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Recent progress on the **Ammonia-Gasoline** and the **Ammonia-Diesel** Dual Fueled Internal Combustion Engines in Korea

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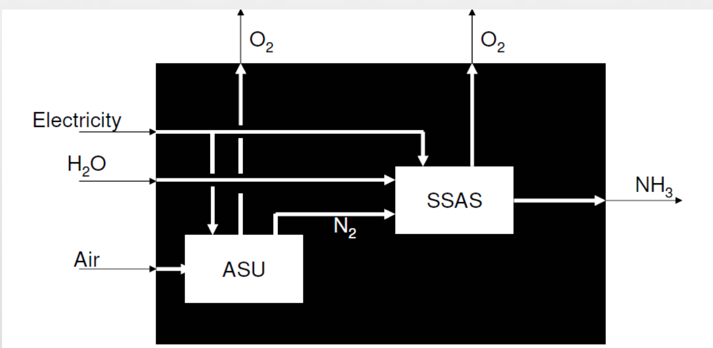
KIER(Korea Institute of Energy Research)



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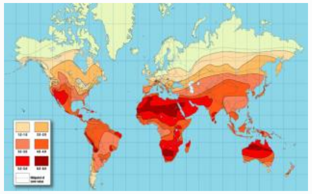
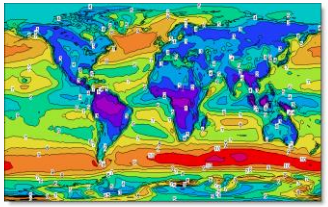
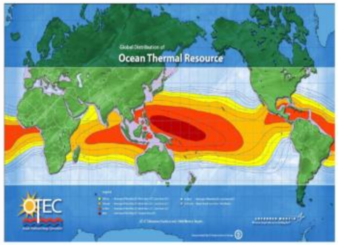
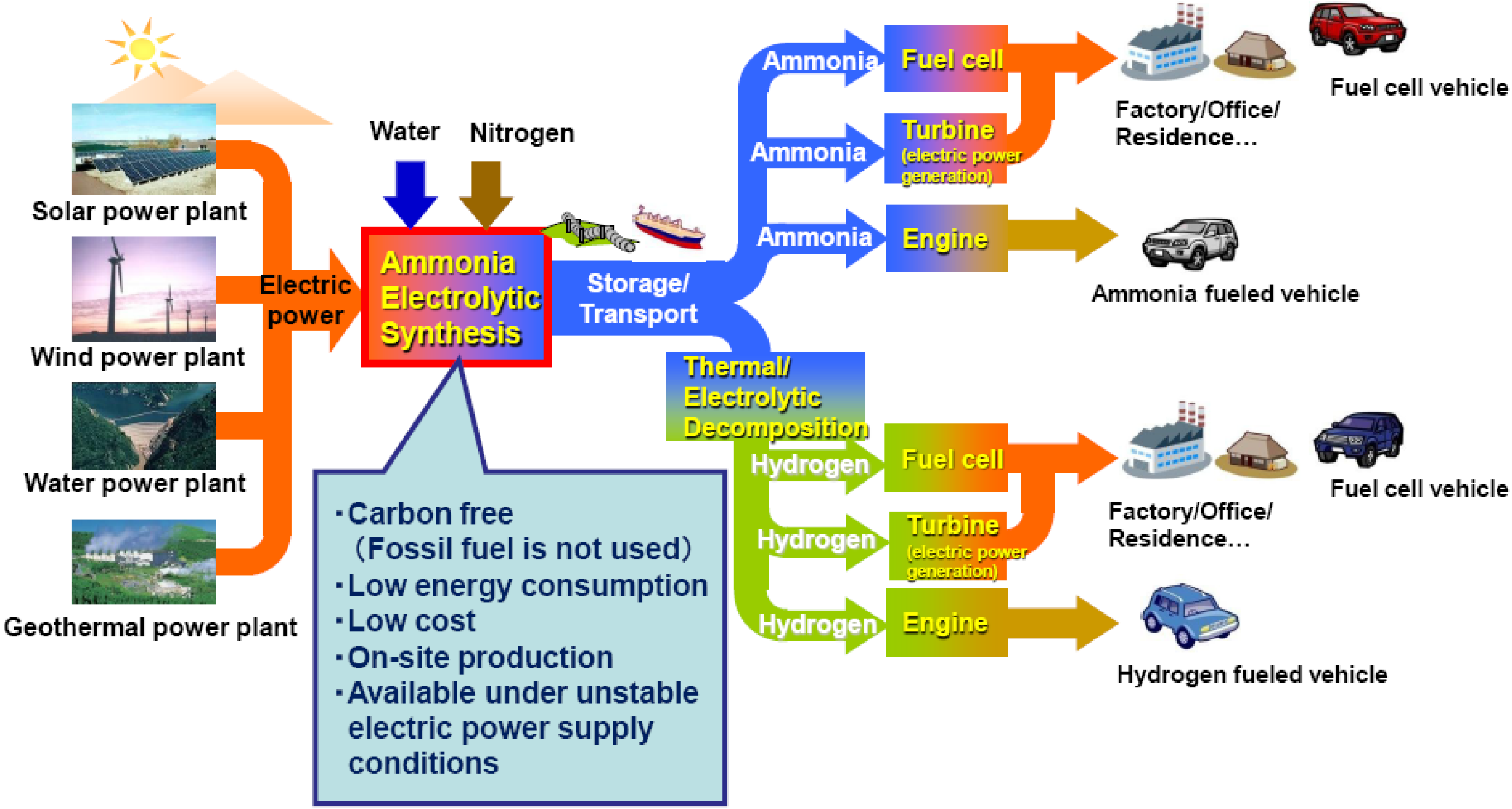
Ammonia Energy System

Production and transportation of ammonia from the renewable energy sources on a global scale









Ammonia storage and transport

Production:
200 Mton/yr

Properties of ammonia fuel

Ammonia Fuel Characteristics

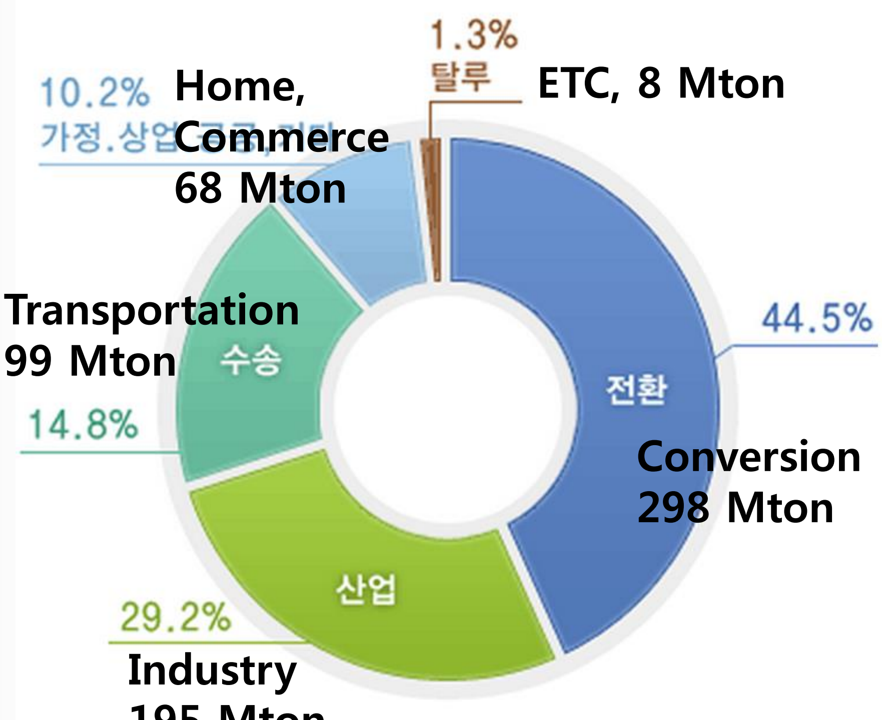
- Challenges
  - Ammonia is very difficult to ignite
    - Octane number ~ 130
    - Autoignition T ~ 651 °C (gasoline: 440 °C; diesel: 225 °C)
  - Ammonia flame temperature is lower than diesel flame T
  - Erosive to some materials
  - Ammonia emissions can be harmful
  - Potential high NOx emissions due to fuel-bound nitrogen

Properties of ammonia fuel

Property	Ammonia	Gasoline	LPG
LHV	18.8 MJ/kg	42.45 MJ/kg	45.7 MJ/kg
Octane Number	>130	92.4	91
Specific gravity of fuel in liquid form	0.64 g/cm3 (15℃)	0.73 g/cm3 (21℃)	-
Stoichiometric air/fuel mass ratio for single fuel	6.1	14.5	-
Flammable equivalence ratio range	0.72 ~ 1.46	0.55 ~ 4.24	-
Flame speed at stoichiometric	0.12 m/s	0.62 m/s	0.83 m/s

Technologies to reduce GHGs

GHG emissions in energy sector (KOREA)



total : 668.82 Mton

GHG reduction Technologies in the transportation sector

1. Fuel Economy improvement

2. EV

3. HEVs
Plug-in HEV
Fuel cell HEV

4. Carbon-free fuel

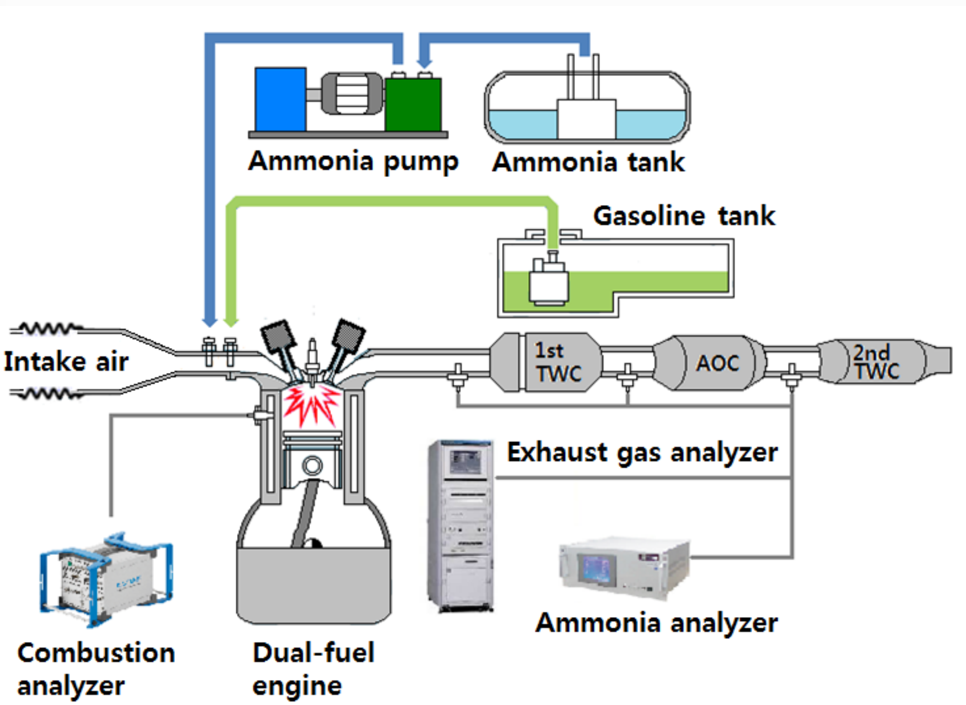
Ammonia vehicle

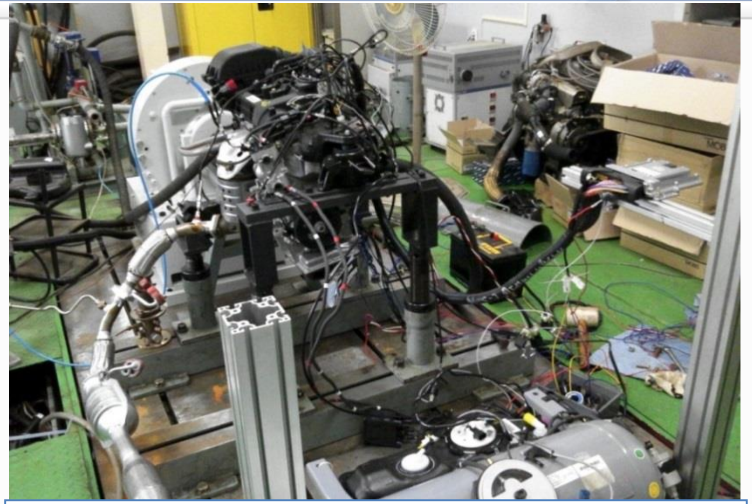
Experimental setup

<u>Base engine: LPG-gasoline Bi-fuel engine</u>

Separate ammonia-gasoline fuel injections

Ammonia-gasoline dual fuel ECU



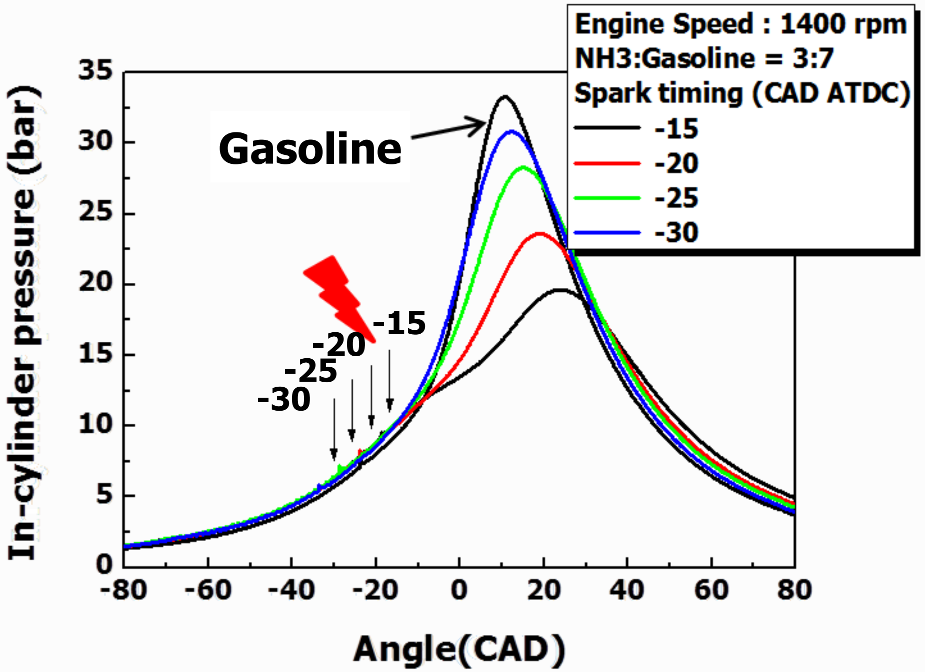


Specification of the test engine

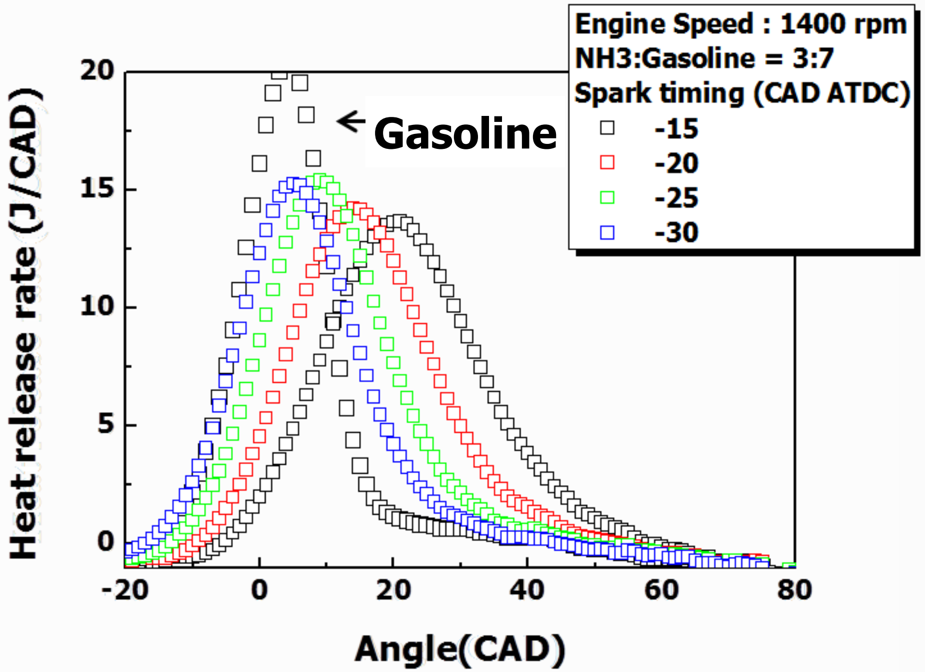
Number of cylinders		3
Bore x Stroke (mm)		71.0 x 84.0
Displacement (cc)		998
Compression ratio		10.5 : 1
Firing order		1-2-3
Intake valve	Opening	BTDC 22.5°~ATDC 27.5°
	closing	ABDC 3.7°~ABDC 53.7°
Exhaust valve	Opening	BBDC 40.6°~BBDC 0.6°
	closing	BTDC 12.6°~ATDC 27.4°

Ammonia-gasoline dual fuel combustion

- ✓ Ammonia burns 1/5 times slower than gasoline.
- ✓ Early ignition enhances the mass burned fraction of fuel mixture.



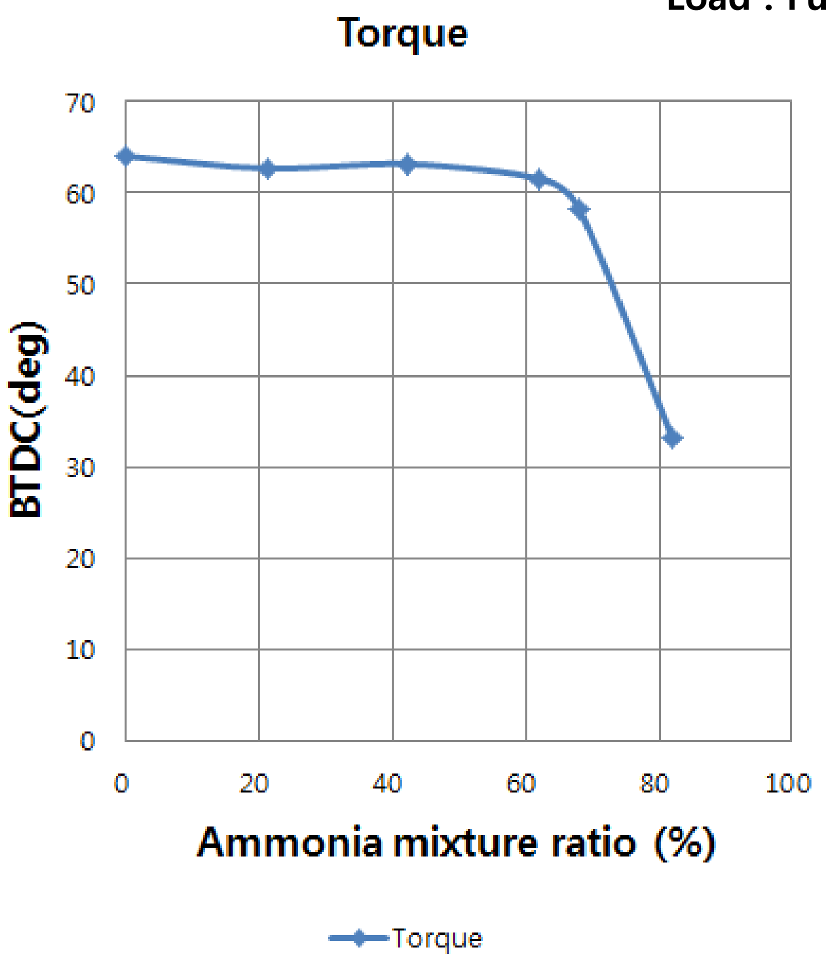
Pressure history with ignition timings

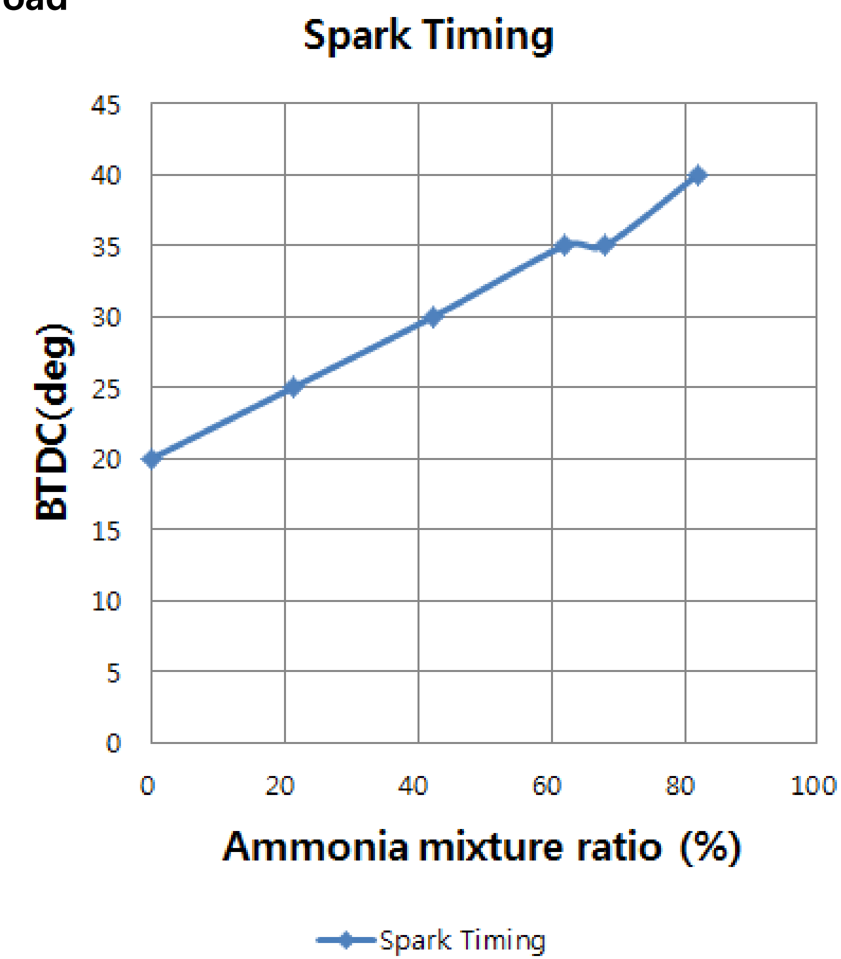


Heat release rate with ignition timings

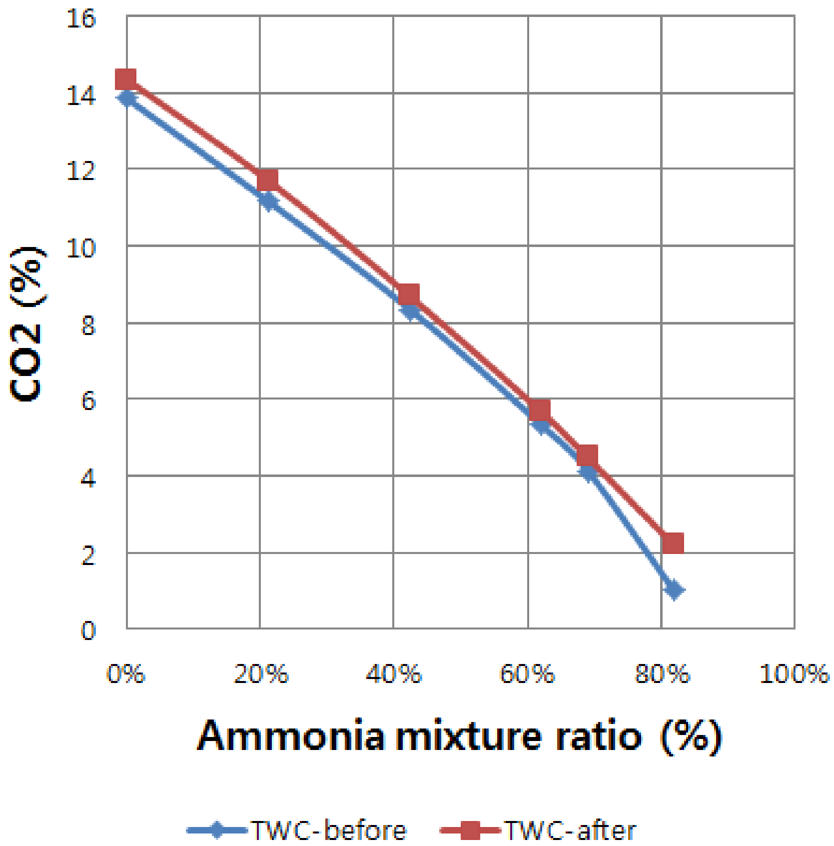
Ammonia-gasoline dual fuel combustion

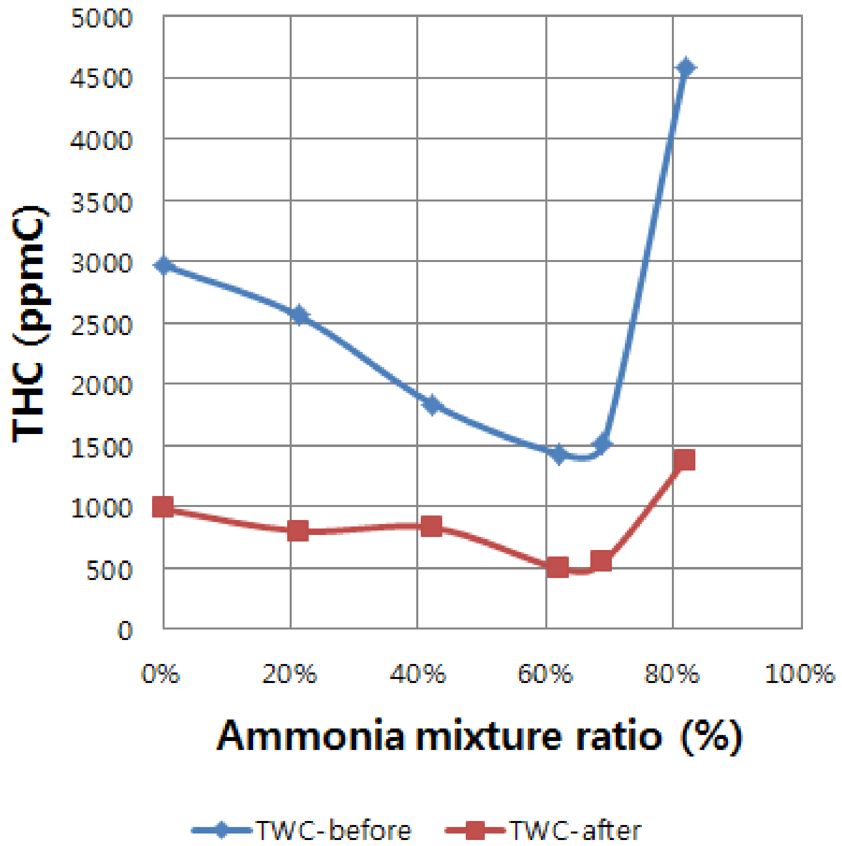
Engine Speed : 1400 rpm
Load : Full-load



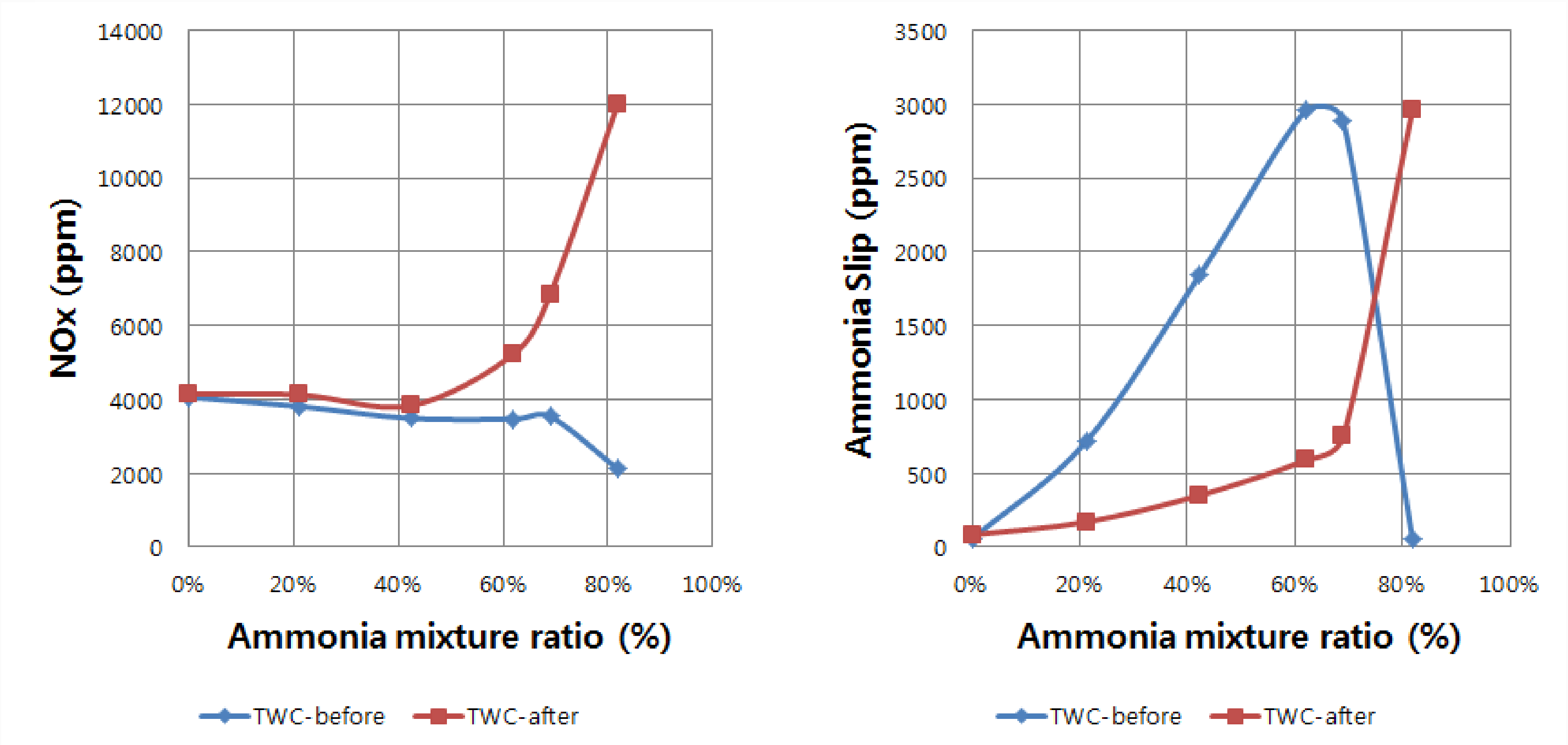


Ammonia-gasoline dual fuel combustion





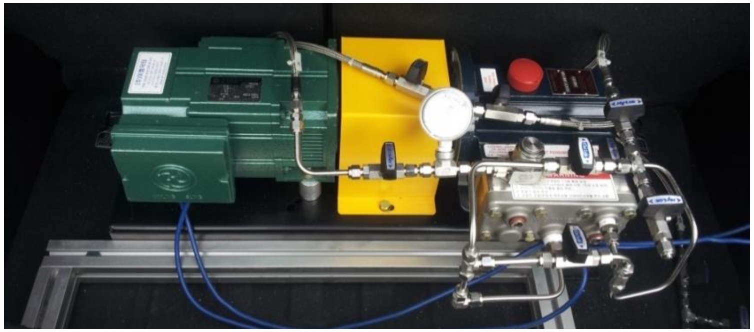
Ammonia-gasoline dual fuel combustion



Ammonia vehicle

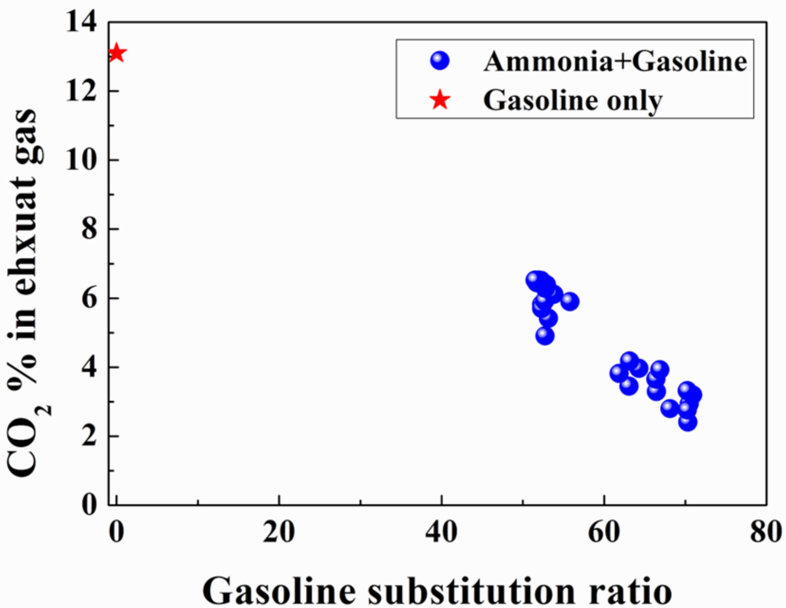
- Ammonia-gasoline dual fuel vehicle
- Separate ammonia/gasoline fuel metering with programmable ECU
- Ammonia / gasoline = 70 / 30 (as the heat value basis)

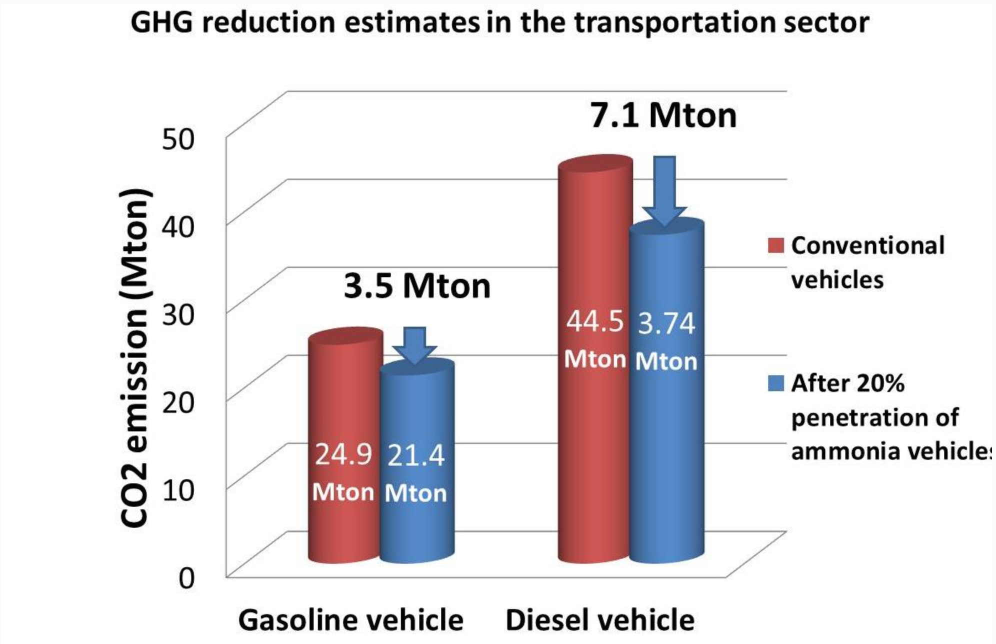




GHG reduction with AmVeh

- CO_2 emission by gasoline only : 13.5%vol
- CO_2 emission by replacing 70% gasoline into ammonia : ~3.5 %vol
- With 20% applications to the local vehicles, 10.6 Mt CO_2 reduction
- This corresponds to the 15% of the total emission a year.



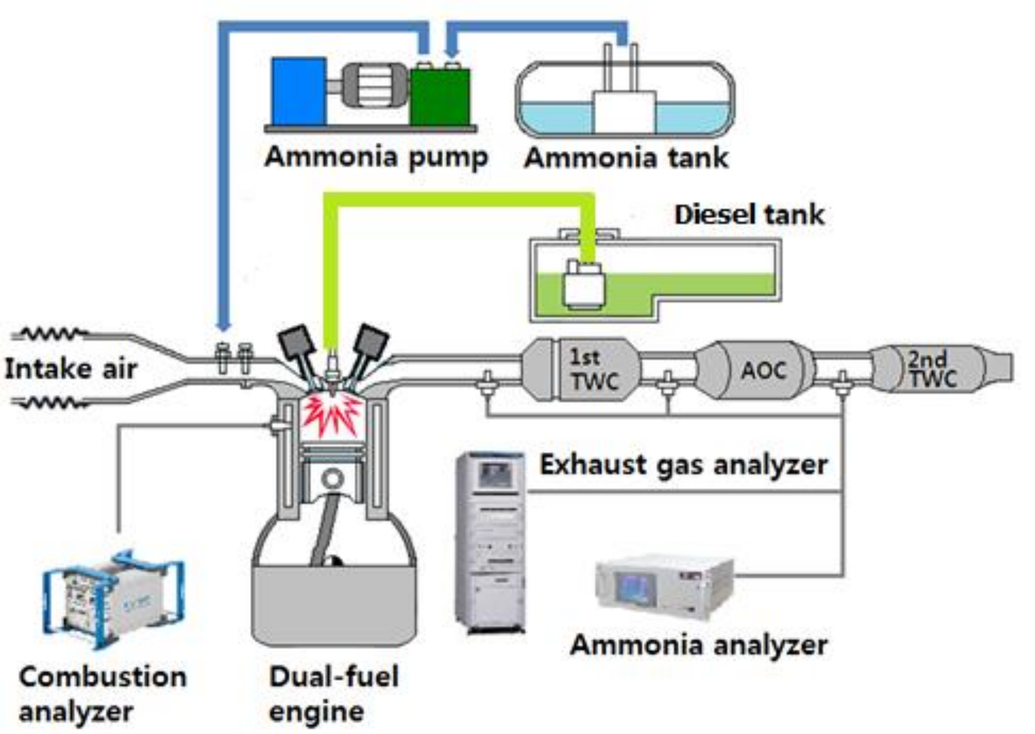


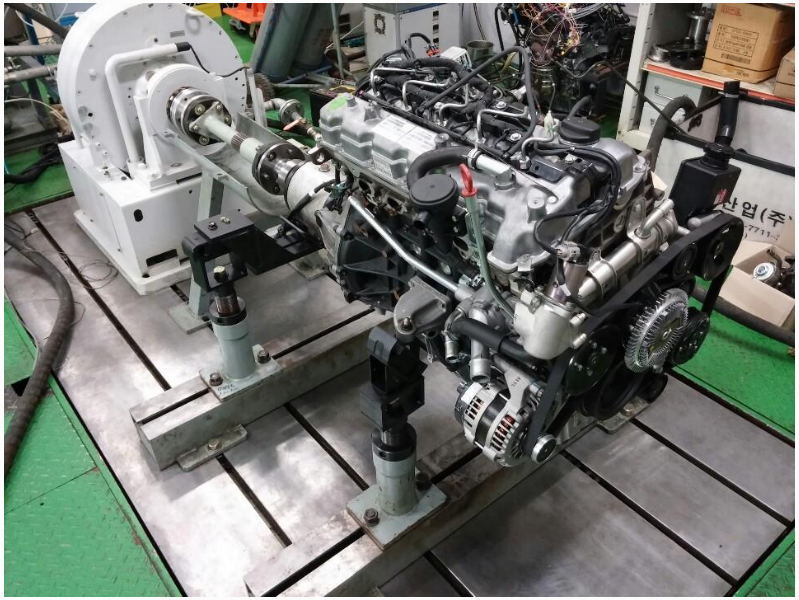
Experimental setup for CI combustion

Base engine: Diesel CRDI engine

Separate ammonia-diesel fuel injections

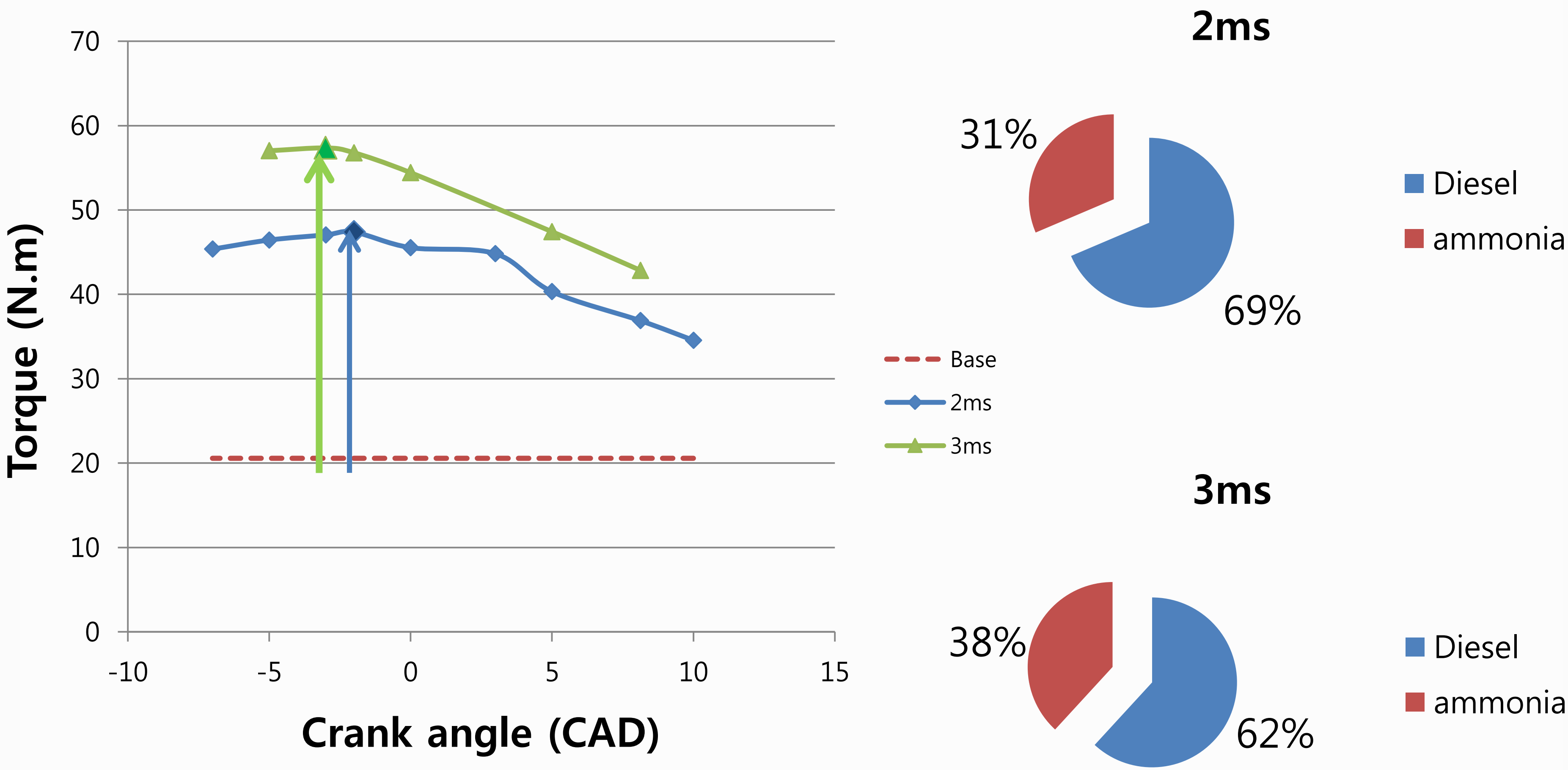
Ammonia-diesel dual fuel controller



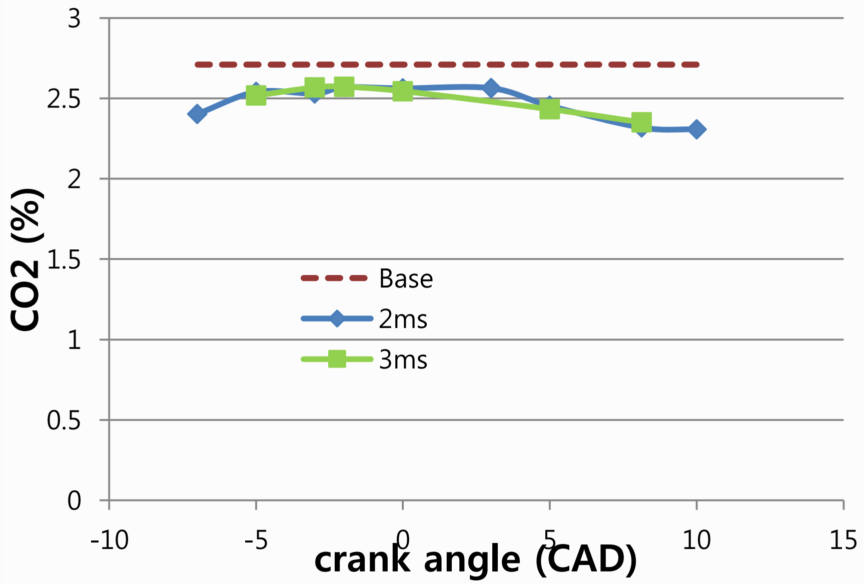


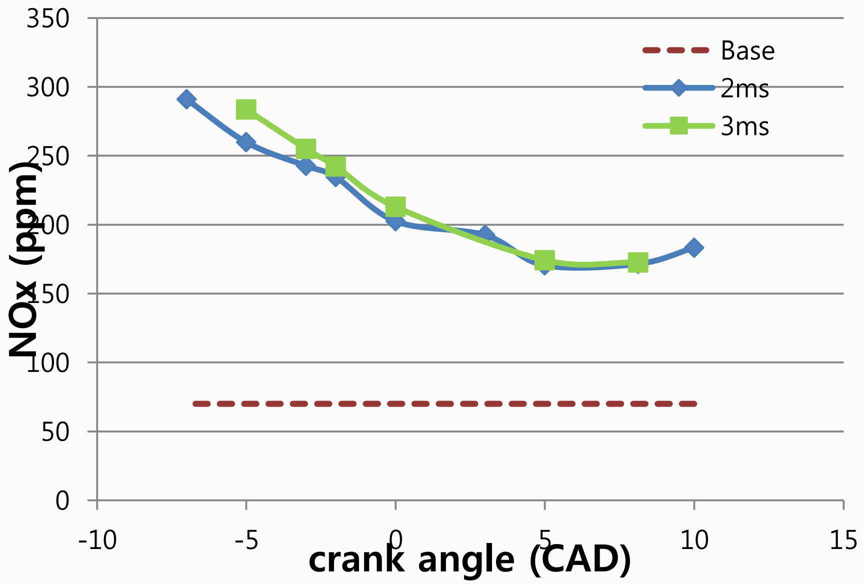
Specification of the test engine	
Number of cylinders	5
Bore x Stroke (mm)	86.2 X 92.4
Displacement (cc)	2696
Compression ratio	17.5 : 1
Firing order	1-2-3

Ammonia-diesel dual fuel combustion

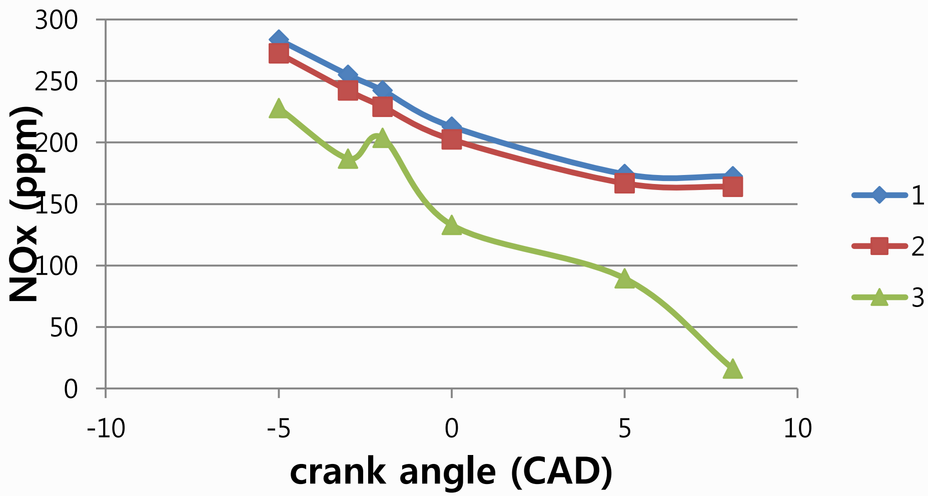


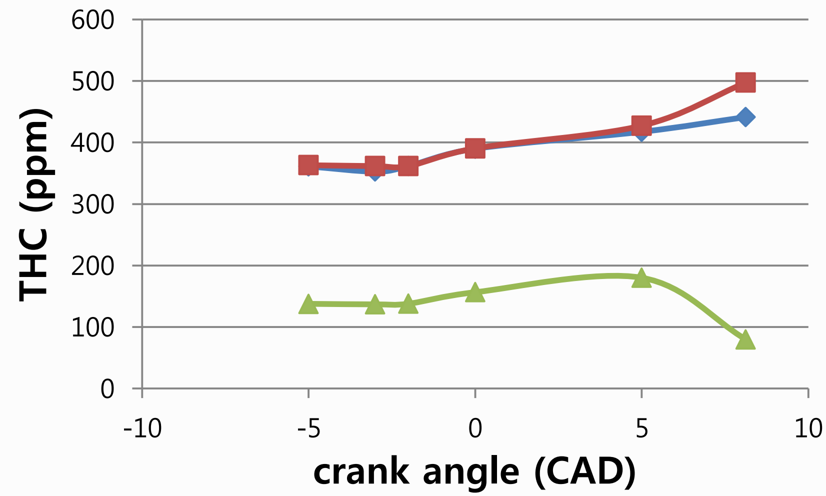
Ammonia-diesel dual fuel combustion





Ammonia-diesel dual fuel combustion





Summary

- Both a spark ignition engine and a compression ignition engine are considered to use ammonia as primary fuel in this study.
- In a spark ignition engine, an ammonia-gasoline dual fuel system was developed and both ammonia and gasoline are injected separately into the intake manifold in liquid phase.
- As ammonia burns 1/6 time slower than gasoline, the spark timing is needed to be advanced near 40 degree before top dead center. As a result, 70% of gasoline is substituted into ammonia and all the same amount of carbon dioxide emission is reduced from the test engine.
- The ammonia-gasoline dual fuel system is also installed into the so-called AmVeh, a vehicle prototype developed in KIER
- In a compression ignition engine, ammonia is taken along with the fresh air from the intake manifold and small quantity of diesel fuel is injected inside the cylinder to have the ammonia-air mixture ignited.
- The final goal of the study is to implement a methodology to ignite ammonia-air mixture and have complete combustion without any use of the conventional fuels.

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Thank you for listening

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Fuel consumption

- Marangoni, Italy
- Base: Toyota GT86-R
- Ammonia/gasoline bi-fuel
- CO_2 free range : 180km
- **FE : 6 km/L (NH_3 100%)**

- KIER, Korea
- Base: Kia Morning G/L bi-fuel
- Ammonia+gasoline dual fuel
- Ammoia:gasoline=70:30
- **FE : 10 km/L (NH_3 70%)**

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