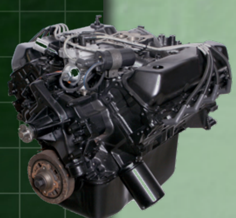
# Hydrogen Engine Center, Inc.

www.hydrogenenginecenter.com

## Ammonia Fuel Network

## Ted Hollinger

## September 28, 2010



# Topic for Discussion

## Converting Liquid $NH_3$ to an Energy Dense Engine Fuel

# Issues to be discussed

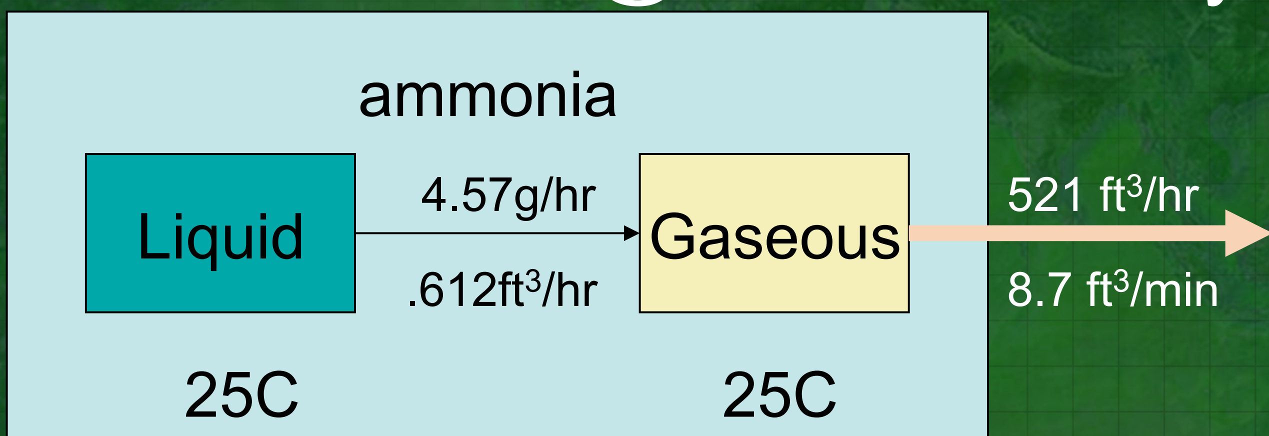
- Ammonia energy requirements
  - ammonia is stored as a liquid and needs to be converted to a gas.
- Ammonia ignition
- Ammonia 'fuel' flame velocity
- Power comparison of ammonia vs NG

# Liquid Ammonia to Gaseous Ammonia

Heat of Evaporation: 1369 KJ/Kg or 589 btu/lb

# Liquid Ammonia to Gaseous Ammonia

## Liquid to Gaseous conversion (evaporation) for a 20 kW ICE @ 35% efficiency




4.57gal/hr x 5.15 lb/gal x 589 btu/lb x kW hr/3412 btu = 4.06kW

4.57gal/hr x 231 $in^3$/gal x $ft^3$/1728 $in^3$ = .612 $ft^3$/hr

.612 $ft^3$/hr x 850 = 521 $ft^3$/hr = 8.7 $ft^3$/min

HEC

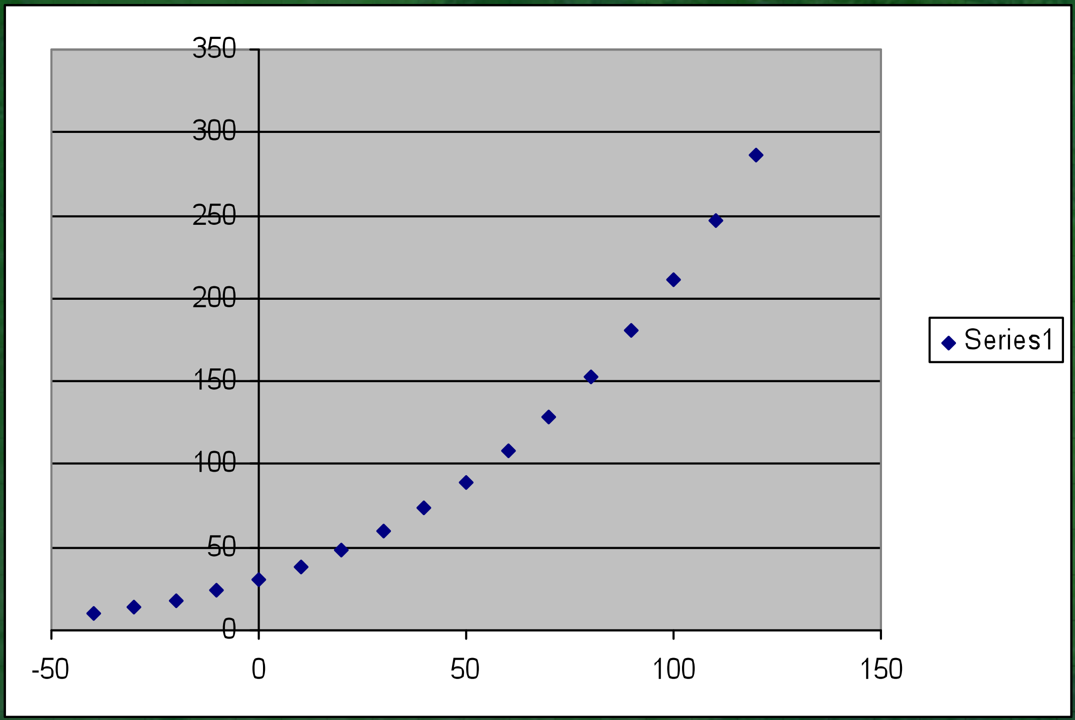
# Liquid Ammonia to Gaseous Ammonia

- An eighty gallon tank of ammonia dropped from 135 psi (90F) to 75 psi (50F) in 30 minutes when the ammonia was removed as a vapor at a similar rate.
- Ammonia needs to be taken from the storage tank as a liquid to avoid freezing up the tank.
- 80 gallon tank

# Liquid Ammonia to Gaseous Ammonia

Energy to heat $NH_3$ gas: .265 w hr/lb C

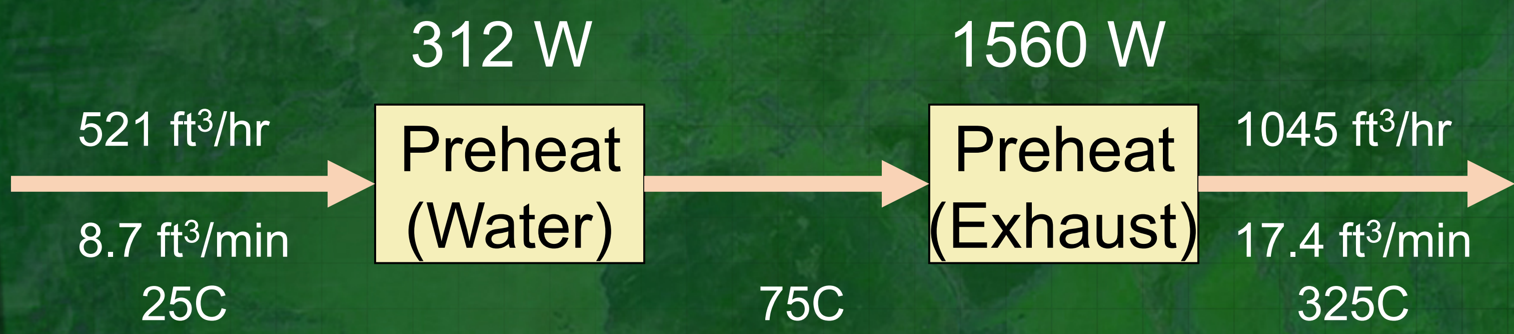
Ammonia tank pressure (psi) vs temperature (F)




HEC

# Hydrogen Source Diagram

## Gaseous $NH_3$ heating




.265 whr/lbC x 50 C x 23.54 lb/hr = 312 W

.265 whr/lbC x 250 C x 23.54 lb/hr = 1560 W

Total power requirement = 1872 watts

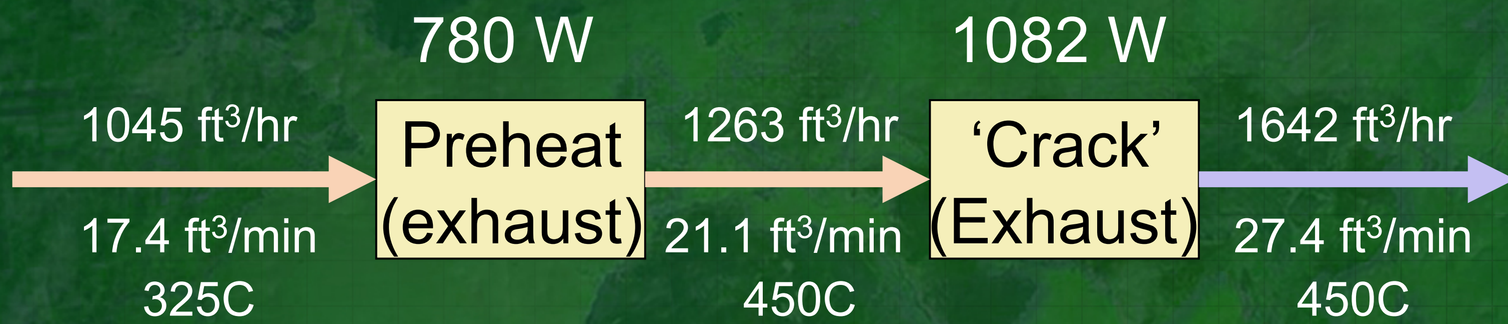
Gas flow = 521 $ft^3$/hr x 598k/298k = 1045 $ft^3$/hr

# Hydrogen Source Diagram

Energy to 100% 'crack' $NH_3$: 8.4 kJ/ft$^3$

# Hydrogen Source Diagram

## Gaseous $NH_3$ heating




.265 whr/lbC x 125 C x 23.54 lb/hr = 780 W

1045 $ft^3$/hr x 723K/598K = 1263 $ft^3$/hr

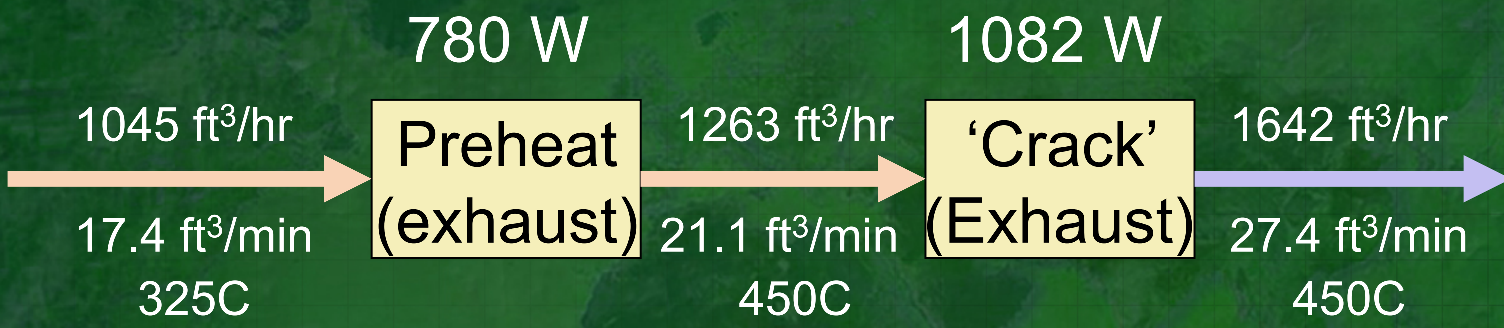
8.4 kJ/$ft^3$ x 1545 ft3/hr x kWhr/3600 = 3605 W (100%)

3605 x 30% = 1082 watts

1263 $ft^3$/hr x 30% x 2 = 758 $ft^3$/hr (25% $N_2$, 75% $H_2$) or 189 $ft^3$/hr $N_2$ and 568 $ft^3$/hr $H_2$. 1263 $ft^3$/hr x .70% = 884 $ft^3$/hr NH3 for a total gas flow of 1642 $ft^3$/hr

# Hydrogen Source Diagram

## Gaseous $NH_3$ heating




Output gas composition by volume is:

- Hydrogen 568 $ft^3$/hr = 34.6%
- Nitrogen 189 $ft^3$/hr = 11.5%
- Ammonia (NH3) 884 $ft^3$/hr = 53.8%

# Total heat requirement

| | |
|---|---|
| • Heat of evaporation: | 4.06 kW |
| • Preheating of $NH_3$ gas: | 2.65 kW |
| • Heat for ‘cracking’ | 1.08 kW |
| • Total heat required: | 7.79 kW |

HEC

# New engineering guide lines

- Heat of Evaporation: 20.3% of output power
- Preheating of $NH_3$ from 25C: 13.3% of output power
- 30% Cracking of $NH_3$: 5.4% of output power
- **Total Power 39% of output power**

HEC

# Ammonia ignition

- By mixing ammonia and a fuel the ignition energy can be lowered.
- HEC chose use hydrogen to lower the ignition energy requirement.
- Adding oxygen by itself made very little difference.

HEC

# Ammonia ignition

- Ammonia has a very high ignition energy
  - > 1000 MJ
- NG (Methane) burns at .30 mJ
- Propane burns at .26 mJ
- Hydrogen has a very low ignition energy
  - .017 MJ

# Ammonia ‘fuel’ flame velocity

- Ammonia is a very slow burning fuel
  - .15m/sec to .23 m/sec
- NG (Methane) burns at .39 m/sec
- Propane burns at .45 m/sec
- Hydrogen is a very fast burning fuel
  - 3.06 m/sec

HEC

# Ammonia 'fuel' flame velocity

- By mixing ammonia and a fuel and/or oxygen the flame velocity can be improved.
- HEC chose to mix ammonia, hydrogen and nitrogen in the proper amounts to simulate NG and with a second formulation simulate propane to exactly match the flame velocity of each fuel.

HEC

# Ammonia Fuel Application

- Video of Fork Truck running will be shown at the end of the presentation

# Power comparison of Ammonia vs NG

- Natural gas has more btus than ammonia, therefore the thought is that you will get more power with natural gas, BUT it's all about the amount of air that is needed.
- Remember it is not a gas pedal, but instead an air pedal. More power is generated by adding air, not fuel. We use a turbo-charger not a super flow fuel pump for additional power.

HEC

# Power comparison of Ammonia vs NG

- $3CH_4 + 6O_2 = 3CO_2 + 6H_2O$
  - 6 $O_2$ used
- $8NH_3 + 6O_2 = 4N_2 + 12H_2O$
  - 6 $O_2$ used
- For the same amount of air we can burn $8NH_3$ or $3CH_4$, therefore we can get more power from ammonia than from NG.

# Thank You!

Hydrogen Engine Center, Inc.
2502 E Poplar St
Algona, IA 50511
www.hydrogenenginecenter.com
Phone:  515-295-3178
Fax:  515-395-1877

# Ammonia reference data

- Gallon of $NH_3$ = 5.15 #
- $NH_3$ is 3/17 hydrogen (17.6%)
- .91 # hydrogen per gal $NH_3$ (2.205#/kg)
- 423 $ft^3$ $H_2$ per kg
- .412 kg $H_2$ per gallon $NH_3$
- 174 cubic feet $H_2$ per gal $NH_3$

# Engineering data

- Gallon = 231 cubic inches
- Cubic foot = 1728 cubic inches
- 1 hp hr = 2545 btu
- 1 kW hr = 3412 btu
- NH3 expands 850 x when evaporated
- $NH_3$ doubles in volume when ‘cracked’
- 450C cracking temperature gives 30% $H_2$