Ammonia has significant potential as an alternative fuel to further the sustainable development of transportation sector. A few of the following alternatives are shown in Fig. 2 for direct ammonia usage in transportation applications.

Currently, the majority of the locomotive fleet is made up of diesel-electric locomotives, operating with either two-stroke or four-stroke prime mover diesel engines that is coupled to an electric generator. Application of ammonia fuel for internal combustion engine (ICE) with the alternative locomotive configurations direct feed, or a combination of direct feed and decomposition subcategory options will bring more sustainable solutions. Additionally, fuel cell driven vehicles and locomotives may contribute to solve the associated matters of urban air superiority and national energy security influencing the rail and transportation sector.

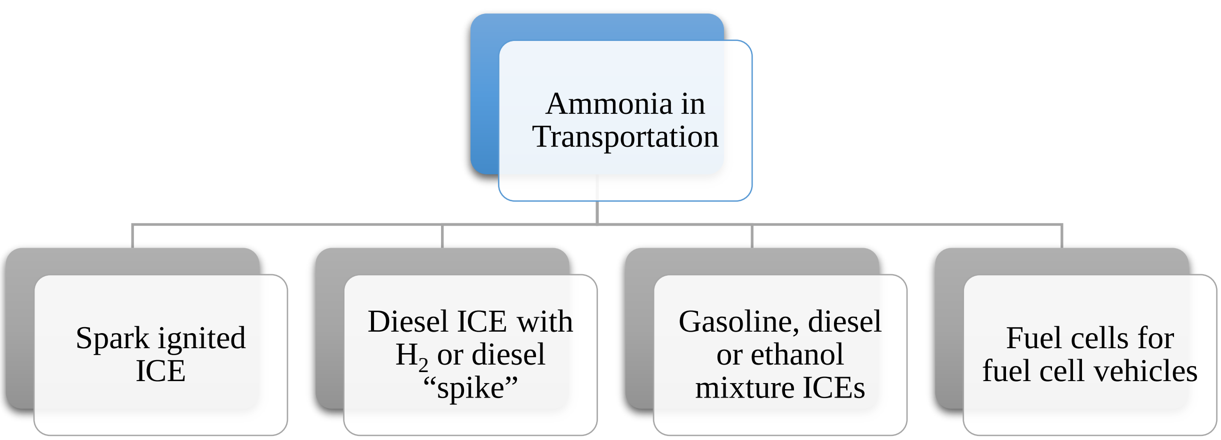

Fig. 2. Ammonia utilization options in transportation sector

IS AMMONIA A CLEAN FUEL?

Compared to gasoline vehicles, ammonia-fueled vehicles do not produce direct CO_2 emission during operation. Since ammonia produces mainly water and nitrogen on combustion, replacing a part of conventional fuel with ammonia will have a large effect in reducing carbon dioxide emissions.

WHAT FACTORS SHOULD BE CONSIDERED IN SETTING RFS TARGETS POST-2020?

- Environmental impact (including the indirect land-use changes)
- Cost
- Availability of clean production routes (e.g. solar, hydropower, wind)
- Blending properties (e.g. combustion characteristics)
- Fuel production life cycle emissions
- Fuel storage and transport infrastructure
- Integrability
- Multi-purpose usage (e.g. power, cooling, heating)

WHICH ENVIRONMENTAL IMPACTS SHOULD BE CONSIDERED?

A life cycle is the set of phases of a product or service system, from the extraction of natural resources to last removal. Overall environmental impact of any process is not complete if only operation is considered, all the life steps from resource extraction to disposal during the lifetime of a product or process should be considered. The selection of future vehicle options can strongly depend on the emission characteristics. As the world struggles with greenhouse gas emission reduction policies, global warming potential is the main characteristics to compare the total CO_2 equivalent emission from the alternative vehicles. Abiotic depletion, human toxicity, ozone layer depletion appear to play an important role for decision of using clean transportation vehicles because there are vast amount of road vehicles in the cities which can cause severe side effects. Moreover, when considering alternative fuels, issues such as land use, fertilizer use, water for irrigation, waste products etc. are necessary points to be addressed. Therefore, indirect land-use changes (ILUC) should be also considered. Indirect land-use changes can also have important social and environmental impacts which can include biodiversity, water quality, food prices and supply, community and cultural stability. Assessing the indirect land-use changes is a knowns as challenging topic. Some methods of quantifying indirect land-use changes can be listed as follows:

- Implementing empirical calculations based on previously experienced indirect land-use changes
- Developing life cycle analyses methodology with lower uncertainty ranges
- Developing integrated models combining the life cycle, sustainability, efficiency, social cost etc.

The following environmental impact categories represent higher significance in life cycle assessment approach, hence suggested to be included in decision making processes:

- Global warming potential is the main characteristics to be compare the total CO_2 equivalent emission from any source.
- Abiotic resources are natural resources including energy resources. Since fossil fuels resources are declining gradually, abiotic depletion potential is also a significant category.
- Human toxicity may play an important role for decision of using alternative fuels.
- Acidification potential is for acidifying substances which causes a wide range of impacts on soil, groundwater, surface water, organisms, ecosystems and materials.
- Marine aquatic eco-toxicity refers to impacts of toxic substances on marine aquatic ecosystems which is more important for maritime transportation sector.
- Land occupation/land use refers to the total arrangements, activities and inputs undertaken in a certain land cover type. The term land use is also used in the sense of the social and economic purposes for which land is managed.

HOW MUCH GREENHOUSE GAS CAN I SAVE IF I DRIVE AN AMMONIA CAR?

Considering a complete life cycle counting the production, transport and usage of the fuel, a diesel driven car can emit greenhouse gas emissions of about 220 g per km. Ammonia driven car can decrease this number down to about 70 g per km if it is produced from solar energy and about 150 g per km if it is produced from hydrocarbon cracking.

IS AMMONIA A COST EFFECTIVE FUEL?

The illustrative cost comparison of various fueled vehicles is shown in Fig. 3 and 4. Considering the current market prices of the fuels, ammonia is the lowest cost fuel corresponding to about 3.1 US$ in a 100 km driving range. This shows that ammonia is a promising transportation fuel in terms of cost. There is an advantage of by-product refrigeration which reduces the costs and maintenance during vehicle operation. Some additional advantages of ammonia are commercial availability and viability, global distribution network and easy handling experience. Ammonia is a cost effective fuel per unit energy stored onboard compared to methanol, CNG, hydrogen, gasoline and LPG as shown in Fig. 3.

In Table 1, the exact fuel energy per mass is given regarding fuel's higher heating value. The volumetric energy of the fuel is found by multiplying the HHV with the density value listed in the third column. Ammonia's HHV is around half of the one of gasoline, and its density is also inferior. Therefore liquid NH_3 stores 2.5 fewer energy per unit capacity than gasoline. If the NH_3 is stored in the form of hexaamminemagnesium chloride to remove the hazard related to its toxicity, the energetic cost to pay for discharging ammonia reduces its HHV. Among alternative fuels, ammonia yields the lowest cost per energy basis. Therefore, it is important to note that low-carbon transportation projects should be eligible for compliance purposes.

Table 1. Comparison of ammonia with other fuels

Fuel/storage	**Pressure (bar)**	**Density (kg m^{-3})**	**HHV (MJ kg^{-1})**	**HHV per Volume (GJ m^{-1})**	**Energy per Volume (GJ m^{-1})**	**Cost per Mass (US$ kg^{-1})**	**Cost Per Volume (US$ m^{-1})**	**Cost per Energy (US$ GJ^{-1})**
Gasoline, C_8H_{18}/liquid	1	736	46.7	34.4	34.4	1.03	754.86	21.97
CNG, CH_4/integrated storage	250	188	42.5	10.4	7.8	0.91	170.60	21.29
LPG, C_3H_8/pressurized tank	14	388	48.9	19	11.7	1.06	413.66	21.74
Methanol, CH_3OH/liquid	1	786	14.3	11.2	9.6	0.41	317.80	28.31
Hydrogen, H_2/metal	14	25	142	3.6	3	3.02	75.49	21.29

hydrides								
Ammonia, NH_3/pressurized tank	10	603	22.5	13.6	11.9	0.23	136.63	10.04
Ammonia, NH_3/metal amines	1	610	17.1	10.4	8.5	0.23	138.14	13.21

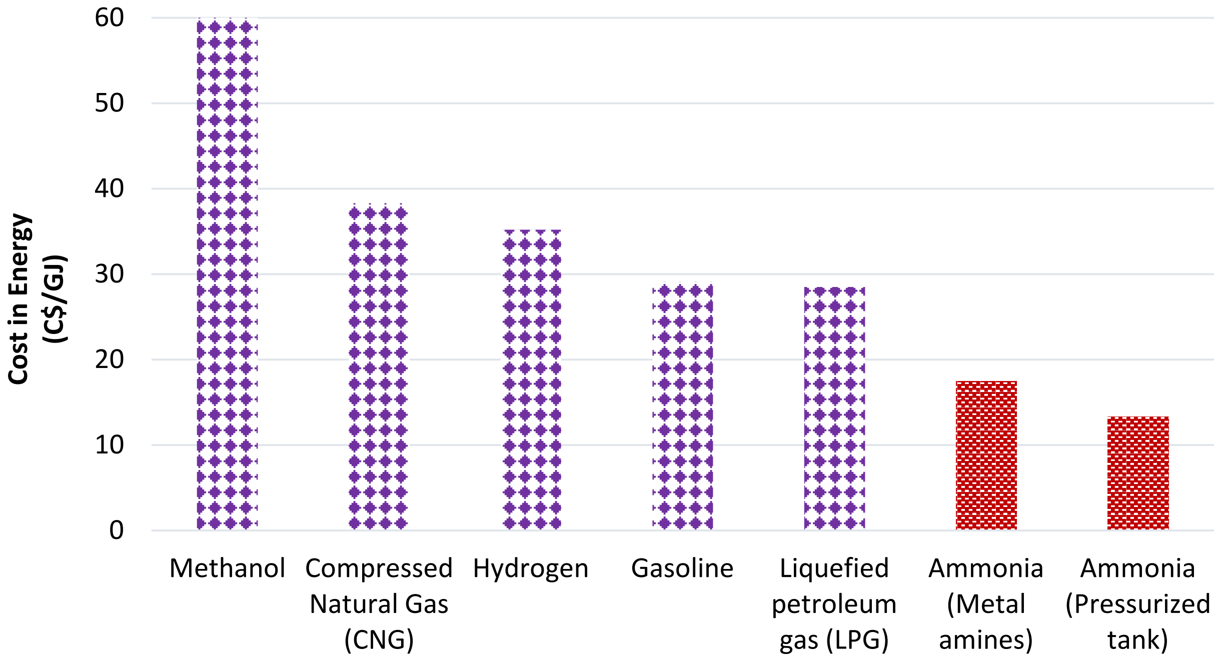

Fig. 3. Comparison of various vehicle fuels in terms of energy cost per gigajoule

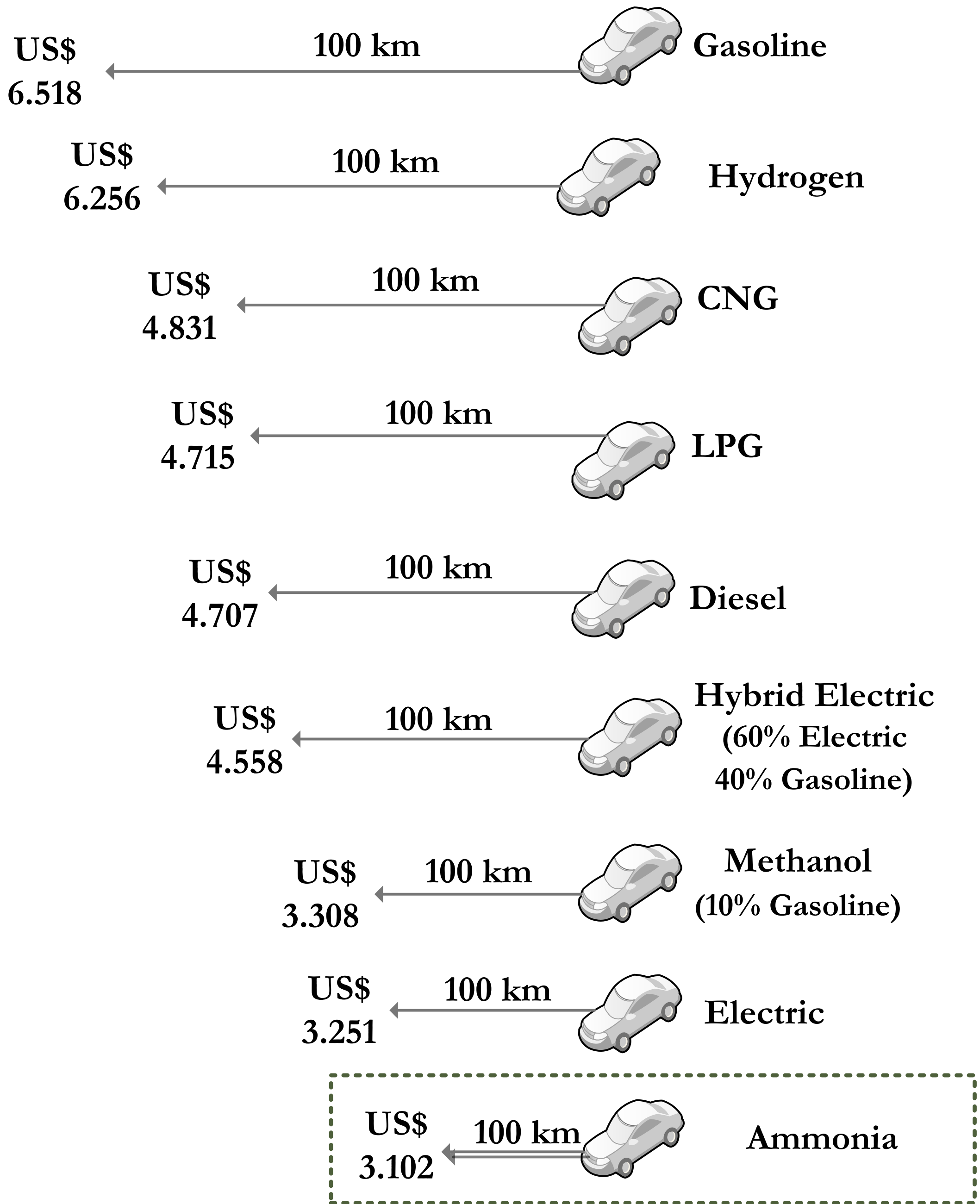

Fig. 4. Comparison of driving cost for various fueled vehicles

WHAT IS THE PROCESS OF AMMONIA PRODUCTION?

A most common ammonia synthesis technique is recognized as Haber-Bosch process in the world. In this process, nitrogen is supplied through air separation process. Hydrogen is mainly supplied using steam methane reforming or coal gasification. However the source of hydrogen can be renewable resources. The Haber-Bosch is an exothermic process that combines hydrogen and nitrogen in 3:1 ratio to produce ammonia. The reaction is facilitated by catalyst and the optimal temperature range is 450-600°C.

Alternative production pathways are also available and under investigation including electrochemical and biological routes. These routes can easily be integrated to renewable energy sources for cleaner production. The electrochemical process can be carried out under ambient conditions or at higher temperatures depending on the type of the electrolyte material used. There are various electrochemical pathways such as molten salt, polymer membrane, liquid electrolyte etc. are intensively being researched at the moment [11-16].

The electrochemical process can be carried out under ambient conditions or at higher temperatures depending on the type of the electrolyte material used. For high temperature electrolytic routes of ammonia production, the use of waste heat from thermal or nuclear power plants or heat from renewable energy sources like solar would make the overall process more environmentally friendly.

One of the key advantages of ammonia is to be a storage medium. Renewable energy generation does not often match electrical demand which causes a requirement of storage. Green ammonia can be manufactured from surplus renewable sources, which would reduce the amount of electricity exported to neighboring jurisdictions at a negative cost.

WHAT IS THE SOURCE OF AMMONIA AND IS IT CLEANER THAN OTHER FUELS?

In terms of conventional resources, naphtha, heavy fuel oil, coal, natural gas coke oven gas and refinery gas can be used as feedstock in ammonia production. Natural gas is the primary feedstock used for producing ammonia in worldwide corresponding to about 72%. However, renewable resources can easily be integrated for ammonia production. In this way, decentralized ammonia production can be realized which further decreases the delivery cost of the fuel. Many studies have been performed to investigate the ammonia production routes and their environmental impacts. Here, some of them are briefly shown.

The production of the different fuels is compared in terms of abiotic depletion of sources as shown in Fig. 5. Ammonia fuel has the lowest abiotic depletion value compared to others although the production process may be fossil fuel based. There are multiple pathways for ammonia production. Ammonia is cleaner when produced from renewable resources. Fig. 6 shows the comparison of ozone layer depletion values for various transportation fuels. Ammonia has lowest ozone layer depletion even if it is produced from steam methane reforming and partial oxidation of heavy oil.

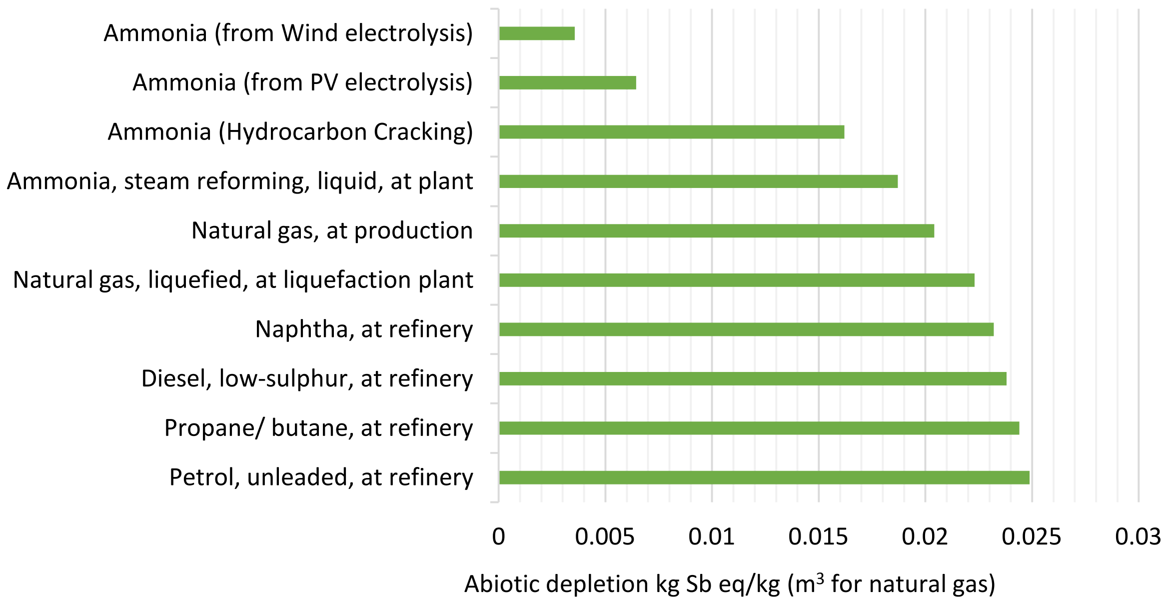

Fig. 5. Abiotic depletion values during production of various fuels

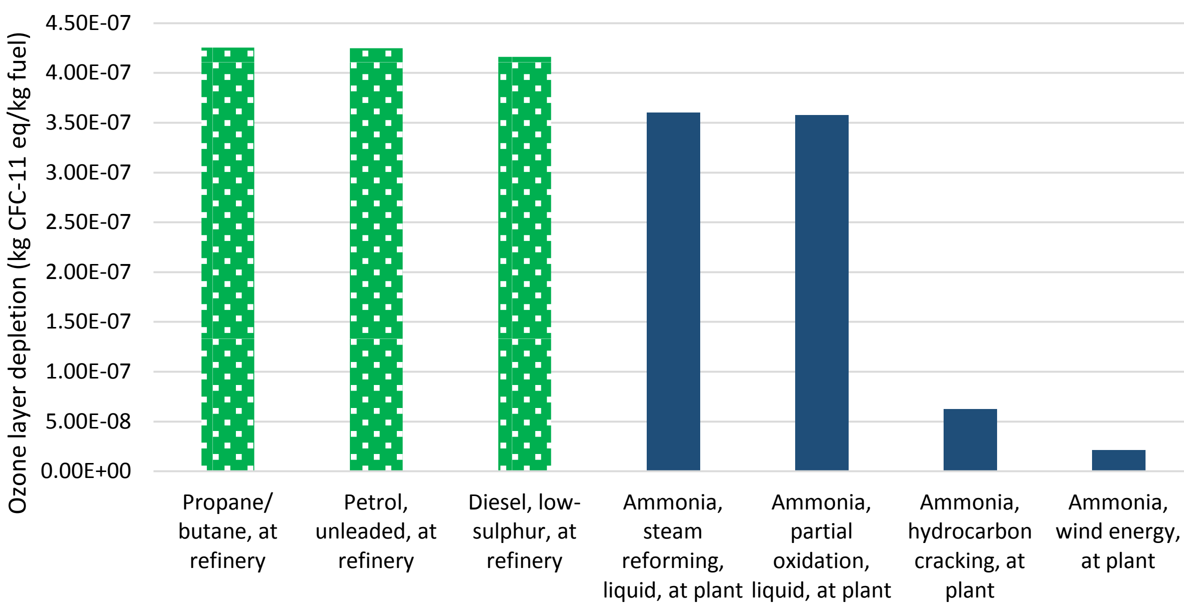

Fig. 6. Ozone layer depletion during productions of various fuels

Fig. 7 compares the total greenhouse gas emissions during production of 1 MJ energy from various resources including gasoline, LPG, diesel, natural gas and ammonia. Production of 1 MJ energy from ammonia has lower emissions than gasoline, LPG, diesel, oil and natural gas.

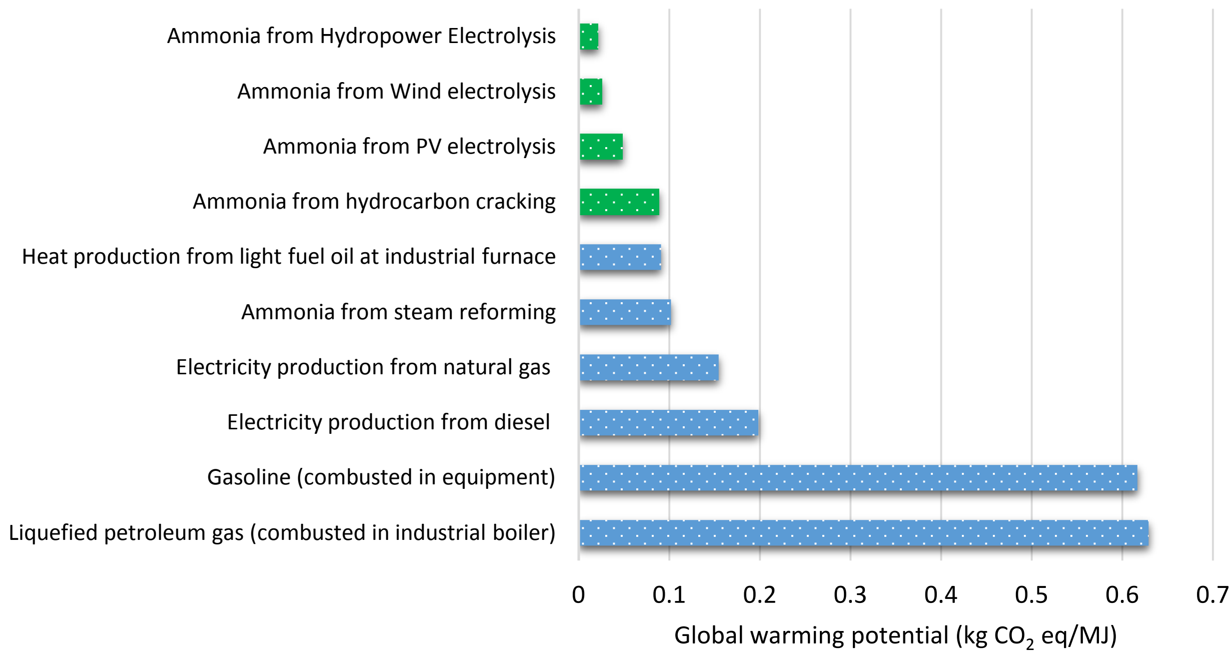

Fig. 7. Comparison of global warming potential of 1 MJ energy production from various resources

Giving priority for complete conversion from fossil fuel based fuels to carbon-free fuels will bring short term and long term solutions to combat global warming. Therefore, the activities to lower the carbon intensity of conventional transportation fuels be eligible for compliance purposes

AMMONIA IN ROAD TRANSPORTATION

Assessing the life cycle emissions from vehicles is a powerful method for transportation sector. The usage of fossil fuel based electricity decreases the attractiveness of electric (EV) and hybrid electric (HEV) vehicles. Henceforth, noteworthy attention should be paid to the power generation technologies and their CO_2 intensity, used to supply electricity to EVs or HEVs. The

GHG emissions of EVs and HEVs are therefore dependent on the CO_2 intensity of the energy mix and differs based on the countries. A characteristic life cycle of a vehicle technology can be categorized into two main steps, namely fuel cycle and vehicle cycle. In the fuel cycle, the processes beginning from the feedstock production to fuel utilization in the vehicle are considered. In the vehicle cycle, utilization of fuel is considered. Among the selected categories, global warming, abiotic depletion and human toxicity results carry more significant decision parameters for road vehicles. The results presented here are given on per km basis based on the fuel consumption rates given in Table 2.

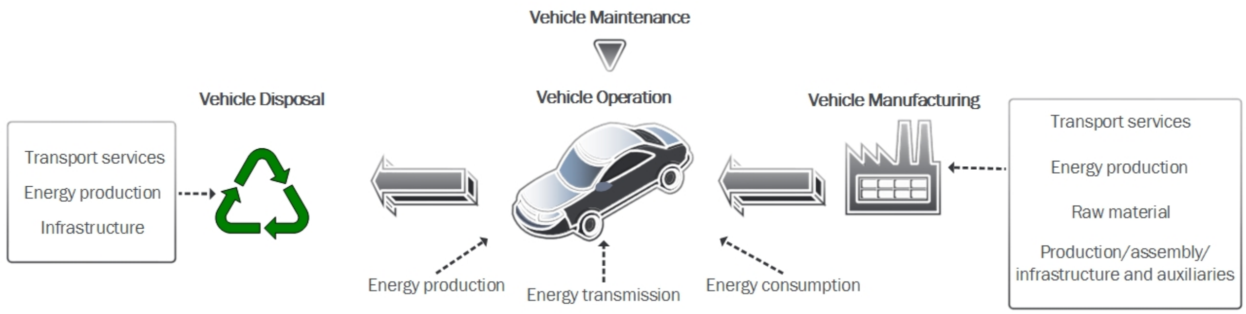

Fig. 8. Complete life cycle of vehicles including fuel/vehicle cycle.

Table 2. Energy consumptions per km for the selected vehicles

Fuel		**Fuel/Energy Consumption**	**Unit**
Gasoline		0.0649108	kg/km
Diesel		0.0551536	kg/km
M90	Methanol	0.1180535	kg/km
	Gasoline	0.0060664	kg/km
Hydrogen		0.0195508	kg/km
Ammonia		0.0926600	kg/km
EV		0.2167432	kWh/km
HEV	Electric	0.1083716	kWh/km
	Gasoline	0.0324554	kg/km
CNG		0.0603914	kg/km
LPG		0.057629687	kg/km

The specific conditions for the selected vehicles are presented herein:

- Gasoline: All processes on the refinery site excluding the emissions from combustion facilities, including waste water treatment, process emissions and direct discharges to rivers are accounted for. The inventory data also includes the distribution of petroleum product to the final consumer including all necessary transports. Transportation of product from the refinery to the end user is considered together with operation of storage tanks and petrol stations. Emissions from evaporation and treatment of effluents are accounted for. Particulate emissions cover exhaust- and abrasions emissions.
- Diesel: Diesel is evaluated as low-Sulphur at regional storage with an estimation for the total conversion of refinery production to low-Sulphur diesel. An additional energy use (6% of energy use for diesel production in the refinery) has been estimated. The other processes are similar to gasoline. Particulate emissions cover exhaust- and abrasions emissions.
- CNG: Natural gas with a production mix at service station is taken into account. The inventory data contains electricity necessities of a natural gas service station together with emissions from losses. The data set represents service stations with high (92%), medium (6%) and low (2%) initial pressure. VOC emissions are obtained from gas losses and contents of natural gas. Particulate emissions cover exhaust- and abrasions emissions.
- Hydrogen: Hydrogen is produced during cracking of hydrocarbons. It includes combined data for all processes from raw material extraction until delivery at plant. The output fractions from an oil refinery are composite combinations of mainly unreactive saturated hydrocarbons. The first processing step in converting such elements into feedstock suitable for the petrochemical industries is cracking. Essentially a cracker achieves two tasks in (i) rising the complexity of the feed mixture into a smaller number of low molecular mass hydrocarbons and (ii) presenting unsaturation into the hydrocarbons to enable more reactivity. The raw hydrocarbon input from the refinery is fed to the heater unit where the temperature is increased. The forming reaction products vary based on the composition of the input, the temperature of the heater and the residence time. The cracker operator selects temperature and residence time to enhance product mix from a supplied input. Cracker feeds can be naphtha from oil refining or natural gas or a mixture of both. After exiting the heater, the hydrocarbon gas is cooled to prevent extra reactions. After that, it is sent to the separation phase where the individual hydrocarbons are separated from one another by fractional distillation. Particulate emissions cover exhaust- and abrasions emissions. In order to have comparable results where hydrogen

comes from non-fossil fuels such as solar PV and nuclear, they are also taken into account in the analyses by applying water electrolysis route. The electrolyzer is assumed to consume about 53 kWh electricity for one kg of hydrogen production.

- Ammonia: Ammonia synthesis process is Haber-Bosch which is the most common method in the world. Ammonia production requires nitrogen and hydrogen. In this study, hydrogen is assumed to be from hydrocarbon cracking as explained in the previous paragraph. Cryogenic air separation is mostly used method for massive amount of nitrogen production. In the life cycle assessment of nitrogen production, electricity for process, cooling water, waste heat and infrastructure for air separation plant are included. Haber-Bosch process is an exothermic method that combines hydrogen and nitrogen in 3:1 ratio to produce ammonia. The reaction is facilitated by catalyst (iron-oxide based) and the optimal temperature range is 450-600°C. Particulate emissions cover exhaust- and abrasions emissions. In order to have comparable results where ammonia comes from non-fossil fuels such as solar PV and nuclear, they are also taken into account in the analyses. The generated hydrogen from electrolyzers are used for ammonia synthesis plant.
- EV: Electricity consumption is included. Particulate emissions comprise exhaust and abrasions emissions. Heavy metal emissions to soil and water caused by tire abrasion are accounted for. In the electricity usage process, electricity production mix, the transmission network and direct SF6-emissions to air are included. In order to present a renewable based scenario for electric vehicles, a mixture of renewables for energy requirement during the operation are also evaluated consisting of 25% biomass, 25% solar PV, 25% wind power and 25% hydropower.
- HEV: Hybrid car is assumed to be 50% electric and 50% gasoline with ICE. Electricity and gasoline consumptions are included. Particulate emissions comprise exhaust and abrasions emissions. Heavy metal emissions to soil and water caused by tire abrasion are accounted for. For the hybrid vehicle’s electricity, a mixture of renewables for energy requirement during the operation are also evaluated consisting of 25% biomass, 25% solar PV, 25% wind power and 25% hydropower.
- Methanol: The selected fuel M90 consists of 90% methanol and 10% gasoline. The raw materials, processing energy, estimate on catalyst use, and emissions to air and water from process, plant infrastructure are included. The process describes the production of methanol

from natural gas via steam reforming process to obtain syngas for the production of methanol. There is no CO_2 use and hydrogen is assumed as burned in the furnace. Raw materials, average transportation, emissions to air from tank storage, estimation for storage infrastructure are included for the distribution part where 40% of the methanol is assumed to be transported from overseas. Particulate emissions cover exhaust- and abrasions emissions.

- LPG: All processes on the refinery site excluding the emissions from combustion facilities, including waste water treatment, process emissions and direct discharges to rivers are considered. All flows of materials and energy due to the throughput of 1 kg crude oil in the refinery is accounted for. Refinery data include desalting, distillation (vacuum and atmospheric), and hydro treating operations. Particulate emissions cover exhaust- and abrasions emissions.

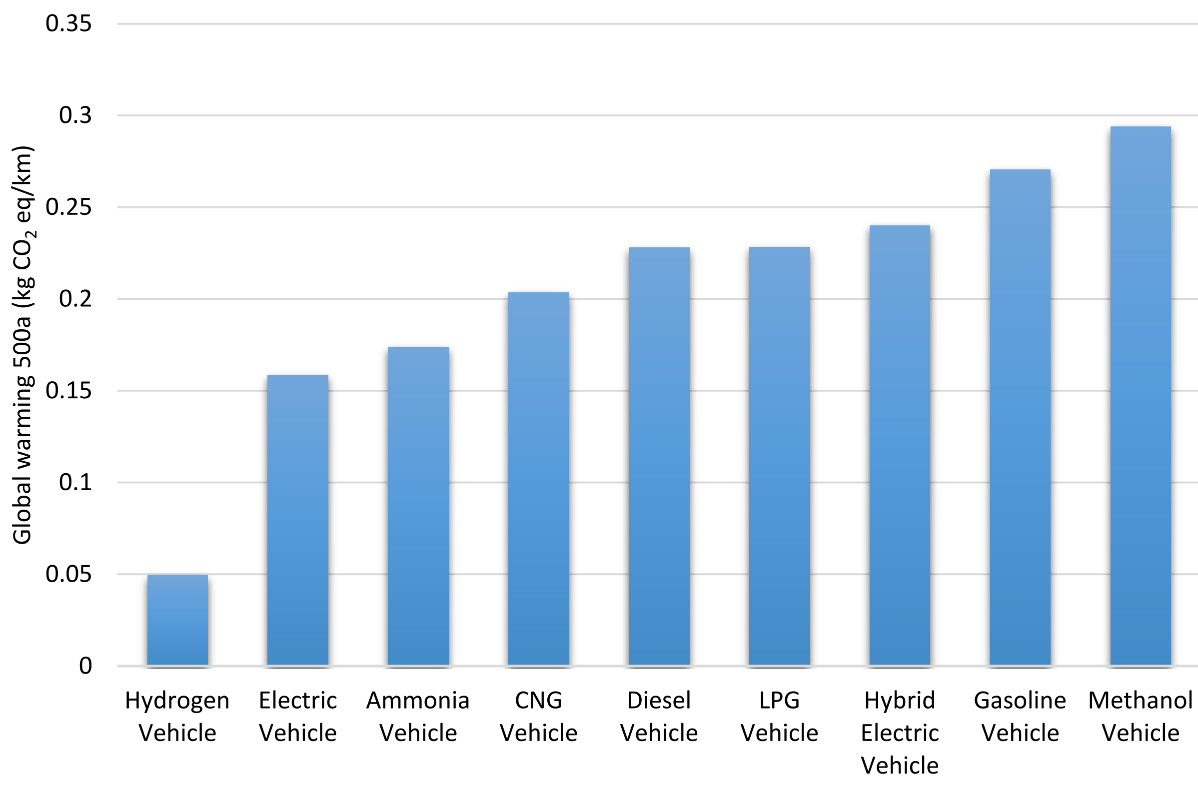

Fig. 9. Life cycle comparison of global warming results for various vehicles

The global warming potentials of assessed vehicles are comparatively shown in Fig. 9. The lowest GHG emissions are observed in hydrogen, electric and ammonia vehicles corresponding to 0.049 kg CO_2 eq/km, 0.15 kg CO_2 eq/km and 0.17 kg CO_2 eq/km, respectively. Hydrogen consumption is quite lower than ammonia consumption in the passenger car because of higher energy density. It is an expectable result that EVs also yield lower global warming potential, however production pathway of electricity has a key role in GHG emissions. If electricity production can be realized by renewable sources such as solar, biomass, hydropower and wind energy, total emissions would decrease for both EVs and HEVs.

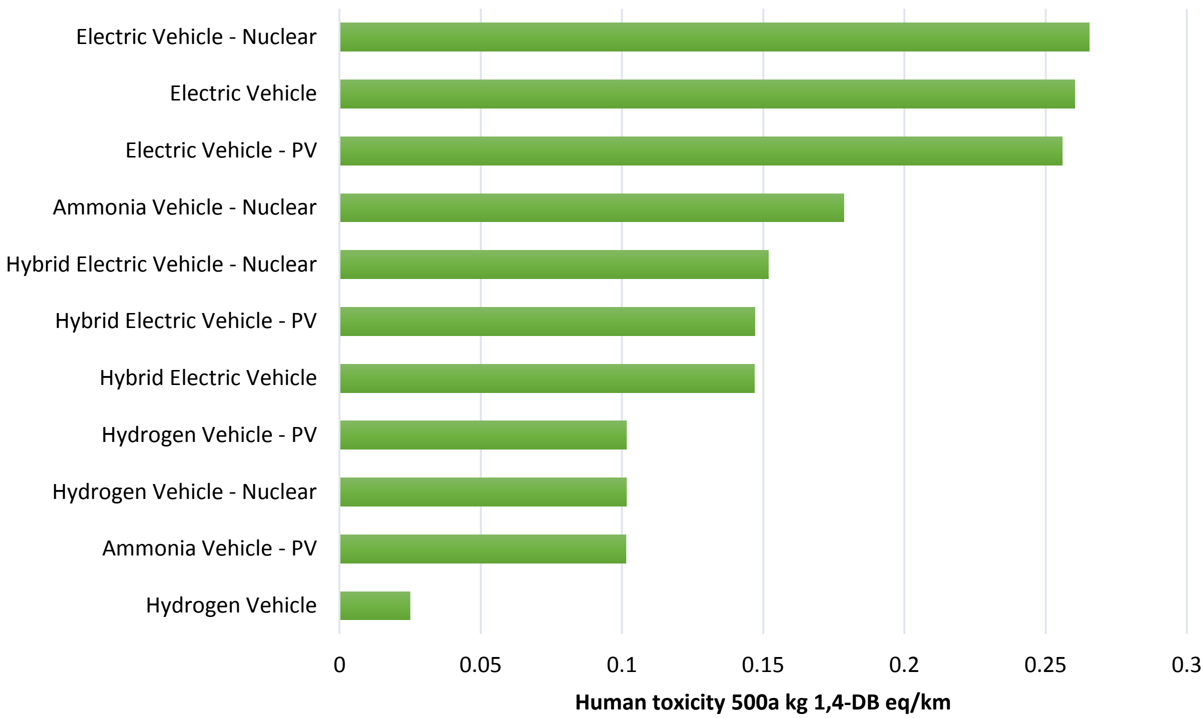

Fig. 10. Life cycle comparison of human toxicity results for various vehicles from nuclear energy and solar PV routes

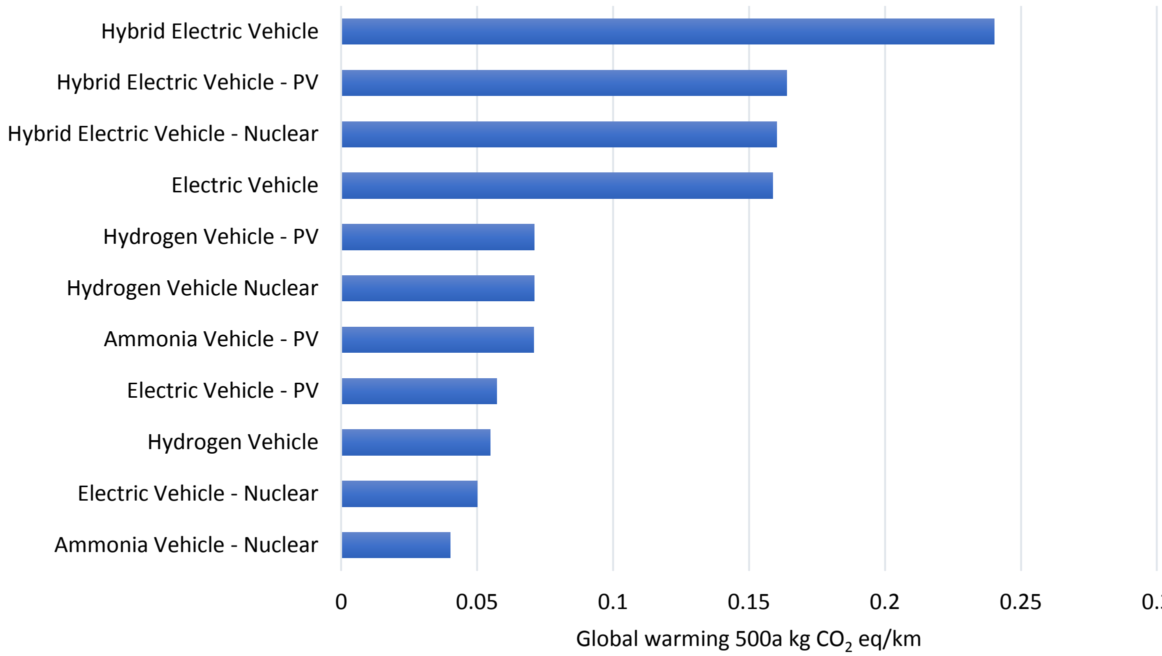

Fig. 11. Life cycle comparison of global warming results for various vehicles from nuclear energy and solar PV routes

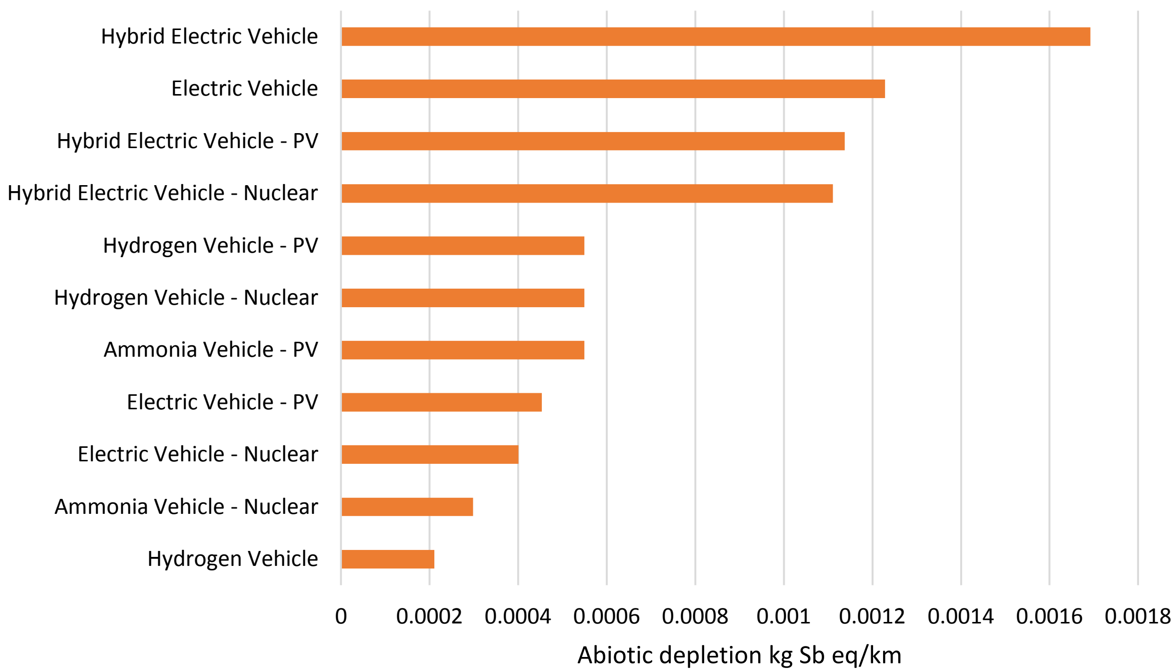

Fig. 12. Life cycle comparison abiotic depletion for various vehicles from nuclear energy and solar PV routes

The electricity from nuclear (25%), biomass (25%), hydropower (25%) and solar PV (25%) are equally used only for the operation processes of the EVs and HEVs vehicles as renewable mix. Utilization of renewable electricity for EVs, HEVs, ammonia and hydrogen vehicles are comparatively shown for various impact categories. For human toxicity category, using solar and nuclear energy does not cause significant reductions for EVs and HEVs as shown in Fig. 10. However, for global warming and abiotic depletion categories, both solar energy and nuclear energy routes lower the environmental impacts more than 50%. Ammonia driven vehicle where the ammonia is produced from nuclear electrolysis method yield the lowest GHG emissions corresponding to about 0.04 kg CO_2 eq. per km as shown in Fig. 11. Hydrogen and EVs (from nuclear and PV) have quite similar greenhouse gas emissions in the range of 0.049-0.057 kg CO_2 eq. per km. In terms of abiotic depletion values, hydrogen vehicle still yields the lowest value whereas nuclear routes for ammonia and EVs further decrease the abiotic depletion impact as shown in Fig. 12.

The results show that hydrogen and ammonia vehicles are the most environmentally benign ones in most of the environmental impact categories. Ammonia as a sustainable and clean fuel has lowest global warming potential after EVs and yield lower ozone layer depletion values than EVs. However, in case renewables are used both for ammonia vehicles and EVs, ammonia can suggest lower environmental impacts. Although EVs do not emit direct CO_2 during operation, the production and disposal processes of batteries bring some consequences which harm the environment in terms of acidification, eutrophication and human toxicity.

AMMONIA IN MARITIME TRANSPORTATION

Decreasing the global warming potential caused by current transportation technologies and fuels can be reduced significantly by replacing alternative clean fuels. Sea transportation vehicles mostly use heavy fuel oil or diesel fuel for power generation. Ocean tankers and freight ships require massive amount of energy for operation.

Being a sustainable energy carrier that can be generated from any primary energy source, ammonia can subsidize to a broadening of maritime fuel resources and may offer the long term option of being generated from renewable resources.

A brief life cycle consideration of maritime vehicles, ocean tanker and freight ship, is shown here where the tankers are driven with hydrogen and ammonia instead of heavy fuel oils in the power engines. Additionally, dual fuel options, heavy fuel oil and hydrogen/ammonia, are investigated.

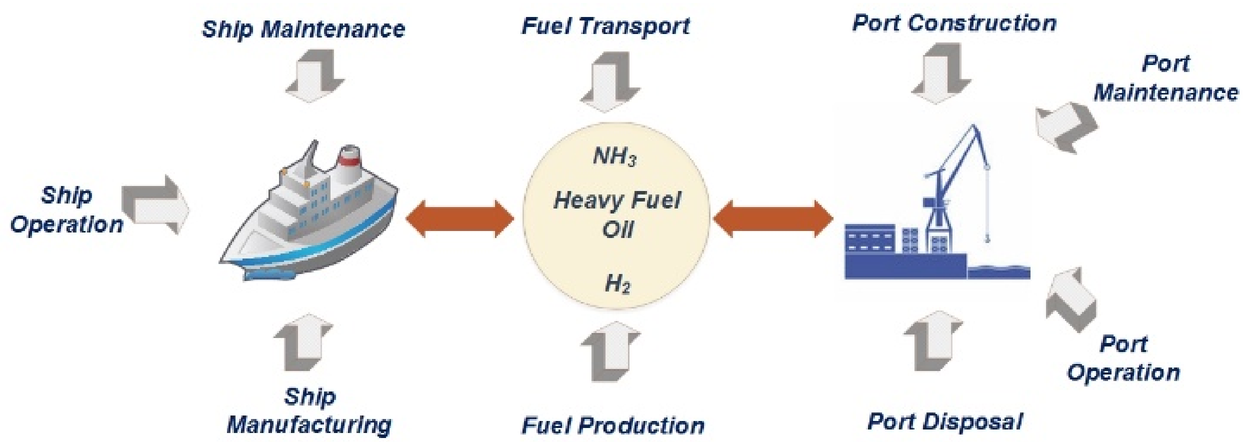

Fig. 13. Life cycle steps of maritime transportation

A comparative life cycle assessment of transoceanic fright ship and transoceanic tanker, is performed to examine the effects of clean fuel driven maritime vehicles on the environment. The complete transport life cycle is evaluated in the life cycle analyses comprising of manufacture of tanker/freight ship; operation of tanker/freight ship; construction and land use of seaport; operation, maintenance and disposal of seaport; production and transportation of hydrogen and ammonia. A tonne kilometer by shipping is defined as unit of measure of goods transport which represent the transport of one tonne by a vessel over one kilometer.

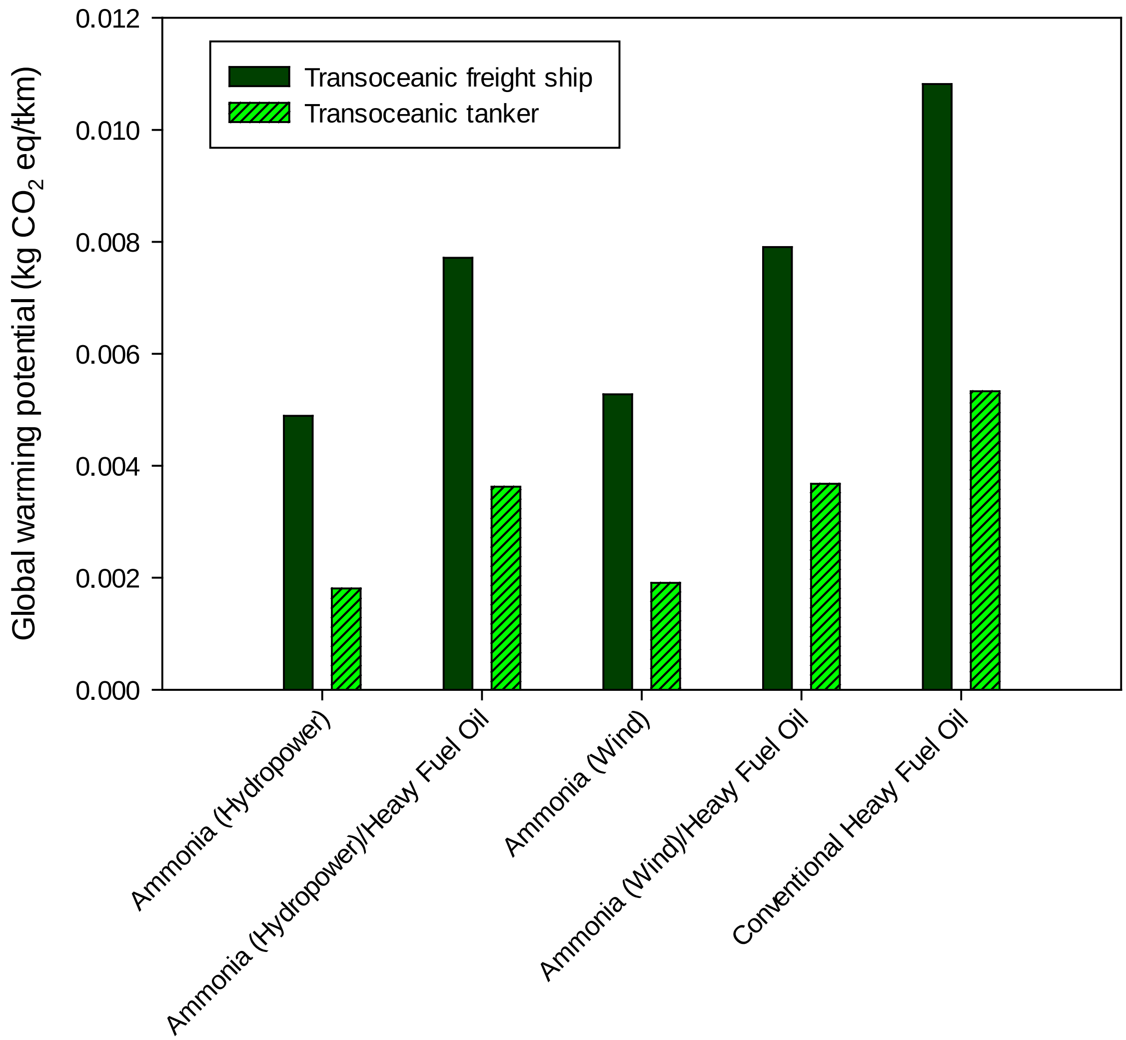

Fig. 14. Global warming potential of transoceanic tanker and transoceanic freight ship per tonne kilometer for clean fuels and conventional heavy fuel oil

The heavy fuel oil combustion significantly contributes to many of the environmental impact. Using ammonia as dual fuel in the marine engines can decrease total greenhouse gas emissions up to 34.5% per tkm. Similarly, sole ammonia driven transoceanic tanker releases about 0.0018 kg CO_2 eq/tkm greenhouse gas compared to 0.0055 kg CO_2 eq/tkm for sole heavy fuel oil tanker as shown in Fig. 14.

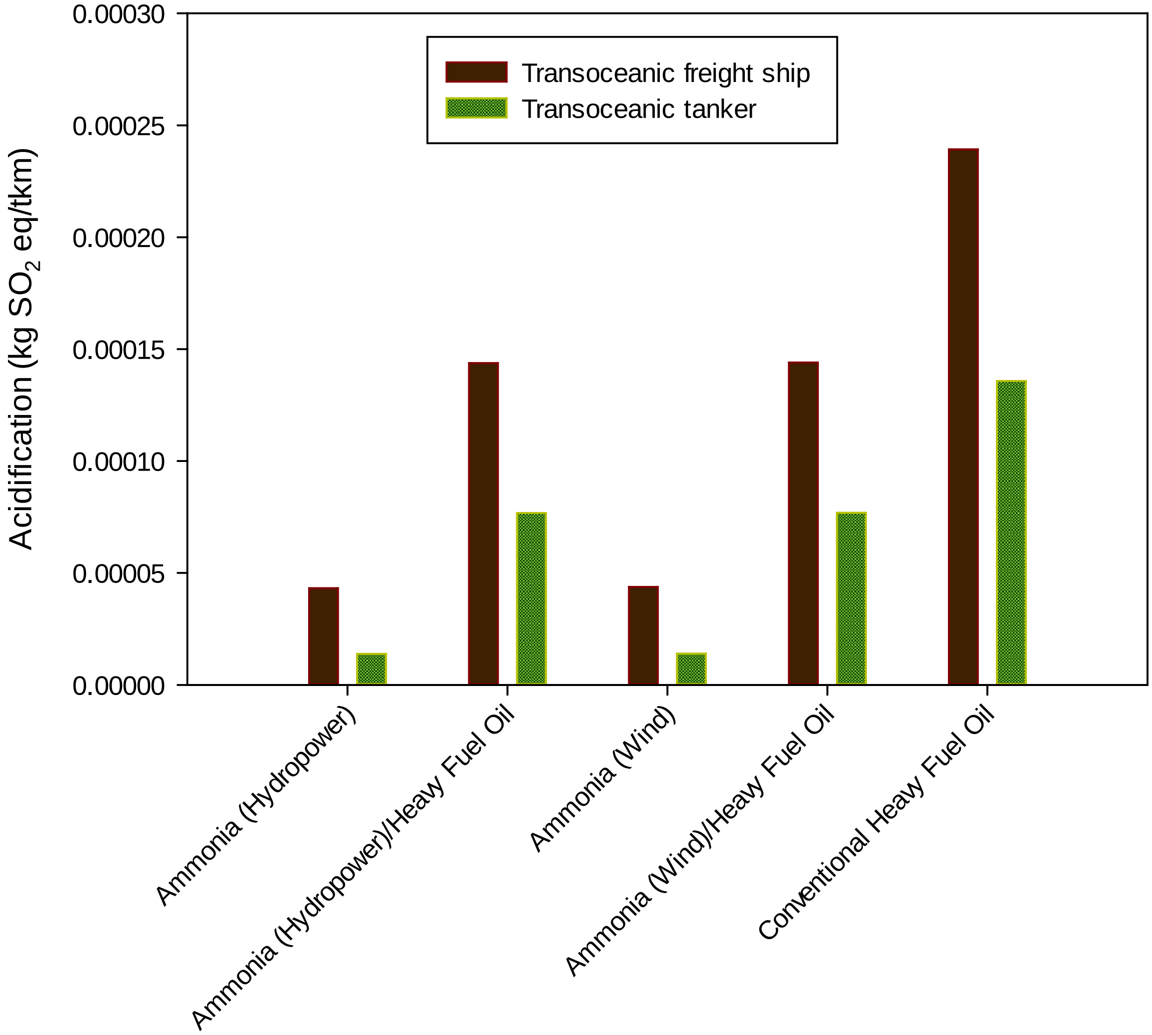

Fig. 15. Acidification values of transoceanic tanker and transoceanic freight ship per tonne kilometer for clean fuels and conventional heavy fuel oil

The acidification values of heavy fuel oil driven transoceanic tanker and freight ship are mainly caused by SO_2 and NO_x emissions (Fig. 15) which corresponds to more than 90% of overall acidification value. The source of SO_2 emission is predominantly the operation of tanker and freight ship (96.8%). This is caused by the sulfur content of the heavy fuel oil hence it is mostly eliminated if ammonia is used.

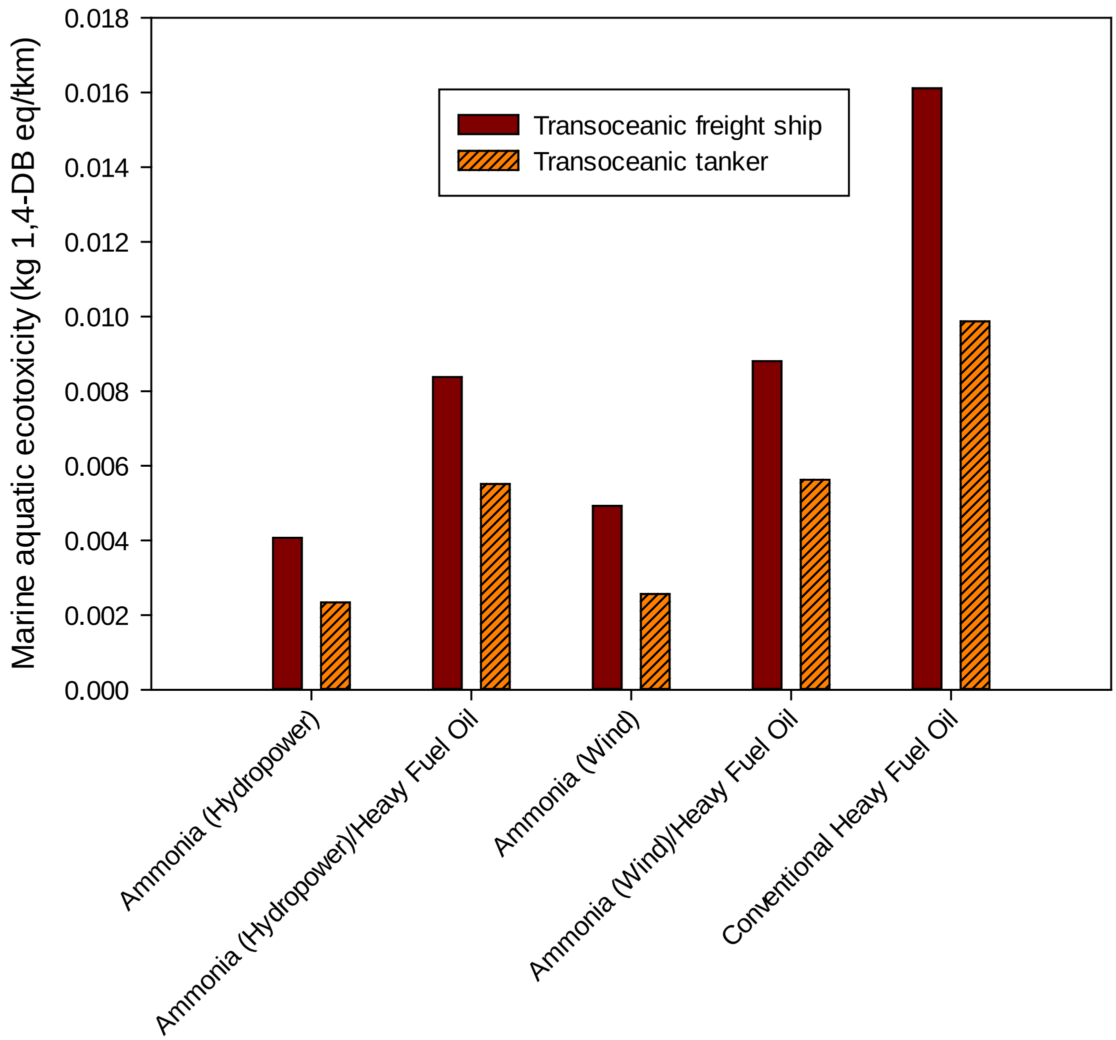

Fig. 16. Marine aquatic ecotoxicity values of transoceanic tanker and transoceanic freight ship per tonne kilometer for clean fuels and conventional heavy fuel oil

Using ammonia (wind energy) in transoceanic tanker as dual fuel with heavy fuel oil lowers the ecotoxicity level about 47% as shown in Fig. 16. For conventional heavy fuel oil driven transoceanic tanker, crude oil is the main depleted source similar to dual fuel options as shown in Fig. 17. For ammonia, the depletion is mainly caused by port operation process rather than tanker/ship operation. As non-carbon clean fuels for maritime ship engines, ammonia yields considerably lower global warming impact during operation. This demonstrates that if clean fuels are even partially replaced with current hydrocarbon derived fuels, total GHG emissions in maritime transportation can be lowered significantly.

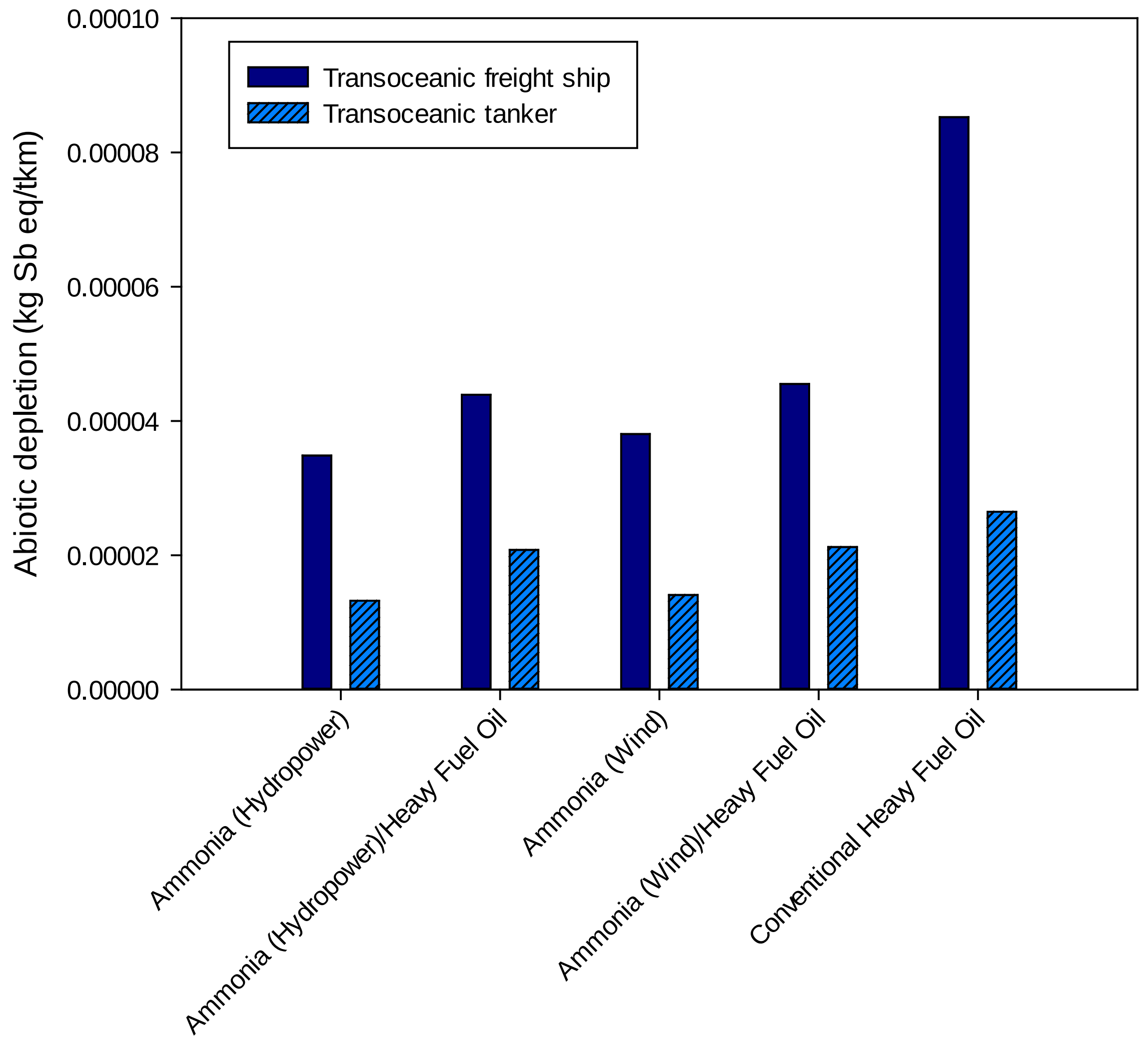

Fig. 17. Abiotic depletion values of transoceanic tanker and transoceanic freight ship per tonne kilometer for clean fuels and conventional heavy fuel oil

AMMONIA IN AVIATION

Petroleum based fuels have combination of accessibility, ease of handling, energy content, performance, and price because of being a mature product. Therefore, these type of fuels are heavily used by the transportation sector including air, road, and sea. However, limited nature, nonhomogeneous source distribution, changing prices, and end use related emissions of fossil fuels have driven most of the industries such as air transportation to search for other alternatives. Aviation is responsible for 12% of CO_2 emissions from all transports sources. The national and international flights overall the world produced 770 million tons of CO_2 in 2015 [17].

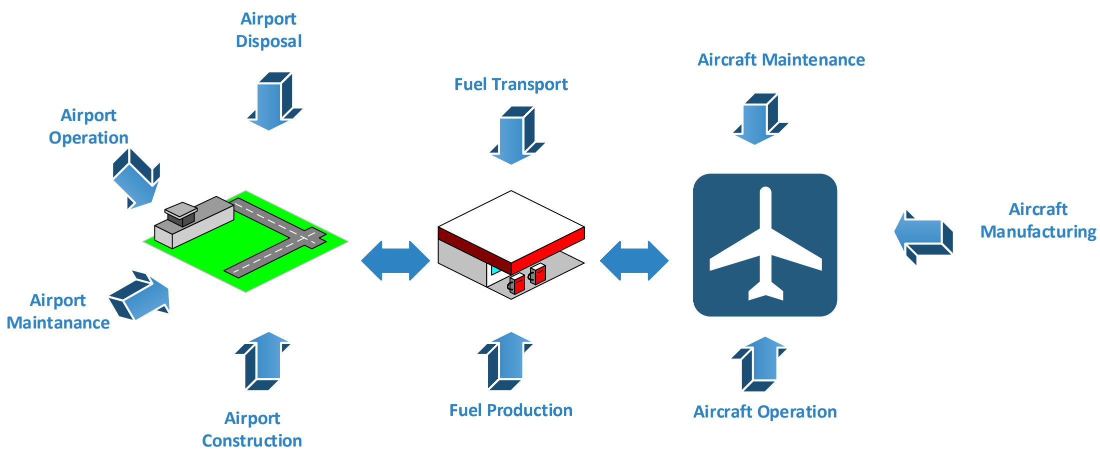

Fig. 18. Illustration of complete well-to-wake life cycle phases used in the LCA study

The overall life cycle emissions of an aircraft running on various aviation fuels are calculated from well-to-wake. The life cycle phases included in the analyses (shown in Fig. 18) are as follows: (i) production, operation and maintenance of the aircraft, (ii) construction, maintenance and disposal of the airport, (iii) production, transportation and utilization of the aviation fuel in the aircraft.

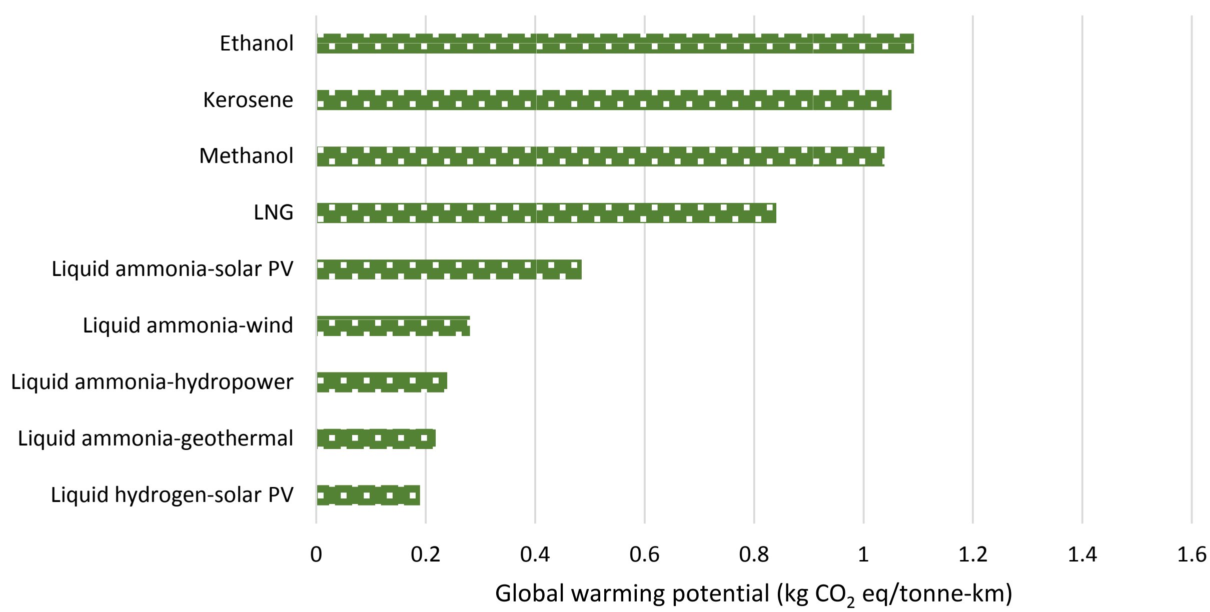

Fig. 19. Global warming potential of various fueled aircrafts per travelled tonne-km

The overall GWP value of ethanol is the highest corresponding to 1.09 kg CO_2 eq/tonne-km since it comes from ethylene which is a hydrocarbon as shown in Fig. 19. Renewable energy usage in the fuel production processes decreases the overall GHG emissions. The hydropower based ammonia fueled aircraft releases about 0.24 kg CO_2 eq per tonne-km. This value goes down to 0.21 for kg CO_2 eq/tonne-km for ammonia fueled aircraft and 0.18 kg CO_2 eq/tonne-km for hydrogen fueled aircraft in case the renewable source is solar energy. Although there are several processes, operation of the aircraft is the second largest contributor corresponding to 34%. Operation and maintenance of the airport is the primary responsible for GWP corresponding to 48.9% in total where it is distributed into sub-processes such as natural gas burning in the furnace (22%), light fuel oil burning in the furnace (5%), lignite burning in the power plant (7%) and hard coal burning (8%)

Renewable based ammonia driven aircrafts can significantly decrease the depletion of abiotic resources down to 0.0014 kg Sb eq/tonne-km which corresponds to about 10% of conventional steam methane reforming based ammonia fueled aircraft as shown in Fig. 20.

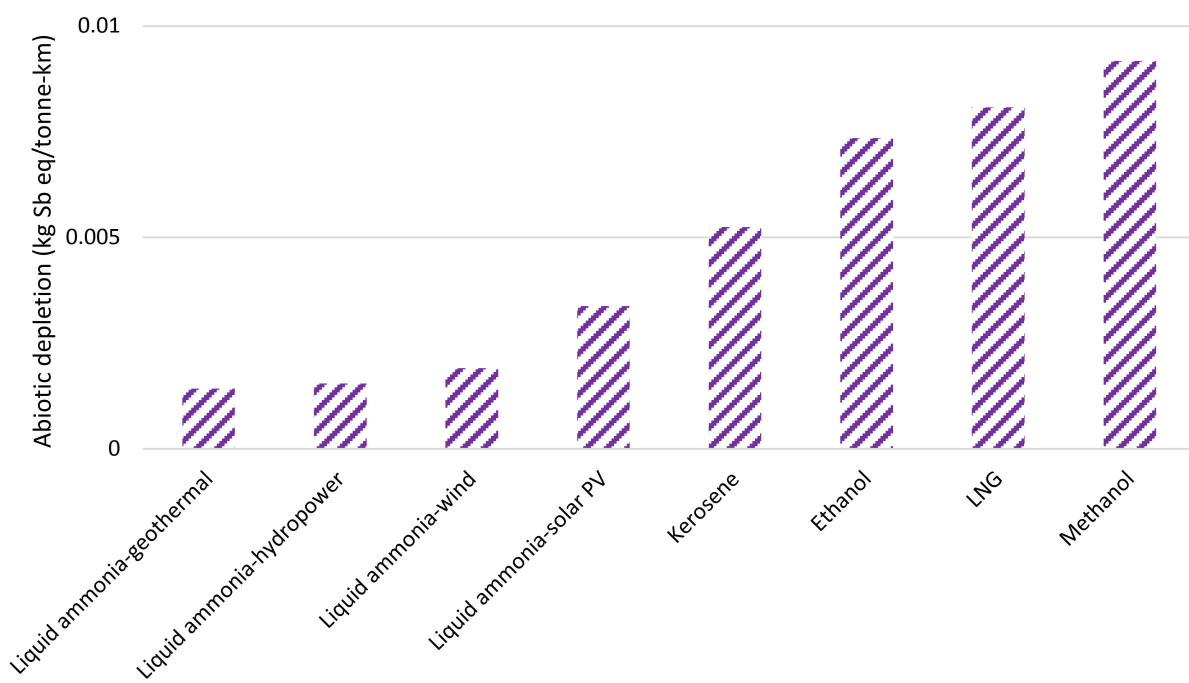

Fig. 20. Abiotic depletion values of various fueled aircrafts per travelled tonne-km

It is common knowledge that of HC, CO, NO_x, PM, and CO_2 which are named as GHG emissions cause environmental damages and adverse effect on human health. The marginal external price of a unit of these emissions is identified as environmental and social costs of emissions. Environmental and social costs of HC, CO, NO_x, PM, and CO_2 emissions of various fueled aircrafts are evaluated in terms of USD/tonne-km as shown in Fig. 21. renewable based ammonia yields lower environmental and social cost of emissions in comparison with kerosene.

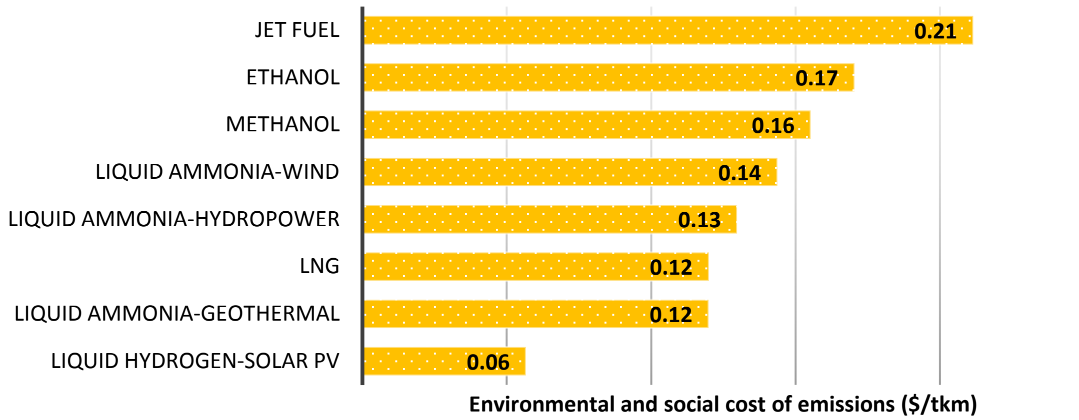

Fig. 21. Total environmental and social cost of emissions for various fueled aircrafts from conventional and renewable resources

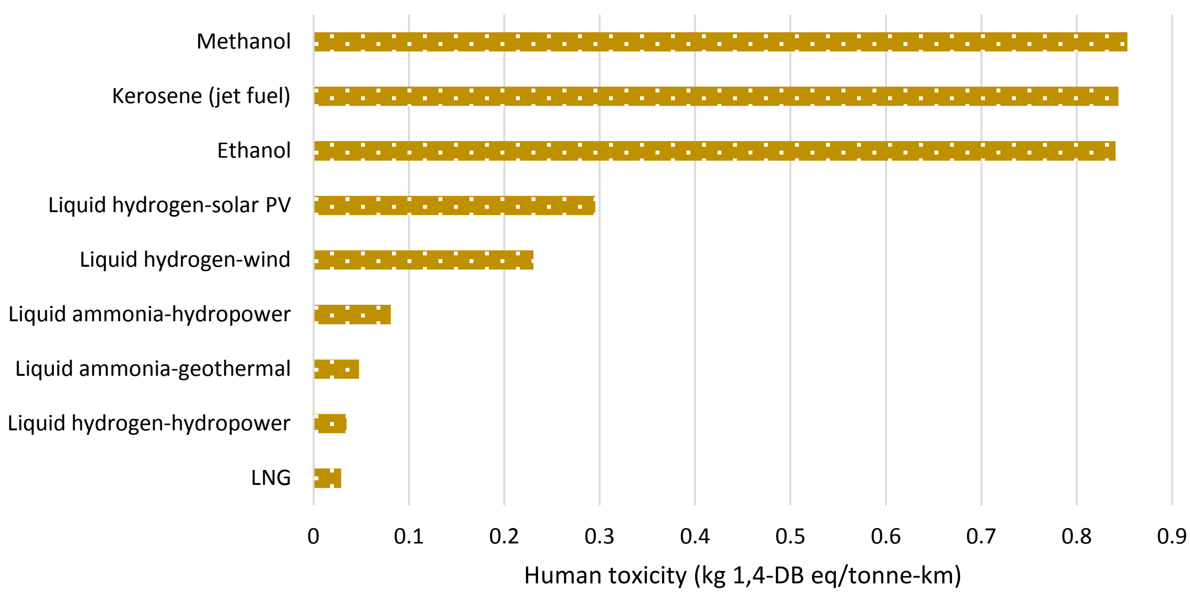

Fig. 22. Human toxicity potential of various fueled aircrafts per travelled tonne-km

Among all alternative aviation fuels, the kerosene jet fuel, methanol and ethanol human toxicity values are greater. Ammonia fuel from hydropower resource has comparable toxicity value corresponding to 0.08 kg 1,4- DB eq/tonne-km with LNG corresponding to 0.03 kg 1,4-DB eq/tonne-km as shown in Fig. 22.

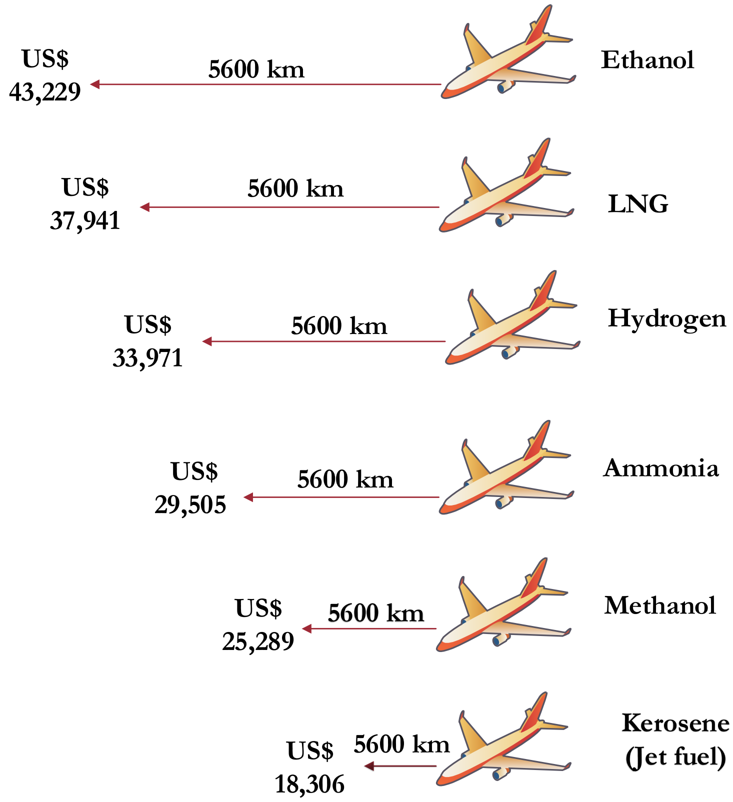

Fig. 23. Comparison of fuel costs during the operation of aircrafts for the given range

Table 3. Average fuel consumption rates and fuel costs for selected alternative fuels

Fuel	**Fuel Consumption (kg/km)**	**Fuel Consumption (kg/tonne-km)**	**Fuel Cost (USD/kg)**
Kerosene (Jet fuel)	7.99	0.217666815	0.409
Methanol	18.06	0.492185866	0.250
Ammonia	18.82	0.512730362	0.280
Hydrogen	2.64	0.071866485	2.300
LNG	9.46	0.257732767	0.716
Ethanol	12.47	0.339891348	0.619

Fig. 23 illustrates the cost of flight for a 5600 km distance in which alternative fuels are used for the aircrafts when the fuel costs and consumption rates in Table 3 are considered. Although LNG represented better environmental performance, the cost of aircraft operation in terms of fuel is the highest for ethanol and LNG. In the calculations, current conventional based routes are taken into account for comparison purposes. Hydrogen fueled aircraft has lower cost compared to these two alternatives. Since the production of kerosene from crude oil is a more mature technology, it represents the lowest cost among all. Liquid ammonia is also low cost alternative compared to hydrogen.

CONCLUDING REMARKS

Ammonia is a carbon-free fuel suitable for use in transportation sector. It has a well-established production and distribution infrastructure, and has zero global warming potential during operation. In addition to its attractive qualities as a fuel, ammonia is widely used as a NOx reducing agent for combustion exhaust gases using selective catalytic reduction (SCR), and its capacity as a refrigerant can be applied to recover and further utilize engine heat that would otherwise be lost. In terms of environmental sustainability, ammonia can be produced using either fossil fuels, or any renewable energy source, using heat and/or electricity, which allows for evolution of ammonia production methods and technologies in parallel with sustainable development. Ammonia as a sustainable fuel can be used in all types of combustion engines, gas turbines, burners with only small modifications and directly in fuel cells which is a very significant advantage compared to another type of fuels. Reducing the total greenhouse gas emissions from marine transportation is possible by using ammonia which is carbon-free fuel. They can be utilized for maritime ship engines directly as supplementary fuels or individual fuels. Ammonia fueled ships yield considerably lower global warming impact during operation. Ammonia as a sustainable and clean fuel in road vehicles yield also the lowest global warming potential after electric and hydrogen vehicles. As a result, ammonia usage in the communities for transportation sector will bring significant cost and environmental benefits together with public satisfaction.

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Transparency in Renewable Fuels

Ontario's Cap & Trade Program states:

The RFS is a technology-neutral policy and a technology-neutral approach lets the alternatives compete on their merits.

In order for renewable fuel technology to compete on its own merits and for the market to decide which technology has the best merits, energy consumers must ultimately participate in selection of renewable fuels.

Ontario's Cap & Trade program has the following participants:

Mandatory participants	Facilities and natural gas distributors with emissions of 25,000 tonnes or more of greenhouse gas emissions per year are required by law to participate in the program. Additionally, fuel suppliers that sell more than 200 litres of fuel per year and electricity importers must also participate in the program.
Voluntary participants	Facilities generating more than 10,000 tonnes but less than 25,000 tonnes of emissions may choose to opt in to the program. These companies will be subject to the same rules as mandatory participants.
Market participants	Companies that do not have emissions to report and therefore do not have a compliance obligation can also participate in the auction. Market participants can include individuals, not-for-profit organizations and companies without compliance obligations.

For the market to decide the winners in the Cap & Trade program, each energy consumer must also be a Cap & Trade participant.

This could be administered through the income tax system, with each family or business entity being issued its own baseline carbon credit. At income tax time, each energy or fuel supplier would provide each consumer a carbon statement that the energy consumer would include in his income tax return. Depending upon each tax entity's carbon consumption, the net carbon credits would translate into additional carbon tax payments or refunds.

TRANSPARENCY VIA A FLOW-THROUGH CARBON TAX

From an energy consumer's perspective, it is impractical to determine his own individual emissions. However, it is simple to determine their expected emissions by the amount of fuel consumed. Therefore, a more practical and transparent way of putting a cost on carbon emissions would be through a flow-through carbon taxation program similar to the GST/HST system. The carbon tax would replace the fuel excise tax and would be applicable to ALL consumable energy and fuel.

This taxation system would start at the producer level. For energy produced in Ontario, the carbon tax would replace the fuel excise tax. The carbon tax would be based on the carbon content of the fuel sourced from fossil sources or of the amount of fossil-carbon consumed to convert a fuel to a consumable form of energy. The carbon tax would then flow through from the producer to the distributor to the consumer.

For a technology-neutral carbon policy, there must be a completely level playing field and there is more to the life cycle environmental impact of the fuel than the amount of carbon dioxide generated from the its combustion. There are nine categories of life cycle environmental impacts caused by the production and utilization of energy that must be considered for a completely level playing field:

Environmental Impact	**Description**
Abiotic Depletion	Abiotic resources are natural resources including energy resources. Since fossil fuels resources are declining gradually, abiotic depletion potential is also a significant category. It is expressed in kg antimony (Sb) equivalents.

Environmental Impact	**Description**
Acidification	Acidification potential is for acidifying substances which causes a wide range of impacts on soil, groundwater, surface water, organisms, ecosystems and materials. kg SO2 equivalents is used to express the acidification potential.
Eutrophication	Eutrophication is the impact of excessive levels of macro-nutrients in the environment which is mainly caused by disposal processes. It is stated as kg PO_4 equivalents.
Global Warming	Global warming potential is the main characteristics to be compare the total CO2 equivalent emission from any source. The greenhouse gasses to air are related to the climate change. Methane, carbon monoxide etc. are in this category.
Human Toxicity	Human toxicity may play an important role for decision of using alternative fuels. It indicates the toxicity level and presented in 1,4-dichlorobenzene ($C_6H_4Cl_2$) equivalent.
Ozone Layer Depletion	Ozone layer depletion increases the amount of UVB that reaches the Earth's surface. Laboratory and epidemiological studies demonstrate that UVB causes non-melanoma skin cancer and plays a major role in malignant melanoma development. Ozone depletion potential of several gasses is specified in kg CFC-11 equivalent.
Terrestrial Ecotoxicity	Terrestrial ecotoxicity refers to the potential for biological, chemical or physical stressors to affect terrestrial ecosystems. Such stressors might occur in the natural environment at densities, concentrations or levels high enough to disrupt the natural biochemistry, physiology, behavior and interactions of the living organisms that comprise terrestrial ecosystems. The results are stated as 1,4-dichlorobenzene equivalents per kg emission.

Environmental Impact	Description
Marine Aquatic Eco-Toxicity	Marine aquatic eco-toxicity refers to impacts of toxic substances on marine aquatic ecosystems which is more important for maritime transportation sector. It considers each substance emitted to the air, water or/and soil. The unit of this factor is kg of 1,4-dichlorobenzene equivalents (1,4-DB eq.) per kg of emission.
Land Occupation/Land Use	Land occupation/land use refers to the total arrangements, activities and inputs undertaken in a certain land cover type. The term land use is also used in the sense of the social and economic purposes for which land is managed. It is mainly expressed as m2a which implies area usage in a year.

Focusing on carbon dioxide alone precludes any consideration of the global warming potential of other greenhouse gas emissions. From the US EPA [1]:

Greenhouse Gas	Global Warming Potential Over 100 years	Notes
CO2	1 by definition	Regardless of the time period used, CO2 is the reference gas. CO2 remains in the climate system for a very long time: CO2 emissions cause increases in atmospheric concentrations of CO2 that will last thousands of years.

Greenhouse Gas	**Global Warming Potential Over 100 years**	**Notes**
Methane (CH_4)	28–36	CH_4 emitted today lasts about a decade on average, which is much less time than CO_2. But CH_4 also absorbs much more energy than CO_2. The net effect of the shorter lifetime and higher energy absorption is reflected in the GWP. The CH_4 GWP also accounts for some indirect effects, such as the fact that CH_4 is a precursor to ozone, and ozone is itself a GHG. (Learn why EPA's U.S. Inventory of Greenhouse Gas Emissions and Sinks uses a different value.)
Nitrous Oxide (N_2O)	265–298	N_2O emitted today remains in the atmosphere for more than 100 years, on average.
Chlorofluorocarbons (CFCs), Hydrofluorocarbons (HFCs), Hydrochlorofluorocarbons (HCFCs), Perfluorocarbons (PFCs), Sulfur Hexafluoride (SF_6)	Thousands or Tens of Thousands	Sometimes called high-GWP gases because, for a given amount of mass, they trap substantially more heat than CO_2.

The carbon tax would be designed to improve upon the reduction of greenhouse gas emissions by including other detrimental effects on the environment. Rather than basing the tax rate solely on the carbon content of the fuel, global warming would be one of the nine environmental impact categories.

Conceivably, some fuels could have a positive effect on a particular type of pollution. In this case, such a process should be given a negative environmental impact factor to reduce its tax rate. An environmental impact multiplier would then be applied to the baseline rate that takes into account the nine environmental impact categories. Each environmental impact category would have an assessment scale of -10 to 10. The environmental impact multiplier would then be based on the sum of the nine assessments.

Ultimately, only electricity or fuels with a zero or negative environmental impact assessment would have a zero carbon tax rate. The cost of the inputs of varying environmental impacts used to generate the each source of electricity would be included in the cost of electricity. This would ensure that that the lowest-cost electricity is produced with the lowest environmental impact.

MANUFACTURING PRODUCTS FROM FUELS

If part of the fuel was then converted to a product, the manufacturer of that carbon-containing product would then get a credit for the carbon that has been prevented from entering the atmosphere.

For example, some biofuel processes can take carbon out of the atmosphere and can permanently sequester it into the ground as biochar. This type of permanent sequestration can result in Terra Preta [2], which has enhanced soil fertility. This process would get a credit for the carbon content of the biochar, less whatever biofuel was consumed to produce the biochar.

For another example, if a manufacturer had a process to produce anhydrous ammonia and elemental carbon from natural gas, the manufacturer would pay the full carbon tax on the natural gas used in its process. It would then get a credit for the elemental carbon, less whatever natural gas was used for process heat. The elemental carbon would carry the maximum carbon tax but the consumer of the elemental carbon would get the full carbon credit if that elemental carbon would be used to manufacture a carbon product, such as graphene. Since anhydrous ammonia has own environmental impact, its carbon tax would be different than that of the natural gas.

TAX ADMINISTRATION

A carbon tax program would be easier to administer at a consumer level than a Cap & Trade program. Businesses are already familiar with the GST/HST system and would not require significantly more bureaucracy to administer. This would also be transparent because the carbon tax portion of the energy cost could be separately broken out in the price as well as the methodology used to calculate the pollution multiplier factors. Consumers would therefore be able to determine the most effective way of reducing their energy costs.

In addition, having a carbon tax would also create growth in the economy with businesses providing ways of reducing energy costs through new equipment sales or retrofitting existing equipment.

This carbon tax should be revenue-neutral and overseen by the Environmental Commissioner of Ontario. The entire carbon tax revenue stream should be collected in its own fund and not go into the general revenue fund. The carbon tax revenue should be returned to the citizens of Ontario in the form of an annual dividend at income tax time, less the cost of administering the program.

Since the carbon tax would replace the fuel excise tax, the government may take some money from the carbon tax fund equivalent to the tax that would have been collected from the fuel excise tax. This is necessary to keep the carbon-tax revenue-neutral. The equivalent revenue removed from the carbon tax fund should be used to fund public transit and/or climate change programs including research and innovation.

CARBON TAX VS CAP & TRADE

The website *carbontax.org* makes an excellent case for why a carbon tax is superior in terms of transparency to cap & trade for reducing carbon emissions:

CAP-AND-TRADE'S INHERENT DEFECTS [3]

A tax on carbon emissions isn't the only way to "put a price on carbon" and provide incentives to reduce use of high-carbon fuels. A **carbon cap-and-trade system** is an alternative approach supported by some prominent politicians, corporations and mainstream environmental groups.

Cap-and-trade was the structure embodied in the Waxman-Markey climate bill that passed the House in 2009 but died in the Senate. And cap-and-trade is the cornerstone of the European Union's "Emissions Trading Scheme" (ETS).

Cap-and-trade systems can be effective under certain conditions. The U.S. *sulfur dioxide* cap-and-trade system instituted in the early 1990s efficiently reduced acid rain emissions from power plants. However, the scale of a *carbon* trading system — it would be up to 100 times larger than that for sulfur — combined with the lack of "technical fixes" for filtering or capturing CO2, rules out sulfur cap-and-trade as a model for carbon. Moreover, evidence from the EU's ETS suggests that price volatility and gaming by market participants have undermined the effectiveness of this complex, opaque indirect method of pricing carbon pollution.

The Carbon Tax Center along with most economists regard a carbon tax as vastly superior and preferable to a carbon cap-and-trade system. Here's why:

- Carbon taxes lend predictability to energy prices, whereas cap-and-trade systems exacerbate the price volatility that historically has discouraged investments in carbon-reducing energy efficiency and carbon-replacing renewable energy.
- Carbon taxes are transparent and understandable, making them more likely to elicit public support than an opaque and difficult to understand cap-and-trade system. The co-author of the U.S. Senate cap-and-trade bill, Sen. John Kerry (now Secretary of State) told a reporter in 2009, "I don't know what 'cap and trade' means. I don't think the average American does."
- Carbon taxes can be implemented more quickly than complex permit-based cap-and-trade systems.
- Carbon taxes aren't easily manipulable by special interests, whereas the complexity of cap-and-trade leaves it rife for exploitation by the financial industry.
- Carbon tax revenues can be more or less guaranteed and integrated into state or federal fiscal policy, owing to their predictability, whereas the price-volatility of cap-and-trade precludes its being counted on as a revenue source.

- Carbon taxes are replicable across borders, since the price "metric" embodied in a carbon tax is far more universal than the quantity-reduction metric underlying cap-and-trade.
- Perversely, cap-and-trade discourages voluntary/individual carbon reductions, since those cause a lowering of prices of emission permits which undercuts low-carbon investments; carbon taxes are free of this unintended negative consequence.

Politically, cap-and-trade has functioned as a "safe harbor" for politicians who grasp the need for pricing carbon emissions but cling to the need to "hide the price" to appease interest groups and/or ordinary citizens. But the point of carbon emissions pricing is to raise the price of emitting carbon. Better to make the price explicit, via a tax, and protect households by making the tax revenue-neutral.

CARBON TAX IN CANADA

On December 9, 2016, Prime Minister Justin Trudeau made the most important energy and environmental policy announcement in half a century with his pledge to create a national clean fuel standard "based on life cycle analysis".

The flow-through carbon tax we propose is consistent with the federal government's **National Clean Fuel Standard** policies [4]:

> OBJECTIVE
>
> The overall objective of a clean fuel standard would be to achieve annual reductions of 30 megatonnes (Mt) of GHG emissions by 2030. This reduction will provide a significant contribution towards achieving Canada's commitment of 30 percent emissions reduction below 2005 levels, by 2030. This reduction is like removing over 7-million vehicles from the roads for a year.
>
> BROAD COVERAGE
>
> A clean fuel standard will encourage the use of cleaner fuels in many sectors of the economy, including the fuels we use in transportation, in our homes and buildings, and the fuels that power our industries. It would address a broad suite of fuels, which could

include liquid fuels (e.g., gasoline, diesel, and heavy-fuel oil), gaseous fuels (e.g., natural gas and propane), and solid fuels (e.g., petroleum coke).

PERFORMANCE-BASED APPROACH

The clean fuel standard would set requirements to reduce the lifecycle carbon intensities of fuels supplied in a given year, based on lifecycle analysis. By contrast to renewable-fuel mandates, this approach would not prescribe the particular low-carbon fuel or technology that must be used; instead, it would focus on emissions reduction. The clean fuel standard would result in decreased emissions while minimizing compliance costs.

This approach would foster the deployment of a broad range of lower-carbon fuels and alternative technologies such as electricity, biogas, hydrogen, and renewable fuels.

MEASURING CARBON INTENSITY BY LIFECYCLE ANALYSIS

Carbon-intensity standards will be set to reduce the lifecycle carbon intensities of all fuels supplied, based on lifecycle analysis. The standards could be set at the facility level, at a sector-wide average, or set on some other basis. Carbon intensity is the measure of how much carbon is emitted into the atmosphere relative to the amount of energy in the fuel consumed.

FLEXIBILITY

The standard will be designed to provide maximum flexibility to fuel suppliers, and it may include provisions to take into account regional differences, similar to those that currently exist under the Renewable Fuels Regulations.

CARBON PRICING AND CLEAN FUEL STANDARD

The clean fuel standard would complement carbon pricing by ensuring consumers have access to a suite of lower-carbon fuels. In doing so, it will also drive down emissions and contribute to a clean-growth economy. By specifically addressing the carbon footprint of fuels, the clean fuel standard will drive innovation and create jobs and opportunities across a number of sectors, including transportation, agriculture, and clean-technology sectors.

The National Clean Fuel Standard policy mandates a broader consideration than simply transportation fuels because it covers ALL fuel uses, which represents about 80% of Canadian energy use rather than just transportation fuels as Ontario's review does. Indeed, Ontario is mandated by the Federal policy to expand their policy review to cover all fuels and to submit them and a reply to the proposed new Federal Policy.

Although Ontario’s Renewable Fuel Standard is applicable to transportation fuels, the Standard’s mandate should be expanded to include 100% of energy production and utilization, in order not only to be compliant with the National Clean Fuel Standard policy, but to exceed it by including the 20% of energy that is electricity that Ottawa left out.

THE GREEN SHIFT – STEPHAN DION

At the federal level, a carbon tax was proposed by Stephan Dion with his Green Shift program [5]. Dion proposed a carbon tax based on the greenhouse gas emissions. It would start out at $10/tonne, rising to $40/tonne within 4 years and be revenue neutral through of tax credits offsetting the revenue. While not specific about the implementation, it appeared that Dion intended to replace the federal excise tax on fuel and replace it with carbon tax applied at the wholesale level. With gasoline being taxed at the equivalent of $42/tonne of carbon dioxide, this carbon tax would not have resulted in any price increases to gasoline.

BRITISH COLUMBIA

Similar to Dion’s Green Shift plan, British Columbia introduced a $10/tonne carbon tax on Carbon Dioxide Equivalent (CO2e) emissions [6], which would rise to $30/tonne by 2012. BC’s carbon tax was revenue neutral by reducing corporate and income taxes subject to annual legislative planning.

ALBERTA

Alberta enacted the *Specified Gas Emitters Regulation* in 2007 [7]. This carbon tax requires a $15/tonne contribution be made to the "Climate Change and Emissions Management Fund"

(CCEMF) by large carbon emitter companies (ie, emitting more than 100,000 tonnes/year of greenhouse gas) to either reduce their CO2 emissions per barrel by 12 percent, or buy an offset in Alberta to apply against their total emissions. In 2016, the contribution was raised to $40/tonne for those large emitters. The intent of tax was to get oil companies and coal-fired generators to reduce their greenhouse gas emissions.

Starting 2017, Alberta will have a similar carbon tax scheme as British Columbia, which will be applied to the entire economy. All businesses and residents will pay a carbon tax based upon the carbon dioxide equivalent emissions, including the burning of wood and biofuels. The initial tax will be $20 per tonne, increasing to $30 per tonne in 2018, and increase thereafter by the rate of inflation plus 2%.

QUEBEC

Quebec enacted Canada's first carbon tax in October of 2007. It introduced a $0.008/litre tax on diesel fuel, which the equivalent of $3.00/tonne equivalent CO2e emissions [8]. This is not a revenue-neutral program because the revenue collected is used to fund energy-efficiency programs including public transit. Quebec's program also does not appear to be transparent because the carbon tax is not broken out as component of Quebec's fuel taxes.

CARBON TAX IN THE USA

There is no carbon tax under consideration at the federal level in the USA. Several states have considered implementing carbon tax programs but no proposals have yet been passed into law. In addition, some municipal level jurisdictions implemented carbon taxes:

- Boulder, Colorado, November 2006
- Bay Area Air Quality Management District, which covers nine counties in the San Francisco Bay Area, May 2008
- Montgomery County, Maryland, May 2010

CARBON TAX IN OTHER COUNTRIES

The following countries have the some sort of carbon tax in place [7]. All appear to base their carbon pricing solely on carbon dioxide emissions.

- Costa Rica
- Denmark
- Finland
- France
- Germany
- Netherlands
- Norway
- Republic of Ireland
- Sweden
- Switzerland
- United Kingdom

Other Considerations

ENERGY STORAGE THROUGH VEHICLE BATTERIES

For Ontario to maximize the consumption of the renewable energy generated in the province and minimize the amount of surplus power exported to neighbouring jurisdictions, Ontario must have the ability to store renewable energy. One such means of storing electricity is through battery technology and every electric vehicle has a battery.

Most vehicles are used for commuting and are therefore parked most of the time either at work or at home. If sufficiently large enough, Ontario's entire fleet of electric vehicles could therefore be used to help balance Ontario's electricity supply when they are plugged-in so that every vehicle owner would be an IESO market participant. This could be accomplished with smart chargers that charge vehicles when there is a surplus and draw power when there is a demand. The vehicle's charge controller would ensure that the vehicle battery would not be drawn down below the necessary charge level for the homeward commute. The spread between the market price to charge the battery at low demand and the price to return electricity at high demand could help with the public's acceptance of electric vehicles.

Besides vehicle owners, IESO should allow each home or business owner to become an IESO market participant. Already, there is home battery technology available to store electricity for the home owner. In addition, other technology is being developed to store electricity (such as solid state ammonia synthesis and ammonia fuel cells) as home appliances, which would help to transform Ontario's grid from central generation to distributed generation. This would facilitate vehicle-to-grid (V2G) technology as well.

EMISSION COMPLIANCE

Greenhouse gas emissions are not limited to combustion. Many fuels themselves are greenhouse gases and fugitive emissions prior to combustion can also have significant adverse effects on global warming. It is crucial that the Ministry of Environment conduct regular inspections of fuel systems to ensure that system operators do not allow any leakage. There must be vigilance about fugitive emissions from the wellhead to the tailpipe.

Methane, for example, is emitted during the production and transport of coal, natural gas, and oil. Methane emissions also result from livestock and other agricultural practices and by the decay of organic waste in municipal solid waste landfills. According to the US EPA, 11% of greenhouse gas emissions in 2014 were from methane compared with 81% for carbon dioxide [9]. Since methane has a global warming potential of 28-36, the relatively smaller methane emission fraction had 3.8 to 4.9 times worse effect on global warming than carbon dioxide.

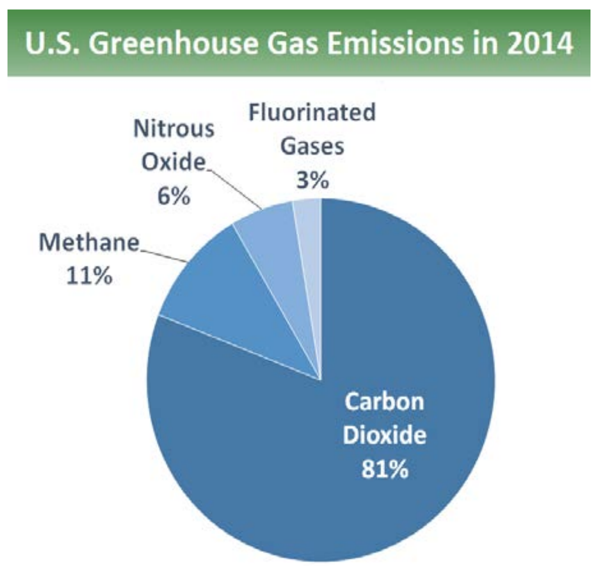

Figure 24 – U.S. Greenhouse Gas Emissions [9]

Natural gas-fueled vehicles have methane emissions both before and after combustion. In the case of LNG vehicles, as the cryogenic fuel warms, some of the methane leaks into the atmosphere as the safety relief valves blow off excess pressure. Both compression and spark ignition engines will have "methane slip" through the exhaust from incomplete natural gas combustion. Both of these sources of methane emissions must be mitigated and these vehicles should be regularly tested for emission compliance.

Figure 25 – LNG Truck Venting Excess Methane Pressure [10]

DEVELOPMENTS IN NH3 FUEL TECHNOLOGY

There has been much research that shows that ammonia can be used to fuel the most polluting forms of transport including marine, truck, and aircraft at less than half the cost and emissions of conventional fuels, even when the ammonia is made from natural gas or coal using appropriate technologies.

There have been some huge developments regarding green ammonia production, conversion of carbon in hydrocarbons into urea and use of NH3 as a fuel, for energy storage, especially in the past few months, including Mr. Gates Breakthrough Energy moving to develop technologies to produce "Zero emission ammonia", many of which actually exist commercially today.

Commercially available technologies have proven that energy and heating and cooling costs can reduced by more than 50% when ammonia is used in the mix, and there are opportunities to use a combination of fossil fuels and electricity in much more profitable ways. There are patented engines that provide CHPC (combined heat, power and cooling) at over 60%, at a fraction of the cost of any other technologies.

Existing natural gas infrastructure and power plants can use ammonia and where NH3 plants are built beside gas plants that burn NH3 with the vast amounts of pure oxygen available results in increases in efficiency as much as 50% with similar reductions in costs and virtually zero carbon, sulfur or nitrogen oxide emitted, and nothing but nitrogen (N2) and water (H2O) created as a result.

A joint submission between *Hydrofuel Inc.* and the *University of Ontario Institute of Technology's (UOIT)* submission to the *Canadian Environmental Assessment Agency (CEAA)* for the Pacific NorthWest LNG Project concluded [11]:

> "For the reasons stated in the above document and supported by Dr Ibrahim Dincer’s group at UOIT (comments and MITACS report attached), Hydrofuel Inc. believes that the Pacific NorthWest LNG Project should not proceed and that the alternative of transporting energy in the form of anhydrous ammonia should be considered instead."

This submission proposes we use ammonia instead, an idea that has gained worldwide academic and public and private sector support as you will see from the details in the 13 points below and the attachments.

Hydrofuel Inc. has completed several projects with UOIT including one that will be ready by the end of March 2017, which will provide an analysis of the economics of converting gas into NH3 and urea for transport to worldwide markets instead of using LNG. We already know that NH3 can be burned and utilized at much higher efficiencies in engines and turbines with lower emissions, adding a price for carbon changes the numbers and adding the life cycle costs will make the economics of do so even more compelling.

In late September, 2016, Hydrofuel Inc. released the *UOIT Green NH3 and Key Life cycle energy research* [12] at the *13th NH3 Fuel Association conference at UCLA* [13], where SIEMENS (supported by Innovate UK. Collaborators include the University of Oxford, Cardiff University and the Science & Technology Facilities Council) announced their "Green" Ammonia technology, pilot plant project, and strategy that *"Green" ammonia is the key to meeting the twin challenges of the 21st century*. [14]

There is worldwide development of dozens of NH3 production and utilization technologies being reported now, and in addition to the *NH3 Fuel Association* website [15] a new *Ammonia Energy* Global Information Portal website [16]

UOIT RESEARCH

- Key Life-Cycle Numbers for NH3, Fossil Fuel and Green Energy production and utilization in agriculture, energy and utilities, and transportation systems [17]
- Comparative Life Cycle Assessment of Various Ammonia Production Methods [18]
- The most recent UOIT/Hydrofuel Inc. peer-reviewed paper published free to read by Springer as part of their Nature SharedIt and formally in *Environmental Management* on ”Impact Assessment and Environmental Evaluation of Various Ammonia Production Processes". The previous paper a "Comparative life cycle assessment of various ammonia production methods" was published in the Journal of Cleaner Power on November 1, 2016. [19]
- Other research Hydrofuel has done with UOIT may be found in the Latest News section of the Hydrofuel web site. [20]

EUROPEAN POWER TO AMMONIA CONFERENCE

1st European Power to Ammonia® Conference announced for May 18-19, 2017 - 1st European Conference on Sustainable Ammonia Solutions aims to gather thought societies, industries and academics, including well-known experts, developers and scientists to present the latest research results, present achievements, application fields and business prospects in energy solutions. This conference welcomes all researchers, industrialists, scientists as well as student and corporate delegates to participate and to have a great experience. [21]

JAPANESE AMMONIA USAGE

Japan has been using ammonia to fuel coal power plants reducing emissions. (Using similar technologies to this used in China for forty years.) Japanese utilities team on CO2-reducing tech for coal plants - Coal-ammonia fuel mix seen lowering emissions by at least 20%. [22]

DR. STEVE WITTRIG, US CLEAN AIR TASK FORCE

The development of the ammonia economy will depend on successful deployment of a range of new technologies in the context of the existing ammonia industry and the world's many existing energy markets. This report *Ammonia Fuel: Opportunities, Markets, Issues* [23] provides a framework for:

- Supply/demand and status of the global ammonia industry.
- Plausible response of growth and prices in response to a giant new market in fuels.
- New incremental applications which may lead to 'disruptive innovation' and rapid takeoff for ammonia fuels.
- Barriers to takeoff.

HYPER HUB PATENT

An improved system of hardware and controls, known as a Hyper Hub, that absorbs electric power from any source, including hydropower, wind, solar, and other renewable energy resources, chemically stores the power in hydrogen-dense anhydrous ammonia, then reshapes the stored energy to the power grid with zero emissions by using anhydrous ammonia to fuel diesel-type, spark-ignited internal combustion, combustion turbine, fuel cell or other electric power generators, and for other purposes. [24]

OTHER DEVELOPMENTS

1. On November 10, 2016, *Ammonia Energy* announced a 2018 pilot plant in Japan will demonstrate a new way to produce ammonia at industrial-scale, with a low carbon footprint. [24]

2. On November 28, 2016, the Trudeau Government announced its new life cycle Clean Fuels Standards policy being formulated for February 2017. [25]

3. On December 2, 2016, *Ammonia Energy* announced *Nuon*'s Power-to-Ammonia update, and the first European ammonia fuel conference in 2017. [26]

4. On December 6, 2016, the Massachusetts Institute of Technology (MIT) released their *PLAN B - FOSSIL FUELS without CO2 emissions*. Using clean-tech and ammonia makes fossil fuels clean and much more profitable. The stored chemical potential in fossil fuels from thermonuclear derived solar energy may be utilized by less conventional means without producing carbon dioxide. Chemical pathways to produce hydrogen or ammonia from hydrocarbons without co-production of carbon dioxide are possible in new process configurations. Such processes may be more cost effective than other options and more readily implemented. [27]

5. Phoenix Energy, a developer of biomass gasification plants based in San Francisco, shared some interesting data today during a Webinar on "The Future of Renewable Methane in Today's Regulatory & Policy Environment." The company operates two plants in California that together produce 5.5 tonnes/day of byproduct carbon in the form of biochar. They are currently selling all of the biochar they can produce into agricultural markets at a price of $1,700 per tonne. [28]

- *Ammonia as a fuel is a real interesting target, where it would allow you to make the transfer of that chemical potential to something that fits in well to our infrastructure … It has the same heat of combustion as methanol, so it has plenty of power per weight. When you burn it though, you only make nitrogen and water. There's ways to get around the issues with NOx and stuff, so this is really a nice fuel. And the wonderful thing about ammonia, if you think about it, if you made it at a price for fuel, it would do something else that's really important for the poor, which is to lower the price of food …*
- *All of the automobile companies have looked at ammonia as a possible fuel, and it's one that is certainly worthy of consideration if one wants to think about what we can do about a liquid fuel that fits into our own infrastructure that can be used more or less in our world as we know it.*

6. On December 14, 2106, *Ammonia Energy* announced the US DOE ARPA-E's REFUEL program awarded $35 Million (US) in funding to a total of 16 projects for carbon-neutral liquid fuels (of these 16 projects, 13 were focused on carbon free ammonia (none for hydrogen not associated with using ammonia), of the three others that went to carbon based energy, two were for Dimethyl ether, one looked at ethanol). [29]

7. On December 14, 2106, *Ammonia Energy* announced the Bill Gates' *Breakthrough Energy Coalition* [30] is starting work on viable grid scale and world class Green NH3 technologies after concluding that one of its initial Technical Quests is to make "Zero-GHG Ammonia Production" a reality. [31]

8. On December 16, 2016, the Trudeau government announced it has delayed the notification date of NRCan's decision on clean energy innovation funding proposals [32]. The date has been changed from late fall 2016 to winter (mid to late February) 2017. As Greg Vezina points out in the upcoming Ottawa Life Magazine article mentioned below, it appears the recent developments in support of ammonia and moving away from bio-fuels and other carbon based technologies combined with the government's new Life Cycle Clean Fuels Policy has caused a major rethink of how they will spend the $billions in proposed funding. All of this is very good news for ammonia energy proponents.

9. On January 27, 2017, *Ammonia Energy* announced more US DOE funding research into sustainable ammonia synthesis. These *Sustainable Ammonia Synthesis projects*, announced in August 2016 and administered by the Office of Basic Energy Sciences, aim “to investigate some of the outstanding scientific questions in the synthesis of ammonia (NH_3) from nitrogen (N_2) using processes that do not generate greenhouse gases.” There are two substantial differences between these awards and the other recent DOE funding for sustainable ammonia technologies, announced in December 2016 and administered through ARPA-E’s “REFUEL” program. [33]

10. Below are links to a number of articles we have written or co-written, and one that has been written about our work.

    A. Four articles co-written for Ottawa Life Magazine.
        i. One of Four: An Alternate View on Pipelines — Transport Ammonia not Crude [34]
        ii. Two of four: Green Ammonia [35]
        iii. Three of four: Canada’s Ammonia Energy Option [36]
        iv. Four of Four: Canada's Life Cycle Clean Fuels Policy Game Changer [37]

    B. Most of the information about ammonia as a renewable fuel is not covered by the mainstream media in Canada with the exception of Ottawa Life Magazine and the Toronto Sun Editor Lorrie Goldstein who has let Greg Vezina write many SUN editorial page articles and who has written about my NH3 work, most recently in:

       “High Cost of Ignorance" a Toronto Sun Editorial page article on Oct. 23, 2016. [39]

11. Research on Cost comparisons of pipelines, distribution and marine transport for natural gas and ammonia [35]. Included are <u>four</u> studies Hydrofuel Inc. have already done with UOIT on point, however, as mentioned above, we are completing our third *MITACS* research report in February, 2017, which will be much more extensive.

A. Ammonia as a Potential Solution for Alberta (Submitted to Alberta Premier) [42]
B. Natural Gas to Ammonia as a Potential Solution for British Columbia (Submitted to BC Premier) [43]
C. *MITACS Report 1* November 2015 - "Comparative assessment of NH3 production and utilization in transportation systems" [44]
D. *MITACS Report 2* June 2016 - "Comparative assessment of NH3 production and utilization in agriculture, energy and utilities, and transportation systems" [45]

After reviewing the links and attachments, you will see that there is very solid scientific and economic research and numerous practical applications that support using ammonia to green hydrocarbons and store renewable energy already commercially available and many more emerging almost daily.

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