The Ideal On-site Produced Fuel

- **Simple process for on-site production**
- **Engines easily modified to use fuel**
- **Uses locally available raw materials**
- **High Specific Energy (kWhr/kg)**
- **High Energy Density (kWhr/liter)**
- **Low Cost**
- **Easily Transported, Stored and Handled**
- **Flammability Low**
- **Toxicity low**
- **Synergistic with solution of other problems**

Hydrogen as On-site Produced Fuel

- **Simple process for on-site production - YES**
- **Engines easily modified to use fuel - YES**
- **Uses locally available raw materials - YES**
- **High Specific Energy (kWhr/kg) - YES**
- **High Energy Density (kWhr/liter) - NO**
- **Low Cost - YES**
- **Easily Transported, Stored and Handled - NO**
- **Flammability Low - NO**
- **Toxicity low - YES**
- **Synergistic with solution of other problems - NO**

Major "show stopper" for hydrogen is the extreme difficulty of storage both on and off vehicle.

The Department of Energy "FreedomCAR" program has devoted major resources to the solution of this problem without success

Hydrocarbons as On-site Produced Fuel

- **Simple process for on-site production - NO**
- **Engines easily modified to use fuel - YES**
- **Uses locally available raw materials - YES**
- **High Specific Energy (kWhr/kg) - YES**
- **High Energy Density (kWhr/liter) - YES**
- **Low Cost - NO**
- **Easily Transported, Stored and Handled - YES**
- **Flammability Low - NO**
- **Toxicity low - NO**
- **Synergistic with solution of other problems - YES**

Fischer-Tropsch technology used in South Africa for over 50 years to produce fuel from coal.

Requires significant carbon to produce mixture of CO and H2 (stores ~ 2.3 H per C)

Complex process with catalyst sensitive to poisoning

Ammonia as On-site Produced Fuel

- **Simple process for on-site production - Moderate**
- **Engines easily modified to use fuel - YES**
- **Uses locally available raw materials - YES**
- **High Specific Energy (kWhr/kg) - YES**
- **High Energy Density (kWhr/liter) - YES**
- **Low Cost - Moderate**
- **Easily Transported, Stored and Handled - YES**
- **Flammability Low - YES**
- **Toxicity low - NO**
- **Synergistic with solution of other problems - YES**

Uses N2 from air and H2 to produce fuel using Haber-Bosch process

Fuel chosen by U.S. Army in 1960s for on-site production using nuclear energy in "Energy Depot Concept"

Norsk Hydro started producing ammonia using hydrogen from water electrolysis in 1928

Primary disadvantage is toxicity

Ammonia Toxicity

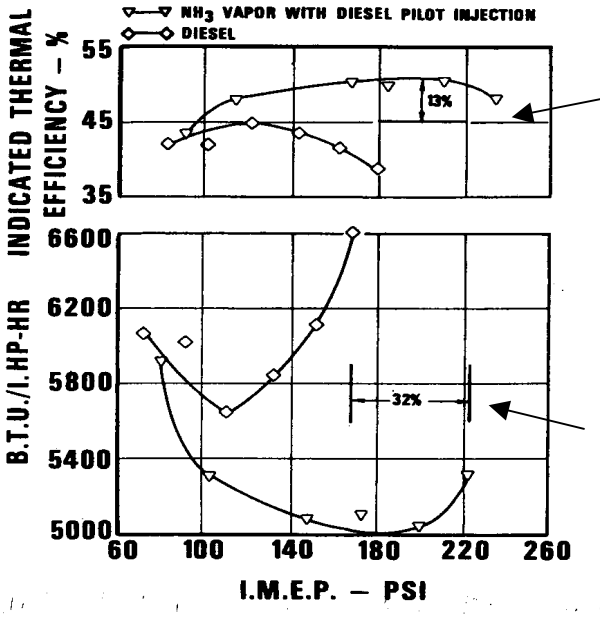
- Energy Density (theoretical max.) of Stored Ammonia as a Fuel - 3.5 kWhr/L
- Specific Energy (theoretical max.) of Stored Ammonia as a Fuel - 5.2 kWhr/kg
- Storage - Ammonia requires pressure tank ~ 10 bar
- Toxicity -
  - time-weighted average (TWA) = 25 ppm
  - short-term exposure limit (STEL) = 35 ppm
  - concentration immediately dangerous to life or health (IDLH) = 500 ppm

Ammonia as Diesel Engine Fuel

Diesel engines are easily adapted to use ammonia as the primary energy source by:

a) Introducing ammonia gas into the air intake
(The low boiling point (-33° C, 1 atm) of ammonia assists operation at low temperatures)

b) Using fuel injectors to supply a small amount of diesel fuel (~ 1-2% w/w of ammonia consumed, reducing diesel consumption by ~40x) to ignite the ammonia cylinder charge



13% higher thermal efficiency

32% higher power output

Ref: Pearsall, T.J., Garabedian, C. G. *Combustion of Anhydrous Ammonia in Diesel Engines* SAE Paper 670947

Fig. 1 - Performance with ammonia fuel versus diesel fuel

I.M.E.P. = Indicated Mean Engine Pressure

Ammonia as Otto Cycle Fuel

Spark Ignition can be used in Otto cycle and diesel engines to eliminate the need for any diesel fuel by:

a) Partially dissociating the ammonia using exhaust heat or electrical resistance heating prior to introduction into the air intake

b) Using long-reach, spark plugs with a high-energy ignition system

Experimental Engine Performance

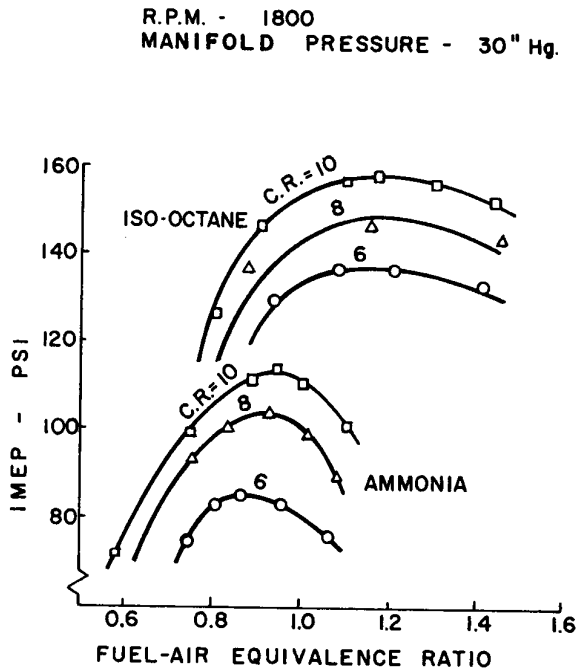


Fig. 20 - Comparative performance of ammonia and isooctane

Comparative performance in a spark ignition engine

Higher fuel consumption due to the lower energy content of ammonia compared to gasoline (isooctane)

Ref: Starkman, E. S., et. al.. *Ammonia as a Spark Ignition Engine Fuel* SAE Paper 660155

Small Electrolysers Commercially Available (303 kW power input)

Electrolyser supplied by Norsk Hydro