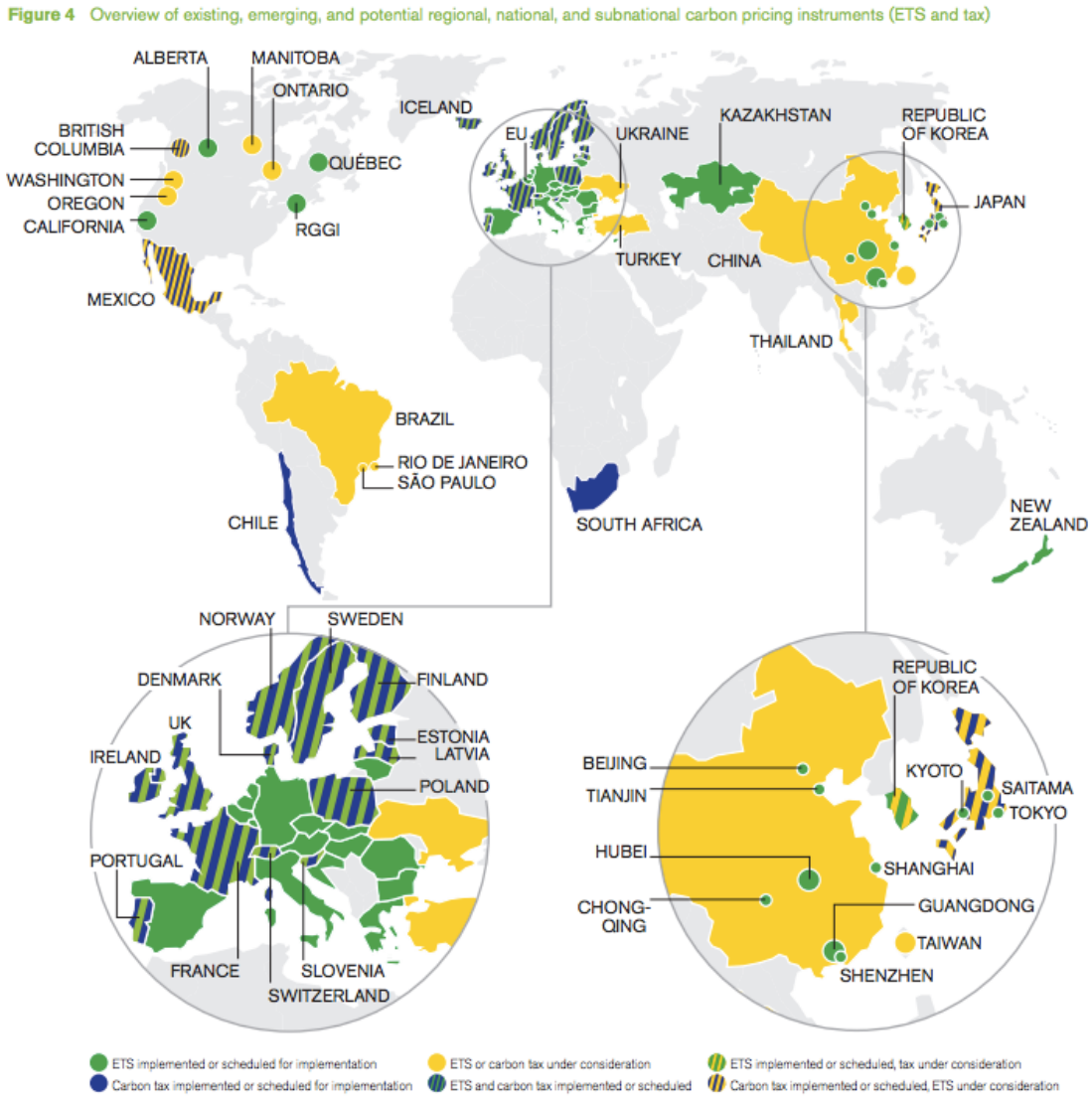
HYDROFUEL® Inc.

Ammonia Solutions©

for cleaner energy production and utilization

The Problem

- The marketplace for conventional and alternative energy is dislocated by uneven government incentives
- Large solar, wind and biomass subsidies have left more promising techologies wanting
- The "**Life Cycle**" health and environmental costs must be included in the price, not just the price of carbon.



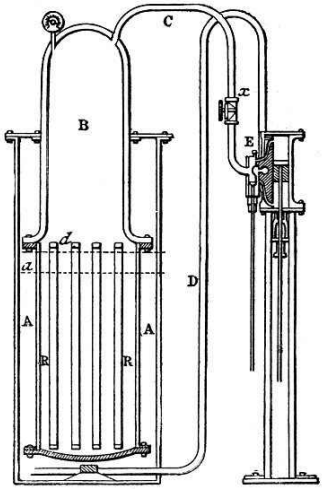
Existing, emerging, and potential regional, national, and subnational carbon pricing intruments (ETS and tax).

The Ammonia Solutions

- 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.
- transported more economically at lower pressures and higher temperature than LNG and can be used in existing natural gas infrastructure with lower risks.
- high-efficiency ammonia/urea plants using natural gas and other hydrocarbon feed stocks can be built beside natural gas power plants and oil sand extraction sites. Utilizing the waste, low- grade heat and excess oxygen results in a significant costs and emissions reduction.

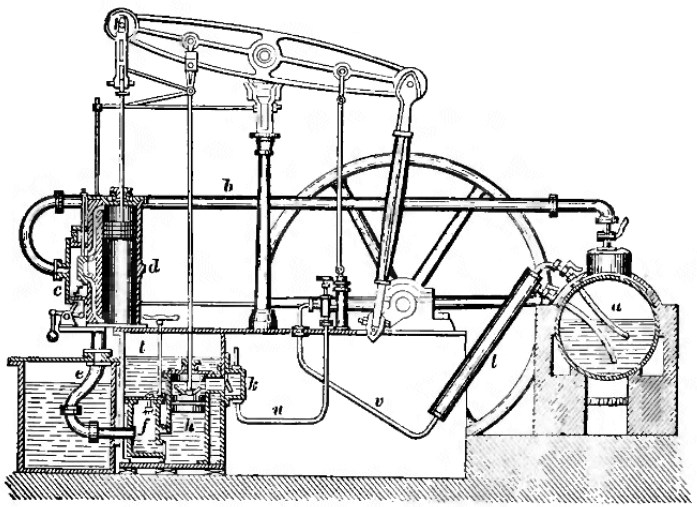
Ammonia (NH3) used as an energy currency since the mid to late 1800s

Lamm's Ammonia Motor: 1869



LAMM'S AMMONIA MOTOR.

Delaporte's Ammonia Engine: 1870



Delaporte's Ammonia-Engine.

MacMahon's Ammonia Streetcar: 1894

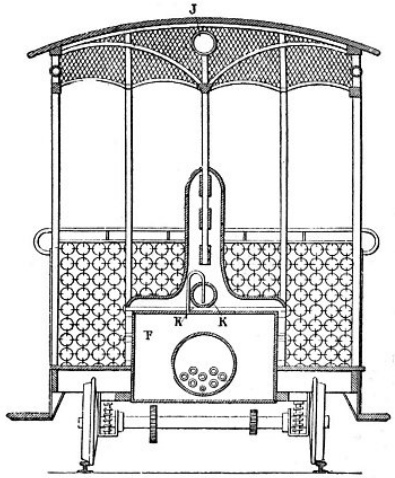
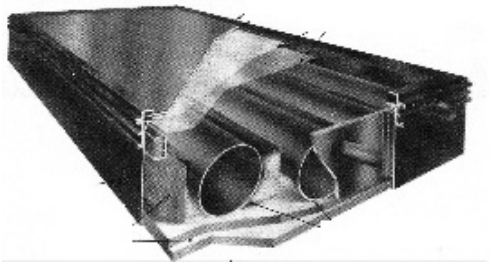


FIG. 12.—CROSS SECTION OF THE CAR.

Tellier's Rooftop Solar Ammonia Indoor Water Pump: 1885



An ammonia filled flat-plate roof-top solar collector similar to hot water heaters today ran a well water pump providing daylignt 300 gallons-per-hour indoor running water.

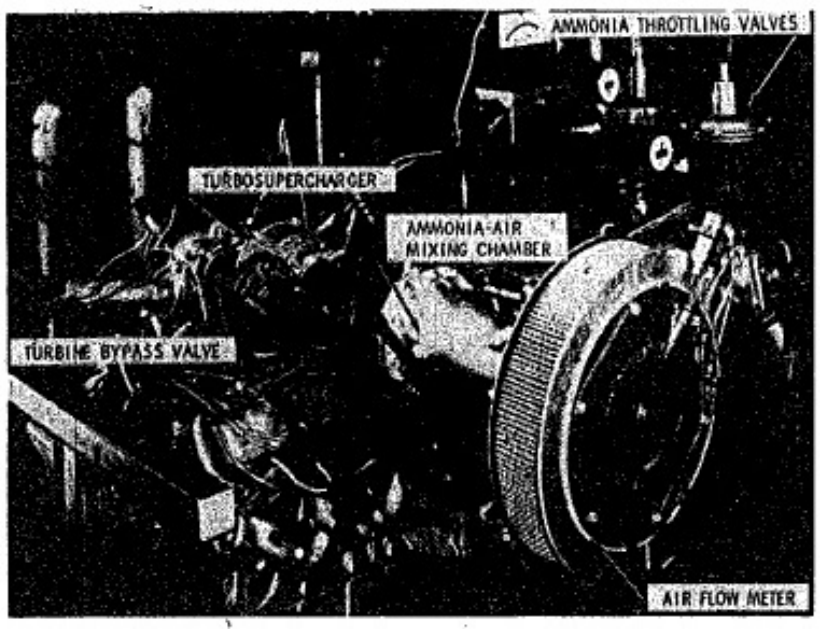
Norway's Norsk Hydro's Ammonia Truck: 1933

There were dozens of privately owned ammonia powered vehicles, primarily in Italy, Germany and Belguim the middle 1930s.

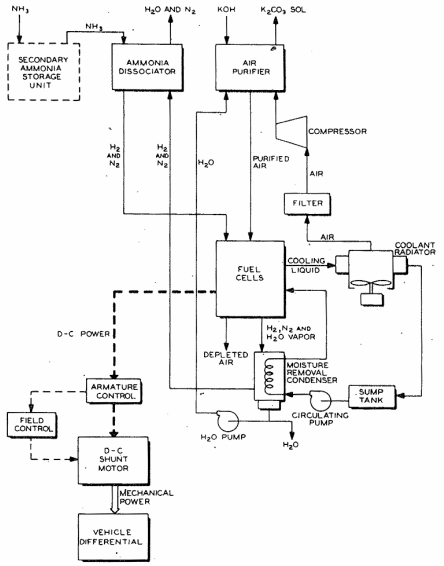
Brussels Belgium's Municipal Ammonia Bus: 1944

Between 1944 and 1946 Brussels ran 12 ammonia powered buses over 100,000 km without a single accident.

US Government Energy Depot Project - General Motors Ammonia Engines/Fuel Cells: 1965

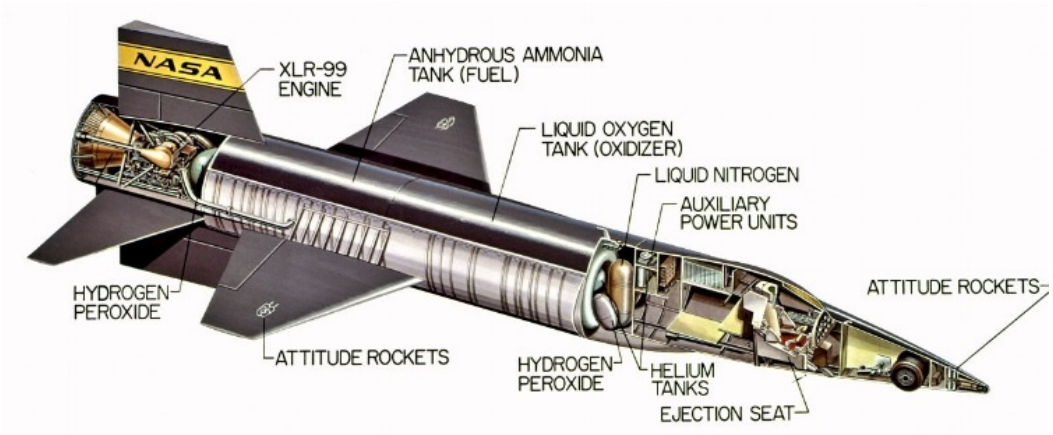


General Motors 218 cu.in. V-8 trubocharged ammonia engine



Disassociated Ammonia/air fuel cell vehicle drive unit

US Air Force/NASA's X-15 Ammonia Rocket Project: 1965



The liquid ammonia and oxygen fueled X-15's official world record for the highest speed ever recorded by a manned, powered aircraft, was set in October 1967

University of Tennessee's Ammonia Car: 1972

U of Tennessee 1972 BMW Isetta Ammonia Car

BMW Isetta converted to run on ammonia fuel by U. of Tennessee students won no emission control awards. The car weighed a mere 1,275 pounds including new bumper.

From: *The Race to Design the Ideal Urban Car*
Popular Science | **Copyright © November 1972**

C.A.E.C.- Canadian Alternative Energy Corp. AND HYDROFUEL Inc.

Established in 1980, CAEC drove an Ammonia (NH3) fuelled Chev Impala across Canada in late 1981, arriving at a Parliament Hill press conference with then Governor General Edward Schreyer on November 5.

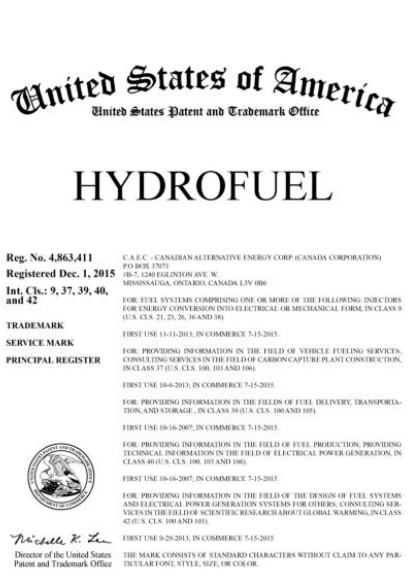
Finance Minister Marc Lalonde driving NH3 car on Parliament Hill, on November 5, 1981

Greg Vezina starting the NH3 car for CBC National News "Back to the Future" news story on November 6, 2006

Link the CBC NEWS Video: https://www.youtube.com/watch?v=8vwmzkn0paM

In 2010 Hydrofuel® Inc. developed an aftermarket multi-fuels conversion system for a 2007 Dodge Ram 3500 Diesel fueled truck and a 2007 Ford Crown gasoline fuelled car to use Ammonia and/or any liquid fuel.

We are the registered owner of the **"Hydrofuel®"** Trademarks for five classifications in the US, three in the in EU and one in Canada



United States of America
United States Patent and Trademark Office

HYDROFUEL

Reg. No. 4,863,411
Registered Dec. 1, 2015
Int. Cls.: 9, 37, 39, 40, and 42

TRADEMARK
SERVICE MARK
PRINCIPAL REGISTER

C.A.E.C. - CANADIAN ALTERNATIVE ENERGY CORP. (CANADA CORPORATION)
P.O BOX 37071
#B-7, 1240 EGLINTON AVE. W.
MISSISSAUGA, ONTARIO, CANADA, L5V 0B6

FOR: FUEL SYSTEMS COMPRISING ONE OR MORE OF THE FOLLOWING: INJECTORS FOR ENERGY CONVERSION INTO ELECTRICAL OR MECHANICAL FORM, IN CLASS 9 (U.S. CLS. 21, 23, 26, 36 AND 38)

FIRST USE 11-11-2013; IN COMMERCE 7-15-2015.

FOR: PROVIDING INFORMATION IN THE FIELD OF VEHICLE FUELING SERVICES; CONSULTING SERVICES IN THE FIELD OF CARBON CAPTURE PLANT CONSTRUCTION, IN CLASS 37 (U.S. CLS. 100, 103 AND 106).

FIRST USE 10-6-2013; IN COMMERCE 7-15-2015.

FOR: PROVIDING INFORMATION IN THE FIELDS OF FUEL DELIVERY, TRANSPORTATION, AND STORAGE , IN CLASS 39 (U.S. CLS. 100 AND 105).

FIRST USE 10-16-2007; IN COMMERCE 7-15-2015.

FOR: PROVIDING INFORMATION IN THE FIELD OF FUEL PRODUCTION; PROVIDING TECHNICAL INFORMATION IN THE FIELD OF ELECTRICAL POWER GENERATION, IN CLASS 40 (U.S. CLS. 100, 103 AND 106).

FIRST USE 10-16-2007; IN COMMERCE 7-15-2015.

FOR: PROVIDING INFORMATION IN THE FIELD OF THE DESIGN OF FUEL SYSTEMS AND ELECTRICAL POWER GENERATION SYSTEMS FOR OTHERS; CONSULTING SERVICES IN THE FIELD OF SCIENTIFIC RESEARCH ABOUT GLOBAL WARMING, IN CLASS 42 (U.S. CLS. 100 AND 101).

FIRST USE 9-29-2013; IN COMMERCE 7-15-2015.

THE MARK CONSISTS OF STANDARD CHARACTERS WITHOUT CLAIM TO ANY PARTICULAR FONT, STYLE, SIZE, OR COLOR.

Director of the United States Patent and Trademark Office

Registrerade / Registered 14/10/2009

No 006331854

KHIM – KONTORET FÖR HARMONISERING I DEN INRE MARKNADEN
GEMENSKAPSVARUMÄRKEN OCH GEMENSKAPSFORMGIVNING

REGISTRERINGSBEVIS

Detta Registreringsbevis är härmed utfärdat för det nedan återgivna Gemenskapsvarumärket. Motsvarande uppgifter har införts i Registret över Gemenskapsvarumärken.

HYDROFUEL

OHIM – OFFICE FOR HARMONIZATION IN THE INTERNAL MARKET
TRADE MARKS AND DESIGNS

CERTIFICATE OF REGISTRATION

This Certificate of Registration is hereby issued for the Community Trade Mark identified below. The corresponding entries have been recorded in the Register of Community Trade Marks.

Ordförande / The President

Wubbo de Boer

Office de la propriété intellectuelle du Canada
Un organisme d'Industrie Canada

Canadian Intellectual Property Office
An Agency of Industry Canada

Marques de commerce
Certificat de renouvellement

Trade-marks
Certificate of Renewal

La présente atteste que l'enregistrement de cette marque de commerce est renouvelé pour une période de quinze ans, conformément à l'article 46 de la *Loi sur les marques de commerce*.

This is to certify that this trade-mark registration is renewed for a period of fifteen years, in accordance with section 46 of the *Trade-marks Act*.

HYDROFUEL

Numéro d'enregistrement / Registration Number: **TMA292,288**
Numéro de dossier / File Number: **473240**

Registraire des marques de commerce
Registrar of Trade-marks

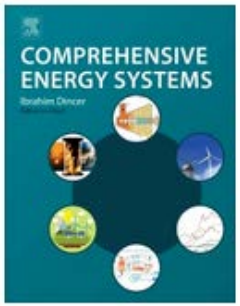
Date d'échéance / Expiry Date: **22 juin/Jun 2029**
Date: **15 sept/Sep 2014**

Canada

OPIC CIPO

Hydrofuel® Inc. and the **University of Ontario Institute of Technology** (UOIT) completed several Ammonia Energy related MITACS and other joint research projects with their results published in multiple peer reviewed journals, by the AIChE, and in the epic 5,540 page "*Comprehensive Energy Systems*".

Clean Energy Research Laboratory at the University of Ontario Institute of Technology.



Comprehensive Energy Systems

1st Edition

Write a review

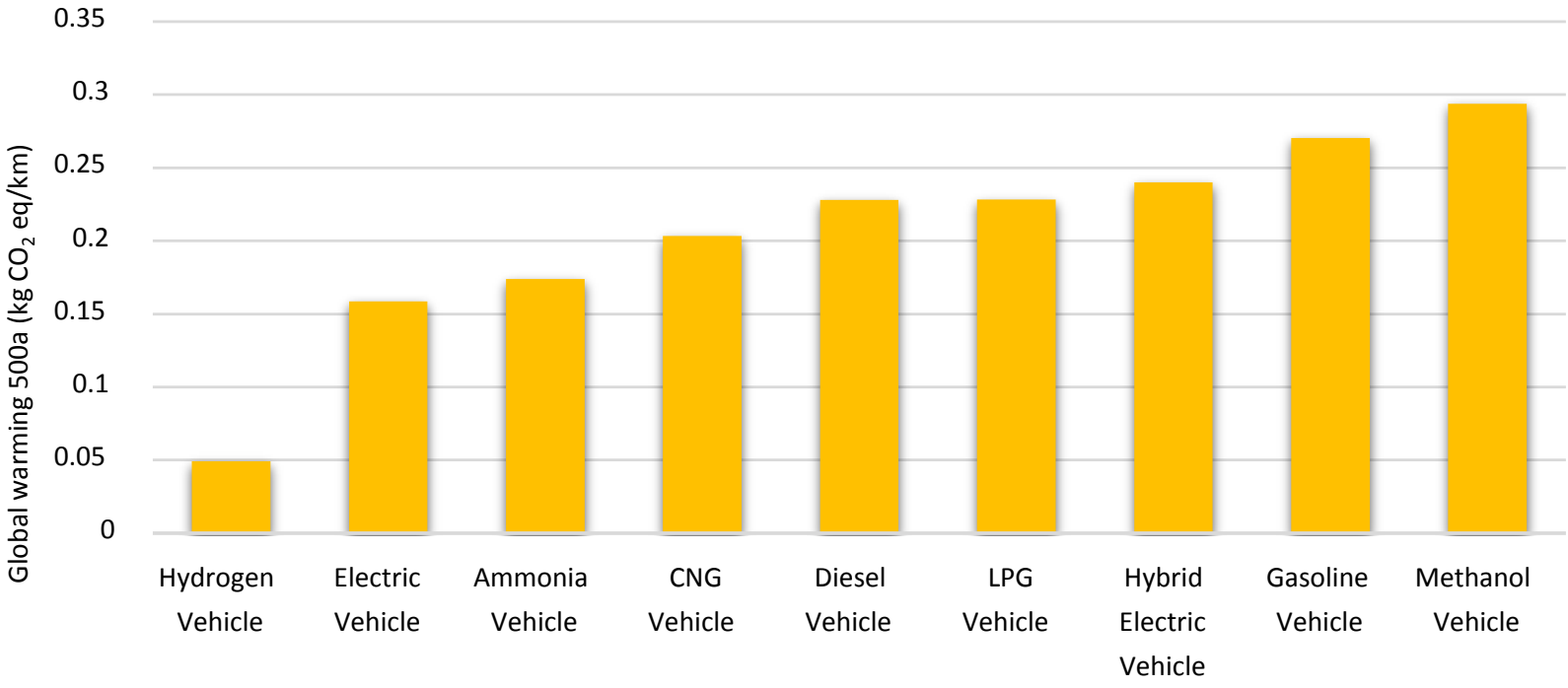
Editor-In-Chiefs: Ibrahim Dincer

eBook ISBN: 9780128149256

Book ISBN: 9780128095973

Our work has also been used as the basis of life cycle energy production and utilization analysis by the OECD, the US DOE ARPA-E and other governmental agencies and NGOs.

UOIT and Hydrofuel's three MITACS research projects, which concluded with the March 2017, 3rd. report, "Comprehensive Evaluation of NH3 Production and Utilization Options for Clean Energy Applications," proves NH3 can be used as a fuel in cars, trucks, buses, locomotives, marine and aircraft applications, and for power storage, generation and combined heating and cooling applications today with lower emissions than all hydrocarbon fuels.



Life cycle comparison of global warming results for various vehicles

Even if ammonia is produced from hydrocarbons, it has similar greenhouse gas emissions with solar energy based route. It is important to emphasize that an ammonia driven passenger vehicle releases less greenhouse gas emissions than compressed natural gas (CNG), liquefied petroleum gas (LPG), diesel, and even hybrid electric vehicles.

QUICK FACTS ABOUT AMMONIA - **Is ammonia a cost effective fuel?**

7. Is ammonia a cost effective fuel?

The illustrative cost comparison of various fueled vehicles is shown in Fig. 2 and 3. 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. 2.

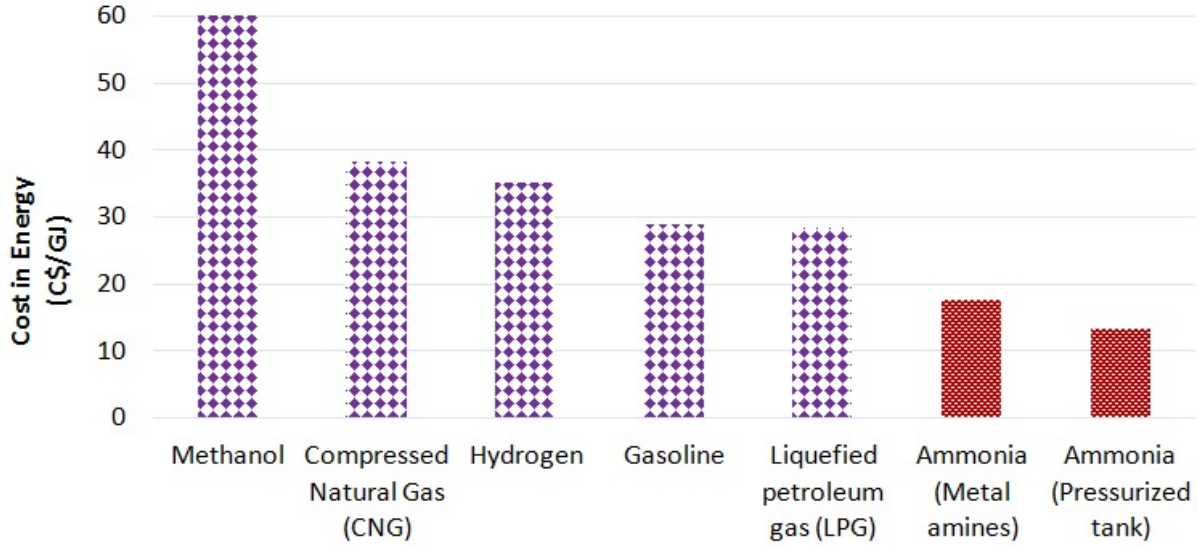


Figure 2 Comparison of various vehicle fuels in terms of energy cost per gigajoule

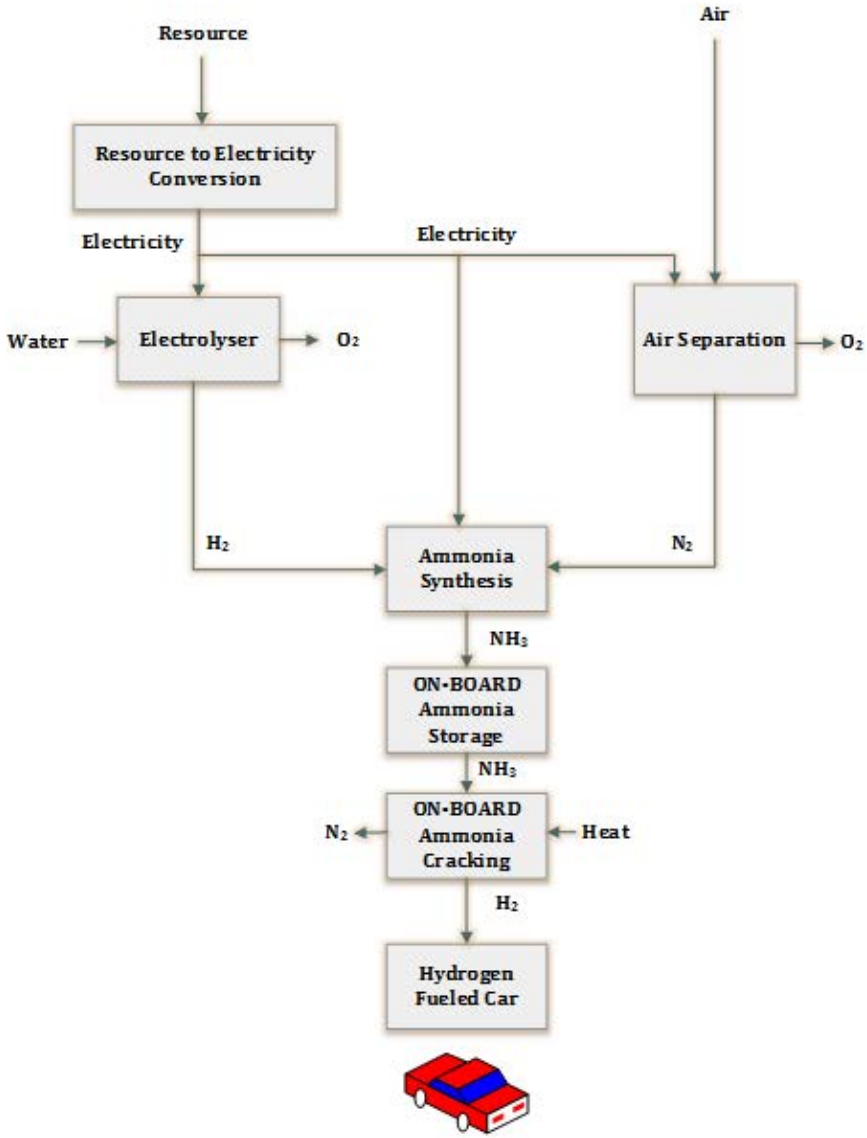


Figure 89 The complete process describing the production, storage and decomposition of ammonia for hydrogen driven vehicle

Using ammonia as dual fuel in the marine engines can decrease total greenhouse gas emissions up to 34.5% per tonne-kilometer.

For ammonia (hydropower)/heavy fuel oil driven tanker, total GHG emissions are caused by mainly operation of tanker corresponding to about 64% whereas maintenance and operation of port has a share of 31%.

If clean fuels are even partially replaced with current hydrocarbon derived fuels, total GHG emissions in maritime transportation can be lowered significantly.

By development and full utilization of renewable energy based ammonia and hydrogen fuels, GHG emissions during operation of the transoceanic tankers can be even zeroed.

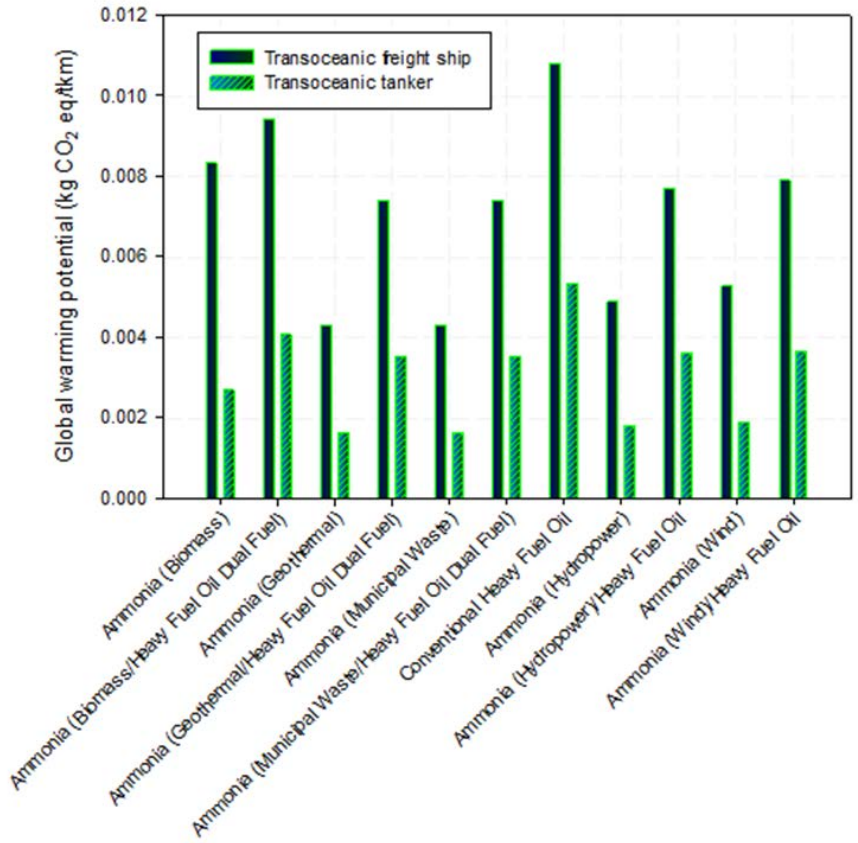


Figure 66 Global warming potential of transoceanic tanker and transoceanic freight ship per tonne kilometer for ammonia and conventional heavy fuel oil

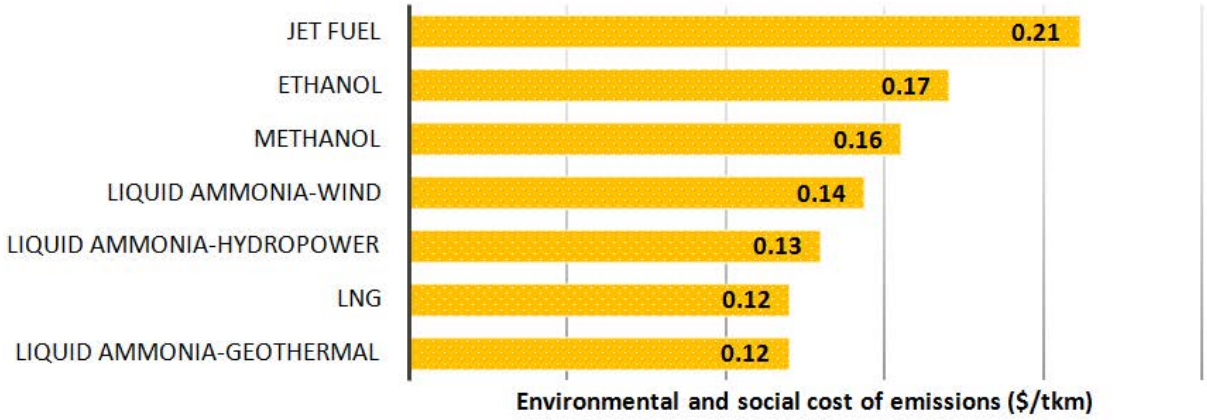


Figure 80 Total environmental and social cost of emissions for various fueled aircrafts from conventional and renewable resources

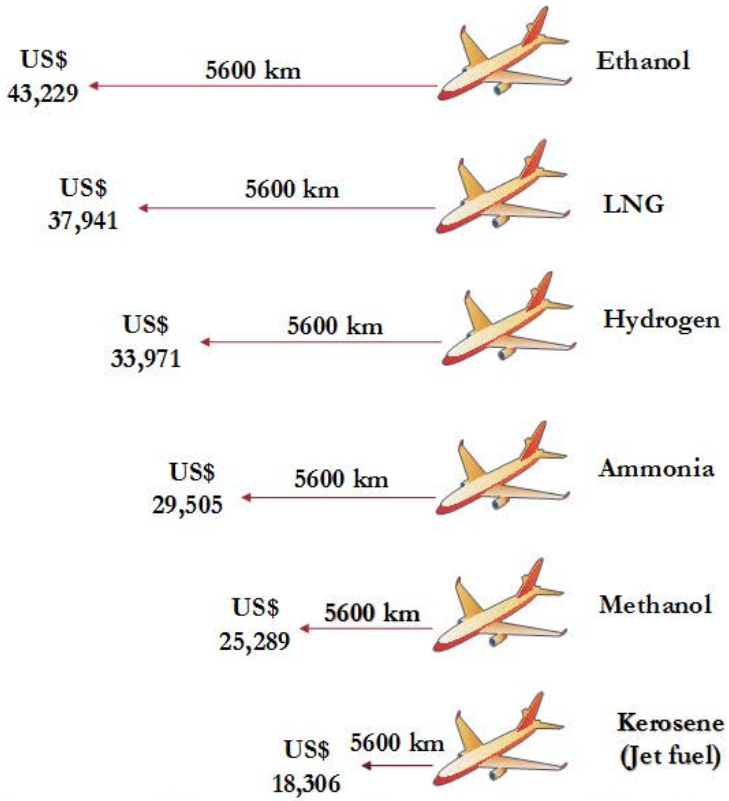


Figure 82 Comparison of fuel costs during the operation of aircrafts for the given range

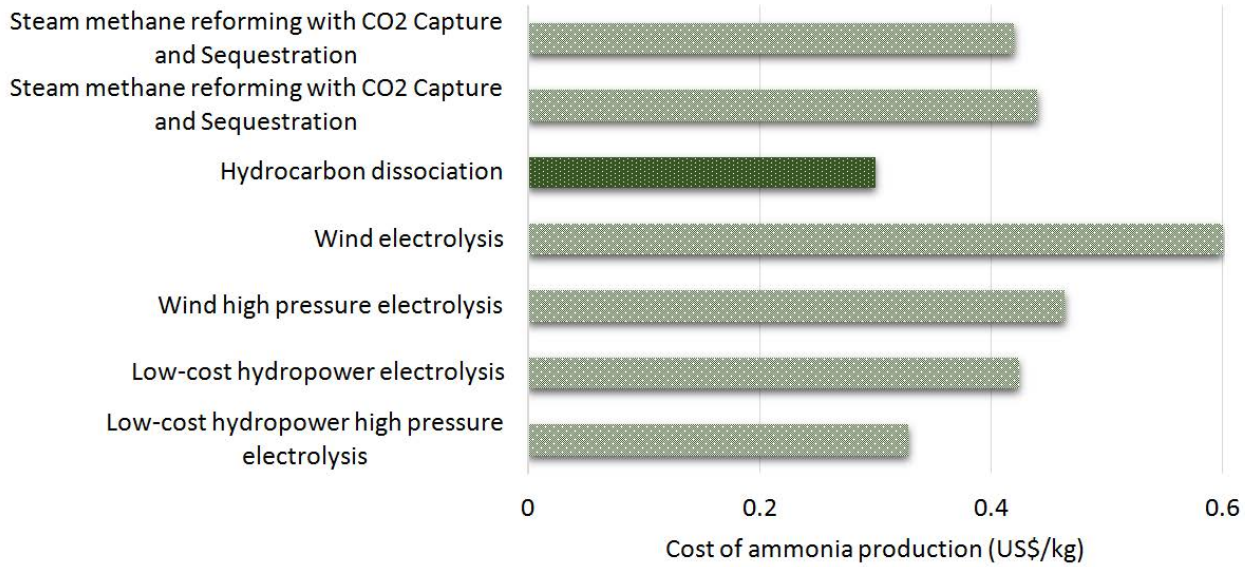


Figure 38 Comparison of cost of production for ammonia using various routes

Ammonia was less costly than LNG in 4 Cases studies, Europe, the US, the Middle East and Canada

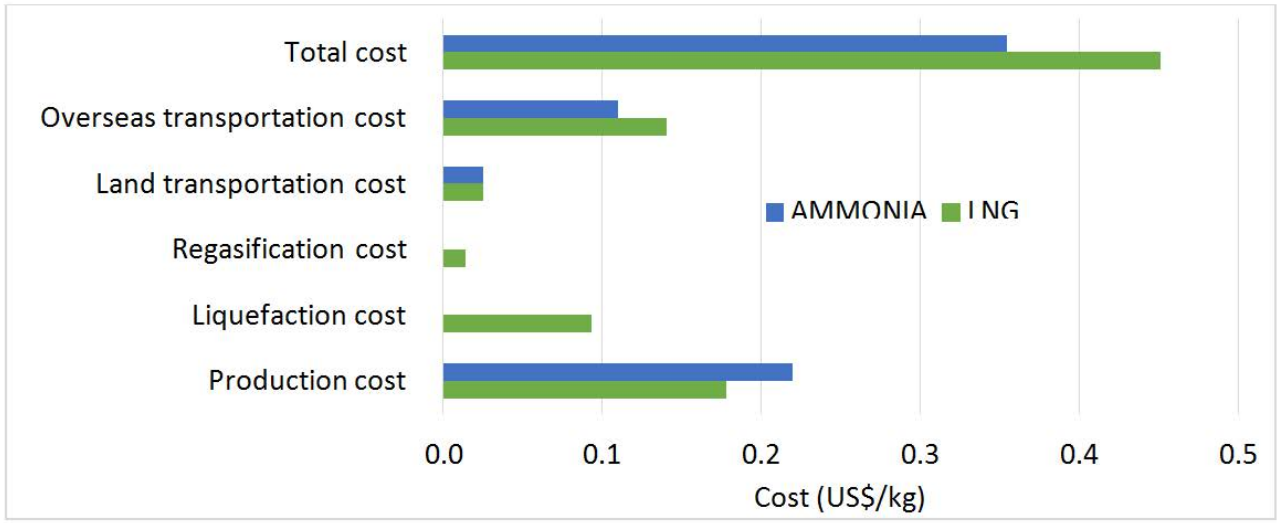


Figure 46 Contribution of sub-processes to total cost of LNG and ammonia for Case 2 in the U.S

Oil sand to Ammonia

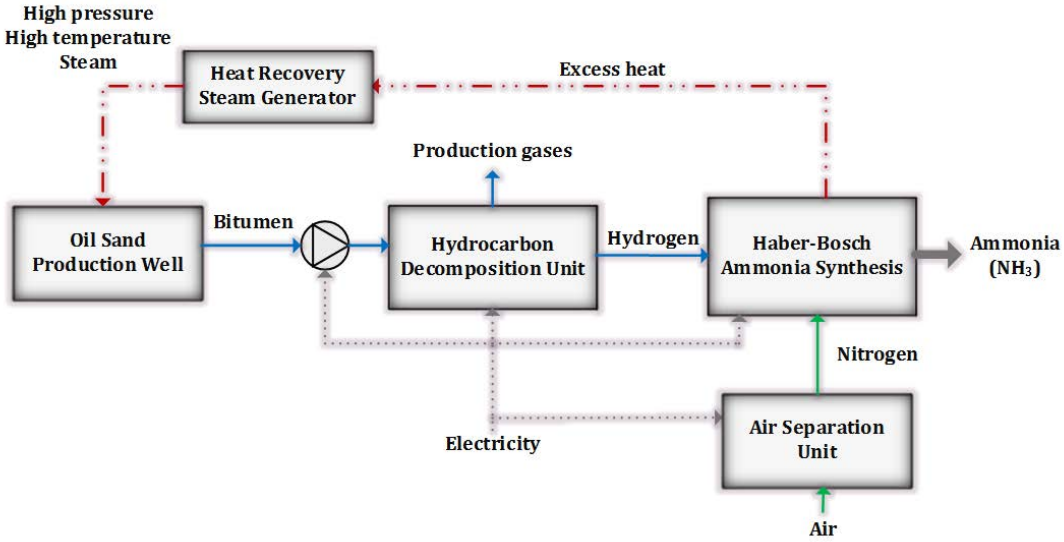


Figure 51 Schematic diagram of oil sand to ammonia plant

There are various alternative pathways for hydrogen production from hydrocarbons such as thermal, non-thermal, plasma routes.

Methane decomposition reaction is moderately endothermic process. The energy requirement per mole of hydrogen produced is considerably less than that for the steam reforming process.

Hydrogen via thermo-catalytic dissociation of hydrocarbons represents an alternative solution. It is accompanied by the formation of carbon deposits. Methane can be thermally or thermocatalytically decomposed into carbon and hydrogen without CO or CO2 production.

The microwave energy can be of sufficient power and duration to cause microwave depolymerization of the high molecular weight materials such as bitumen.

Optimized ammonia synthesis using the excess heat in Haber-Bosch ammonia plant for oil sand bitumen extraction which is used for hydrogen production via microwave dissociation process is possible.

ECONOMIC ANALYSES **OF SOLAR ENERGY BASED** AMMONIA PRODUCTION

In this section, the exergoeconomic analyses of the experimental systems are performed. The purchased costs of the experimental systems in this study are presented in the following tables. The experimental systems are divided into three main sub-systems;

- Photoelectrochemical hydrogen production reactor
- Electrochemical ammonia production reactor
- Integrated system comprising of solar light concentrator and splitter, PV cell and support mechanism.

The support mechanism used in the integrated system consists of wood and metal parts. The highest cost is for the PEC hydrogen production reactor which corresponds to about 68% of total cost as show in Fig. 102.

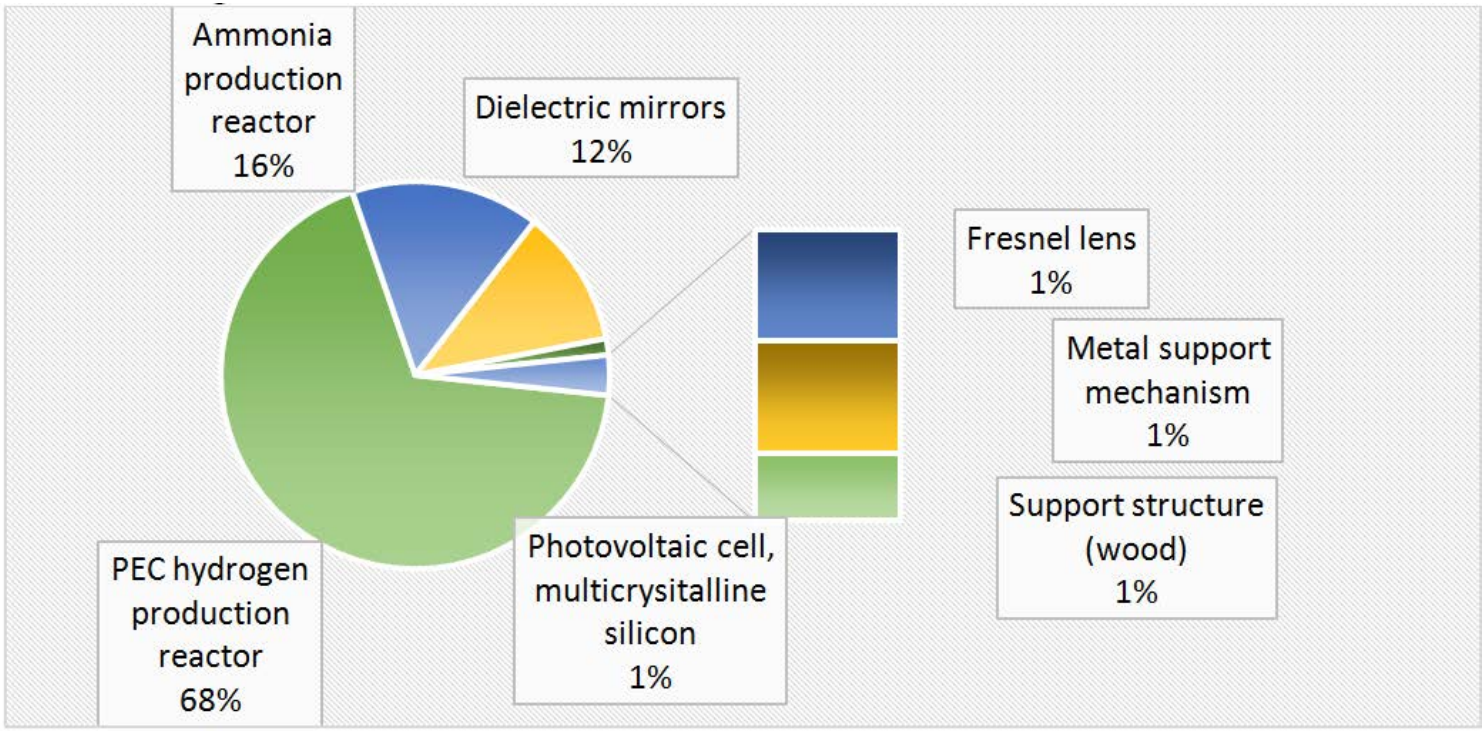


Figure 102 Cost breakdown of the integrated system for hydrogen and ammonia production

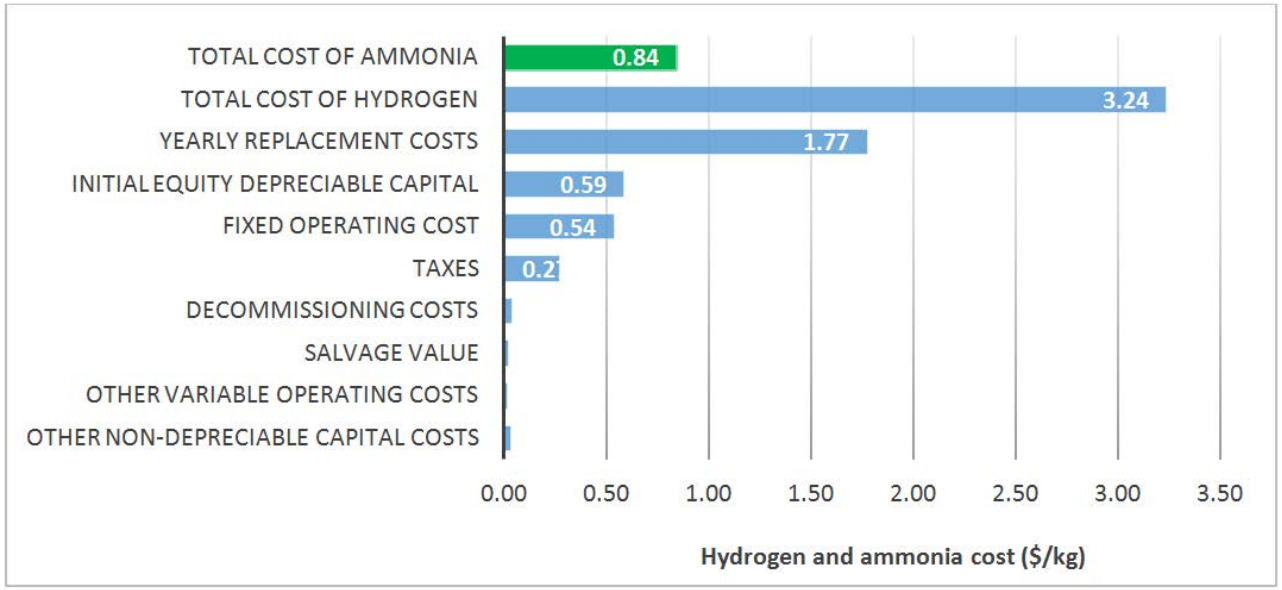


Figure 110 The calculated cost of hydrogen and ammonia with contributing factors for a 1000 kg/day concentrated PEC hydrogen production plant

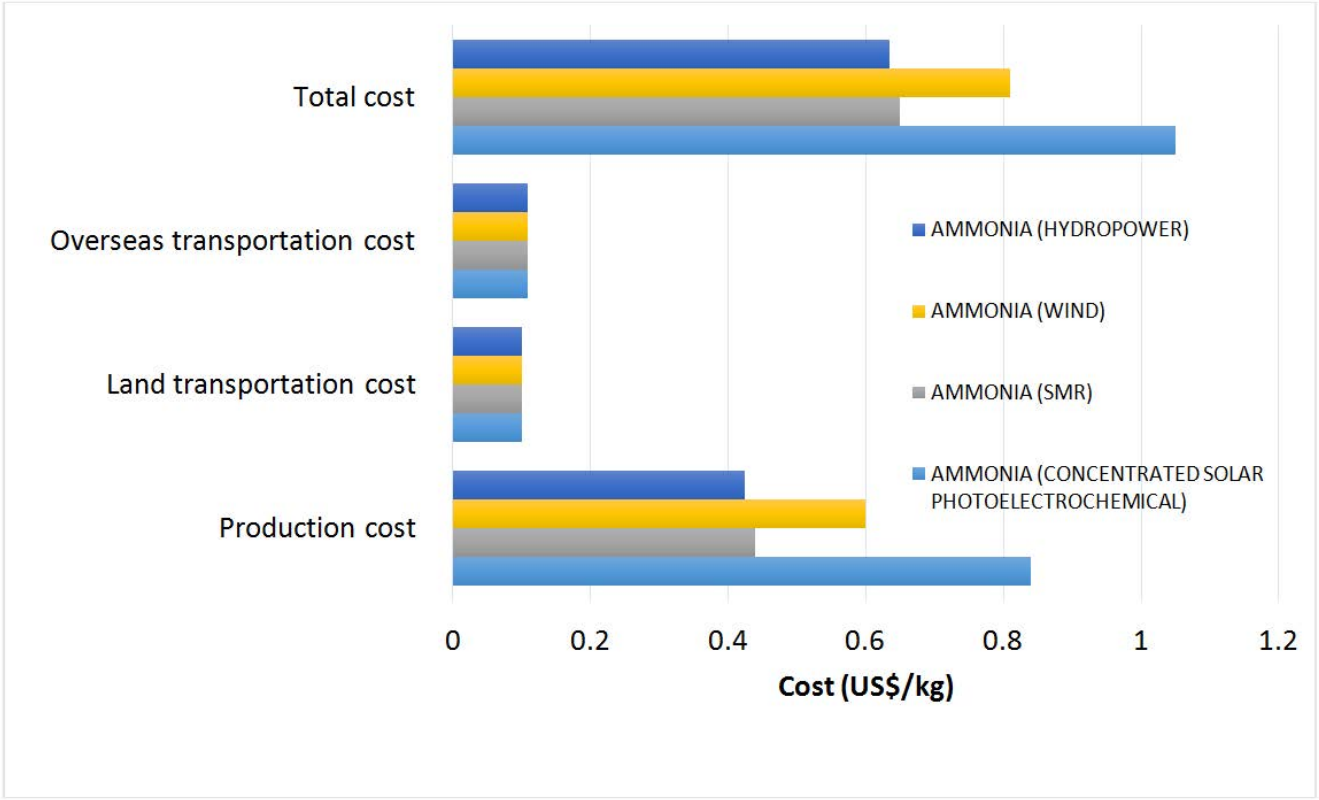


Figure 115 Comparison of ammonia costs using different production routes in Ontario

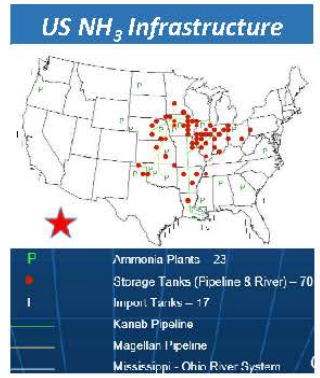
WAKE UP TO THE NH_3 ECONOMY

NH_3 IS VERY COST COMPETITIVE.
Diesel @$2.50 gal - $20/mmbtu LHV
NH_3 @$300/tonne - $16/mmbtu LHV

CONTACTS:
gvezina@nh3fuel.com
tswittrig@gmail.com

Ammonia (NH_3):

- Is the second largest synthesized industrial chemical in the world.
- Contains about 48% more hydrogen by volume than liquid H_2.
- Does not emit CO2, SOX, PM during utilization (cars, powergen)
- Can be stored and transported under relatively low pressures.
- Can be produced from varied resources from coal to renewables.
- Can utilize steel pipelines (e.g., oil, gas) with minor modifications.
- Incomparably flexible fuel (engines, turbines, boilers, fuel cells)
- Enables distributed power generation and smart grid applications.
- Is a non-GHG refrigerant (auto AC, refrigerated transport)



PIPELINE

RAIL

OCEAN
RIVERWAYS

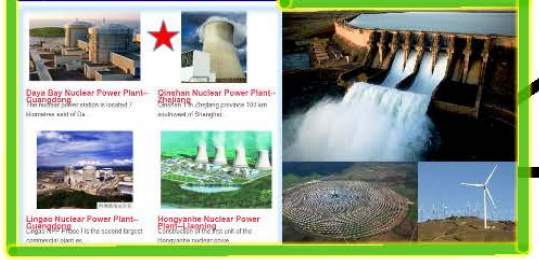
ROAD

NH_3

Gas to NH_3 ~$200/T

CO_2

Storage of CO2 in deep reservoirs to store utility scale power and produce geothermal energy.



GAS

e^-

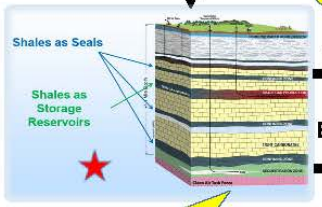
H_2

HVDC

e^-

H_2

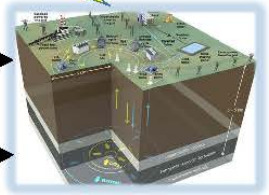
LOCAL ammonia for regional use and clean energy



Sequestration in empty gas reservoirs or saline aquifers

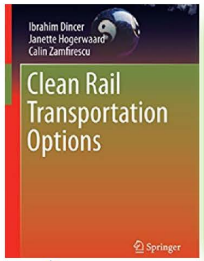
EARTH BATTERY

ENHANCED OIL/GAS RECOVERY



CTRL-CLICK ★'s FOR MORE INFO

NH_3 TRANSPORTATION

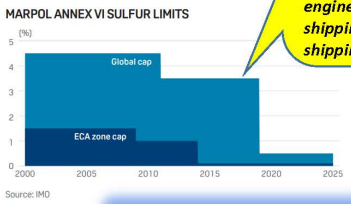


Ammonia as a Sustainable Transportation Fuel.

- High octane rating of NH3 (110-130) for ICE applications
- Global production and distribution infrastructure developed over 100 years ★★
- Can be thermally cracked for H2 and exhaust heat recovery
- NH3 is safer than other fuels due to high rate of dissipation in air, strong (self-alarming) odor at very low concentration (~ 5 ppm in air), and is considered nonexplosive due to its very narrow flammability range.

Professor Ibrahim Dincer (UOIT) is one of the world's leading experts on sustainability, systems analysis, ammonia as an energy vector and machine design ★

Shipping industry must displace a large fraction of high S bunker fuel by 2020. Large growth of ammonia shipping could facilitate ammonia engines for ammonia shipping. And additional shipping. ★



Greg Vezina has a 35 year history building and developing ammonia cars ★

NH_3 REFRIGERATION

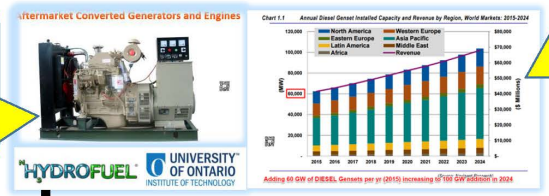
★ Ammonia Refrigerant

- Systems cost 10-20% less to build than CFC systems
- Ammonia is 3-10% more efficient than CFCs, saves power.
- Ammonia has an Ozone Depletion Potential (ODP) rating of 0 and a Global Warming Potential (GWP) rating of 0.
- Ammonia is substantially less expensive than HCFCs

★

NH_3 POWER

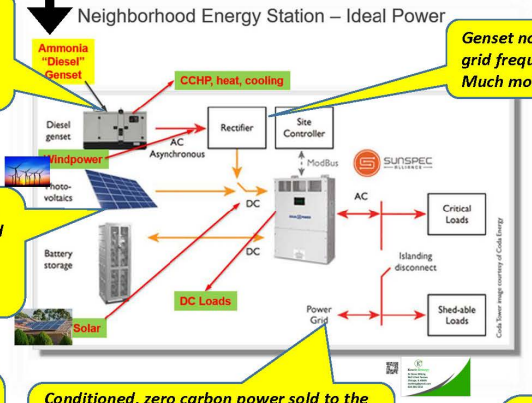
Hydrofuel® will convert diesel gensets to zero carbon ammonia gensets. (Also no SOX, soot and PM). ★



At least 60 GW of diesel genset capacity added every year (equivalent to 60 large nuclear reactors or the output of about 60 world scale ammonia plants. ★

★

Zero carbon power provided immediately when sun/wind slows or demand is high.

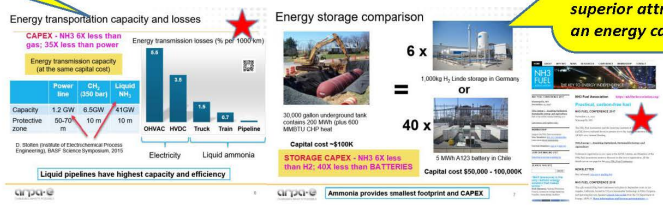


Genset not tuned to grid frequency. Much more efficient.

Efficient conversion of DC & unregulated AC power to conditioned power for the grid.

Much cheaper and safer energy storage than batteries or hydrogen

Conditioned, zero carbon power sold to the grid when profitable. Ancillary value - 5 min ramp, voltage/frequency support, black start, 3+ days supply.



DOE/ARPA-E is beginning work with NH3 Fuel Association based on ammonia's superior attributes as an energy carrier.

CTRL-CLICK ★'s FOR MORE INFO

Use of NH3 fuel to achieve deep greenhouse gas reductions from US transportation | Energy Reports - ScienceDirect
Aggressive implementation of NH3-fueled vehicles replacing light duty gasoline vehicles eliminates most of the annual LDV CO2 emissions projected in the reference case in the year 2040, with a 96% reduction from reference case levels, equivalent to a reduction of approximately 718 million metric tons CO2 equivalent in that year's emissions.
https://www.sciencedirect.com/science/article/pii/S235248471500027X

Feasibility Study on the Supply Chain of CO2-Free Ammonia with CCS and EOR | Institute of Energy Economics, Japan - IEEJ
Japan to use ammonia fuel to reduce total CO2 emissions by 80% in 2050 for electrical power generating.
https://eneken.ieej.or.jp/en/genre/economy_list.php?l1_s=0 and https://eneken.ieej.or.jp/data/8371.pdf

Alternatives to Electricity for Transmission, Firming Storage, and Supply Integration for Diverse, Stranded, Renewable Energy Resources: Gaseous Hydrogen and Anhydrous Ammonia Fuels via Underground Pipelines | ScienceDirect
https://www.sciencedirect.com/science/article/pii/S1876610212014609

Flexible production of green hydrogen and ammonia from variable solar and wind energy close to cost competitive with fossil fuels Chile and Argentina, two countries with world-class variable renewable energy (VRE) potentials. | ResearchGate
https://www.researchgate.net/publication/333221154_Flexible_production_of_green_hydrogen_and_ammonia_from_variable_solar_and_wind_energy_Case_study_of_Chile_and_Argentina

"Levelized cost of energy storage" #Ammonia is the only grid scale option | US-DOE ARPA-E
The US Department of Energy, which is funding a portfolio of renewable ammonia synthesis technologies through its Advanced Research Project Agency (ARPA-E), has demonstrated that ammonia is already the lowest-cost, proven technology for long-term, large-scale energy storage, where long-term refers to any time period greater than one day.
https://nh3fuelassociation.org/2016/07/06/ammonia-for-energy-storage-and-delivery/
https://i0.wp.com/ammoniaindustry.com/wp-content/uploads/2016/10/ARPA-E-ammonia-LCOES.png?ssl=1

Ammonia for energy storage: a "revolutionary disruption" | The Japan Times
A recent opinion piece in The Japan Times predicts a "revolutionary disruption coming to the energy sector," and suggests that using ammonia for energy storage will prove to be "a game-changer at least on the scale of the shale oil and gas revolution."
https://www.ammoniaenergy.org/ammonia-for-energy-storage-a-revolutionary-disruption/

Tohoku team finds swirling ammonia in combustion chambers can help reduce NO emissions | Green Car Congress https://www.greencarcongress.com/2018/10/20181015-tohoku.html

New catalyst turns ammonia into an innovative clean fuel | Kumamoto University, Japan
https://phys.org/news/2018-04-catalyst-ammonia-fuel.html

Plastic fantastic: How does Tokyo recycle its waste? | The Japan Times 1,000+ workers process 195 tons of waste plastic a day, making 175 tons of ammonia. https://www.japantimes.co.jp/life/2017/06/10/environment/plastic-fantastic-tokyo-recycle-waste/#.XLo4U9jaskI

CSIRO extracts pure H2 from ammonia in live Toyota and Hyundai driving test | electrive.com
https://www.electrive.com/2018/08/09/csiro-extracts-pure-h2-from-ammonia-in-live-driving-test/

Diesel generators and trucks to use green ammonia fuel.

TFX International SPECIALIZED VEHICLE TRANSPORT will provide two diesel fuelled generators and transport trucks to be converted to use Hydrofuel® ammonia fuel over three years.

Hydrofuel Inc.'s *Ammonia Solutions*© aftermarket multi-fuels engine retrofit system will be used for a low emission combination of diesel and ammonia fuel, and zero emission hydrogen oxygen assisted NH3 fuel.

NH3 HYDROFUEL® Inc.

Ammonia Solutions©

for cleaner energy production and utilization