Review of ammonia as an electrofuel for Internal Combustion Engines

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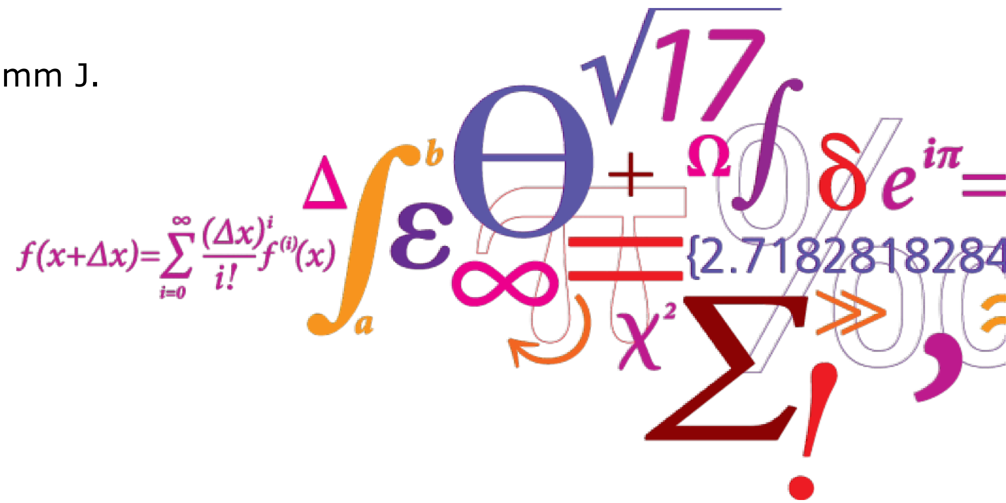
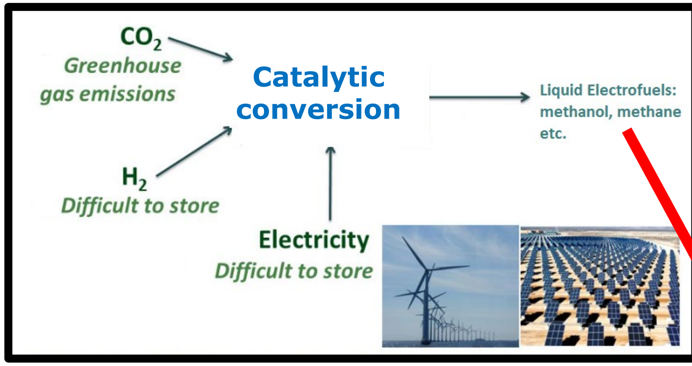
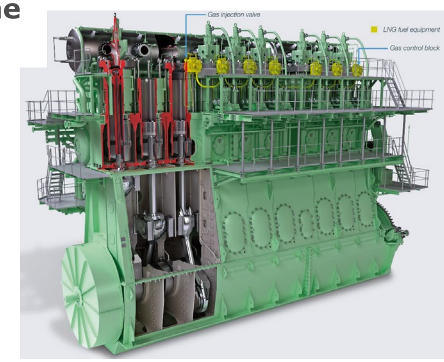


Electrofuels/ammonia

Electrofuels



Application as an engine fuel



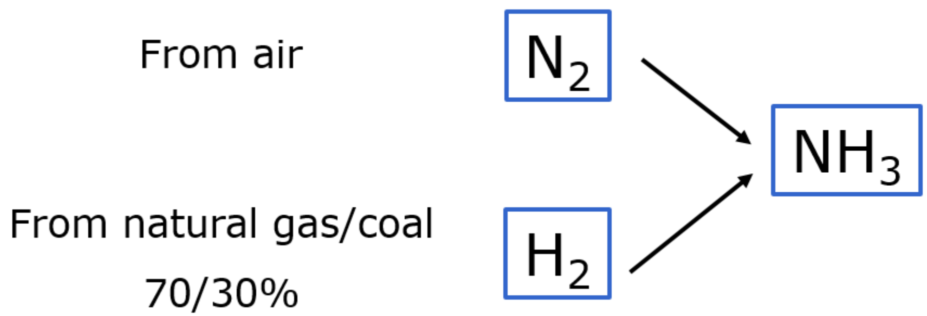
Examples:

- Liquid fuel production: methanol
- Biogas enrichment
- Hydrogen
- Ammonia! (if no carbon source is available)

Ammonia Production

Ammonia: NH_3

Haber-Bosch:



Ammonia application today: mainly industry

Possibilities: peaker plants, IC engines

Substitution of: natural gas HFO

Ammonia distribution and storage

Pipelines:

	Efficiency*	Capacity°	Cost
Natural gas	97%	1,464MW	-
Hydrogen	87%	1,207MW	0,5-3,2 $/kg
Ammonia	99%	2,251MW	0,034 $/kg

*: conditioned for vehicle application purposes

°: based on a 12-inch nominal pipeline

	Energi content (LHV) [MJ/Kg]	Energi content (LHV) [MJ/L]	Octane	Cetane	Laminar Flame velocity [m/s]*)
Diesel	45.6	38.6		~50	
Gasoline	46.4	34.2	92-95		0.28
Liquified Ammonia	18.6	11.5	>130		0.015
Liquified Hydrogen	120	8.491	>130		3.51
Methane	49.6	20.3 (LNG)	120		0.34
Methanol	19.7	15.6	108.7		0.43
Ethanol	26.9	21.3	108.6		0.41
DME	28.4	19.3		60	

*) Stoichiometric combustion

For compressed hydrogen divide by 2-4!

Storage:	
Ammonia stored at 17 bars:	13,8 MJ/l
Liquid hydrogen at -253^{0}C:	10,0 MJ/l

Vessel storage:	
Ammonia (typical capacity):	15-60.000 t
Hydrogen (with current techn.):	<900 t

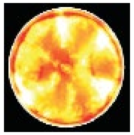
Ammonia as an IC engine fuel

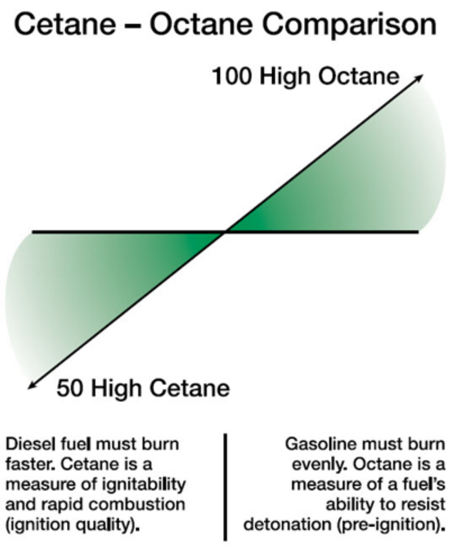
Diesel

HFO

HVO, SVO, FAME

DME





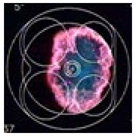
Gasoline

MeOH, EtOH

Hydrogen

LPG

CNG, LNG



Ammonia?

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Ammonia

Barriers:

Low flame speed

Additional fuel/ig. improver needed (CI application)

Poisonous

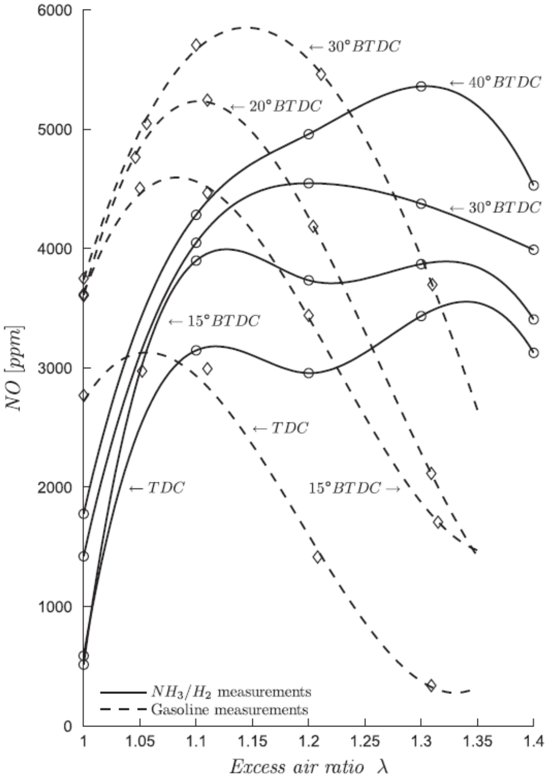
Materials

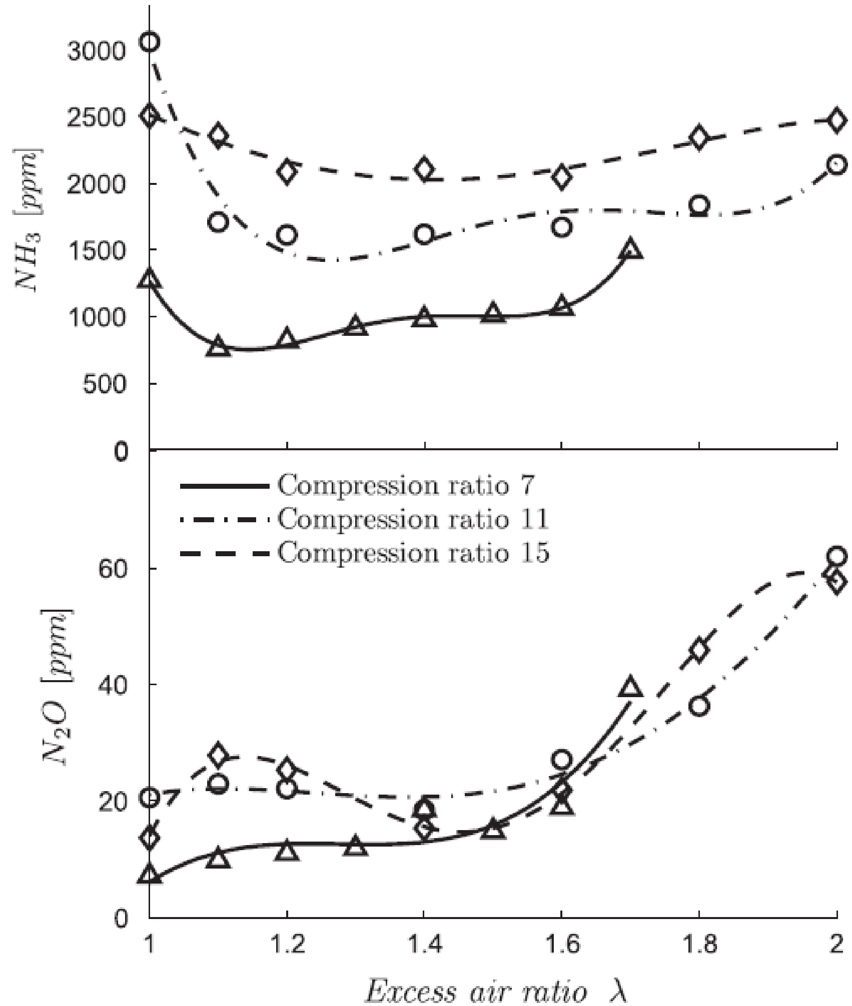
Heat of vaporization

Emissions unknown (N_2O?)

Ammonia	Additional fuel	Result	Comments
	None	☹ ☹ ☹	High compression needed (CR 35:1) to achieve combustion
Gaseous in intake	Hydrogen in intake	☺ ☺ ☺	Applied in SI engine, 5 vol-% hydrogen achieves good combustion – only tried at limited operating conitions, NOx and N2O? (SCR needed)
Gaseous in intake	Gasoline DI	☹	Difficult at many operating conditions (low flame speed), Low BSFC, Fuel NOx high
Dissolved in gasoline	Gasoline	?	Higher power with moderate ammonia concentrations, but not much info
Gaseous in intake	Diesel DI	☺ ☹	Possible but high BSFC, high fuel NOx production at lower loads, N2O? (SCR needed), higher CO and HC
Gaseous in intake	Biodiesel DI	☺ ☹	As above with even higher NOx
DI	DME DI	☹	Cyclic variations, higher CO HC and NOx

SI engine application





SCR Necessary!

CI engine application

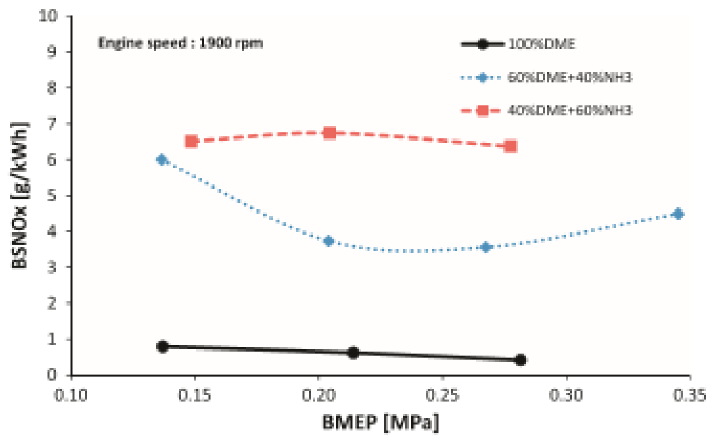


Fig. 15. NOx emissions for various fuel mixtures.

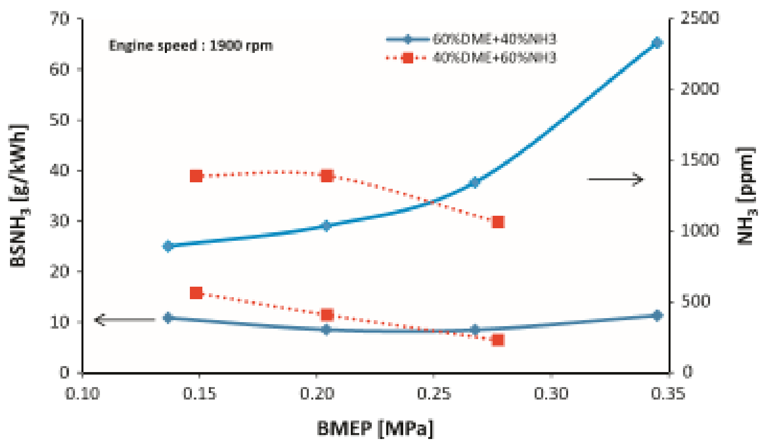


Fig. 16. Ammonia emissions for fuel mixtures containing ammonia.

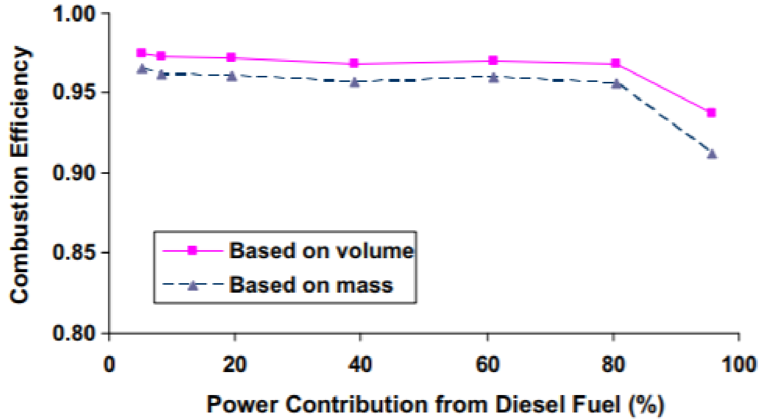
Ammonia emissions seems to be much higher in CI engines!

SCR Necessary!

CI engine application

Ammonia injected into the air stream

DI of diesel fuel



However, poor engine efficiency for ammonia due to cyclic variations!

Very high emissions of unburned ammonia!

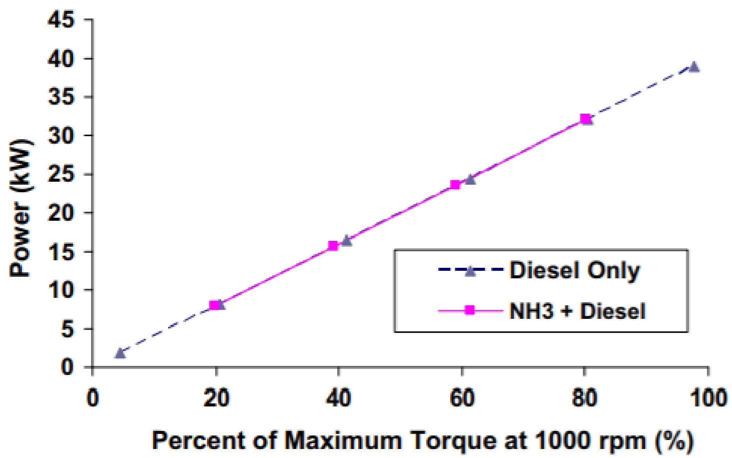


Fig. 15. Measured engine power using "diesel fuel only" (dashed line) and various combinations of ammonia/diesel fuel (solid line).

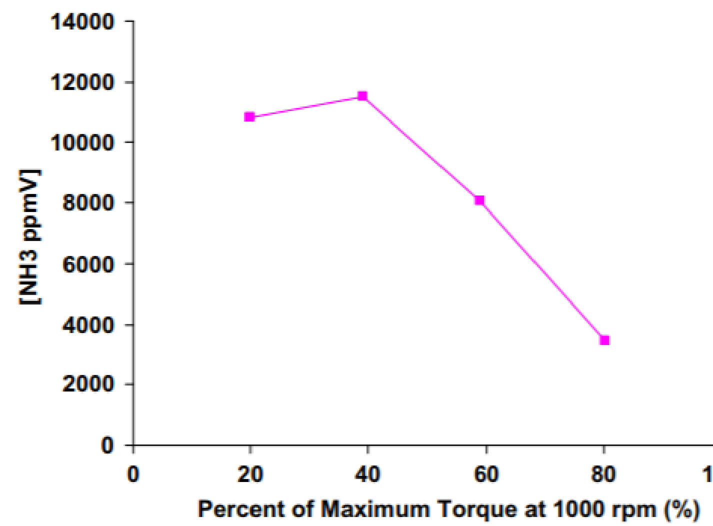
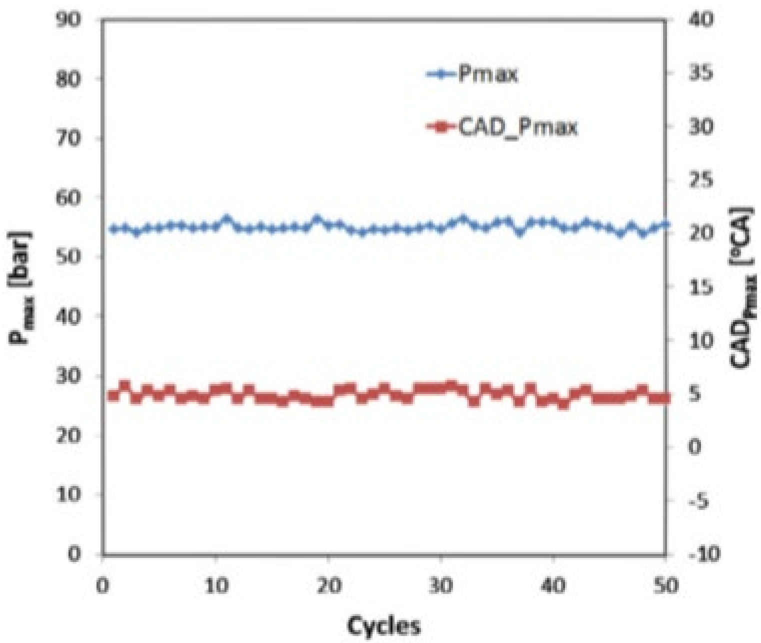


Fig. 18. Ammonia concentration in the exhaust, ppmV, for corresponding engine torque using combinations of ammonia/diesel fuel.

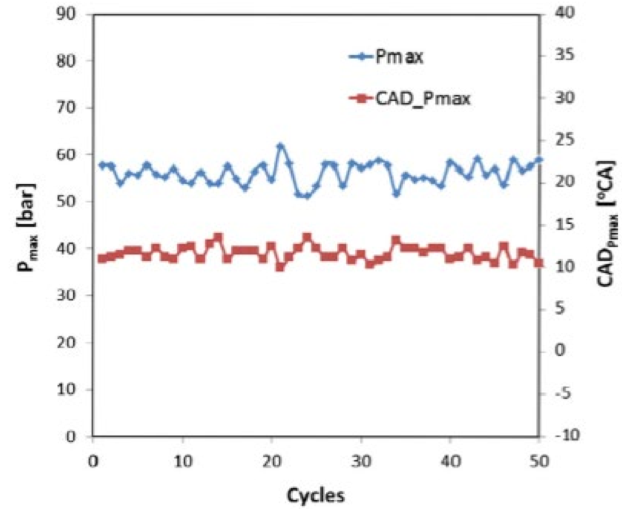
Aaron et. Al. Fuel, 2011

CI engine application

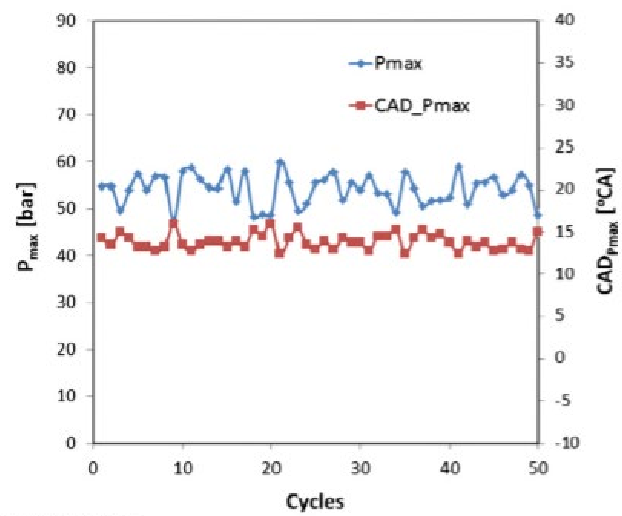
100%DME, SOI = 10 BTDC,



60%DME–40%NH_3, SOI = 20 BTDC.



(b) BMEP=0.21 MPa



(c) BMEP=0.35 MPa

Ryu et. Al. Applied Energy, 2014

Conclusions:

- Ammonia cannot be applied as the only fuel
- Different concepts have been studied
  - SI engine application with hydrogen is most promising so far
- Fuel NOx production is a new issue to consider
- N2O emissions have to be adressed
- BSFC is quite poor in CI engines
- SCR is needed to reduce NOx

Thank you for your attention !

Electrofuels/ammonia

Investigated applications

Ammonia: NH_3

Haber-Bosch:

From air — N_2

From natural gas/coal — H_2

70/30%

N_2 + H_2 → NH_3

Ammonia application today: mainly industry

Possibilities: peaker plants, IC engines

Substitution of: natural gas, coal (70, 30%) HFO