HYDROFUEL®

# Ontario's First-Ever Hydrogen Strategy Public Comments

January 18, 2021

## Introduction

This document is Hydrofuel Inc's comments about Ontario's first-ever hydrogen strategy discussion paper. The paper sets out a vision for a new hydrogen economy in the province - one that will attract investment, and lead to more job creation, while helping reduce greenhouse gas emissions using low-carbon hydrogen. This strategy will eventually help Ontario achieve its greenhouse gas reduction target.

The province hopes to achieve the following goals for its hydrogen strategy:

- help lower greenhouse gas emissions;
- support a reliable and affordable energy system in Ontario;
- help the hydrogen sector in Ontario tap into growing global demand for hydrogen and hydrogen-related solutions; and
- reduce regulatory barriers and support partnerships with the private sector, academia and other governments.

## Hydrofuel Inc.'s Comments

We at Hydrofuel Inc. (Hydrofuel) have been following the federal and provincial governments' climate change strategies over the years. Human activity to this point in time has required the combustion of fossil fuel for economic growth. The natural processes to sequester ancient carbon into fossil fuel that have taken hundreds of millions of years to occur are effectively being reversed within an instant of geologic time. Many scientists now believe that we are in the midst of the sixth great extinction, which is being driven by this human activity.

Hydrofuel welcomes Ontario's Hydrogen Strategy because we believe that hydrogen is a key part of reducing greenhouse gas (GHG) emissions and the best way build a vibrant low-carbon economy. While the discussion paper is comprehensive about hydrogen, it makes no mention of the other hydrogen: *anhydrous ammonia* (NH3) other than a passing mention of hydrogen's use in fertilizer.

There is a strong need for both shortcut and complementing solutions in hydrogen economy where ammonia appears to be a leader because NH3 can be used as a fuel, refrigerant, working fluid, chemical, agent, hydrogen storing medium, carbon capturing agent, etc. For these reasons, ammonia is a unique shortcut option and carbon-free solution. Ammonia is a multi-functional green solution for many useful commodities!

Ammonia contains about 48% more hydrogen by volume than even liquefied hydrogen. That is to say, a cubic meter of liquid hydrogen contains 71 kg of hydrogen compared with 105 kg for liquid anhydrous ammonia. Ammonia's physical properties are similar to those of propane (a liquefied petroleum gas), which make it far easier to handle than either compressed or liquefied hydrogen. In fact, the amount of fuel energy contained in the diesel fuel tanks of a transport truck carrying compressed hydrogen is greater than the amount of hydrogen being transported.

We were surprised to see that the discussion paper's authors did not spent much time researching the vast amount of existing literature about NH3 as an energy carrier and a motor fuel. Ammonia has been used as a motor fuel for decades and Belgium used NH3 to during the 2$^{nd}$ World War to fuel their buses due to a shortage of diesel fuel [1] [2].

The US Department of Energy published *Potential Roles of Ammonia in a Hydrogen Economy* in 2006 [1], which concluded:

> *Due mainly to its high hydrogen capacity, ammonia has the potential for use as a carrier for hydrogen delivery and distribution and, perhaps, as an onboard storage medium. … Although DOE is not currently funding conventional fuel processing of ammonia for on-board hydrogen storage, the potential use of ammonia as an energy carrier, particularly during the transition towards the hydrogen economy, is not disqualified. Ammonia may be considered as a potential hydrogen carrier for hydrogen delivery and for off-board storage, such as at refueling stations and for stationary power applications.*

Vito Agosta, Professor Emeritus at NYU Tandon School of Engineering, wrote an article for ASME in 2010 entitled *The Ammonia Economy* [2], where he stated:

> *About 40 years ago, I was a project leader on an Army research contract to produce fuel from air and water suitable to be used immediately in Army vehicles and devices. The family of fuels that could be produced were those that contained hydrogen, nitrogen, and oxygen, e.g., hydrogen, ammonia, hydrazine.*
>
> *The advantages of using hydrogen are that it burns well in energy devices; has very wide limits of flammability, making for stable combustion; and has a large heat of combustion per unit mass.*
>
> *There are also disadvantages to hydrogen. It detonates very easily. When used in diesel engines, it needs to be compressed for injection into the cylinder. But doing so can consume up to 15 percent of its output power, thus compromising its efficiency. At low pressure, its heat of combustion is low per unit volume. Although Honda has introduced a hydrogen-powered car employing a fuel cell that offers many advantages, and Toyota and others will soon follow suit, in the immediate future hydrogen will not be readily*

*available at the corner fuel station. The present fueling procedure is complicated for the average layman.*

*On the other hand, ammonia-based fuels offer a great potential for universal use. The present disadvantage is that pure ammonia is not suitable for use in high-speed engines. Its flame speed is too low.*

*However, ammonia can be doped by environmentally friendly chemical additives, and thus be compatible in high-speed engines. Ammonia is already compatible in other energy devices, such as low-speed engines and fuel cells. It is an abundantly produced chemical used in industry and agriculture. Production facilities can easily be expanded.*

*There are environmental impacts in its production, largely energy costs for production of the hydrogen needed to make ammonia. These effects can be ameliorated by careful evaluation and selection of sources of hydrogen and energy to produce it. In addition, handling and storage technologies are presently available and can readily be transferred to the general population.*

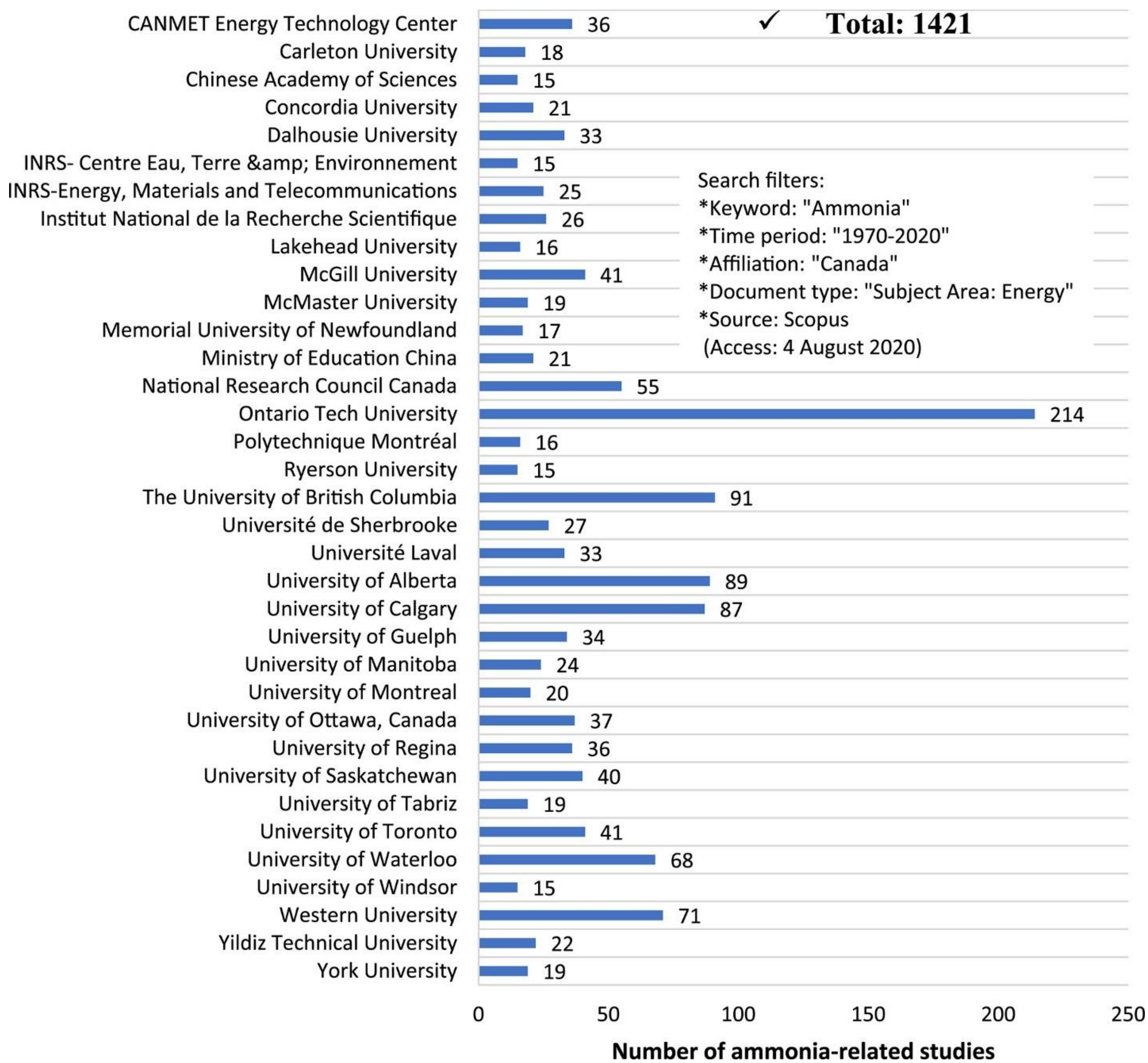
*Ammoniated fuel will power an engine or burner with very little modification. Thus, the transition to an ammonia-based fuel economy can be as slow or as fast as societal conditions permit.*

*In summary, there are many advantages to be achieved by adopting this alternate fuel technology of an ammonia-based fuel. Its application can be immediate. Our dependence on fossil fuels will be lessened, engines and burners will operate with cleaner burn at higher efficiencies, and environmentally friendly liquids such as ammonia, water, alcohols, or waste liquids can be used as emulsificants in a broad range of proportions. In addition, waste storage areas, e.g., those at industrial sites and farms, can be cleaned. Finally, with the introduction of this technology, society can function as before with its normal patterns of behavior, and without being put into harm's way.*

The ammonia economy is intended to expedite implementing and completing the hydrogen economy in many sectors successfully. Several countries have already initiated their own ammonia programs, and Canada must announce its ammonia program without delaying it any further since this will expedite the switch to hydrogen economy and complete transition in a safer and smother manner.

The Hydrogen economy needs comprehensive and substantial infrastructural changes. By including ammonia in the Ontario Low-Carbon Hydrogen Strategy, we can eliminate most of these requirements and provide most feasible solutions. Ontario Technical University (OTU) is a world-wide leader in ammonia research and using their resources can help Ontario can be the leader in in Canada's transition to a low-carbon, hydrogen economy.

Ammonia energy appears as a research topic in 1421 studies conducted in Canada from 1970 to the present and *OTU, founded in 2002,* has been the pioneer institute of Canada for ammonia-related studies in the subject area of energy by conducting 214 studies in this field so far. As an energy carrier and storage media for hydrogen, ammonia attracts the attention of researchers and sponsors. However, the gigantic gap between the number of hydrogen-related and ammonia-related energy studies shows that the awareness of researchers regarding the potential of ammonia for clean energy transition is not where it should be. On the other hand, considering hydrogen and ammonia together for energy applications may increase the feasibility while decreasing the costs. [5]



## Level Playing Field

Hydrofuel believes that, while there must be a price on pollution (including GNG emissions) that reflects its cradle-to-grave cost, Canada's current carbon pricing strategies of Carbon Taxation and Cap & Trade are poorly conceived and ineffective. We believe that a flow-through pollution tax (similar in many ways to Ontario's Harmonized Sales Tax), would be far more effective, transparent, and fair. Hydrofuel submitted this idea to the Ontario's public consultation regarding "*Developing a modern renewable fuel standard for gasoline in Ontario*" [3] and the federal government's public consultation regarding "*Clean Fuel Standard Discussion Paper*" [4]: and we stated that:

*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. The Environmental Impacts to be considered are:*

*Abiotic Depletion*

*Acidification*

*Eutrophication*

*Global Warming*

*Human Toxicity*

*Ozone Layer Depletion*

*Terrestrial Ecotoxicity*

*Marine Aquatic Eco-Toxicity*

*Land Occupation/Land Use*

The Harvard-published report, *The Cost of Reducing Greenhouse Gas Emissions* [5], had a similar recommendation:

> *What is the most economically efficient way to reduce greenhouse gas emissions? The principles of economics deliver a crisp answer: reduce emissions to the point that the marginal benefits of the reduction equal its marginal costs. This answer can be implemented by a Pigouvian tax, for example a carbon tax where the tax rate is the marginal benefit of the emissions reduction or, equivalently, the monetized damages from emitting an additional ton of carbon dioxide (CO2). The carbon externality will then be internalized and the market will find cost-effective ways to reduce emissions up to the amount of the carbon tax.*

Governments particularly like Cap & Trade for carbon pricing because is extremely opaque but useful for promoting their own lobbyist-influenced, preferred technologies. Although technology has greatly progressed since 2013, the United Kingdom had the following experience according to *International Institute for Sustainable Development* [6]:

> *Wind turbines cost 10 times the estimated benefits in terms of emissions cuts, and solar panels cost close to 100 times the benefits. Each ton of CO2 avoided costs about £1,200. The EU's "cap and trade" system is estimated to cost less than £4 for each ton avoided – so we pay almost 300 times too much.*

Instead of letting market forces determine effective and economical carbon-free technologies, American states had a similar experience with mandated renewable energy programs [7]:

> *A working paper co-authored by University of Chicago scholars found that these popular programs—enacted in 29 states and the District of Columbia—are inefficient in reducing carbon emissions and come at a high cost to consumers. They found these Renewable Portfolio Standards increased prices by as much as 17 percent, making the policy's cost of reducing carbon emissions more expensive than current estimates of the benefits.*
>
> *"The increasing urgency of climate challenge means that the case for ruthlessly seeking out the least expensive reductions in carbon emissions is rapidly strengthening," said study co-author Michael Greenstone, the Milton Friedman Distinguished Service Professor in Economics and director of the Energy Policy Institute at the University of Chicago. "This study joins a growing body of evidence that demonstrates that when climate policies favor particular technologies or target something other than the real enemy—carbon emissions—the result is less effective and more expensive than is necessary. In contrast, the global experiences from carbon markets and taxes*

*make clear that much less expensive ways to reduce CO2 are available right now."*

Leveling the playing field domestically levels the playing field globally.

## Biofuels Are Not the Answer

Biofuels cannot be a true answer in the Hydrogen Strategy due to several deficiencies and issues. Governments often promote the increased use of biofuels (eg, ethanol and biodiesel) as means of reducing greenhouse gas emissions, thereby mitigating climate change. Ontario, for example, has recently increased the ethanol addition to gasoline from 10% to 15% - with the main benefit being the growth of the ethanol industry rather than reduced GHG emissions. [8]

However, this approach is flawed firstly because carbon isn't sequestered from the carbon cycle and secondly because a significant amount of fossil fuels is required to produce biofuels. The net effect is a continued increase in atmospheric carbon. The net benefit of using biofuels to mitigate climate change is ineffective and the best case would be a very minor reduction in overall GHG emissions.

Related and more significant to a net increase in biofuel carbon emissions is the shift of agricultural land from food production and forests from pulp & paper product to hydrogen production. There is no way to grow enough biomass (typically from corn in North America) for biofuel to displace petroleum to any great extent and, with the removal of carbon, there is even less of hydrogen fuel. As crops and forests are grown for fuel, this diversion of resources places upward pressure on the price of food and pulp & paper. The pressure on food prices has already been long reported in many Organisation for Economic Co-operation and Development (OECD) articles, among which are:

*BIOFUELS: IS THE CURE WORSE THAN THE DISEASE?* [9]:

*"The current push to expand the use of biofuels is creating unsustainable tension that will disrupt world markets without generating significant environmental benefits."*

*"When such impacts as soil acidification, fertilizer use, biodiversity loss and toxicity of agricultural pesticides are taken into account, the overall environmental impacts of ethanol and biodiesel can very easily exceed those of petrol and mineral diesel."*

*Rising Food Prices: CAUSES AND CONSEQUENCES* [10] :

> *Feedstock demand for biofuel production is expected to increase further, albeit at a slower rate than in the past three years, and under current policy settings appears to represent a permanent factor in price formation. Unlike strong income growth in developing countries, this is a new source of demand which is seen as one of the factors lifting prices to higher average levels in the future.*
>
> *Finally, the nature and composition of demand are factors that may increase the future variability in world prices. First, industrial demand for grains and oilseeds and in particular policy-driven demand for biofuels production is generally considered less responsive to prices than traditional food and feed demand. Second, food demand becomes less responsive to price changes as incomes rise and the commodity share in the food bill falls. Such changes are permanent factors that may lead to greater volatility in future world prices.*

While the biofuel lobby purports that this will have no effect on food prices, this can only be possible IF there is a significant amount of available arable agricultural land that is not being farmed. The basic law of supply and demand requires that if supply decreases without a corresponding decrease in demand, the price will increase.

Other comments about Biofuels:

| **Source** | **Article Content** |
|---|---|
| *Biofuels 'worse than petrol' for the environment, new study finds* [13]<br>John DeCicco, University of Michigan | The underpinnings of policies used to promote biofuels for reasons of climate have now been proven to be scientifically incorrect. |
| *U.S. corn ethanol "was not a good policy": Gore [12]*<br>Reuters | A food-versus-fuel debate erupted in 2008, in the wake of record food prices, where the biofuel industry was criticized for helping stoke food prices. Gore said a range of factors had contributed to that food price crisis, including drought in Australia, but said there was no doubt biofuels have an effect.<br>“The size, the percentage of corn particularly, which is now being (used for) first generation ethanol definitely has an impact on food prices. … The competition with food prices is real.” |

| Source | Article Content |
|---|---|
| *Al Gore accepts science at last: Corn ethanol "was not a good policy" [13]*<br>The Wall Street Journal | "It is not a good policy to have these massive subsidies for first-generation ethanol," Al Gore told a gathering of clean energy financiers in Greece this week. The benefits of ethanol are "trivial," he added, but "It's hard once such a program is put in place to deal with the lobbies that keep it going."<br>The subsidies continued through the 1990s, with the ethanol lobby finding a sympathetic ear in Clinton EPA chief and Gore protege Carol Browner, who in 1994 banned the gasoline additive MTBE and left ethanol as the only option under clean air laws. When the Senate split 50-50 on repealing this de facto mandate, then Vice President Gore cast the deciding vote for . . . ethanol. |
| *Rule on Ethanol Is Upheld - AL Gore Breaks Tie [14]*<br>The New York Times | But other senators said the rule would raise fuel prices, cost hundreds of millions of dollars in lost gas taxes and provide no environmental benefit over methanol oxygenates.<br>The rule's critics also said it was a boon to the Archer Daniels Midland Company, a corn processing giant, which has more than 60 percent of the ethanol market. But supporters said new farmer cooperatives would get the added business and Archer Daniels' overall ethanol market share would shrink. Ethanol is the only widely produced renewable fuel. |

| **Source** | **Article Content** |
|---|---|
| *Canada lags the United States in climate accounting of biofuels [15]*<br>International Council on Clean Transportation | The Clean Fuel Standard (CFS), a major pillar of the Pan-Canadian Framework on Clean Growth and Climate Change, aims to reduce GHG emissions by 30 million tonnes of CO2e annually by 2030 by reducing the GHG intensity of liquid, gaseous, and solid fuels used in transport, buildings, and industry. However, Canada's climate goals are threatened by an accounting error: ignoring emissions from indirect land-use change (ILUC) when quantifying the greenhouse gas (GHG) performance of biofuels. On its current pathway, the CFS could hit its target on paper but will fall far short in real GHG reductions.<br>ILUC is an unavoidable consequence of most types of biofuels. When commodities like corn, canola, and tallow are used for biofuel production, they are diverted from existing uses such as food, livestock feed, soap making, etc. In order to meet the growing demand for these resources, agricultural land expands. Even if the corn and canola used for biofuel does not come directly from recently cleared cropland, it still causes land clearing elsewhere and spurs the associated GHG emissions from deforestation and soil disturbance. There is a broad consensus among scientists that ILUC significantly undermines the climate benefits of biofuels.<br>While the CFS is expected to drive increased consumption of biofuels, biogas, and solid biomass fuels, the Canadian government has stated that it will not factor in the impacts of ILUC emissions in the standard. Instead, the proposed policy will only compare the direct emissions from feedstock and fuel production to the GHG intensity of fossil fuels. This flawed accounting methodology will substantially over-report the true GHG savings of biofuels and, as a result, Canada will claim 30 million tonnes CO2e savings in 2030 while actually delivering far lower. |
| *Biofuel 'a costly misadventure' – Opinion [16]*<br>The Western Producer | Biofuels are the most misguided public policy being introduced in Canada that achieves no public policy objective. The stated public policy objectives of Bill C-33 and the mandating of ethanol and biodiesel are: to provide alternate energy and lessen Canada's dependence on fossil fuels; to reduce CO2 emissions; and to provide a market for farmers' grain. Ethanol manufacturing is energy intensive and uses large amounts of fossil fuel to grow the crop, transport it and distill it into ethanol. |

## Electric Vehicles Are Not the Answer Either

While electric vehicles (EV) are superior to internal combustion engine (ICE) powered vehicles in many ways, the only way for the general public to embrace them is to make the overall (capital and operating) cost competitive with ICE-powered vehicles. Although EV technology is progressing rapidly, this is extremely difficult to achieve at this time because batteries are still very expensive relative to their energy density (kWh/kg and kWh/m³). The fact that EVs do not have tailpipes does not automatically reduce vehicle carbon emissions.

| **Source** | **Article Content** |
|---|---|
| *Subsidizing electric vehicles inefficient way to reduce CO2 emissions: study [17]*<br>Physics Org | In subsidizing electric vehicle purchases, Ontario and Quebec end up spending up to 29 times and 16 times, respectively, the carbon market price for each tonne of GHGs eliminated.<br>"Common sense, both economically and ecologically speaking, argues in favor of reducing these subsidies, and even eliminating them," the study concludes. |
| *Are Electric Vehicle Subsidies Efficient? [18]*<br>IEDM/MEI | Subsidies for the purchase of electric vehicles have little effect on GHG emissions and are much more expensive than other incentive measures that achieve the same results. Between different methods that produce the same results, the more expensive method should never be favoured. If the goal is to obtain the greatest emissions reductions for the amounts spent, then subsidies for the purchase of electric vehicles are actually the least efficient, most expensive way to get there. The Quebec and Ontario governments should abolish them. |
| *Electric Vehicle Subsidies in the Era of Attribute-Based [19]*<br>Canadian Public Policy<br>University of Toronto Press | Electric vehicle (EV) subsidies are costly and ineffective policy mechanisms in the battle against greenhouse gases. Furthermore, their operation is not well understood given the new regulatory environment governing emissions standards and fuel efficiency that is common to the United States and Canada. Given these standards, the sale of more EVs permits manufacturers to sell fossil fuel vehicles with higher carbon dioxide (CO2) emissions. Paradoxically, more EV sales result in more CO2 emissions. |
| *Federal policy reverses benefits of alternative fuel vehicles [20]*<br>Carnegie Mellon University study published in the journal Environmental Science & Technology | Alternative fuel vehicles (AFVs), such as electric vehicles, can reduce U.S. petroleum consumption and can also potentially reduce emissions. However, a new Carnegie Mellon University study finds that under U.S. federal policy, AFV sales trigger the opposite effect. |

Hydrogen fuel cell (HFC) powered vehicles substitute a battery for a fuel cell and hydrogen storage tank. While this may increase may improve refueling time, it also presents new challenges, some of which are difficult or impossible to overcome.

HFC have been around for decades and are efficient. The challenge with them is with the transport and storage of hydrogen. The low energy density of compressed hydrogen gas makes storage and transport very expensive. Transporting compressed hydrogen gas any significant distance by truck can consume more energy in diesel fuel than what is contained in hydrogen. Liquefied hydrogen is obviously more energy dense than compressed hydrogen gas but a significant amount of energy must be expended to liquefy hydrogen and keep it refrigerated because its boiling point is –423°F (–253°C). Liquefaction requires about 30% of the energy content of liquid hydrogen while compression to 800 bar requires about 10-15% of energy carried by the hydrogen.

Hydrogen's molecules are very small and difficult to contain. Hydrogen will slowly leak out from hoses and its rate of leakage is much higher than larger molecule gases like ammonia and propane. Hydrogen also causes embrittlement in metals which requires periodic replacement of metallic tubing, valves, and tanks.

Hydrogen is typically transported as a compressed gas and a 40-ton truck that can carry 26 tons of gasoline can only carry about 400 kg (0.4 tonnes) of compressed hydrogen due to the weight of the high-pressure hydrogen tanks.

## Blue Hydrogen and Ammonia from Fossil Fuels

BLUE hydrogen and ammonia from hydrocarbons are viable with $30-$60 per ton carbon tax [23].

We can safely and sustainably exploit our natural gas, oil and bitumen resources at huge profits compared to many green energy solutions exempted from carbon and life cycle pollution. There is no need for a price on carbon and life cycle pollution higher than $30 to $50 per ton with no exemptions for any forms of energy, let alone a $170 per ton price on CO2 with 80-90% industry and 100% green energy exemptions. We need a 'fair' price on all energy pollution. Lower cost hydrogen and ammonia production from hydrocarbons with less life cycle and carbon pollution than wind, solar, ethanol or biofuels has been already proven to be viable in Canada according to research form the IEA with ONLY a $30 per ton carbon tax on ammonia and $60 per ton for hydrogen.

This level of pollution pricing on all forms of energy would also benefit the production and use of renewable energy even though the life cycle pollution would be priced or taxed, or even if all pollution was exempted, as it the case in much of the USA including in Arizona.

Nikola plans on producing the hydrogen for its vehicles itself and just signed an agreement with the Arizona Public Utilities Commission (APS) for electricity to do it that has dropped for the market price of *3.5 cents per kilowatt-hour*, to a much lower special contract rate of *2.7 cents per kilowatt-hour*. (Natural gas, nuclear power, and coal provided almost all of Arizona's net electricity generation in 2018. Together they fueled 89% of the state's utility-scale net generation). [24]

The net cost to eliminate the CO2 in the production and use of hydrogen and ammonia from methane makes it less than half the cost of any renewable form of energy including wind, solar, biofuel, ethanol, hydro or even nuclear power. The total life cycle costs are even lower. The cost of BLUE hydrogen are about one third the cost of GREEN hydrogen.

The cost of BLUE hydrogen and ammonia from hydrocarbons with ZERO CO2 and lower life cycle emissions are between 25% and 35% of the cost of GREEN hydrogen and ammonia today (both which are exempted from carbon and all life cycle pollution pricing in Canada, even when the electricity used to make it is generated using natural gas, biofuel, ethanol, gasoline, diesel or coal feedstocks).

There are multiple existing technologies in use today at grid or world class scale that eliminate the CO2 produced making hydrogen/ammonia from natural gas at low incremental costs. There are others under development, particularly in Canada where there is a commercial demonstration by Proton Technologies that, as mentioned above, will produce H2 (or NH3) from hydrocarbon resources and abandoned oil and gas wells with low to zero CO2 emissions for as little as 10% of the cost of producing them today. When these technologies reach commercial scale in the near future the cost of BLUE hydrogen and ammonia made from hydrocarbons could be as little as 10% to 20% of the equivalent cost of making it from ANY other form of energy including nuclear power, and still be a fraction of the fraction of the cost of GREEN hydrogen or ammonia made from electricity going forward for decades.

Petroleum-based hydrocarbon resources already exist. The challenge to their continued use is cost-effective clean tech to reduce and eliminate carbon and life-cycle pollution. Most renewable resources are created from cradle to grave and the infrastructure and industrial capacity needed to produce them is many times greater than hydrocarbons. The fastest way to get to large-scale development of green energy is to use hydrocarbon resource sustainably as the bridge.

There will be a stampede to monetize global hydrocarbon energy reserves profitably instead of spending three or more times as much on the short to medium term green or renewable technologies that must mature and be backed up by 100% additional generating capacity primarily from hydrocarbon or nuclear energy (much of which will be wasted to grid manage gating hydro plant water at or blowing nuclear plant steam), or be tripled to provide equivalent stored back up power with 50% net efficiency.

Either way, most renewable energy (excluding a limited amount of hydro electric power) generating capacity must be at least tripled to provide base-load and interruptible electrical power (with round to round generation, storage and regeneration at 50% efficiency) representing 20% of our energy demand, and increased a dozen or more times to provide enough base-load and on-demand renewable energy to replace the 80% of energy we use that is liquid fuels with electricity.

The naked truth few seem to be willing to tell is that the real costs to increase renewable energy production by any measure in Canada is many times the cost of producing cleaner energy from existing gas, oil and bitumen reserves.

According to independently verified research there are 400% to 500% greater profits available from converting natural gas to ammonia for transport to markets in North America and overseas than is possible with LNG using the same natural gas and there are even higher profits for jurisdictions that have no gas to import it and export ammonia. The life cycle and carbon emissions of ammonia verses LNG are much lower even when the CO2 is emitted where the NH3 is produced because the carbon in the gas is not transported to be emitted by the end user.

The CO2 from the production of ammonia from natural gas can be totally eliminated for $30 to $60 per ton maintaining 80% of the increased profits while producing the greenest and cleanest energy possible from either hydrocarbons, and clean ammonia made from electricity generated from renewable energy at as low as $0.02/kWh. [26]

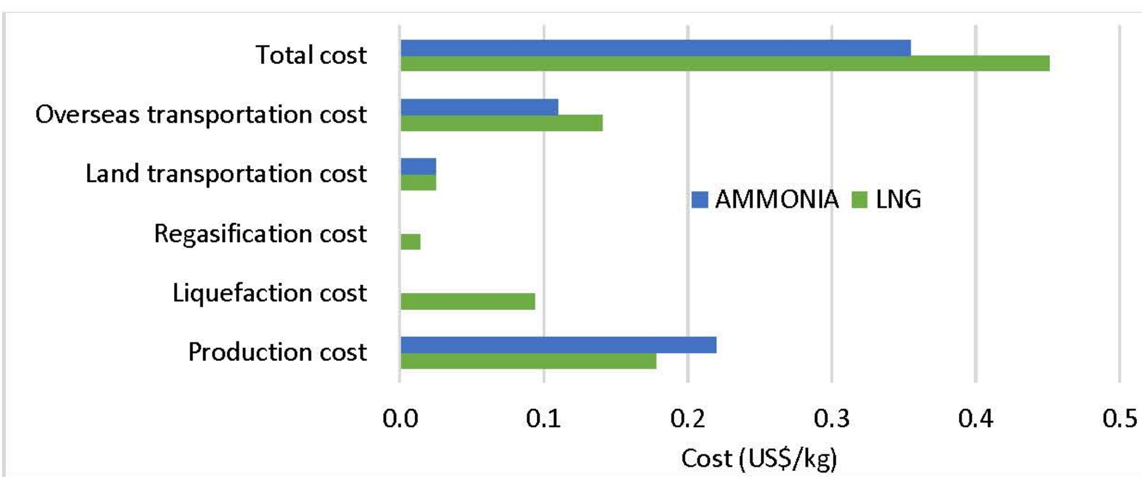



Figure 46 Contribution of sub-processes to total cost of LNG and ammonia for Case 2 in the U.S

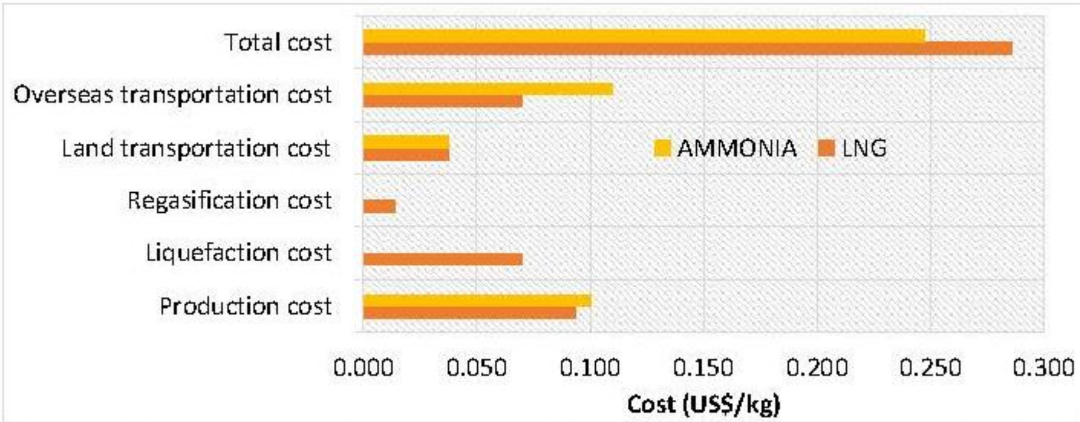



Figure 48 Contribution of sub-processes to total cost of LNG and ammonia for Case 3 in Middle East

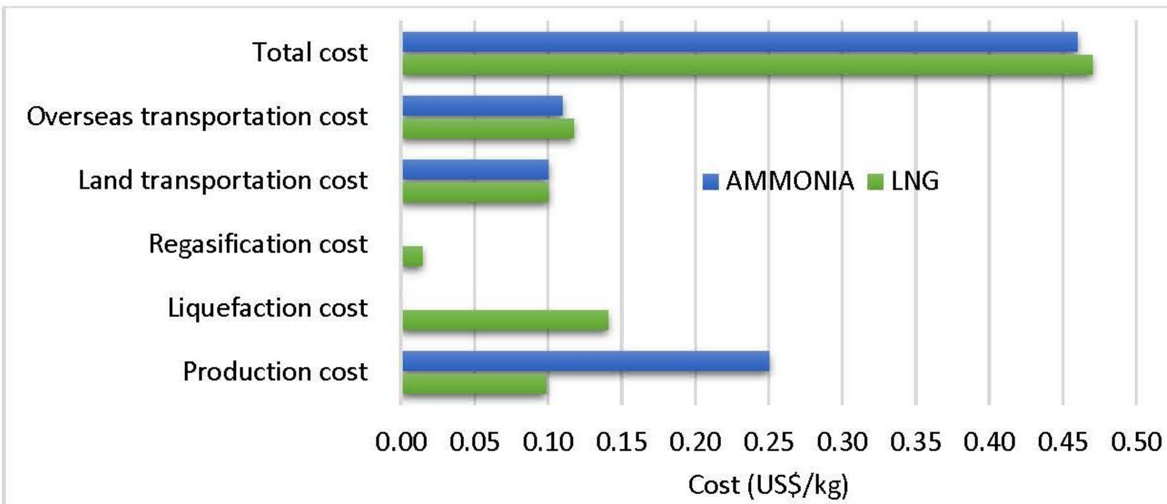



Figure 50 Contribution of sub-processes to total cost of LNG and ammonia for Case 4

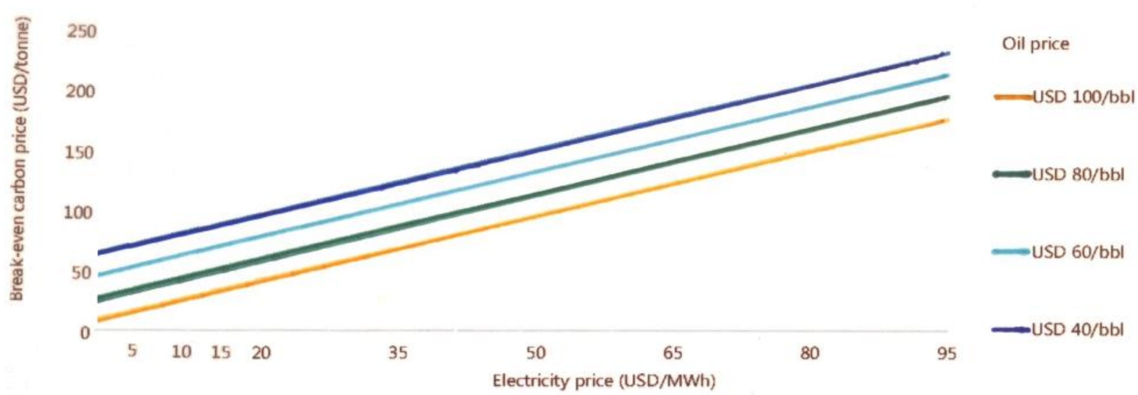
Ammonia energy and fuel applications have been proven to be safer, lower cost and more readily deployable than using hydrogen itself in most applications due to energy density, temperature and pressure issues for storage and transport, including for use in passenger vehicles.

As noted above, the "*MITACS PHASE 3 - Comprehensive Evaluation of NH3 Production and Utilization Options for Clean Energy Applications*" [24] and several other research projects we did with Ontario Tech University published by the AIChE and in several journals, and other ammonia energy and fuel research they have done in the last 20 years, combined with other research noted in the 5,540 page, $4,200 USD "*Comprehensive Energy Systems*" [25] concluded that using ammonia energy or fuel production or utilization technologies improved every industrial, power generation, agricultural and transportation application, except transoceanic air flight.

ZERO CARBON Green Ammonia from electricity is competitive with ZERO CARBON Fossil based NH3 in Canada with $40 - $60 per ton Carbon Tax with no Industry exemptions. With electricity at 2 cents per kWh and a $40-$60 per ton carbon tax without exemptions it is cost-effective to produce ammonia with zero carbon emitted, same thing with hydrocarbon based ZERO CARBON BLUE Ammonia from lower net cost natural gas in Canada that otherwise emits 2 tons of CO2 for every ton of NH3 (only costing $6 per ton under Justin Trudeau 90% Industry exemption to the $30 per ton 2020 carbon tax).

The Future of Hydrogen    Chapter 5: Opportunities for hydrogen in transport, buildings and power

**Figure 58.** **Break-even carbon price for ammonia to be competitive with fossil fuels**




Note: More information on the assumptions is available at www.iea.org/hydrogen2019.
Source: IEA 2019. All rights reserved.

**For a bulk carrier, policies equivalent to a carbon price of USD 40–230/t$CO_2$ would be needed to make ICE engines running on ammonia competitive with fuel oil. The break-even carbon price is highly sensitive to both the oil price and electricity price.**

**The Future of Hydrogen** - G20, June 2019, Japan, p. 142 | IEA – Modified for Canada [28]

## Blending H2 with Natural Gas

At first glance, blending H2 into the natural gas distribution pipelines is a great idea because Ontario's end-use consumption of natural gas is approximately 1000 PJ per year so a 10% blend of hydrogen with natural gas will correspondingly reduce GHG emissions – which is the operative goal. Given that two-thirds of natural gas in Ontario is consumed by its residential and commercial sectors, infusing hydrogen into gas supply lines sooner makes for good government GHG reduction optics.  However, aside from "end-user apprehension" of hydrogen infusion in natural gas used for home-heating, it is extremely risky in the long-term because of hydrogen embrittlement [21] [22].

With H2 having a lower density than methane, compressing H2 in natural gas pipelines would lead to additional inefficiency thorough increased pumping losses. A better alternative would be to transport NH3 through natural gas pipelines. NH3 does not have embrittlement issues and, being a liquid, the pumping losses would be much lower. A natural gas pipeline converted to NH3 use would also be able to transport a much greater amount of hydrogen than even liquefied H2 but without any of the cryogenic issues. [23] [24]

An additional risk to blending H2 with natural gas is the potential for increased demand for this blended fuel. With enough demand, there is the very real possibility that additional natural gas wells will be created. The risk of methane leakage is already great with existing natural gas infrastructure but additional wells mean additional opportunities for leakage [25] [26] [27].

## Unpredictable Renewable Power

While some forms of renewable power can be somewhat predictable, it is variable from the aspects of both weather and climate. As a result, fossil fuel generation capacity must always back renewable power when the wind isn't blowing, not enough rain has fallen, or when the sun goes down.

*Unreliable Nature of Solar and Wind Makes Electricity More Expensive, New Study Finds* [28]:

> *The higher cost of electricity reflects "the costs that renewables impose on the generation system," the economists note, "including those associated with their intermittency, higher transmission costs, and any stranded asset costs assigned to ratepayers."*
>
> *But are renewables cost-effective climate policy? They are not. The economists write that "the cost per metric ton of CO2 abated exceeds $130 in all specifications and ranges up to $460, making it at least several times larger than conventional estimates of the social cost of carbon."*
>
> *The economists note that the Obama Administration's core estimate of the social cost of carbon was $50 per ton in 2019 dollars, while the price of carbon is just $5 in the US northeast's Regional Greenhouse Gas Initiative (RGGI), and $15 in California's cap-and-trade system.*

*The Reason Renewables Can't Power Modern Civilization Is Because They Were Never Meant To* [29]:

> *Over the last decade, journalists have held up Germany's renewables energy transition, the Energiewende, as an environmental model for the world.*

*But then, last year, Germany was forced to acknowledge that it had to delay its phase-out of coal, and would not meet its 2020 greenhouse gas reduction commitments. It announced plans to bulldoze an ancient church and forest in order to get at the coal underneath it.*

*Solar and wind advocates say cheaper solar panels and wind turbines will make the future growth in renewables cheaper than past growth but there are reasons to believe the opposite will be the case.*

## Ammonia – Electricity in a Bottle

Ontario's non-fossil (ie, renewable and nuclear) power generation resources are an excellent means of manufacturing *green* ammonia. Ammonia is the second-most manufactured commodity world-wide and is primarily manufactured from *brown* sources (ie, fossil fuels). There are several interesting facts about anhydrous ammonia (NH3) that are relevant to power generation:

- NH3 is an energy currency, which means that it can be readily created from electricity and NH3 may be readily converted back into electricity. Effectively, NH3 is bottled electricity, which for Ontario means that its vast electrical resources can be readily exported by pipeline, railcar, and ocean tanker.
- NH3 contains more hydrogen per unit volume than liquefied hydrogen but is stored and handled very much like propane, which obviously avoids the significant costs and transportation issues of cryogenic liquids.
- When NH3 is burned, the products of combustion are atmospheric nitrogen (N2) and water (H2O), neither of which are greenhouse gases.
- If NH3 is spilled, although concentrated amounts are toxic, it readily dissipates into air and water and the effects are temporary with minimal cleanup costs. NH3 is also not a greenhouse gas and is broken down by photodissociation in the atmosphere.
- NH3 has 150% greater energy intensity per liter than compressed hydrogen

## Made in Ontario

## Balancing the Grid

It is challenging to match renewable power generation with electrical consumption. We believe that it would be far better to produce sufficient low-cost power and have a dispatchable means storing electricity chemically in the form of green NH3 rather than exporting it to neighbouring jurisdictions at a loss. Our solution is to manufacture green ammonia from surplus electricity using SSAS and store a sufficient amount so as to generate electricity using DAFC on demand. Since NH3 is a high-value product, any NH3 produced in excess of the amount required to balance Ontario's grid would be sold as a commodity in the world market.

The technology being developed by Dr Dincer in Canada is similar in some ways to that is being demonstrated by Siemens at the Rutherford Appleton Laboratory in the UK except that SSAS is more efficient than the Haber-Bosch process used in the *Siemens Green Ammonia Demonstrator* [33]and is easier to implement. Similarly, DAFC has a higher efficiency than conventional hydrogen fuel cells. SSAS and DAFC are scalable processes and the combination is ideal for distributed generation. *Hydrofuel is currently working to commercialize OTU's SSAS and DAFC technologies with the ability to balance Ontario's grid.*

## Domestic Energy Benefits

The world bank study found a jurisdiction could spend 10 times the amount on domestic energy instead of imports and it would be just as well off because the money circulates in its own economy instead of leaving and coming back in as bargain basement investments.

Brazil has had much experience with developing its own 2-pronged domestic energy industry, which included increase domestic petroleum supply augmented by renewable fuel. This experience is directly applicable to Ontario developing a similar ammonia-based energy industry.

*Growing Green: The Economic Benefits from Climate Action* [34]

> *Measures that reduce energy waste raise economic efficiency and thus contribute to growth. But policies that promote climate change mitigation can also contribute to economic growth more directly. The low-carbon transition is well under way and requires massive investments that generate economic opportunities and jobs*

*Ethanol Demand Driving the Expansion of Brazil's Sugar Industry* [35]:

> *The single most important factor driving the original expansion of the Brazilian sugar industry was the Proálcool program (Programa Nacional do Álcool), Brazil's national alcohol program. The program was created to reduce dependence on oil at a time when over 80 percent of the oil consumed was imported and Brazil was reeling from the major oil price rises of the 1970s. Initiated in 1975 as a government-mandated program to regulate the fuel alcohol content in gasoline, the Proálcool program was ultimately responsible for the expansion of sugarcane production and the development of two types of ethanol: hydrous alcohol for use in pure alcohol vehicles and anhydrous alcohol for blending with gasoline.*
>
> *Since its inception, the Proálcool program has served to dampen the effect of increases in crude oil prices. The program provides incentives for greater use of fuel alcohol when oil prices are high or reduces the ethanol content in the gasoline blend when ethanol supplies are low in the face of rising international*

*sugar prices and exports. By the 1990s, low sugar prices in global markets, combined with higher expected returns to soybeans and red meats and poultry, resulted in less area planted to sugarcane and diminished domestic support to ethanol production.*

*Since 2002, Brazil's sugar-ethanol complex has benefited from domestic and foreign demand, more favorable expected returns to sugarcane producers, expansion in arable land, and technological advancements in new sugarcane varieties. As demand for Brazilian ethanol continues to rise, the production of ethanol will continue to exceed that of sugar in the sugarcane production mix. Ethanol's share of sugarcane production is expected to rise as demand for flex fuel cars—which are expected to account for over 95 percent of all new cars introduced in the market—increases.*

## Growing Ontario's Economy

While seemingly good-intentioned, the former Liberal governments were ineffective in their efforts to move Ontario to a sustainable low-carbon economy and the Green Energy Act became a debacle. However, the Green Energy Act was extremely successful in saddling Ontario with an expensive and unpredictable electricity supply. The Green Energy contracts have resulted in the explosion of the Global Adjustment Charge, which is necessary to pay for the over-priced electricity contracts. As a further insult to Ontario businesses, the *Industrial Conservation Initiative* makes Ontario manufacturers uncompetitive by interfering with production.

The only way to drive down the cost of electricity is to generate more low-cost power in Ontario. The majority of Ontario's power is produced by CANDU nuclear reactors but, because nuclear power generation does not ramp up or down quickly, the OPG runs them base-loaded to provide 60% of Ontario's supply. OPG in-service nuclear generating capacity is 5728 MW and Bruce Power's is 6,288 MW for a total of 12,016 MW, but typically produces about 10,000 MW.

Ontario taxpayers are stuck between a rock and hard place because the more electricity they conserve to keep their hydro rates down just end up increasing the Global Adjustment Charge. The net result is that it is impossible to reduce their electrical costs and this puts Ontario businesses at a huge competitive disadvantage compared to neighbouring jurisdictions. The only way to reduce the Global Adjustment and pay down the enormous provincial debt incurred by the Green Energy Act is to sell much more power but the ever-increasing electrical rates only serve to encourage energy conservation.

The best way to reduce the cost of electricity is to have Ontario's lowest cost generators run at maximum capacity and have a dispatchable load absorb excess power in real time. The only practical way to do this is for an Ontario manufacturer to manufacture a high demand, valuable commodity in real-time according to available low-cost electricity. That commodity is anhydrous ammonia, which is the second-most manufactured commodity world-wide and the process to manufacture it is *Solid State Ammonia Synthesis*.

Besides NH3’s obvious use as fertilizer, it could also be used as a motor fuel for heavy duty vehicles [36]as well as marine transport [37] [38] [39] [40]. It has also been shown to work successfully in rail locomotives in the UOIT Clean Rail Study [41] and has been prototyped Vehicle Projects in 2006 [42].

Because NH3 is an energy currency, higher-cost peaking plants could be replaced with localized distributed power generation. *Natural Resources Canada* presented a study about *Direct Ammonia Fuel Cell* distributed generation and combined heat and power in 2005 [43].

## Remote Communities

In the news of the recent past has been the plight of First Nations communities in Canada. Very often, these communities are remote and isolated from other communities. The isolation has adverse effects not only on the local economies but also on the physical and mental health of the communities' aboriginal inhabitants.

On the 2016 Attawapiskat suicide crisis [44], Federal Minister of Health, Dr. Jane Philpott stated:

> *"When I think that there are communities in our country where … young people in groups are deciding that there is no hope for their future, we must do better, we have to find a way to go forward."*

These remote communities are very often located in Canada's north and are surrounded by vast, renewable energy resources (ie, wind and hydroelectric). Because of their remoteness, there has been no way to harvest these resources and transport them to southern communities where renewable electricity is desperately needed. Indigenous people are ideally suited to husbanding these resources and ensuring that harvesting renewable energy resources are done in a sustainable manner. Investing in renewable energy in Canada's North would create vibrant and prosperous northern First Nations communities.

The lowest cost and most beneficial option from an economic and social perspective for heat and power generation in remote communities is ammonia usage. The operation of diesel engines with fuel ammonia has the lowest cost based on the current market prices. Considering the technology development of ammonia production, the cost of ammonia will continue to decrease which will bring additional reductions in total cost. Production and utilization of ammonia in diesel generators have significantly lower environmental impacts in terms of climate change and global warming. [54]

OTU has developed the SSAS technology to store renewable energy chemically in the form of anhydrous ammonia (NH3). The University of Minnesota has already pioneered similar technology (based on the Haber-Bosch process) with their small-scale wind to ammonia project [45]. We are working with OTU to commercialize utility-scale chemical storage of electricity using anhydrous ammonia in their Clean Energy Research Lab (as well as alternative fuel vehicles in their Automotive Centre of Excellence).

Until SSAS and DAFC become commercially ready, a simple and economical way to transition remote communities to hydrogen would be to retrofit the diesel generators with Hydrofuel's aftermarket conversion technology (*TFX press release* [56]) followed by OTU's new ammonia engine and fuel system in remote communities with OTU's ammonia fuel system (ie, Patent US8272353, CA 2654823 "Methods and Apparatus for Using Ammonia as a Sustainable Fuel, Refrigerant and NOx Reduction). This technology increases the thermal efficiency of the existing diesel generators while reducing their GHG emissions and enhancing their district heating and cooling capability.

In addition to the high cost of building wind and hydroelectric generators in remote locations, the cost of building and maintaining high voltage transmission lines to Ontario's grid can be prohibitive. It is far more economical and safer to build pipelines to transport NH3 either directly to an NH3 piping network or to bulk transportation nodes (ship, rail, and truck) than to build and maintain thousands of kilometers of overland and undersea high voltage power lines.

As one of the world's most manufactured commodities, surplus NH3 can be readily sold as a fertilizer or as a chemical feedstock but has the potential to also be converted back into grid-scale electricity with conventional thermal power generation or with OTU's new DAFC technology. This would create hundreds of well-paying jobs in remote communities and complement the provincial hydrogen economy. [54]

## Hydrofuel's Business Plan

Hydrofuel has a multi-faceted plan to help Ontario transition to a hydrogen economy, which includes NH3 transportation, NH3 power, and NH3 district heating and cooling [51]. Our primary focus initially is to build retrofit fuel systems for diesel-powered heavy-duty vehicles and stationary engines. We have been developing technology to use NH3 as a carbon-free motor fuel for many years now. While diesel-NH3 fuel systems are not completely carbon-free, they are important in the transition to a low-carbon economy because they retrofit existing diesel engines and their ability to revert to diesel operation mitigates any fuel-availability anxiety for consumers. Please refer to our UOIT MITACS Research [48] for more information and MITACS Phase 3 Report [49] is the most comprehensive of the three.

An added benefit of NH3 use, manufactured with green hydrogen, is exempt from Canada's proposed Clean Fuel Standard (CFS). Hydrofuel has knowhow with and the technology to co-fire NH3/ammonia with diesel or gasoline, safely, in a manner that can reduce corresponding GHG emissions by up to half:

- The Canada Energy Regulator reports that Ontario consumes 25% of the 12,000 PJ of end-use energy in Canada; that 1/3 of the 1500 PJ of Canada's end-use road motor gasoline and ¼ of 800 PJ of Canada's end-use diesel is consumed by Ontario.
- Life Cycle Analysis (LCA) adjustments pursuant to the CFS, will increase Ontario's foreseen CO2 emissions from these 700 PJ of diesel & gasoline - from 50 Million tonnes to approximately 63 Million tonnes per year.
- This LCA, correctly, imposes an increase in the emission reduction goal of 30% by 2030 and net zero by 2050; it is another obstacle to achieving to GHG reduction.
- Before electricity could become a replacement fuel for its 9 million road vehicles and 1 million off-road vehicles, Ontario would need to, correspondingly, increase its current grid capacity from 500 PJ to 1200 PJ. Retrofitting vehicles to operate, safely, with NH3/ammonia would enhance likelihood of achieving GHG reduction goals.
- Imperative is mindfulness of Impact Assessment Act and CCME requirements regarding potential hindrances in meeting Canada's climate change commitments.

In addition to co-firing NH3 in internal combustion entire with its retrofit fuel systems, Hydrofuel also intends to promote the co-firing of NH3 in thermal power plants as is already been done elsewhere in the world. [56] [57] [58]

A secondary focus would be to build waste-heat recovery systems using OTU's Heat Engine System for Power and Heat Generation (Patent US20140053544A1, CA2824759A1), which uses NH3 as the working fluid. This technology is ideal for operations that generate waste heat and have a need for both electricity and domestic hot water.

Later on, once we commercialize OTU's SSAS and DAFC technology, we intend manufacture green ammonia as an IESO dispatchable load but our long-term plan is to use green ammonia for distributed power generation and district heating and cooling.

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