



Review of ammonia as an electrofuel for Internal Combustion Engines

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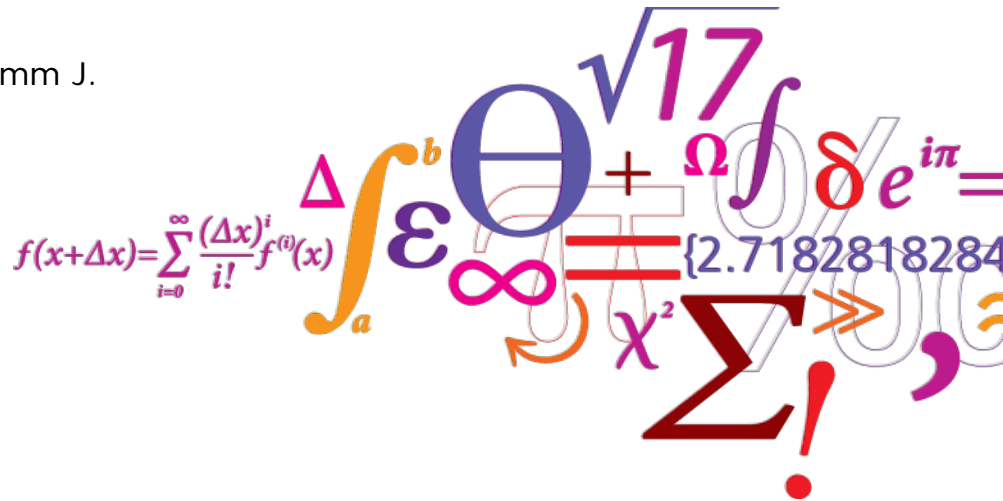
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Review of ammonia as an electrofuel for Internal Combustion Engines

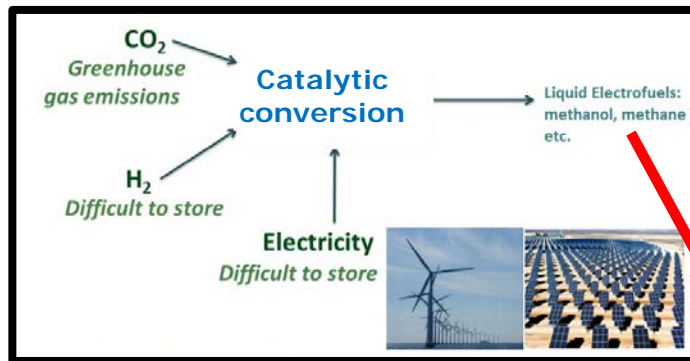
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Technical University of Denmark

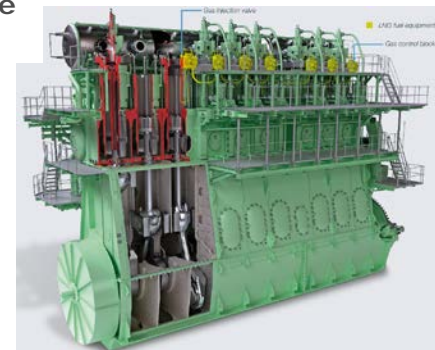


Electrofuels/ammonia

Electrofuels



Application
as an engine
fuel



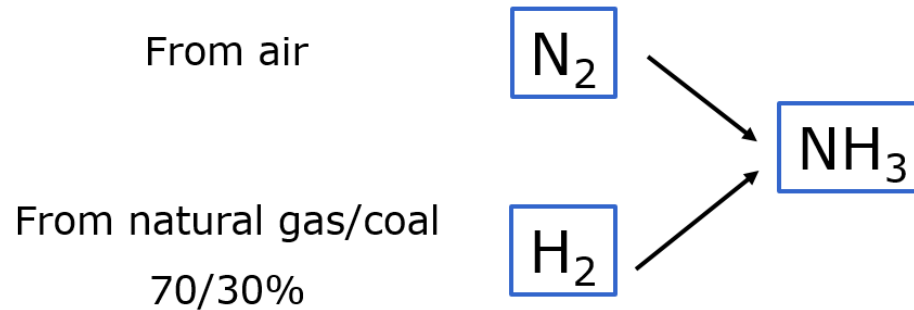
Examples:

- 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 ^o	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

^o: 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°C:	10,0 MJ/l

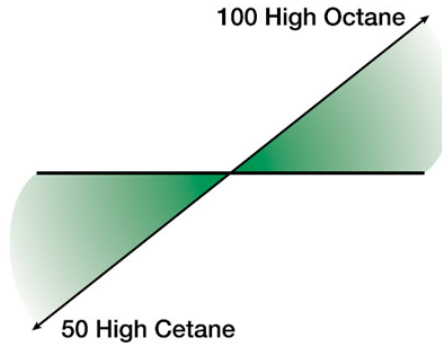
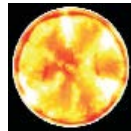
Vessel storage:

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

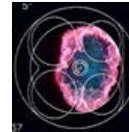
Ammonia as an IC engine fuel

Cetane – Octane Comparison

Diesel
HFO
HVO, SVO,
FAME
DME



Gasoline
MeOH, EtOH
Hydrogen
LPG
CNG, LNG



Diesel fuel must burn faster. Cetane is a measure of ignitability and rapid combustion (ignition quality).

Gasoline must burn evenly. Octane is a measure of a fuel's ability to resist detonation (pre-ignition).

Ammonia?

	Energi content (LHV) [MJ/Kg]	Energi content (LHV) [MJ/L]	Octane	Cetane	Laminar Flame velocity [m/s]*)
Diesel	45.6	38.6		~50	
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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

Ammonia

Barriers:

Low flame speed

Additional fuel/ig. improver needed (CI application)

Poisonous

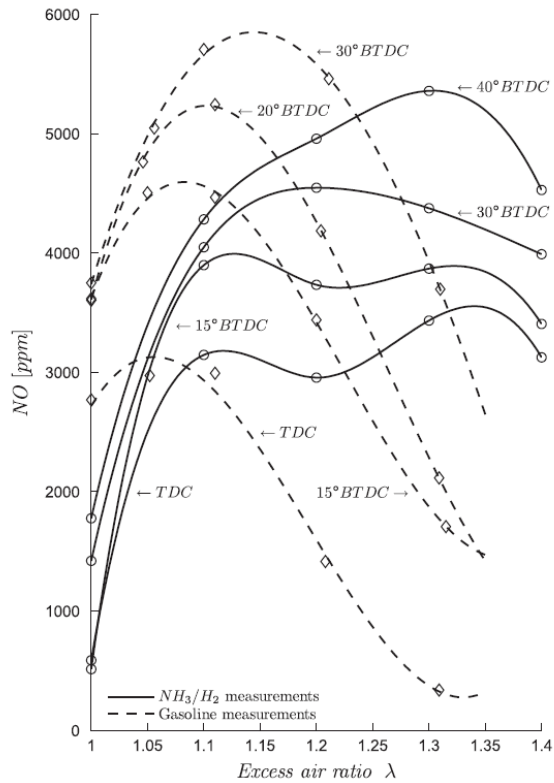
Materials

Heat of vaporization

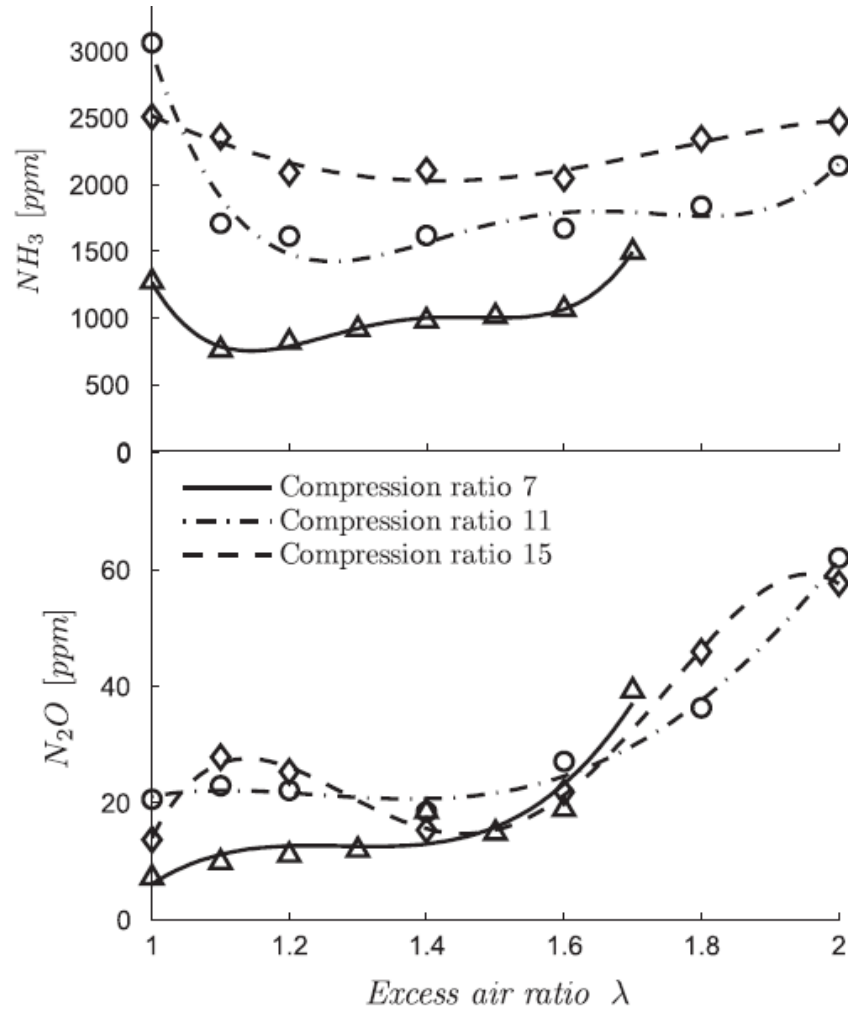
Emissions unknown (N₂O?)

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 conditions, 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!



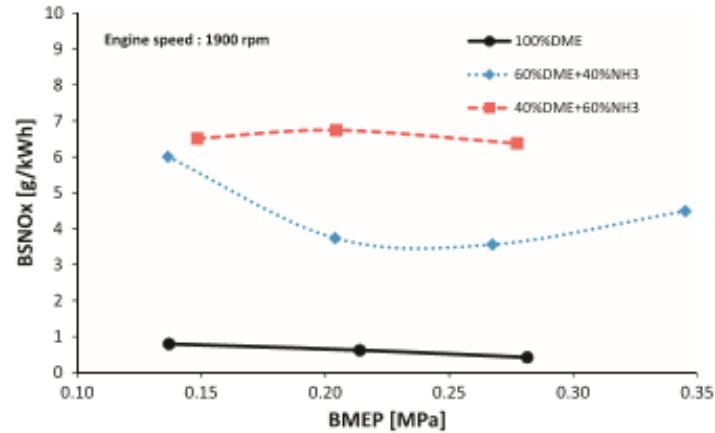


Fig. 15. NOx emissions for various fuel mixtures.

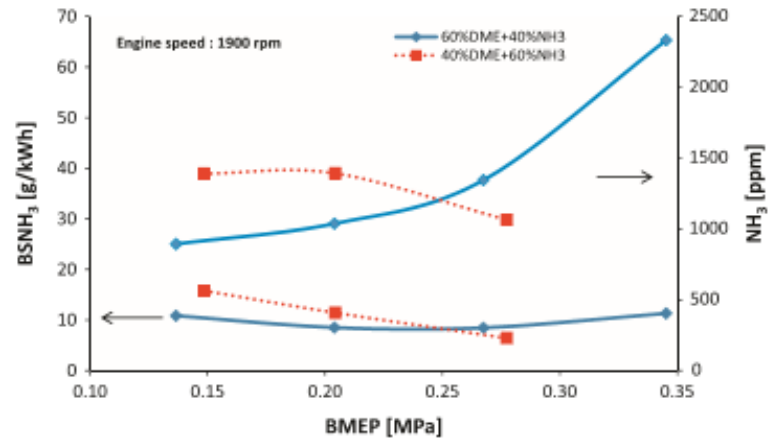


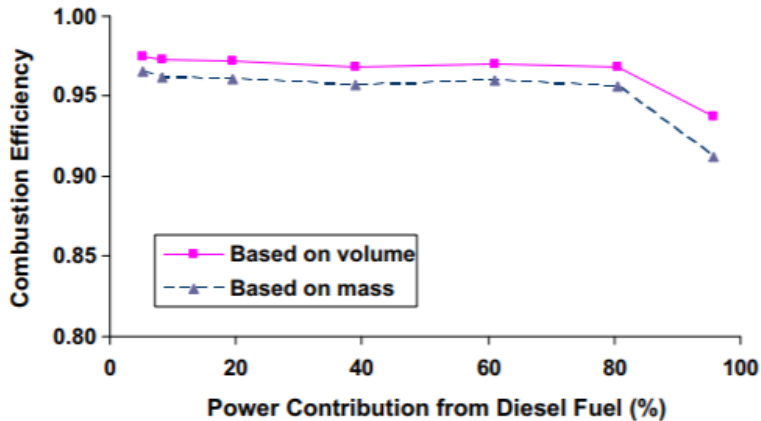
Fig. 16. Ammonia emissions for fuel mixtures containing ammonia.

Ammonia emissions seems to be much higher in CI engines!

SCR Necessary!

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!

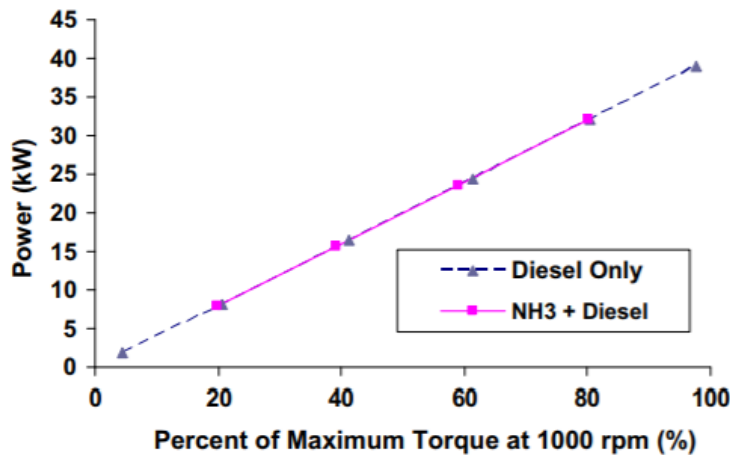


Fig. 15. Measured engine power using "diesel fuel only" (dashed line) and various combinations of ammonia/diesel fuel (solid line).

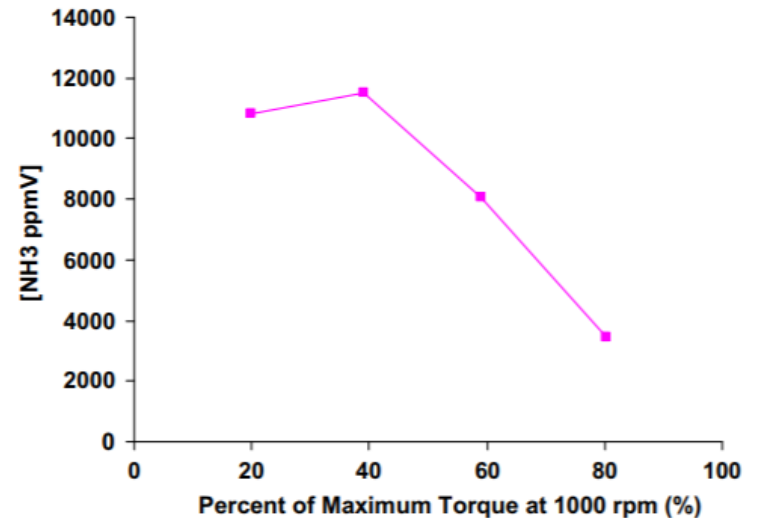
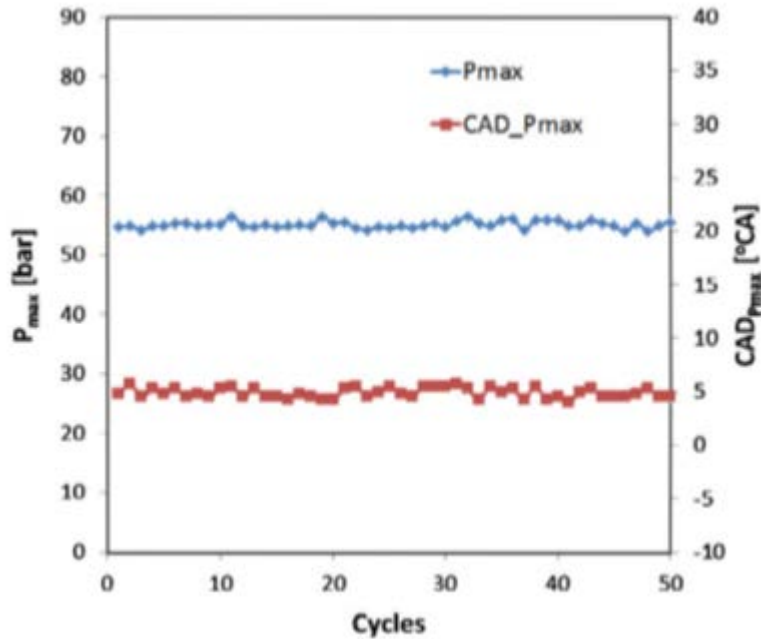


Fig. 18. Ammonia concentration in the exhaust, ppmV, for corresponding engine torque using combinations of ammonia/diesel fuel.

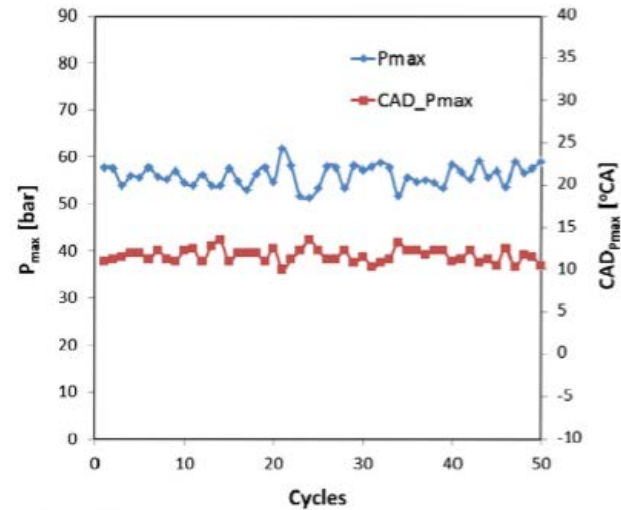
CI engine application

100%DME, SOI = 10 BTDC,

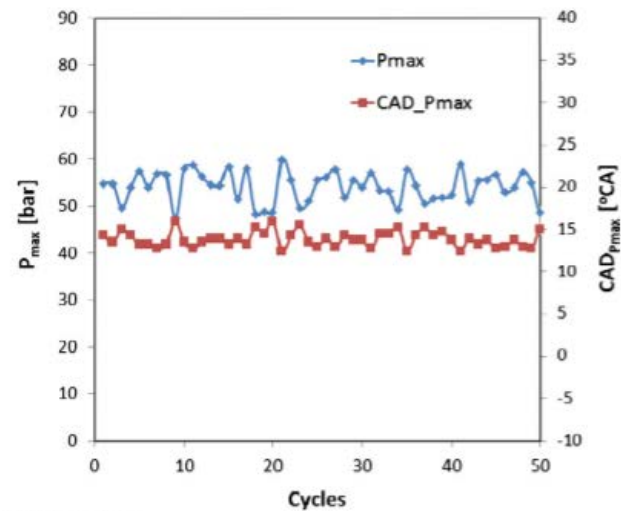
60%DME-40%NH₃, SOI = 20 BTDC.



(b) BMEP=0.21 MPa



(c) BMEP=0.35 MPa



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 NO_x production is a new issue to consider
- N₂O emissions have to be addressed
- BSFC is quite poor in CI engines
- SCR is needed to reduce NO_x

Thank you for your attention !