浙江大学 ZHEJIANG UNIVERSITY 动力机械及车辆工程研究所 Institute of Power Machinery and Vehicular Engineering

Decarbonization of the transport sector: The application of low and zero carbon fuels in internal combustion engines

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1. Background

Climate change: the long road to a global deal

Nov 29 - Dec 11
Paris Climate Conference
Climate change pact adopted in principle.
Purpose: to hold global warming to "well below" two degrees Celsius (3.6 degrees Fahrenheit) over pre-Industrial Revolution levels, and to strive for 1.5 C (2.7) if possible.

2015 COP21 Paris

1972 Stockholm — 1st United Nations conference on the environment

1992 Earth Summit Rio de Janeiro — 1st UN environment treaty* *(non-binding)*: industrialised nations agree to **reduce greenhouse gas (GHG) emissions to 1990 levels**

Annually since 1995 — COP** meetings: annual negotiations on an international deal to curb climate change

1997 Kyoto — The Kyoto Protocol *(legally-binding)*: rich nations agree to **cut emissions to 5.2% below 1990 levels by 2012**

2007 Bali — The Bali Action Plan: guidelines for reaching an accord to **extend the Kyoto Protocol after 2012**

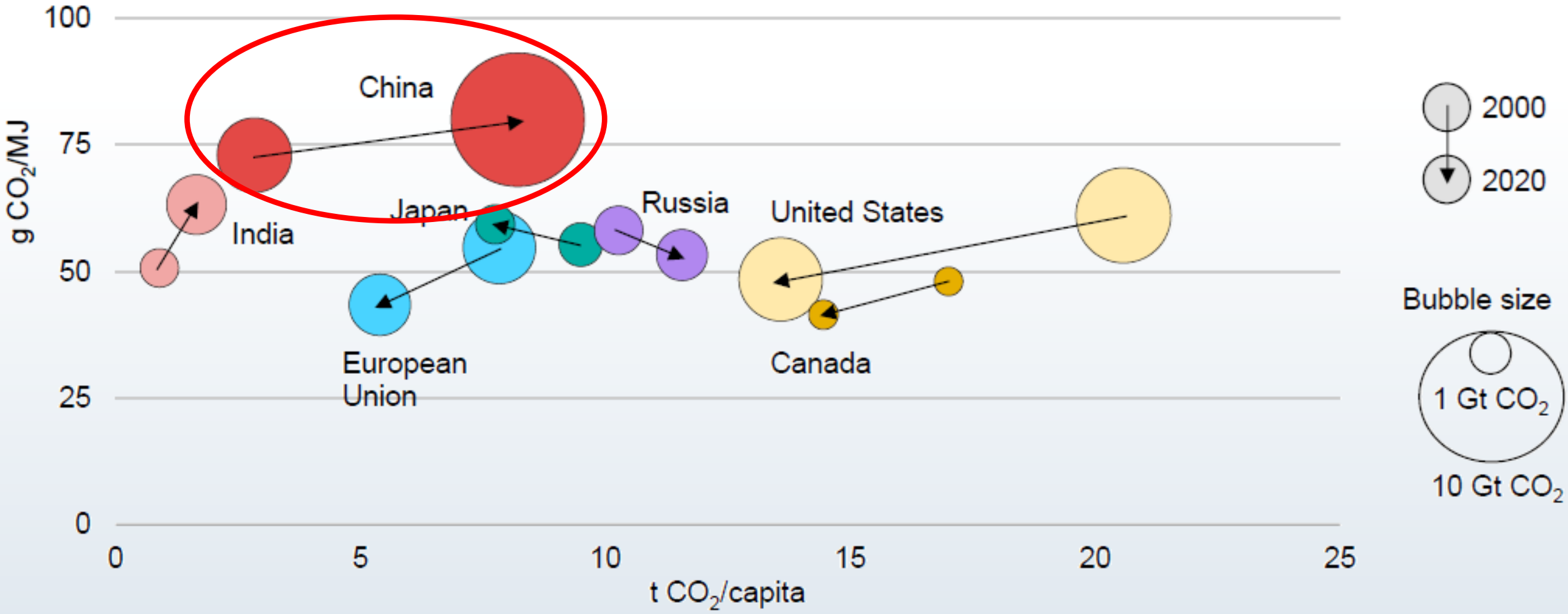
2009 Copenhagen — **Talks on a new climate treaty fail.** But industrialised countries pledge to give poor nations $100 billion a year, from 2020, to help adapt to climate change

2011 Durban — The Platform for Enhanced Action: commits all states to reaching a **legal accord by 2015 to cut emissions**

2014 Lima — All nations are invited to submit voluntary national pledges to cut GHG emissions

1. Background

CO_2 emissions intensity of primary energy demand relative to CO_2 emissions per capita by country/region, 2000 and 2020



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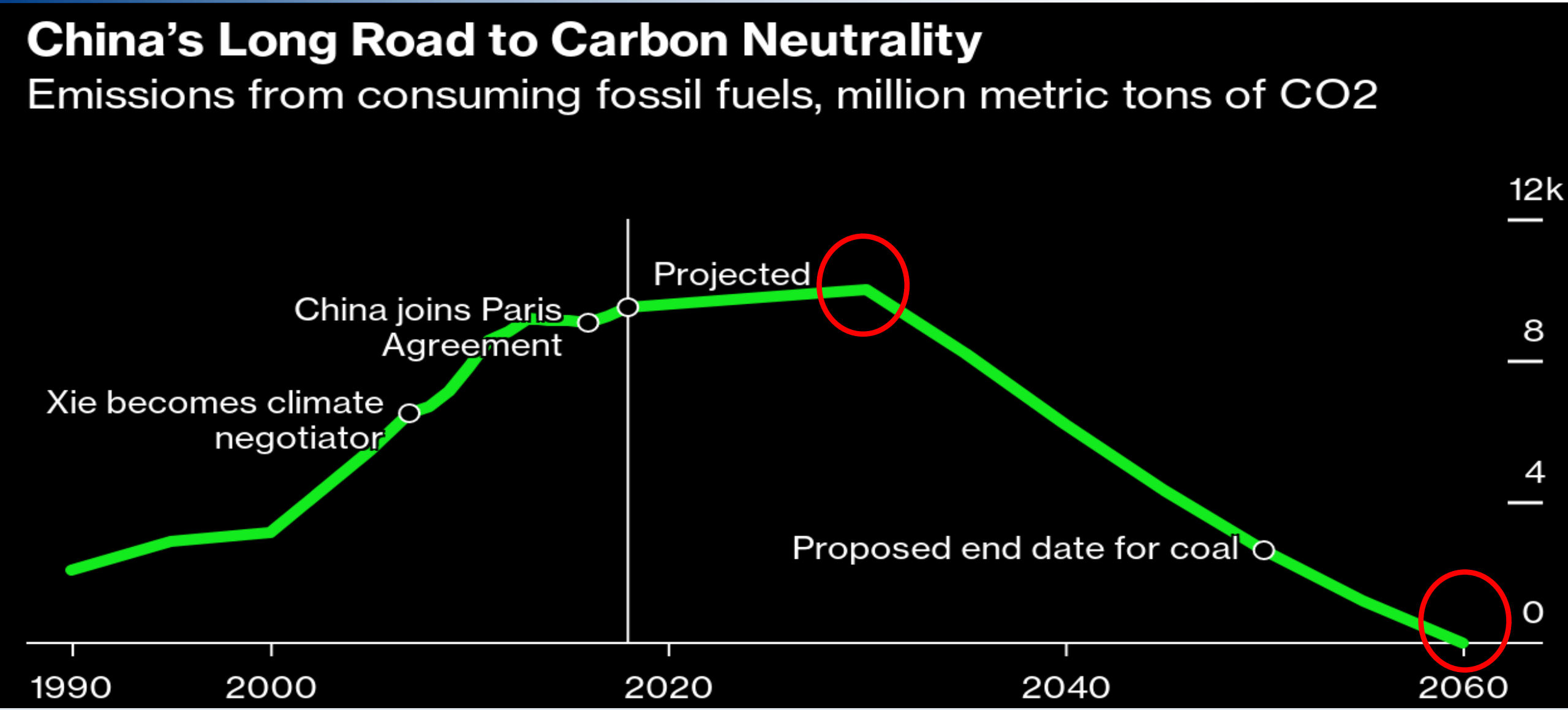
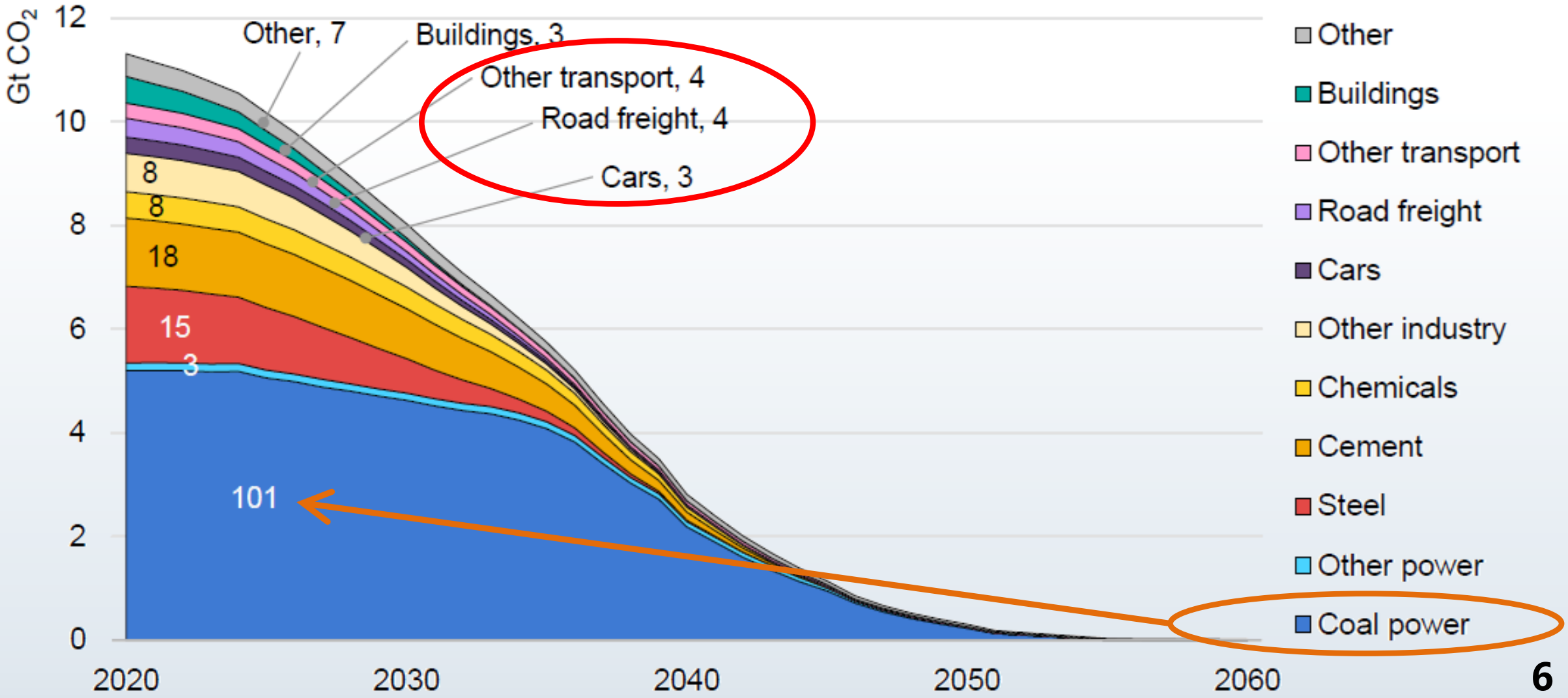


1. Background

CO_2 emissions from existing energy-related infrastructure under typical lifetime assumptions and operating conditions in China

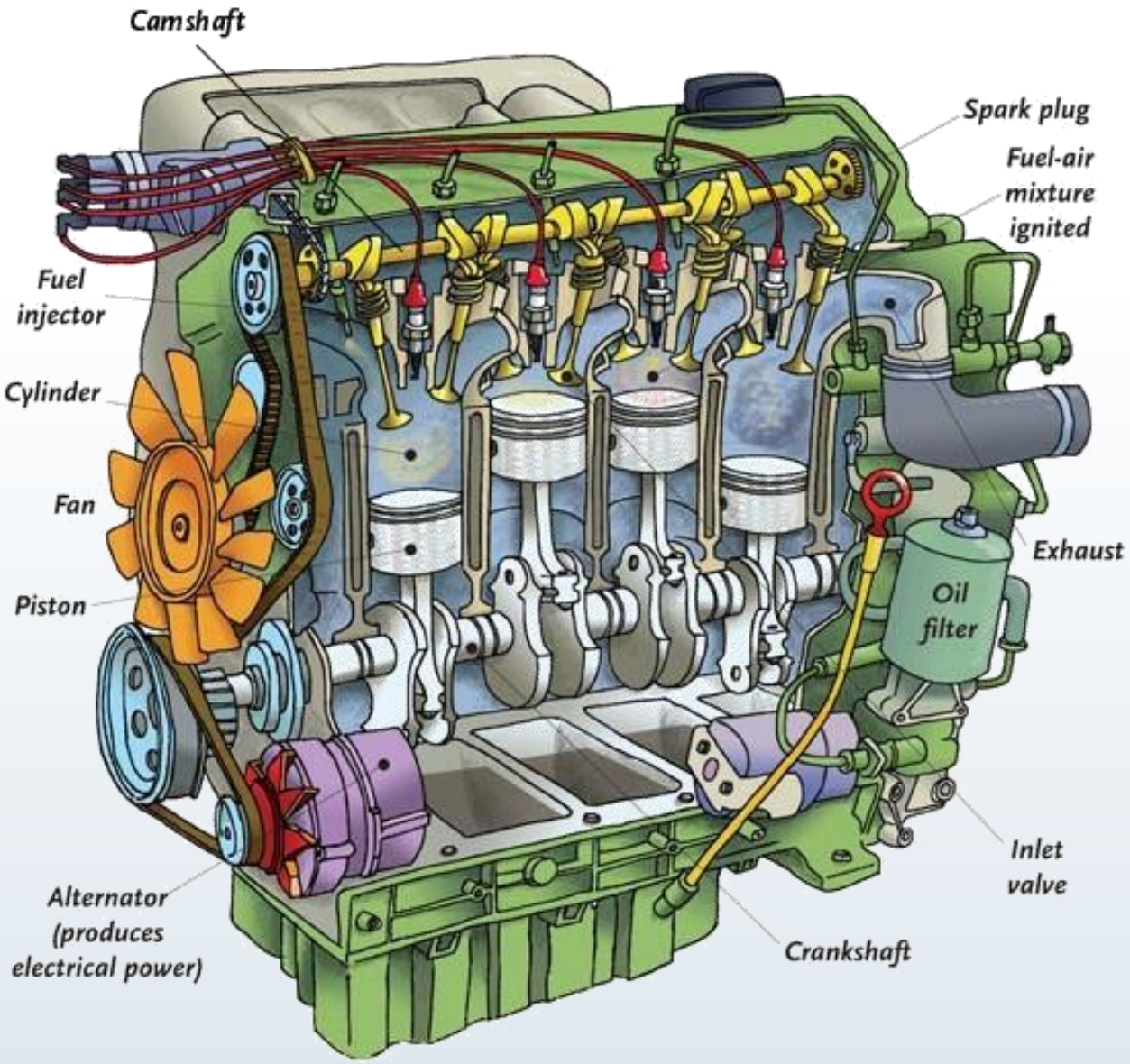


2. Internal combustion engines

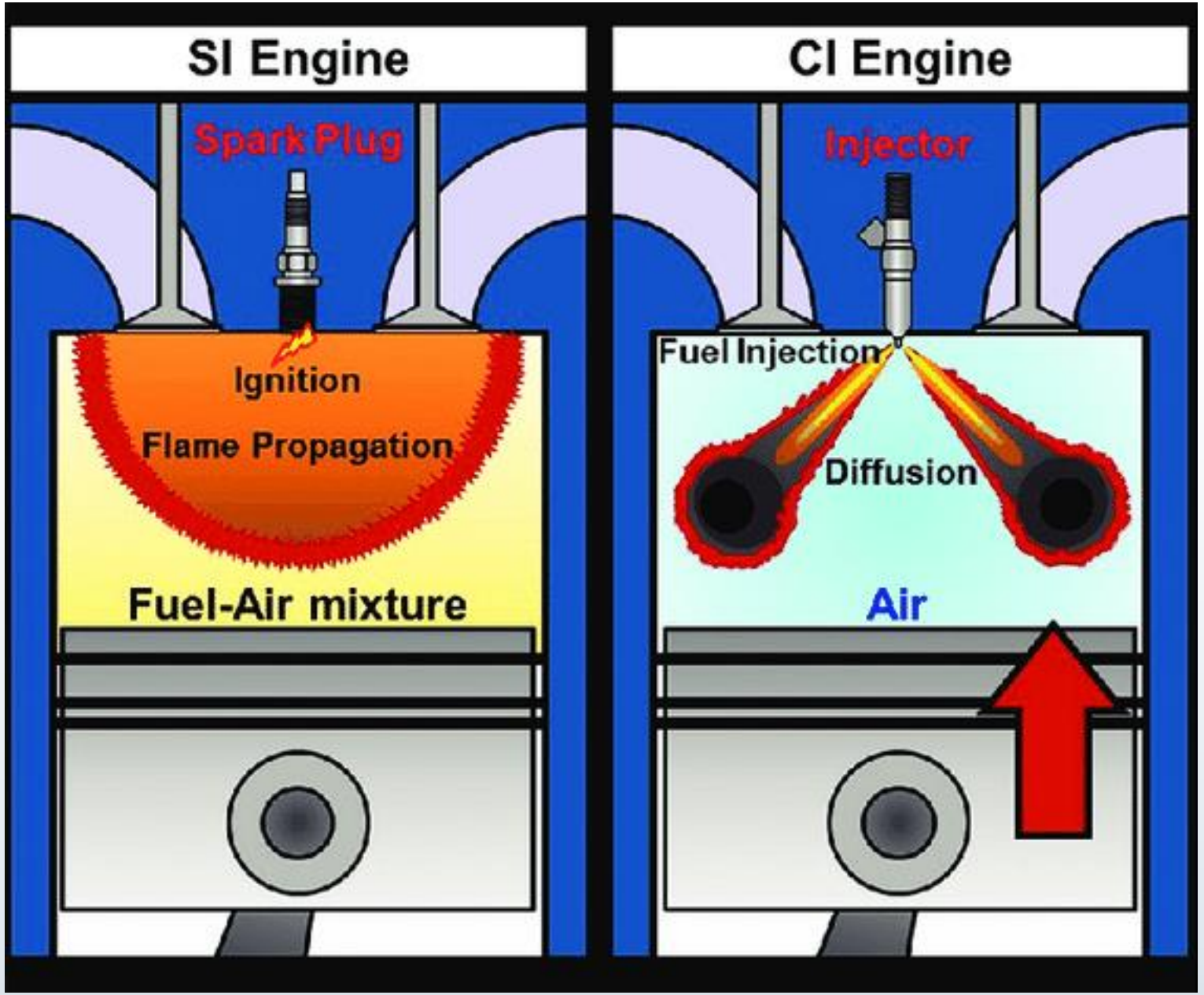
- Cars
- Trucks
- Locomotives
- Marine vessels
- Aircraft
- Stationary applications

2. Internal combustion engines

- Internal combustion engines (ICEs) are **not** a source of pollution
- Emission pollution from internal combustion engines comes from fuel combustion
- The application of low-carbon fuels in ICEs can help reduce greenhouse gas emissions
- Applying zero-carbon fuels in ICEs can help eliminate carbon-based emissions



2. Internal combustion engines



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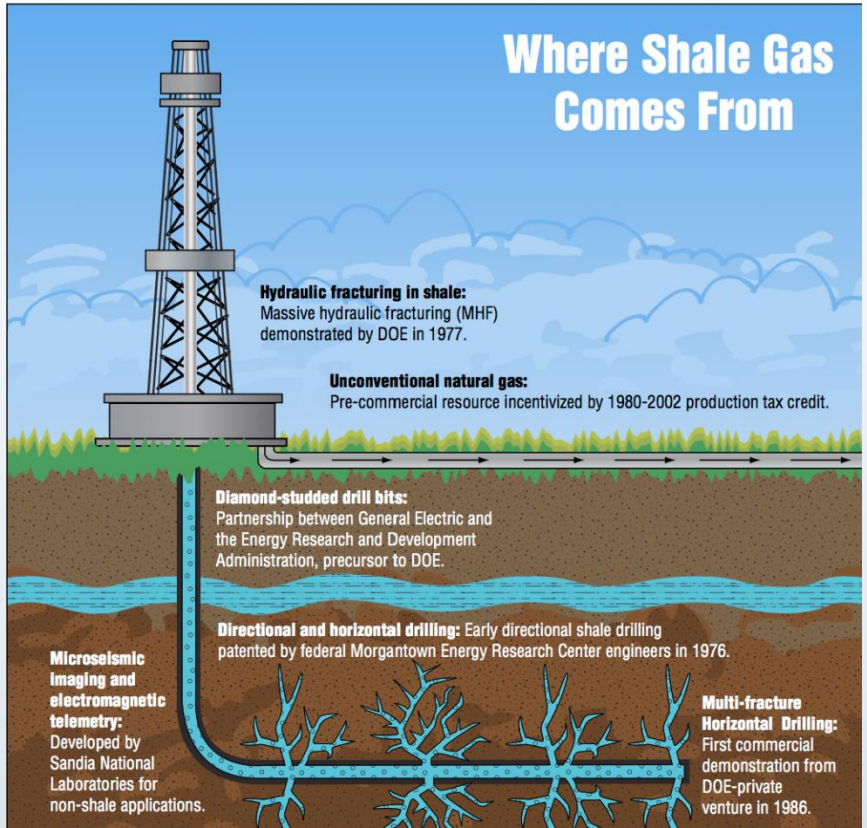
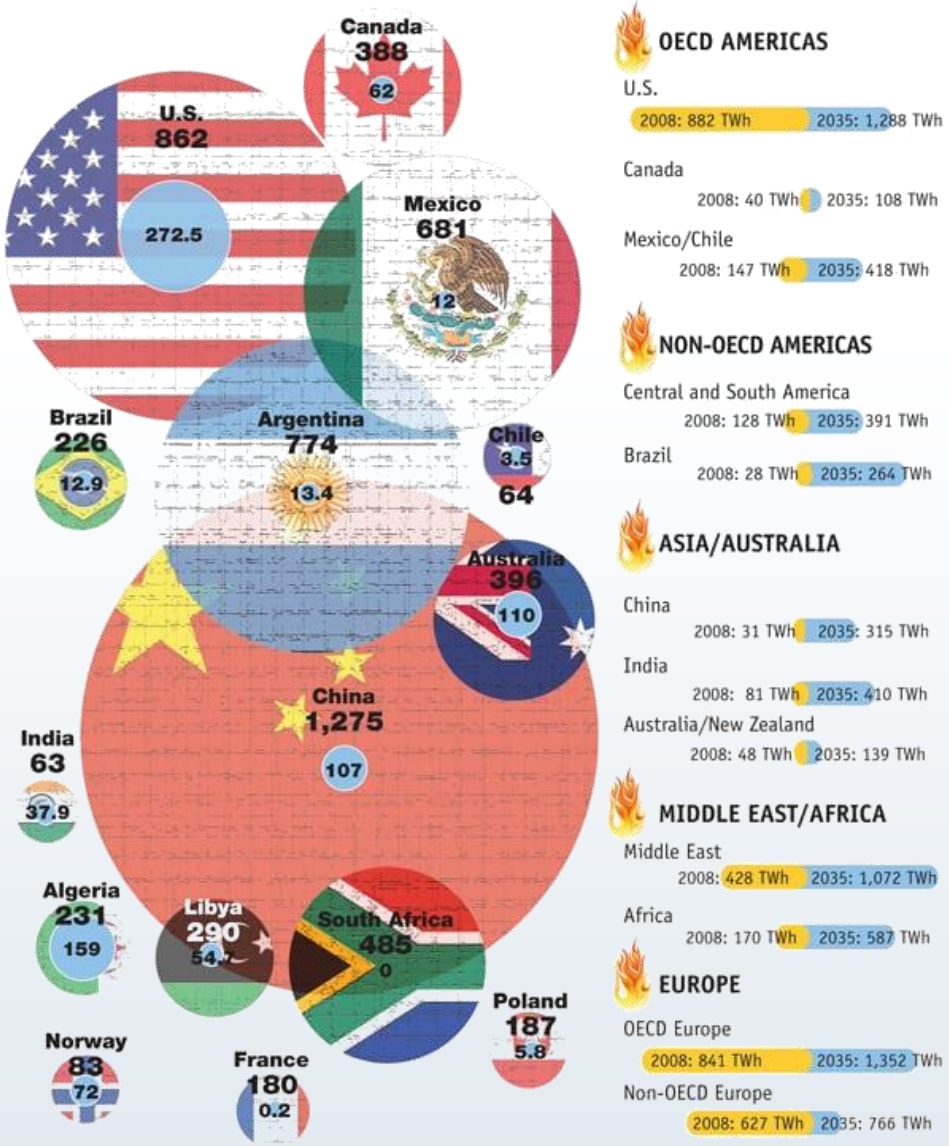
Natural gas (NG) fuel properties

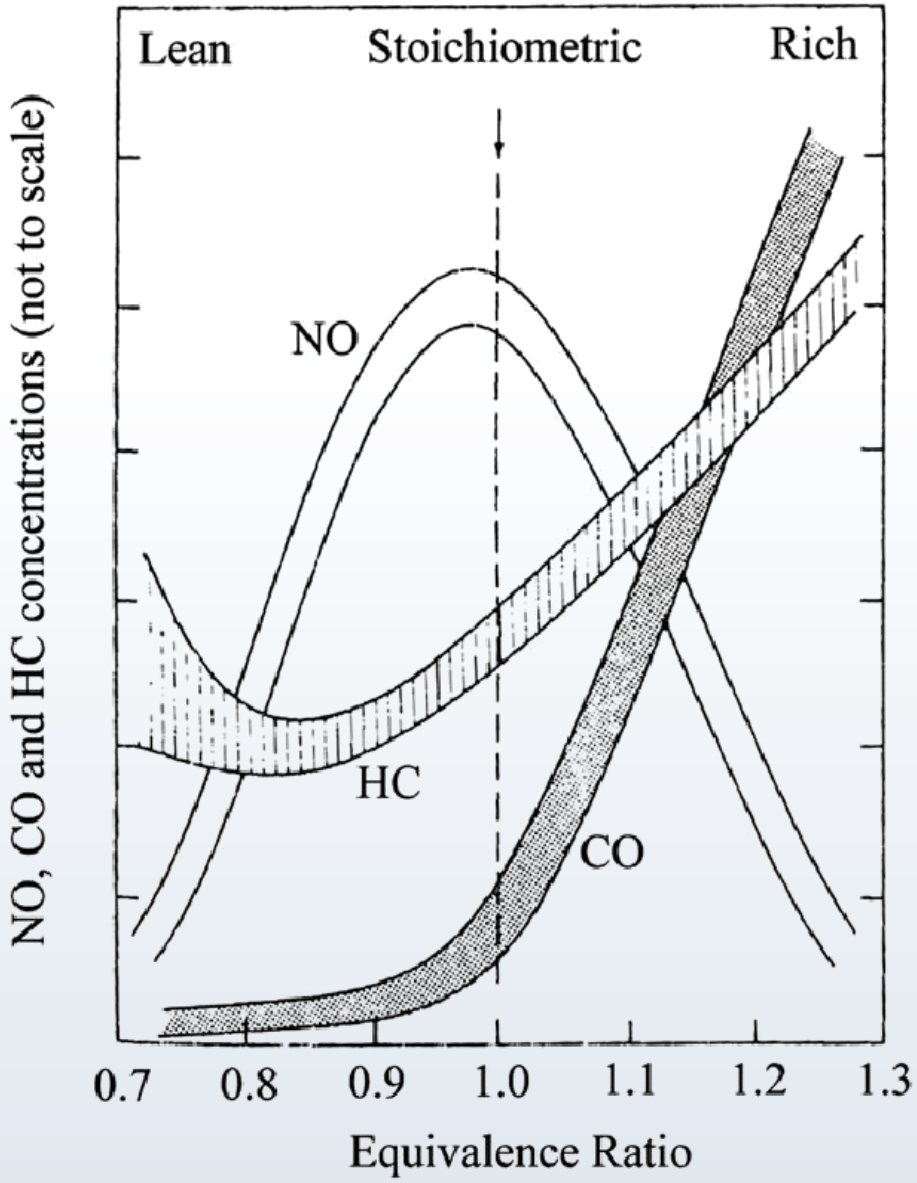
- The main component is CH_4
- A higher H/C ratio
- Abundant, low cost





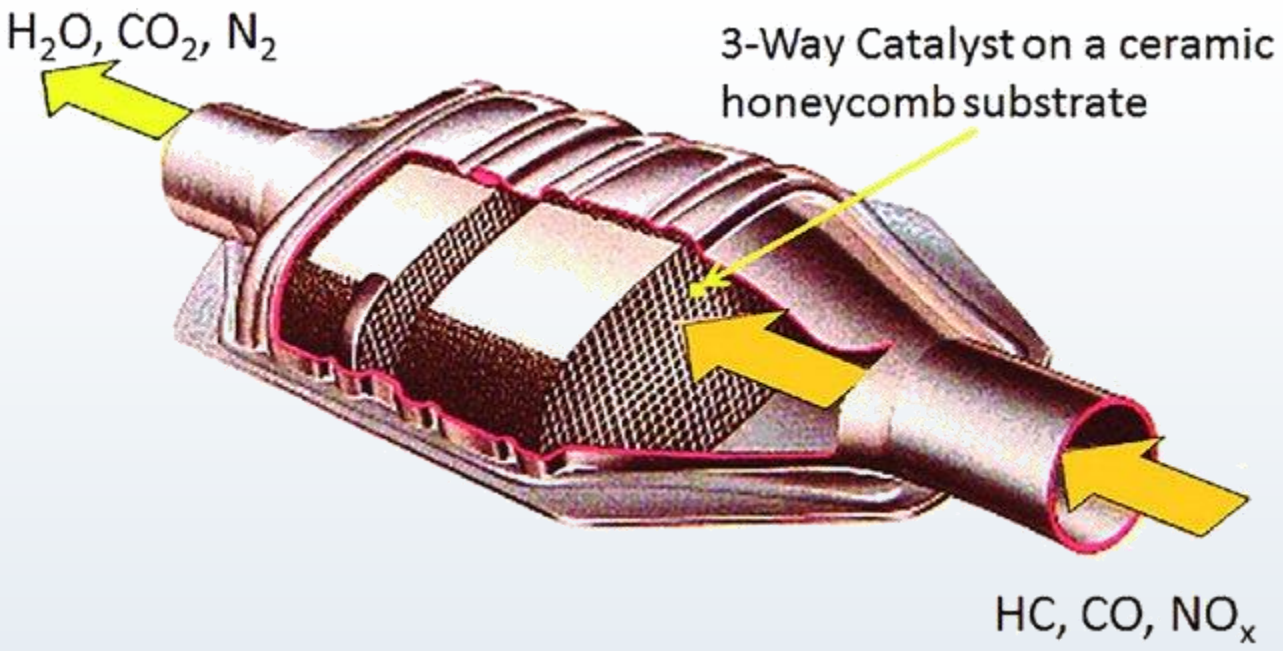
The benefits/challenges of natural gas (NG) engines

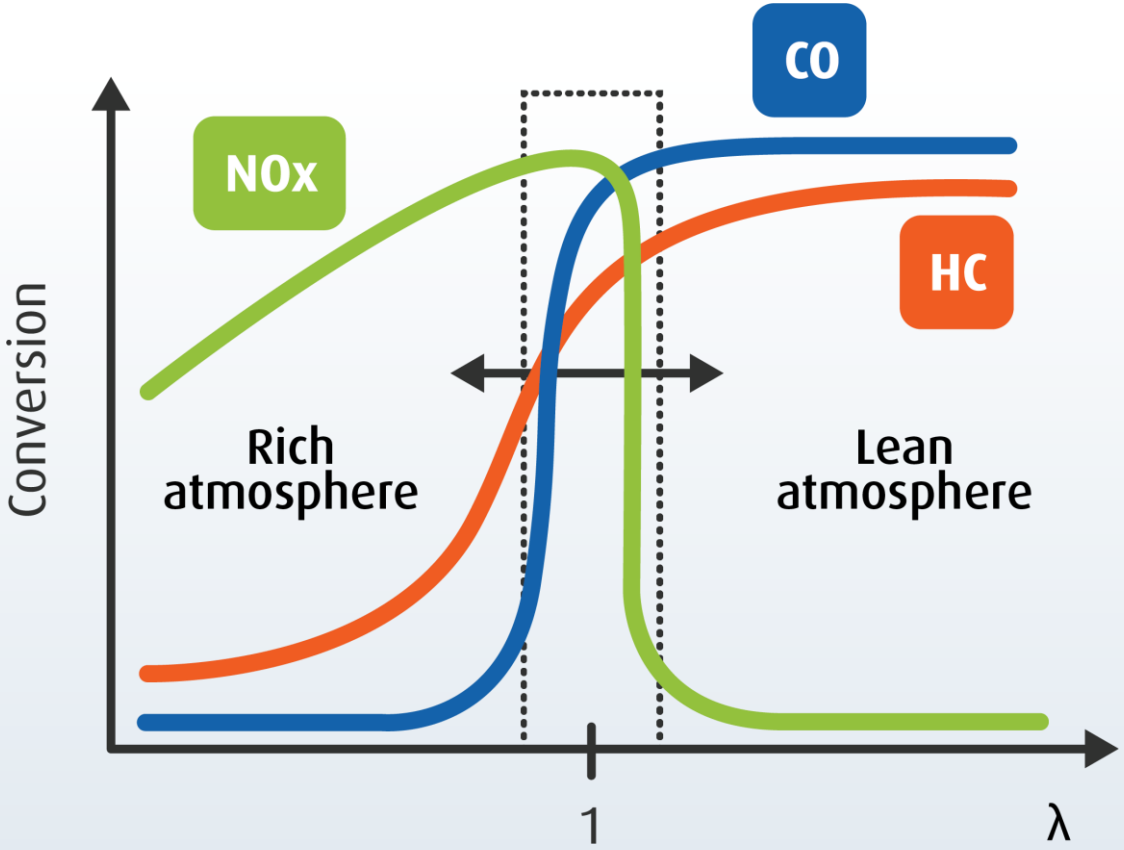
- Lower emissions (CO_2, soot, NOx, CO, UHC)
- Higher compression ratio and lean-burn limit can increase thermal efficiency
- NG composition varies with geographical source, time of year, and treatments applied during production and/or transportation
- The non-methane compounds in the NG can have a strong influence on the engine efficiency and emissions



Natural gas (NG) spark ignition (SI) engines

- Lean or stoichiometric operation?





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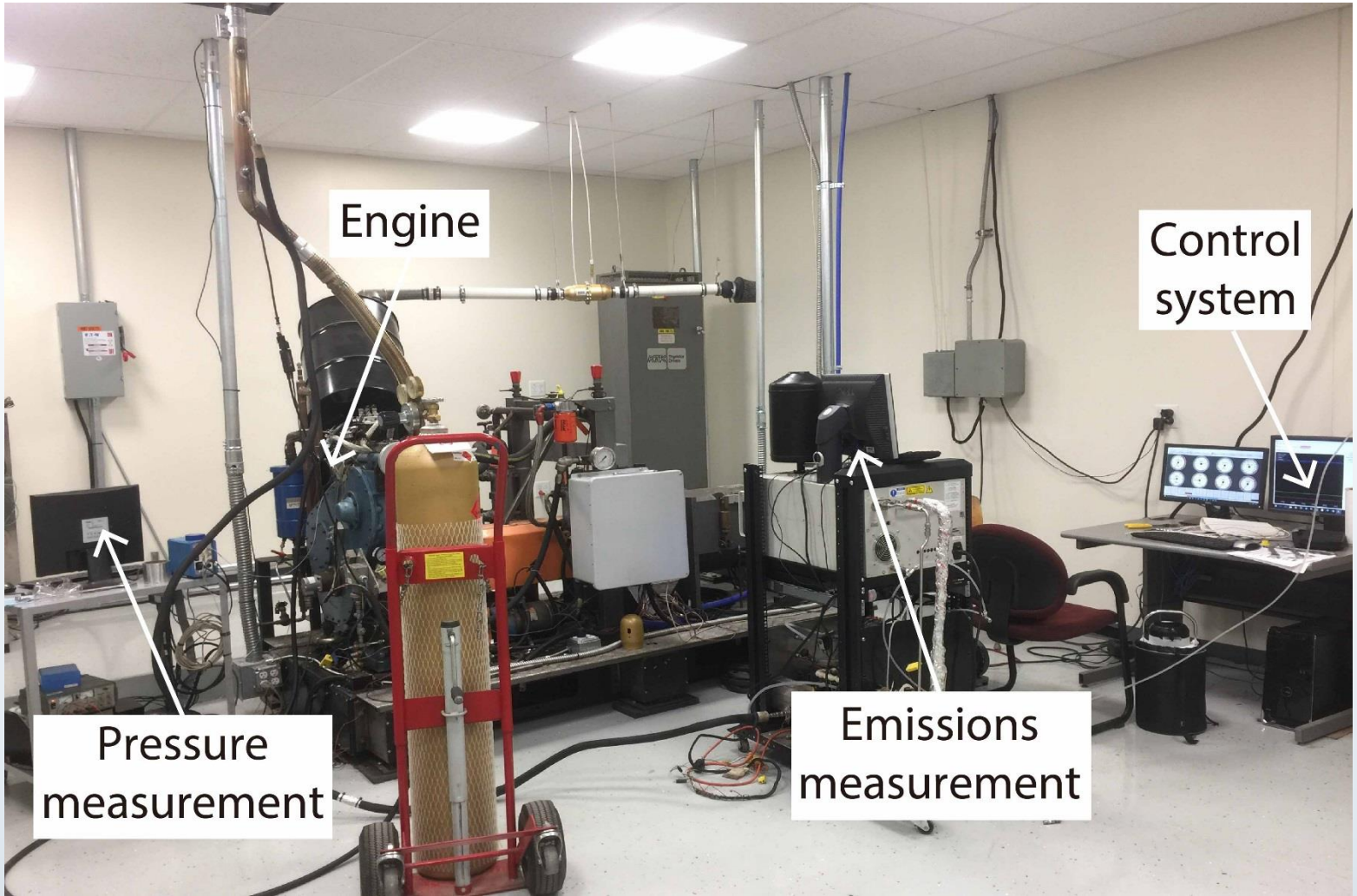

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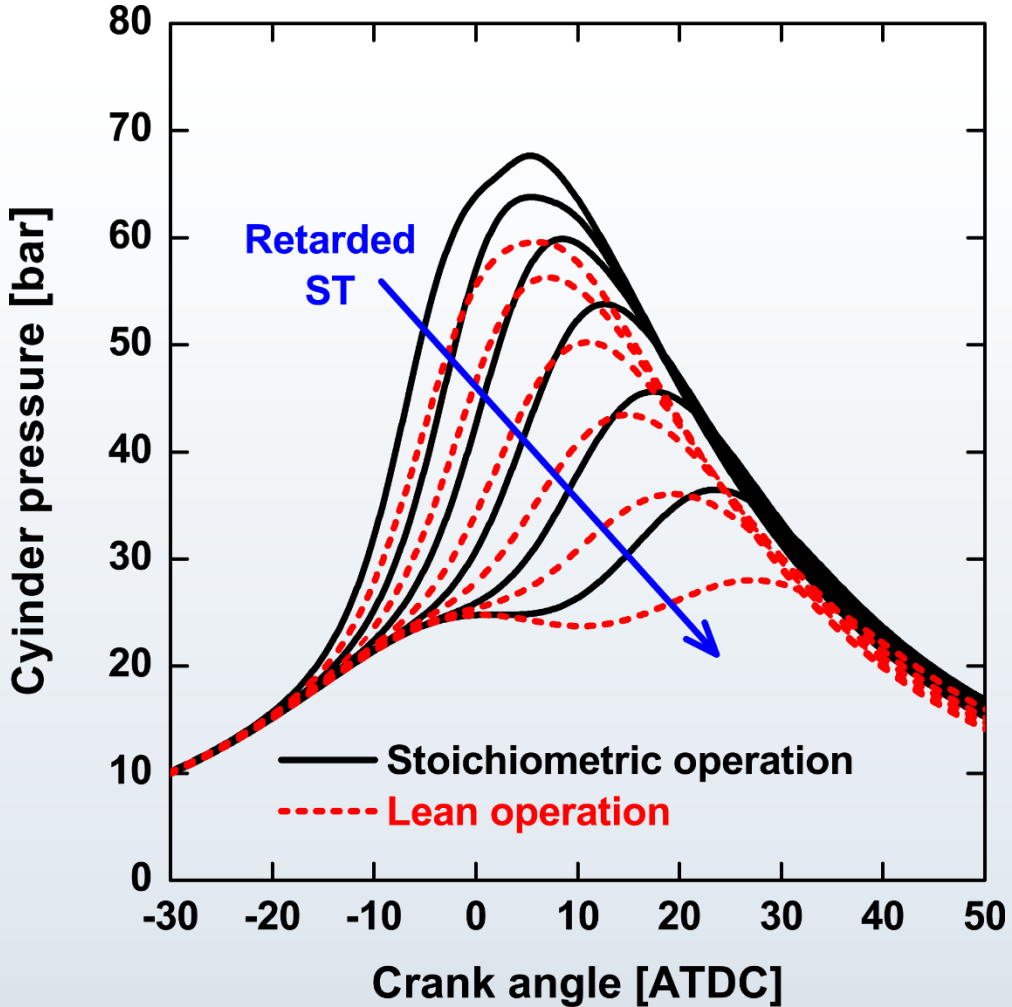

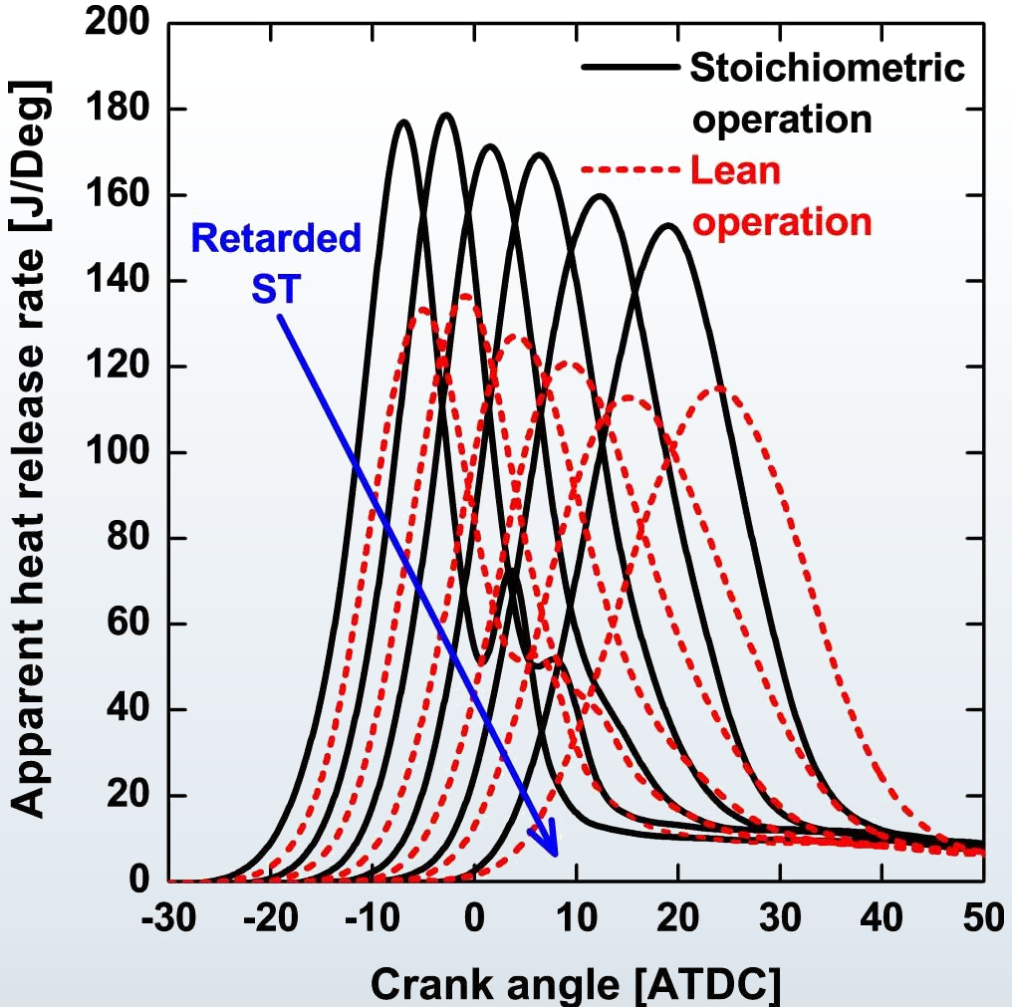

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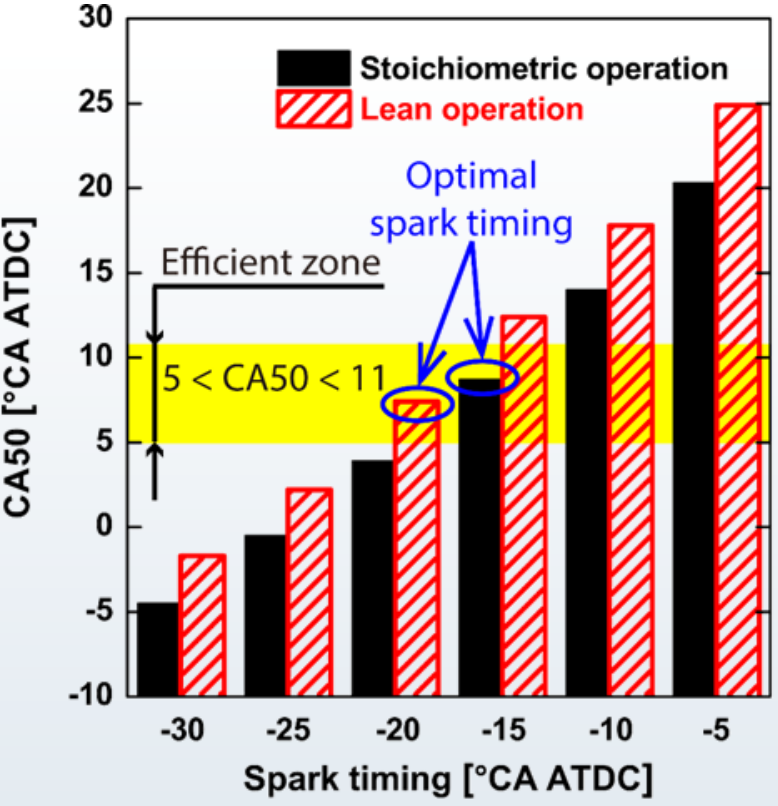

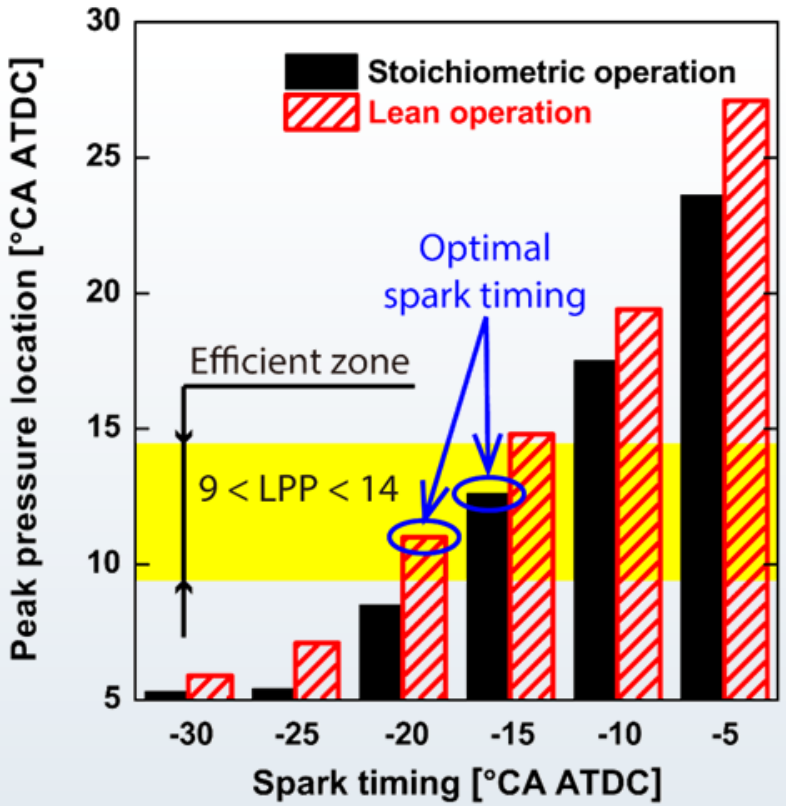

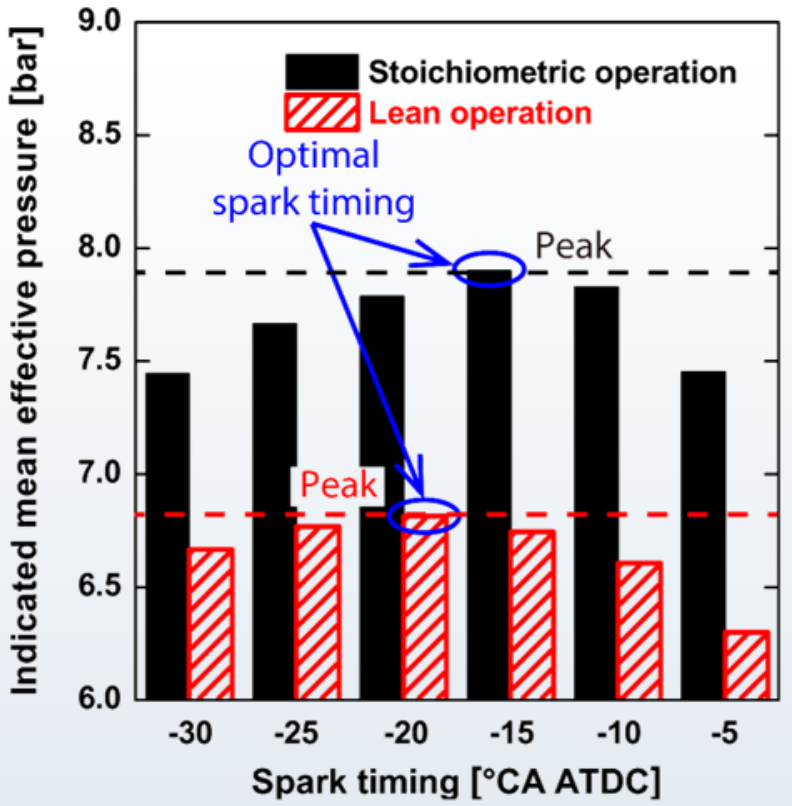

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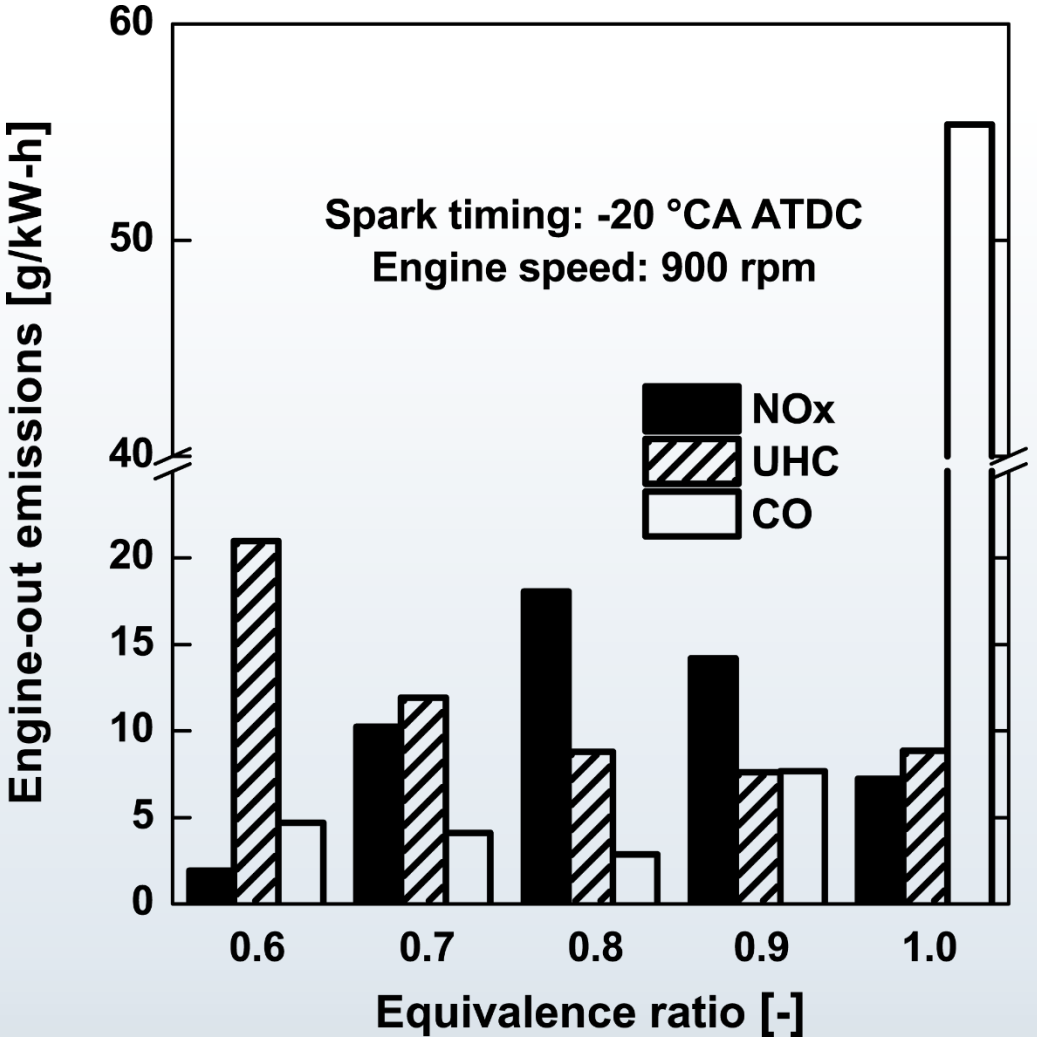

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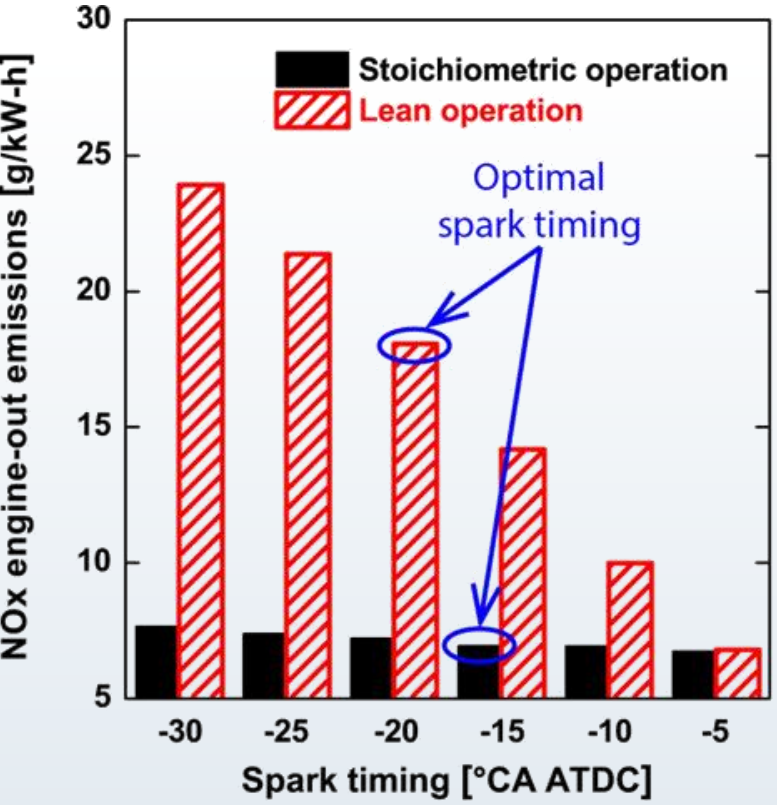

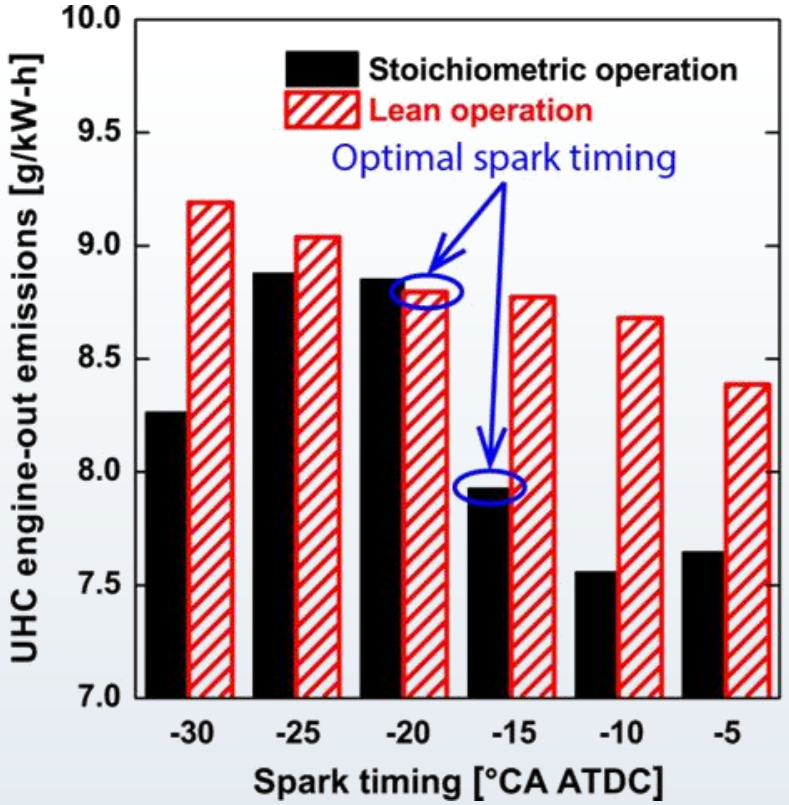

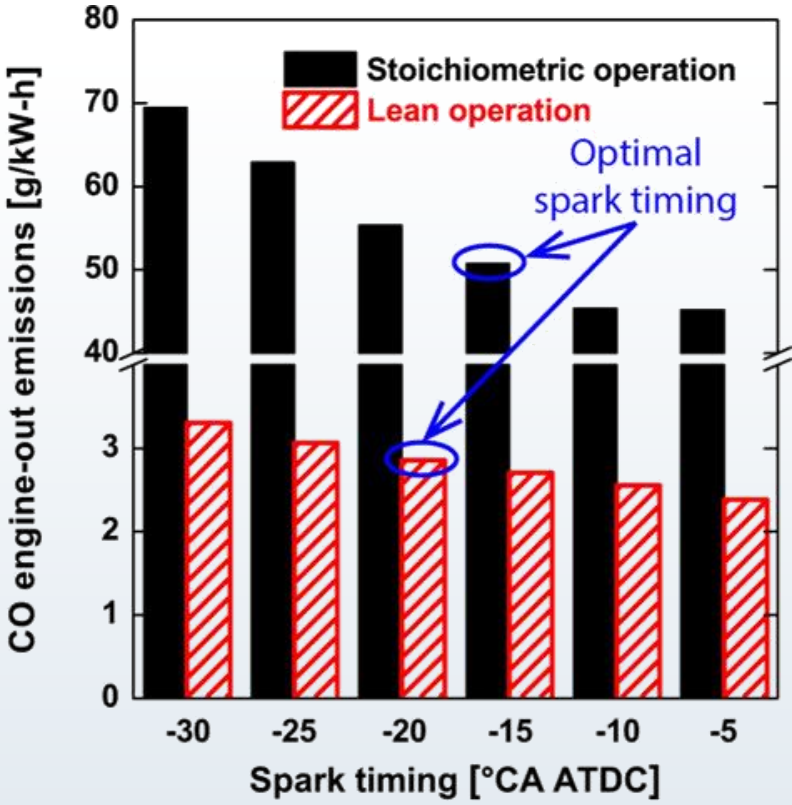

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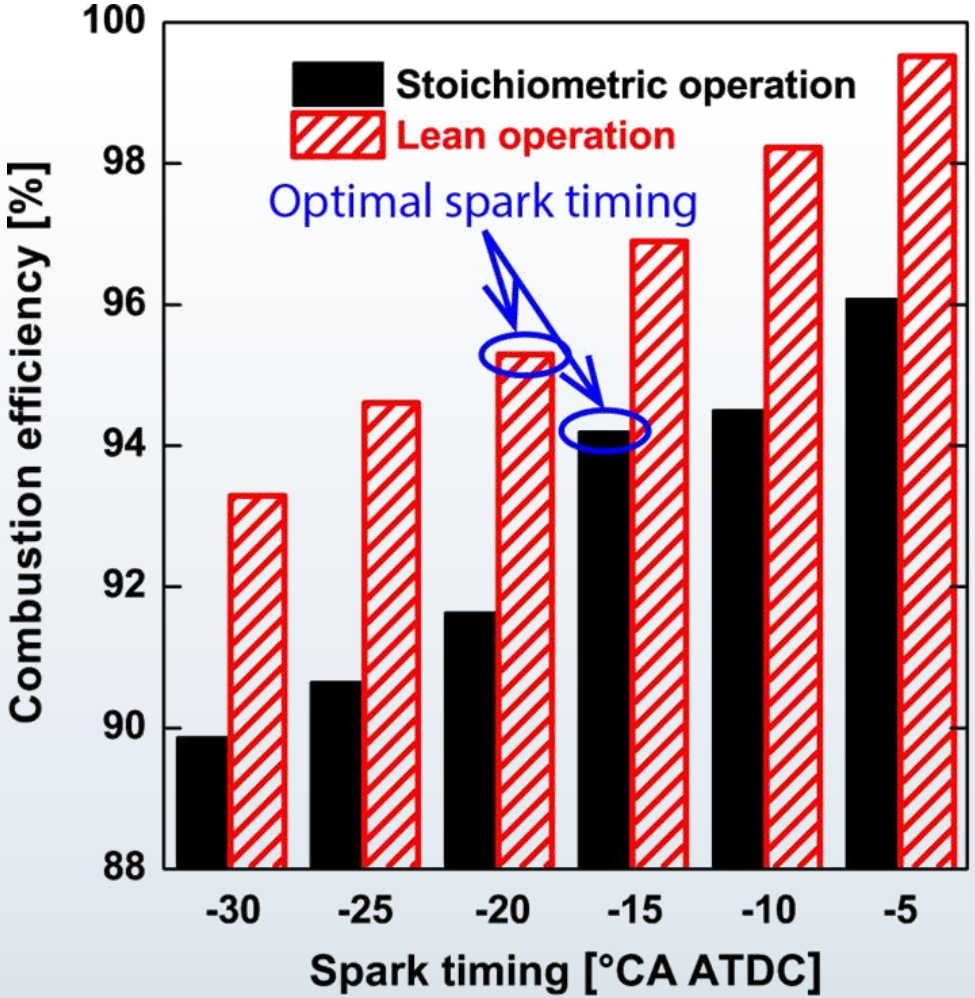
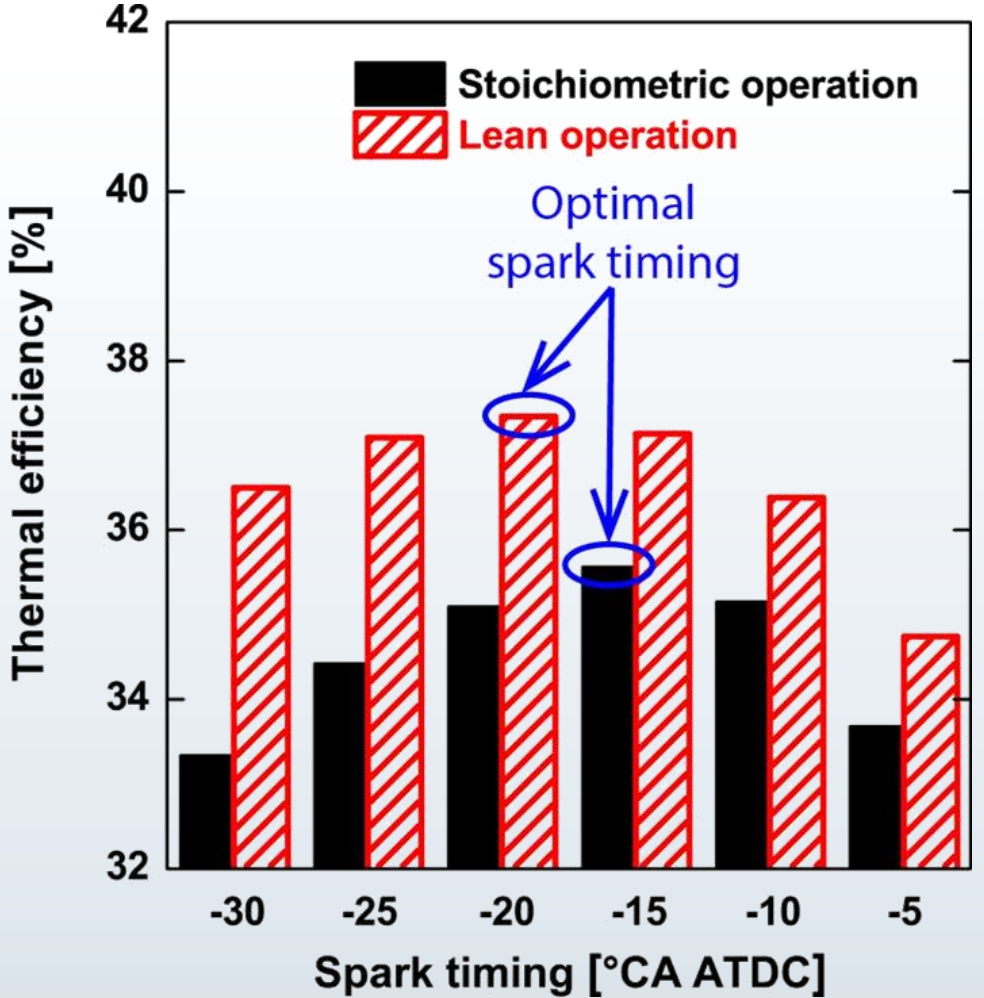
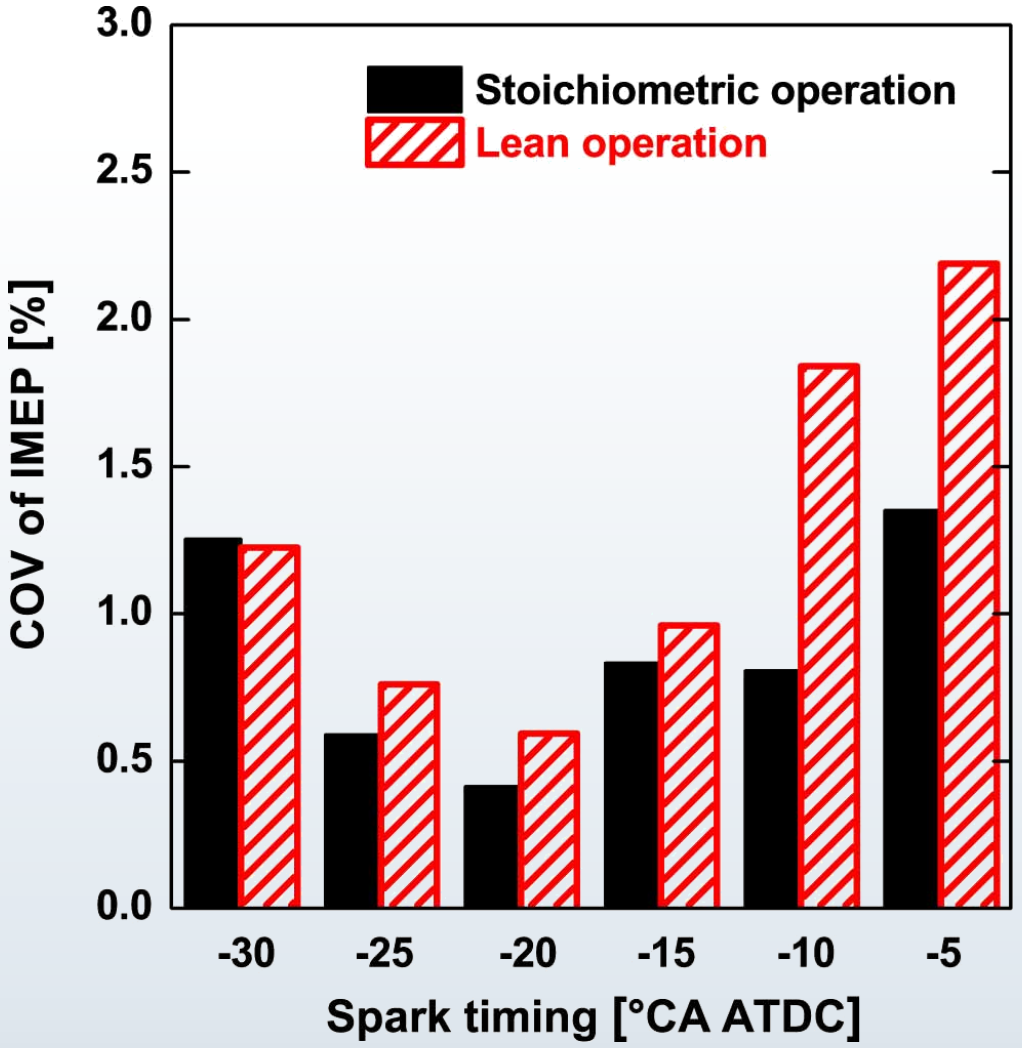




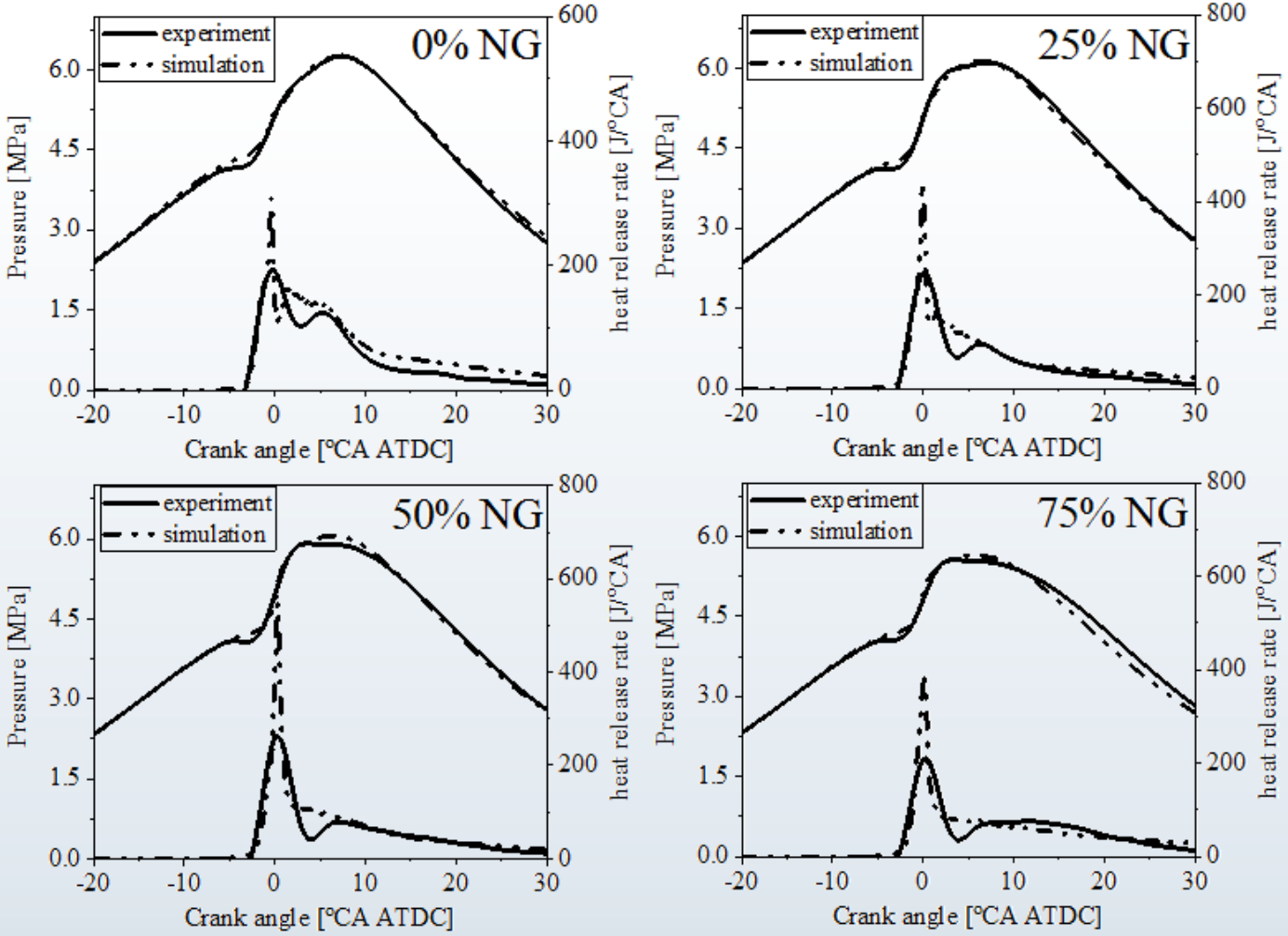
Natural gas (NG) spark ignition (SI) engines

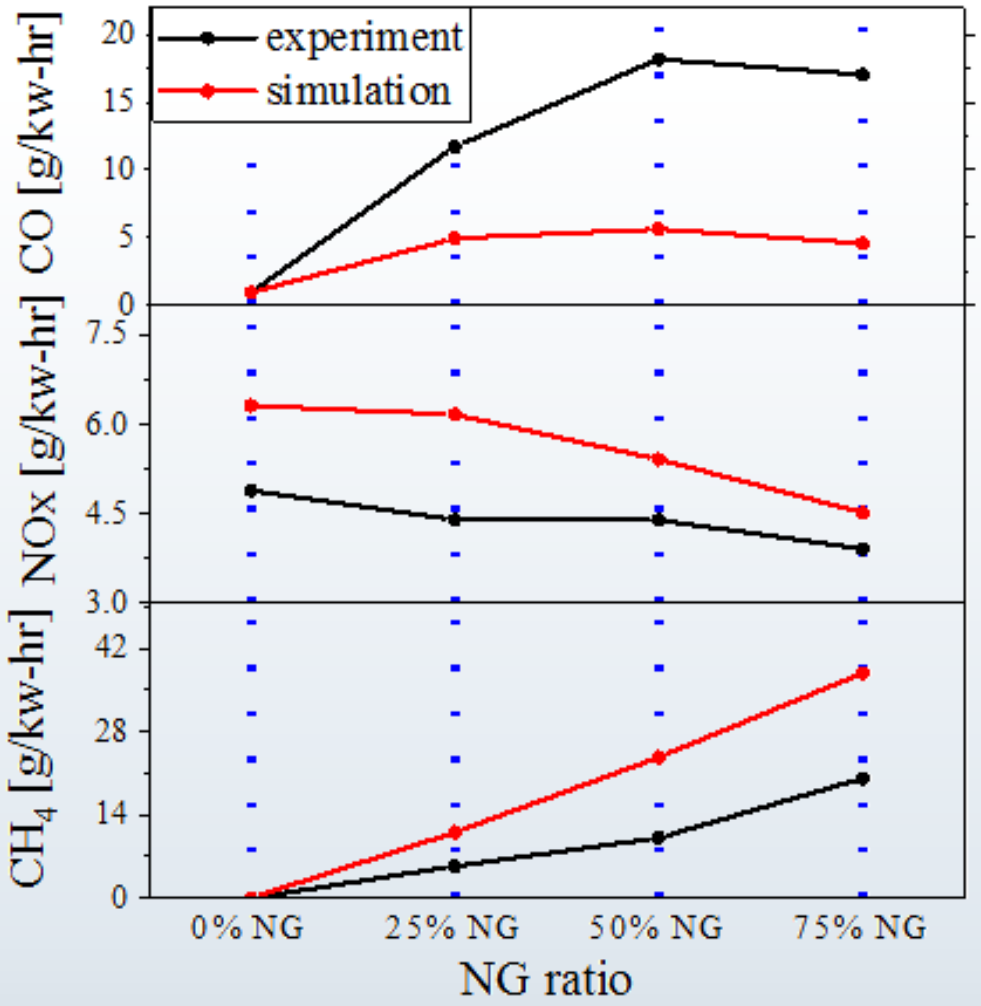
- Lean or stoichiometric operation?
  - ✓ Lean: Stationary applications
  - ✓ Stoichiometric: On-road vehicles



Pilot diesel ignition natural gas (NG) engines

- Natural gas/diesel fuel proportions?





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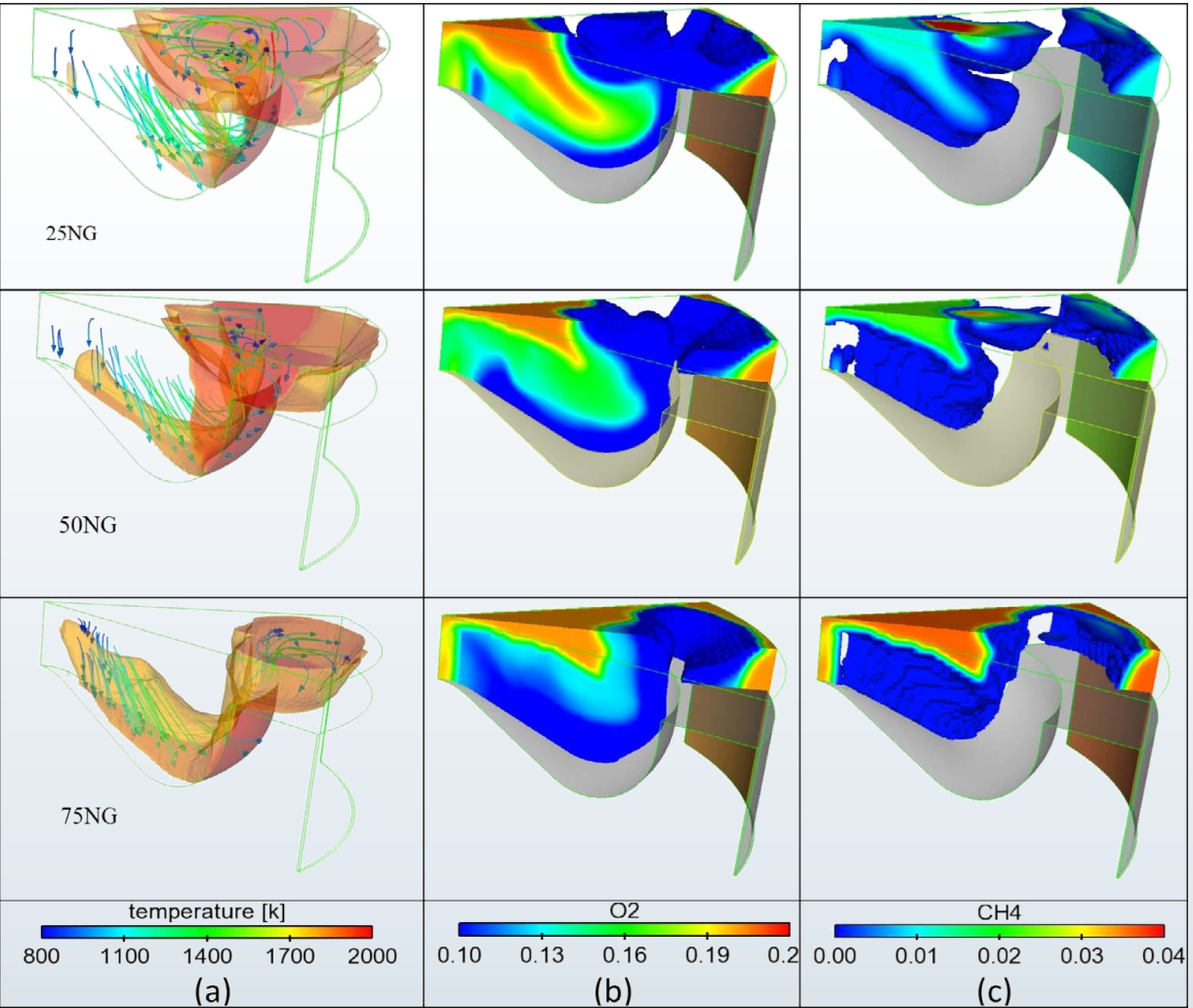
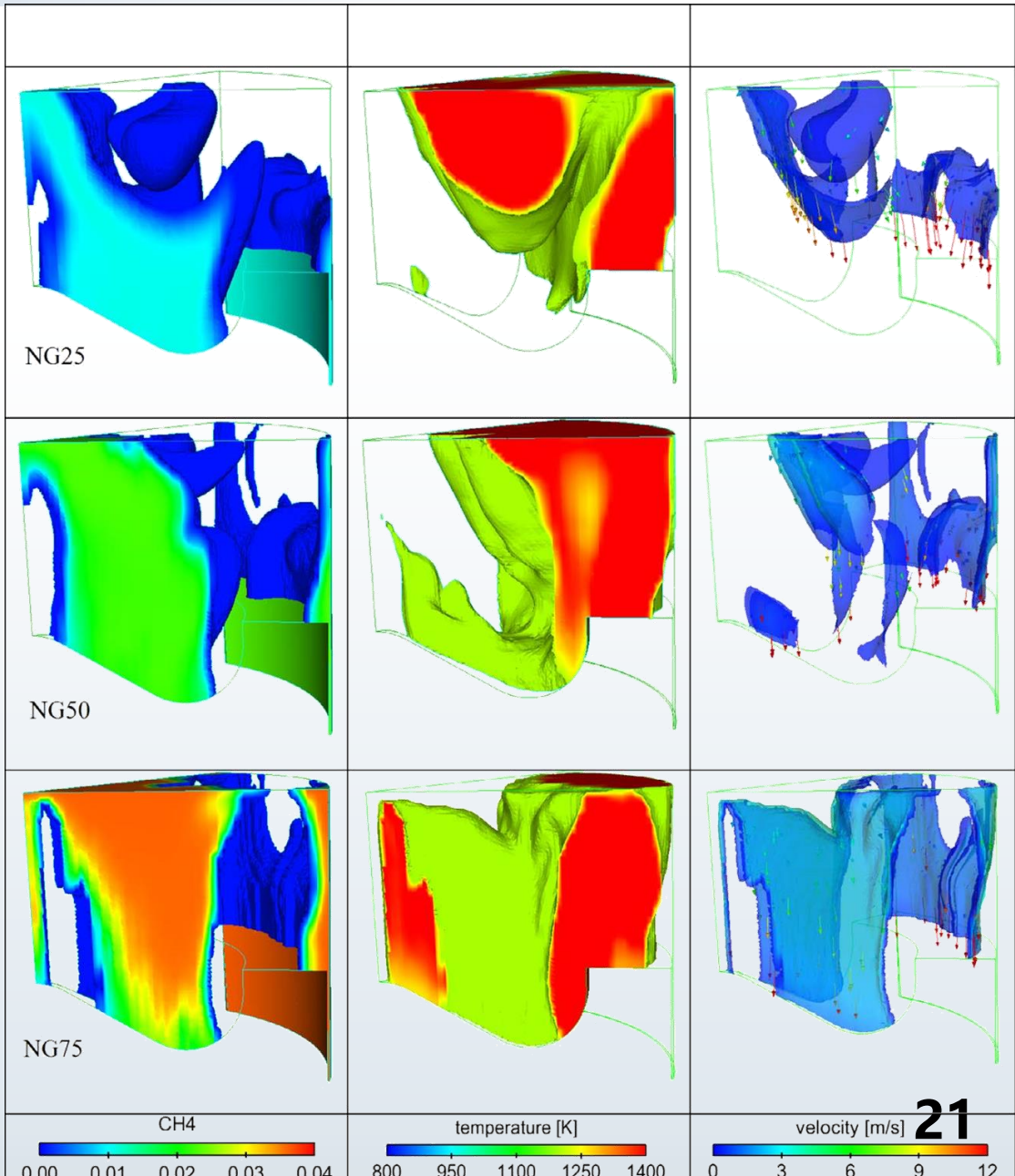
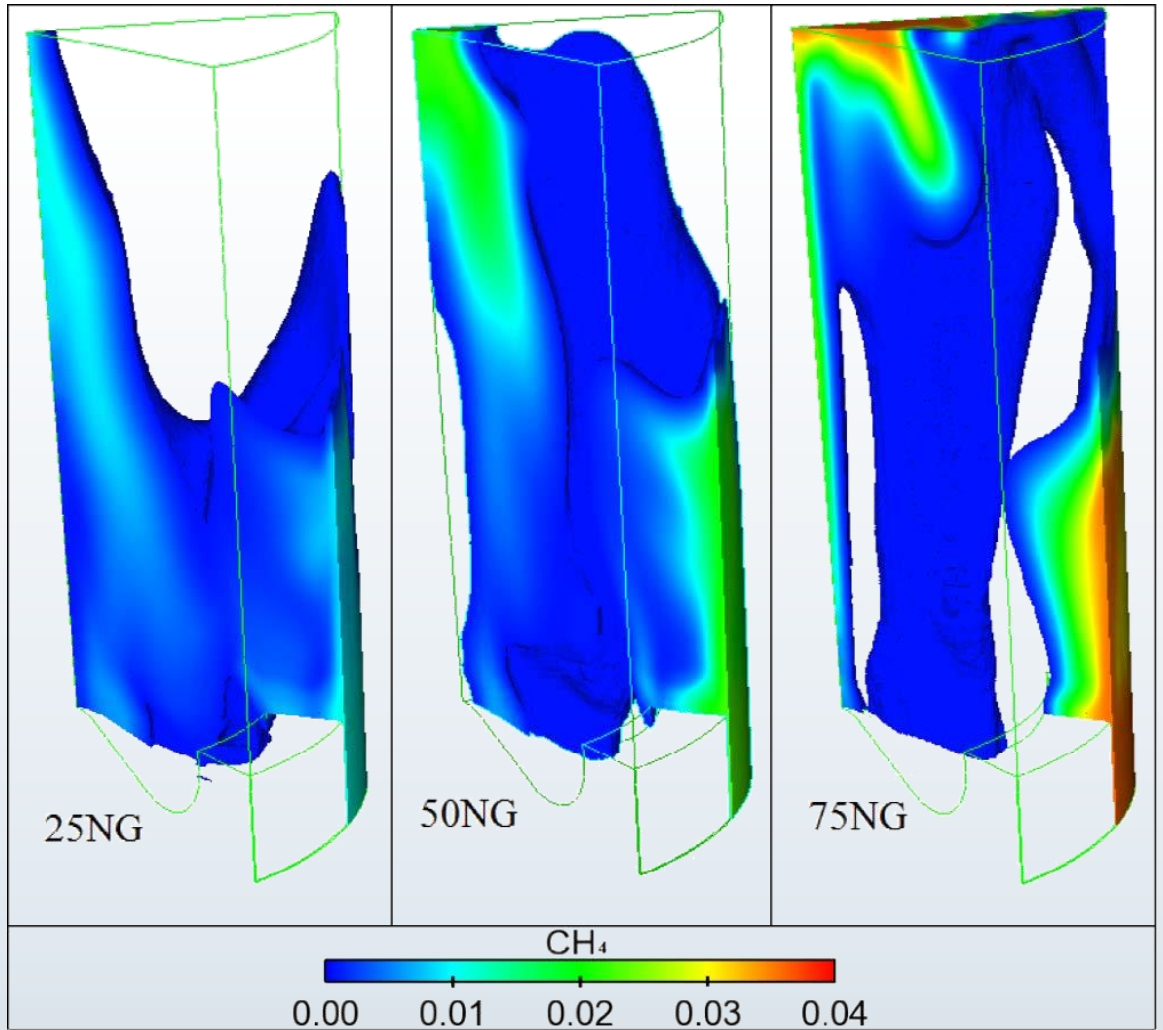




Pilot diesel ignition natural gas (NG) engines

- Natural gas/diesel fuel proportions?
  - ✓ Methane slip
  - ✓ Low load low speed conditions



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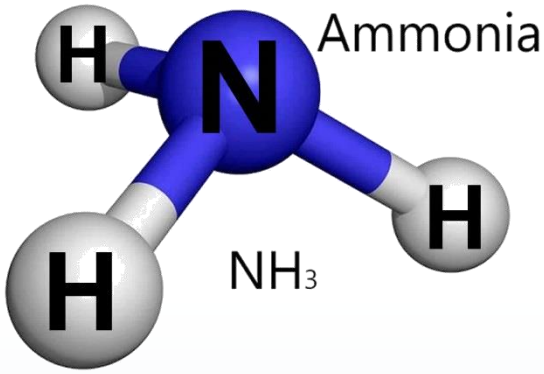
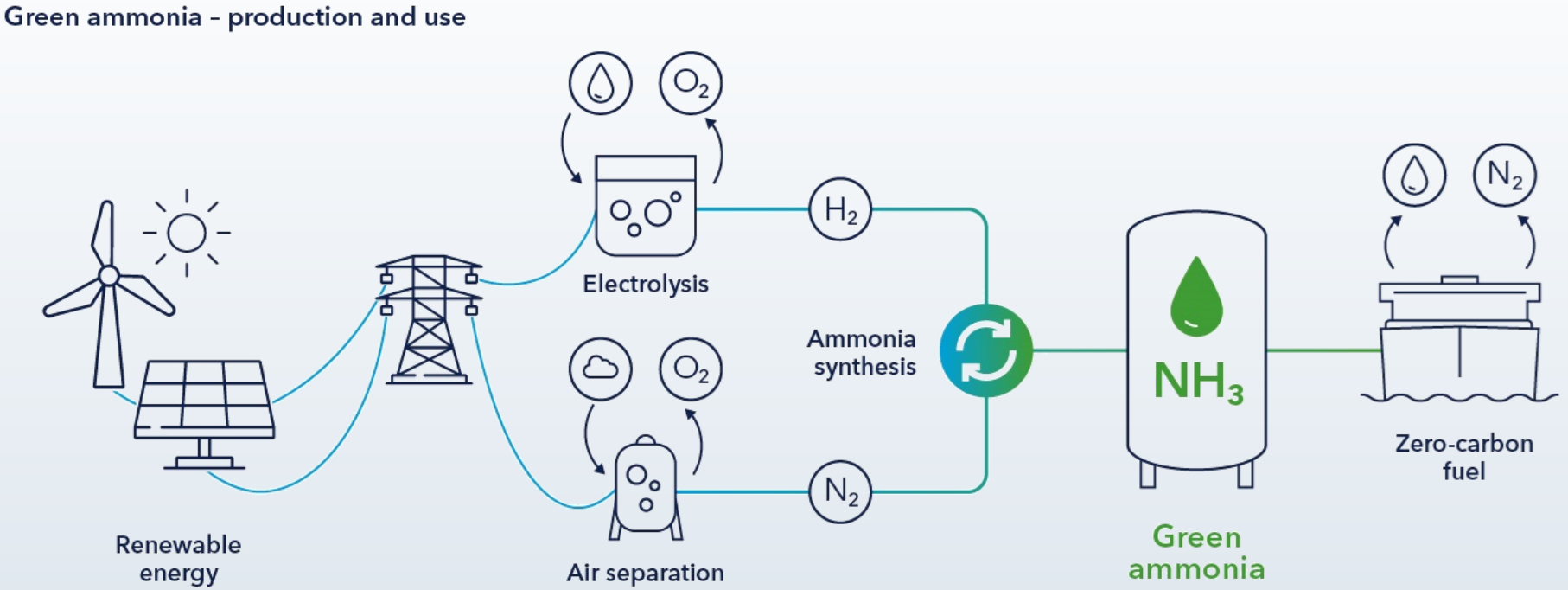
Ammonia fuel properties

- Easy to store and transport
- Mature production facilities
- Unfavorable combustion properties





The benefits/challenges of ammonia engines

- Lower carbon-based emissions
- Slow laminar flame speed – reduced efficiency, high cycle-to-cycle variations
- Higher ignition energy
- Fuel NOx

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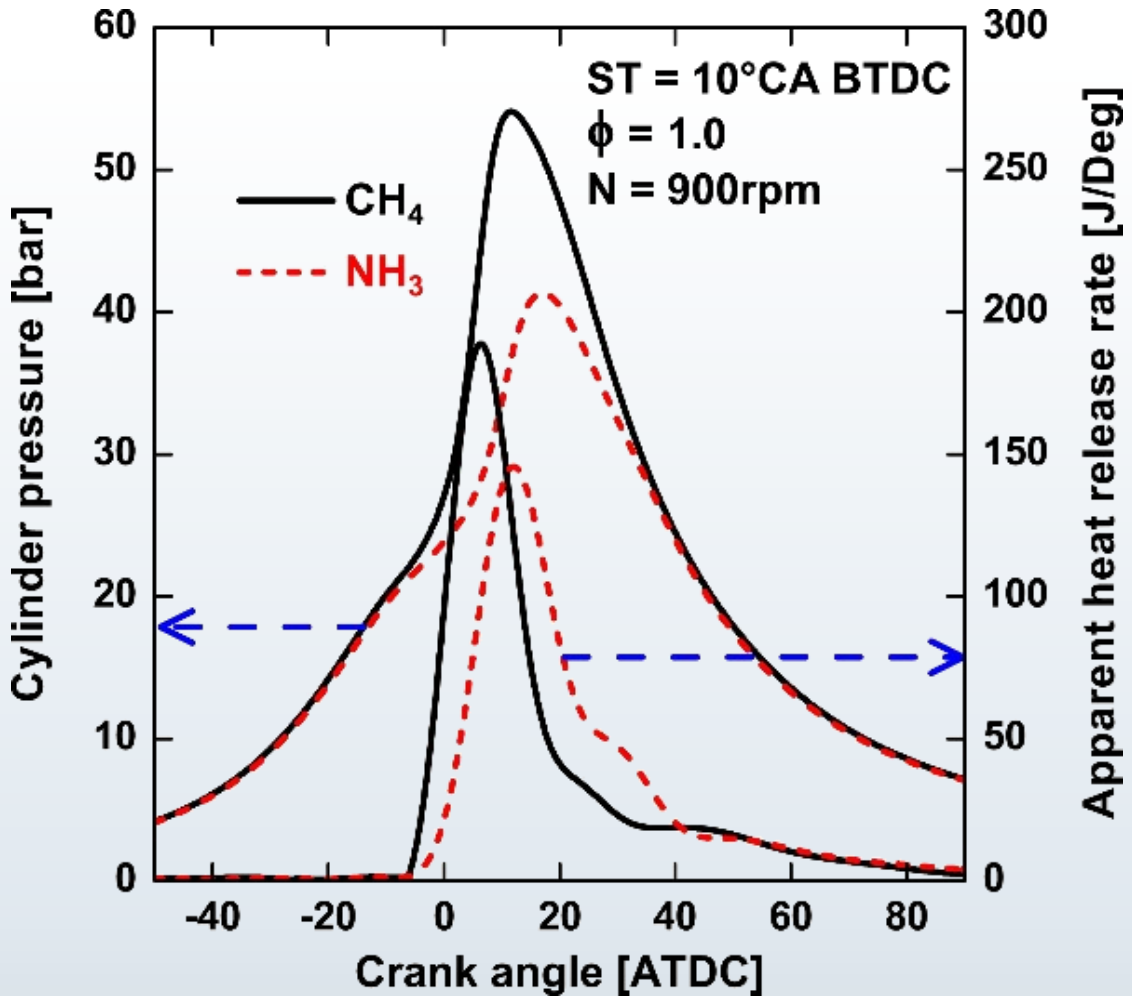
Ammonia spark ignition (SI) engines

- Hydrogen addition?



Performance	CH_4	NH_3
Ignition lag [°CA]	12.0	16.0
DOC [°CA]	60.6	62.8
IMEP [bar]	9.28	8.46
ISFC [g/kW·h]	188.6	505.5
η_{th} [%]	37.9	37.1
η_{comb} [%]	98.3	95.0
ISNO [g/kW·h]	7.86	4.07
$ISNO_2$ [g/kW·h]	0.0014	0.0013
ISN_2O [g/kW·h]	/	0.03
$ISNO_X$ [g/kW·h]	7.86	4.10
ISCO [g/kW·h]	5.80	/
$ISCH_4$ [g/kW·h]	0.70	/
$ISNH_3$ [g/kW·h]	/	11.62
ISH_2 [g/kW·h]	0.26	0.35

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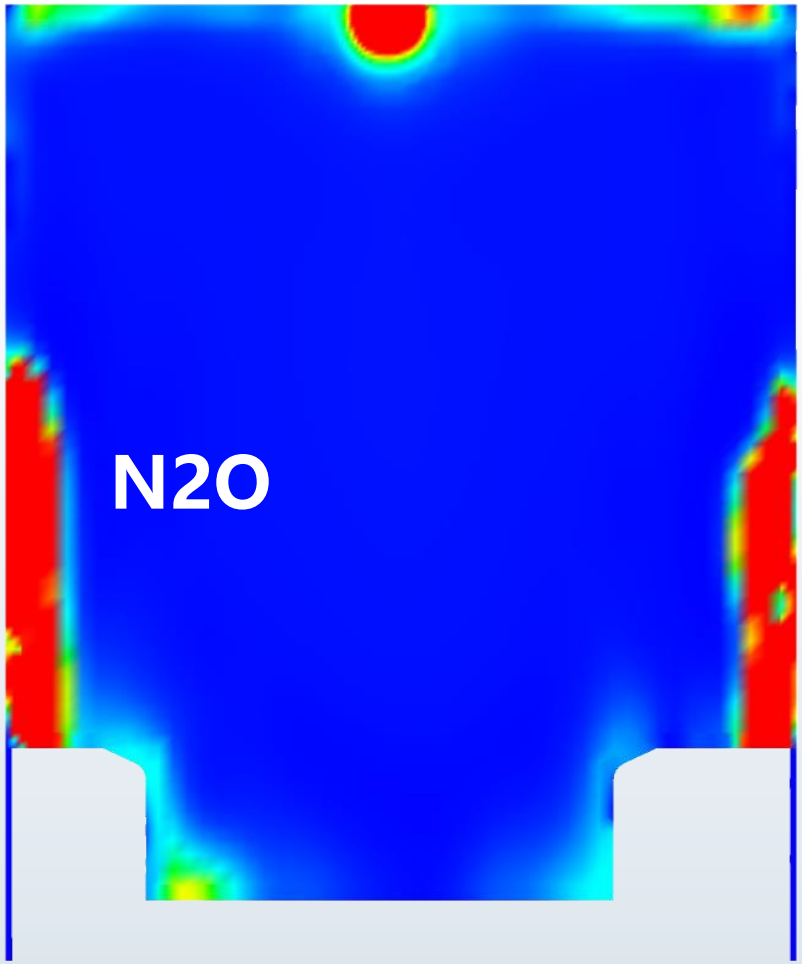

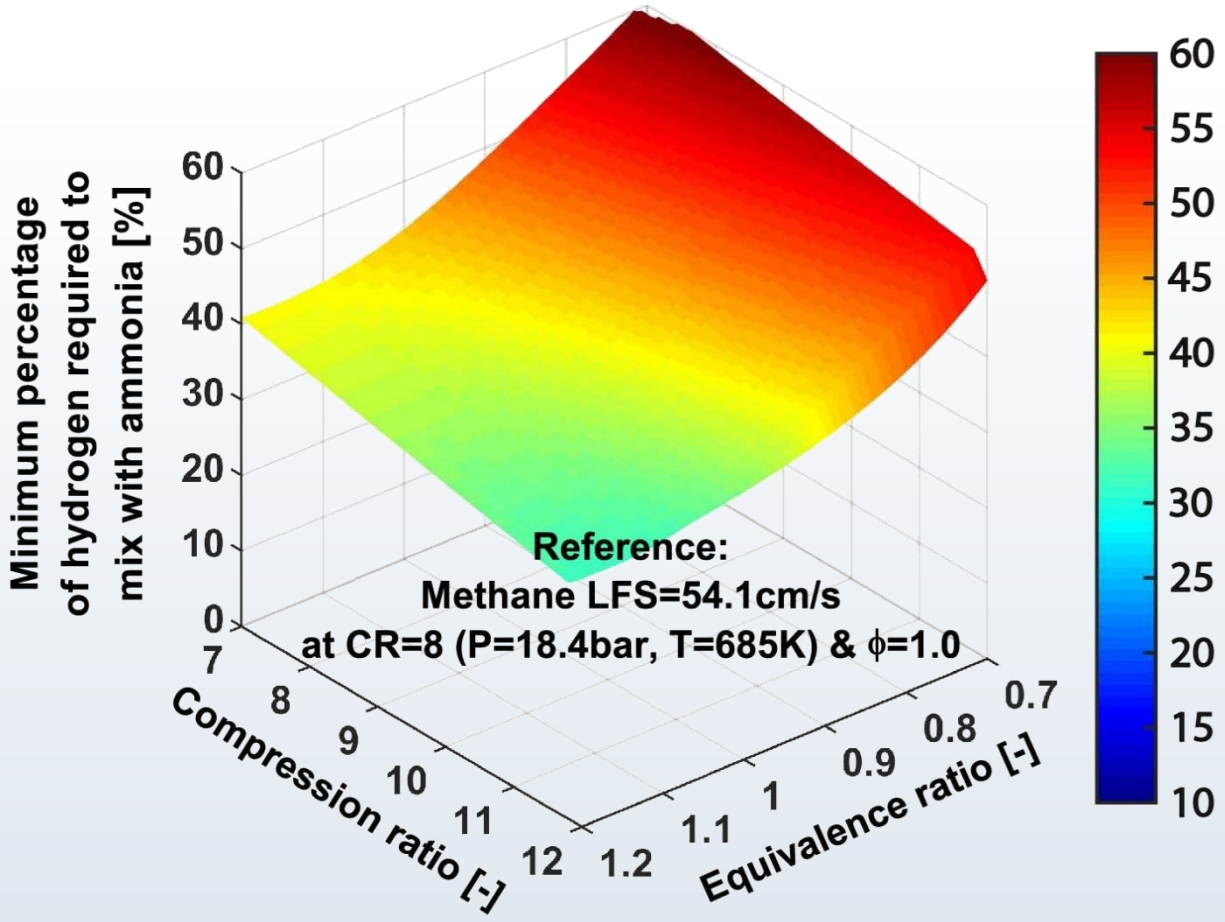

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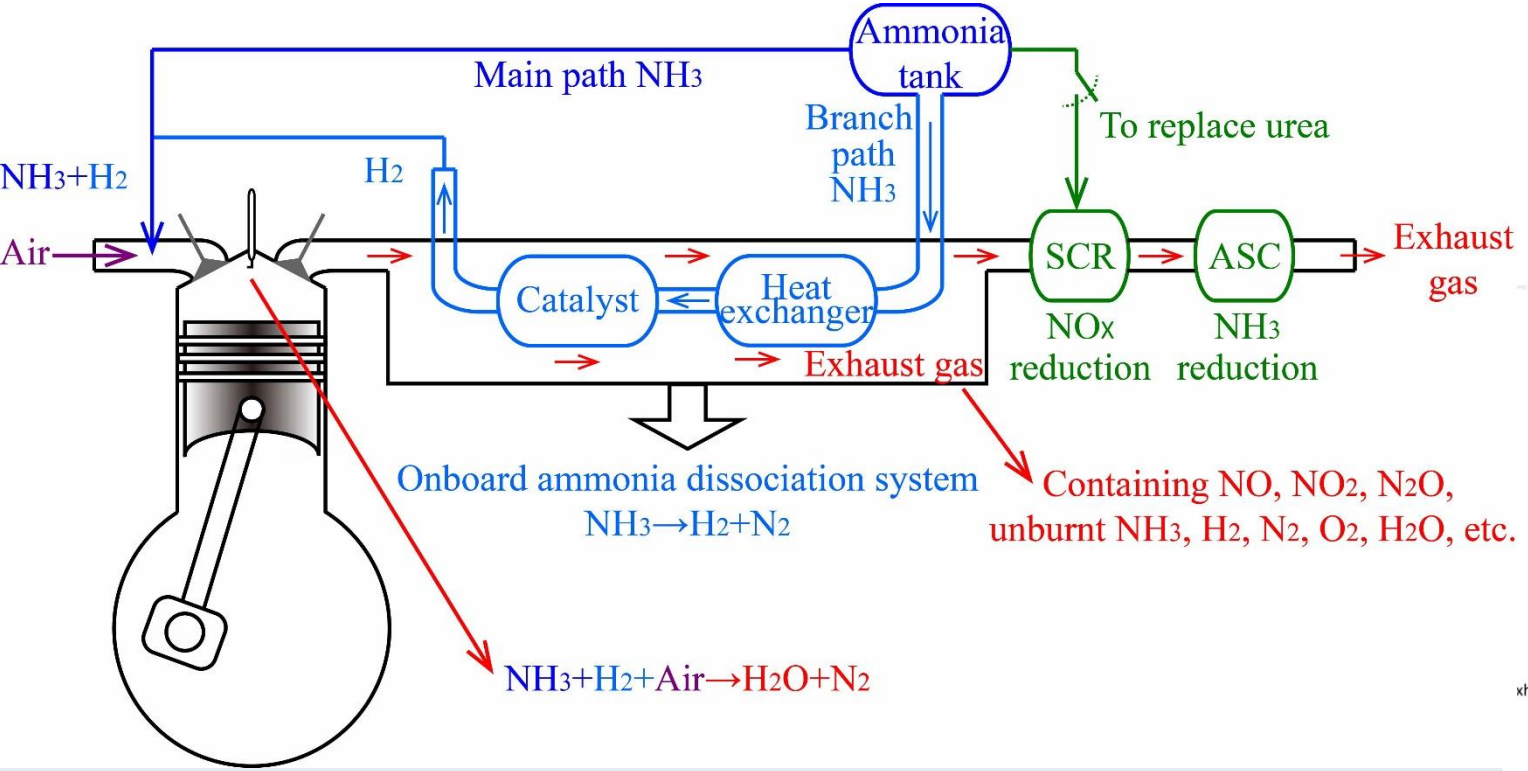
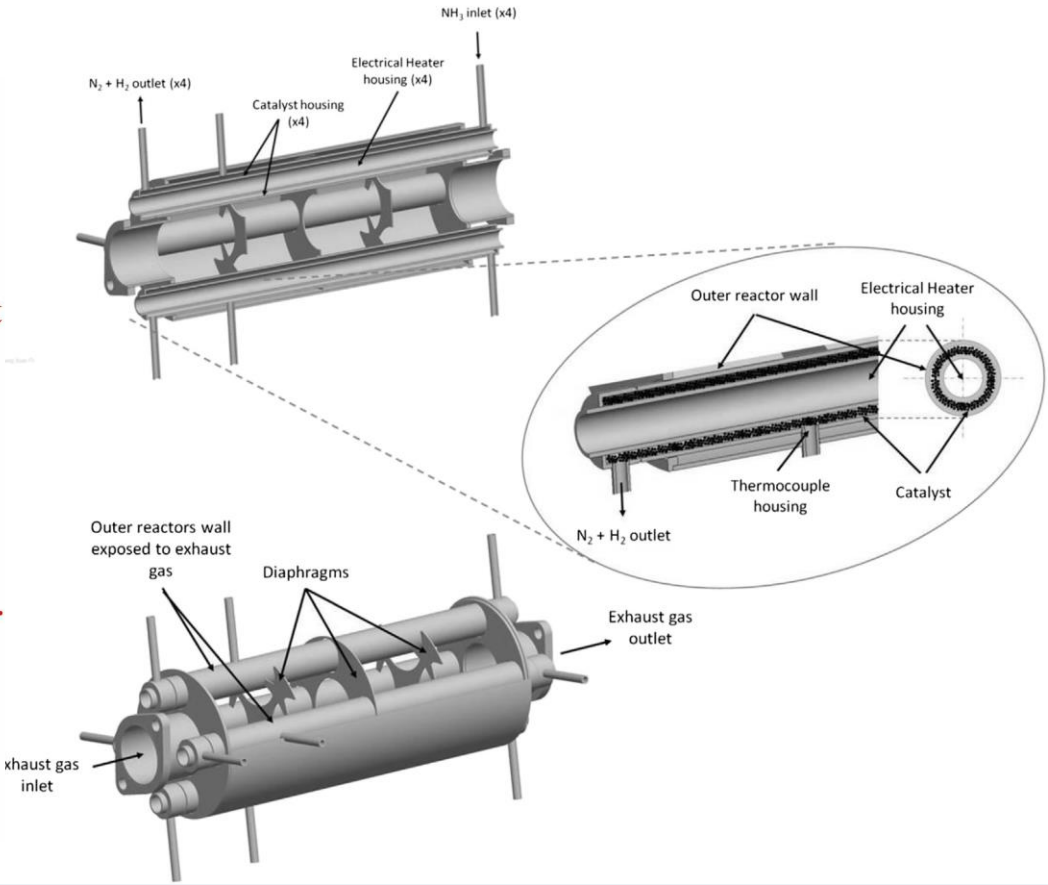
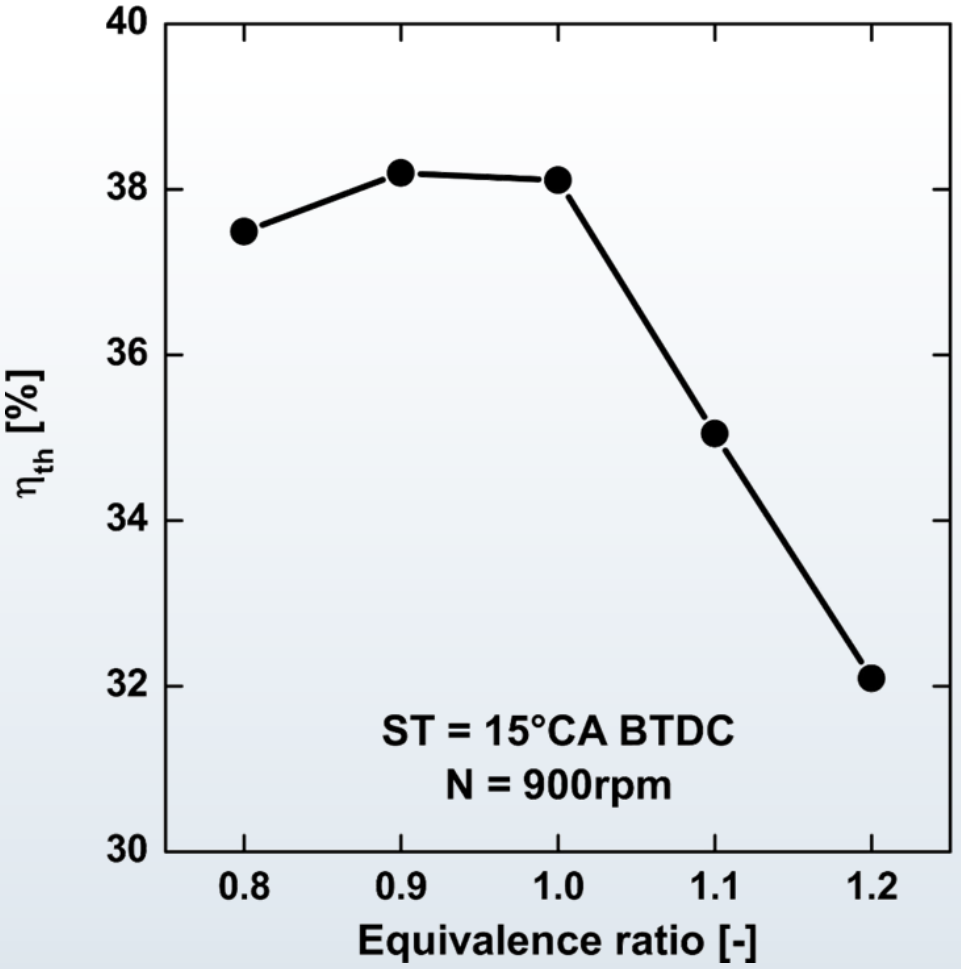
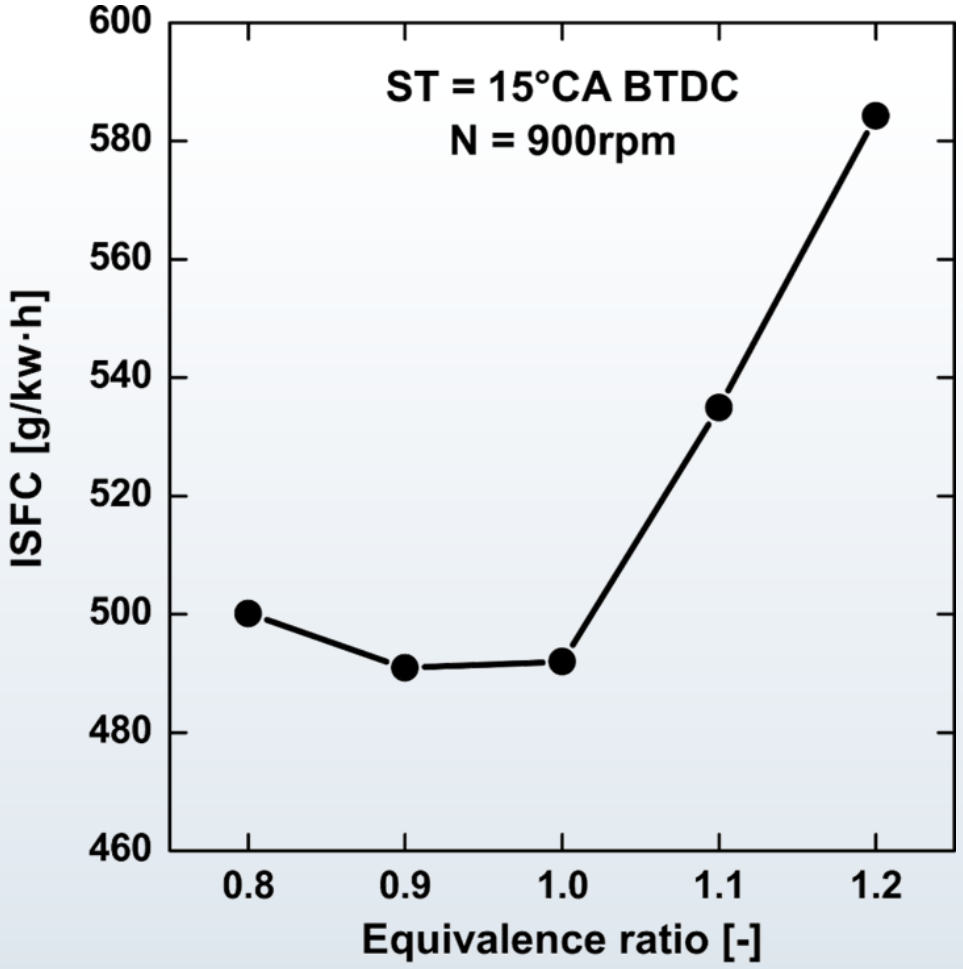




Ammonia spark ignition (SI) engines

- Lean, stoichiometric, or rich operation?





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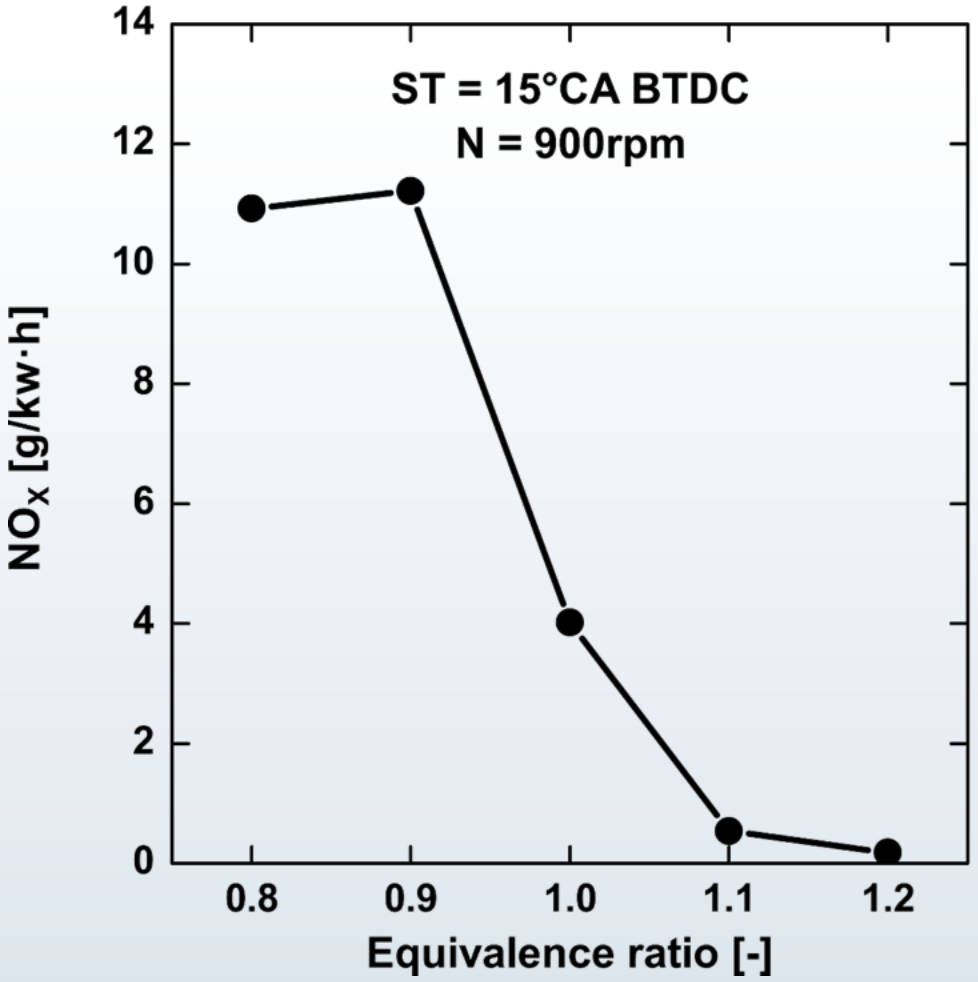

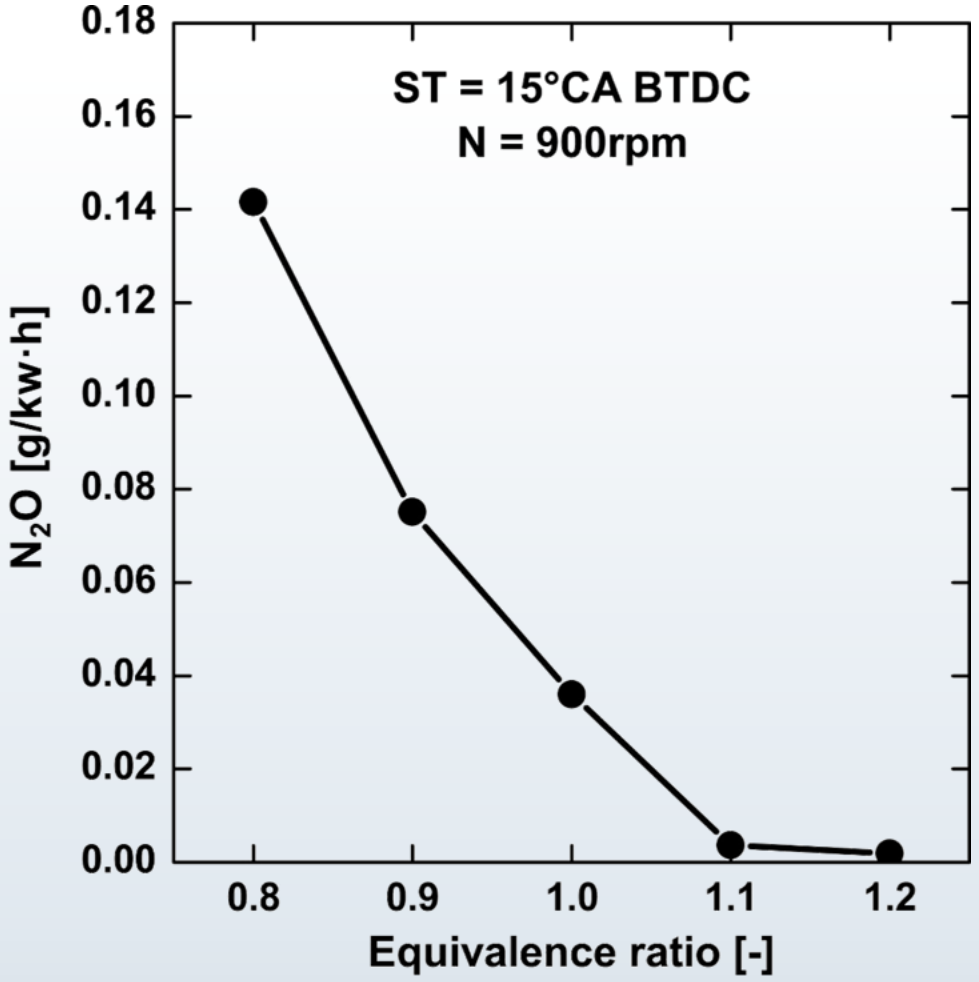

Ammonia spark ignition (SI) engines

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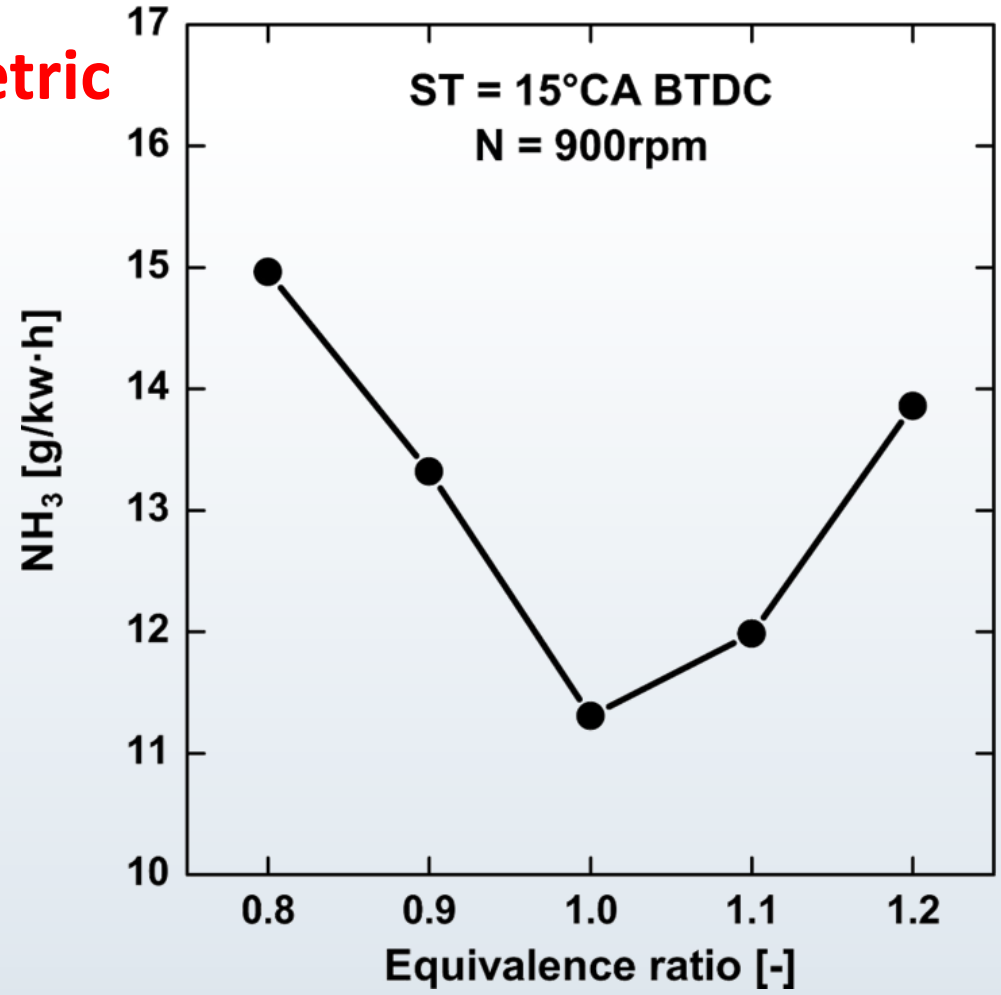
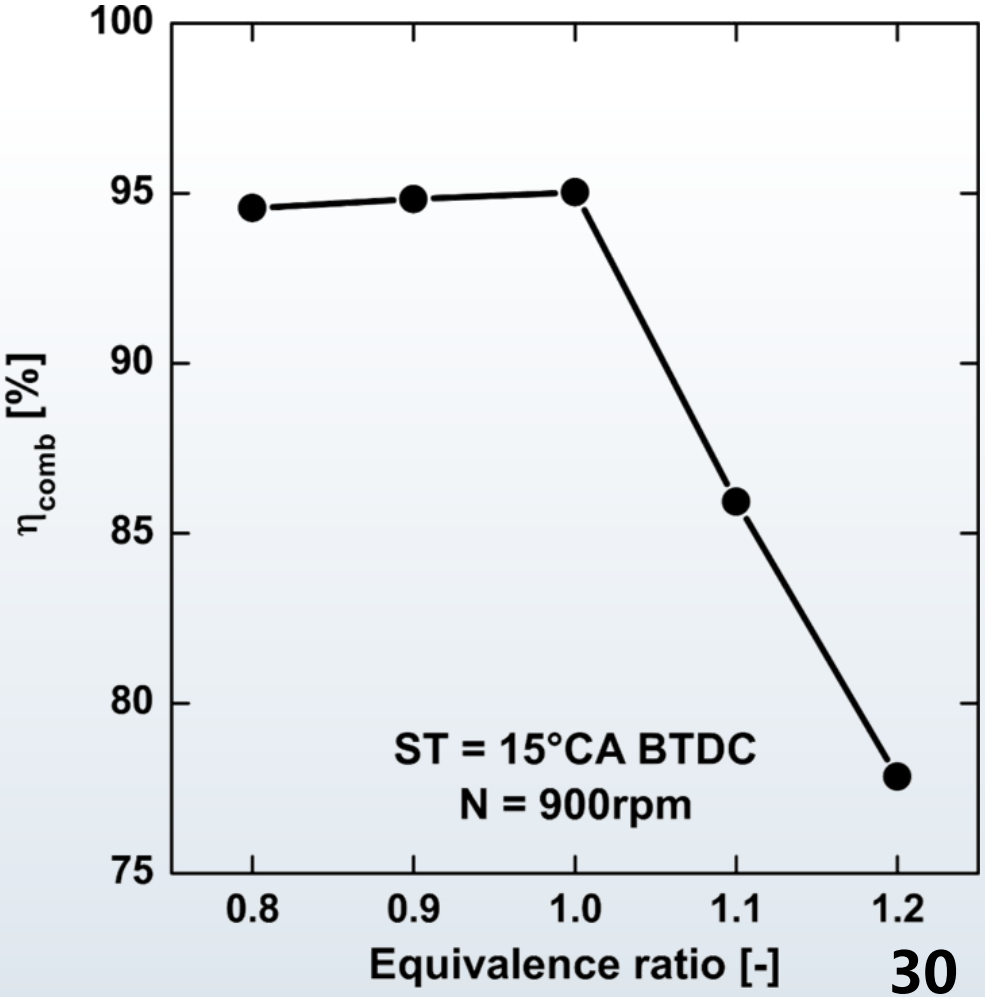
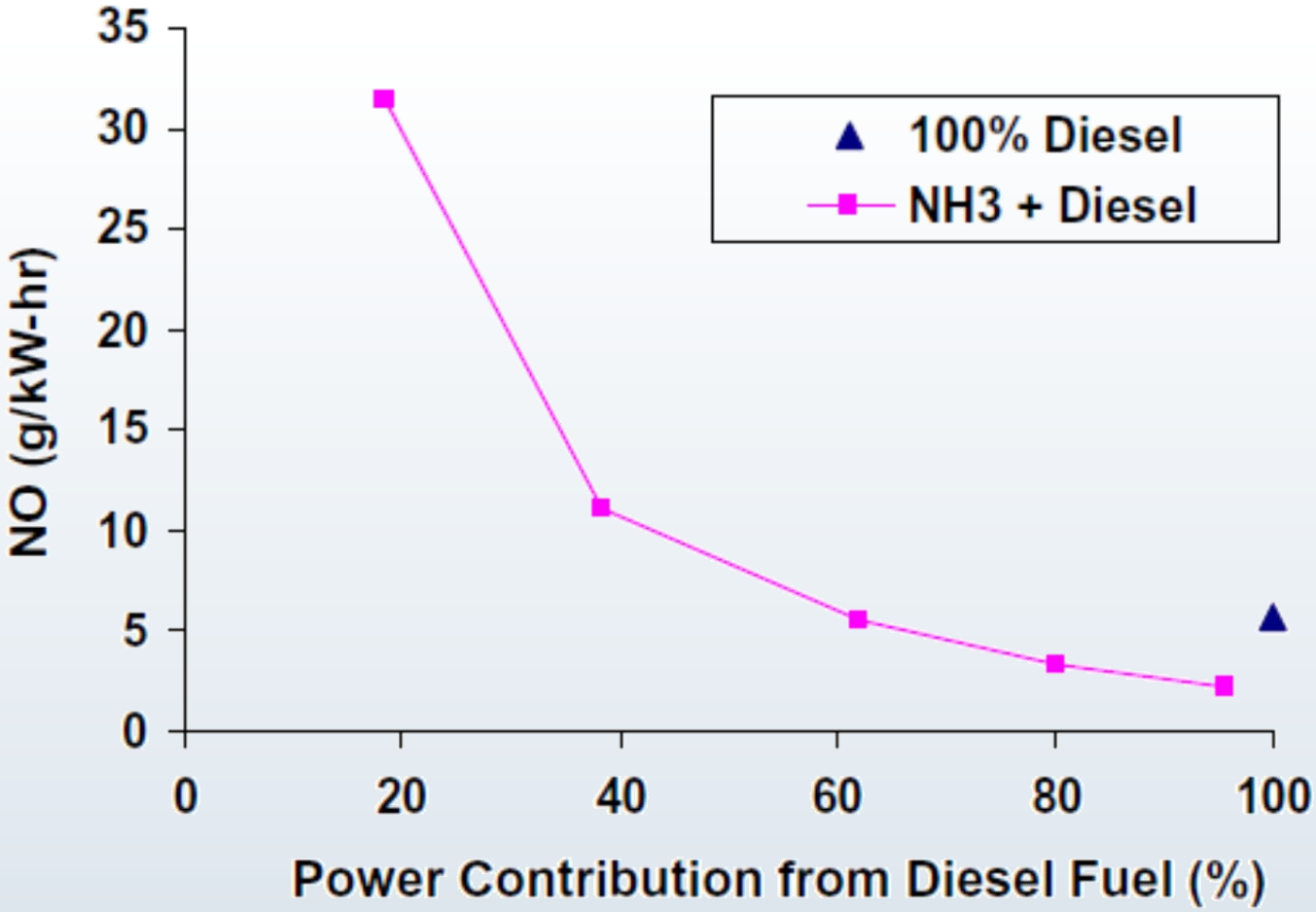
✓ **stoichiometric**





Pilot diesel ignition ammonia engines

- Ammonia/diesel fuel proportions?



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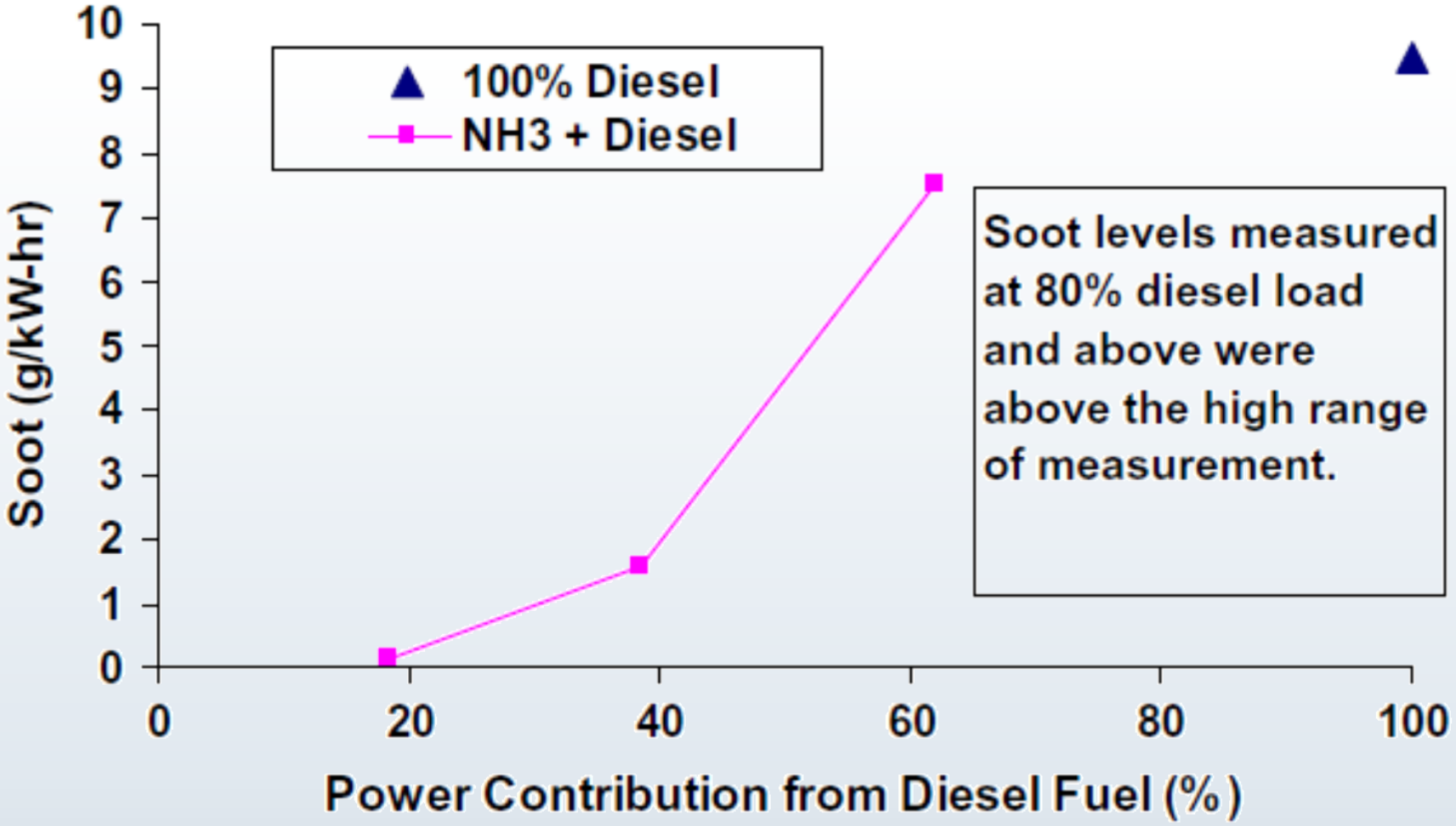

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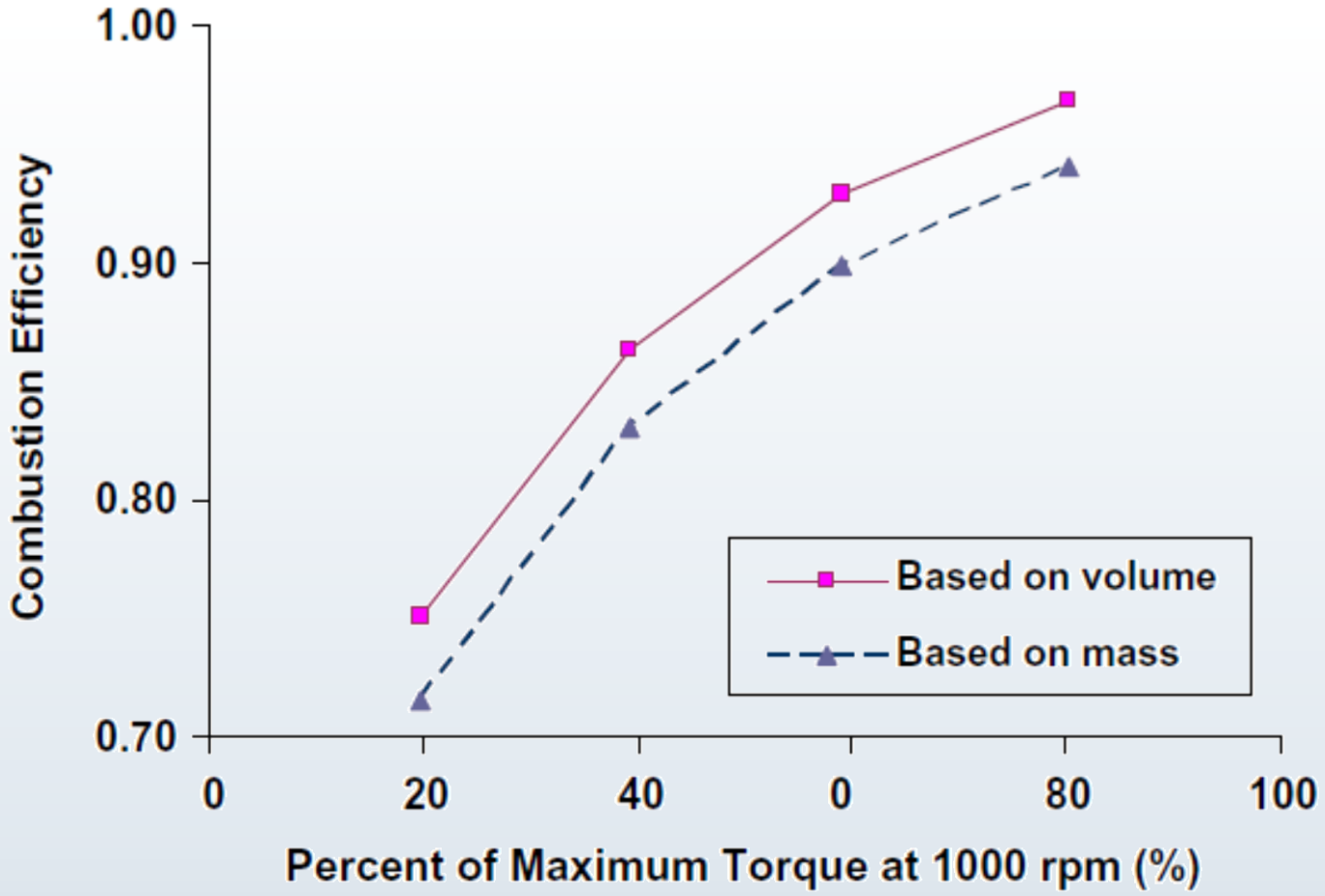

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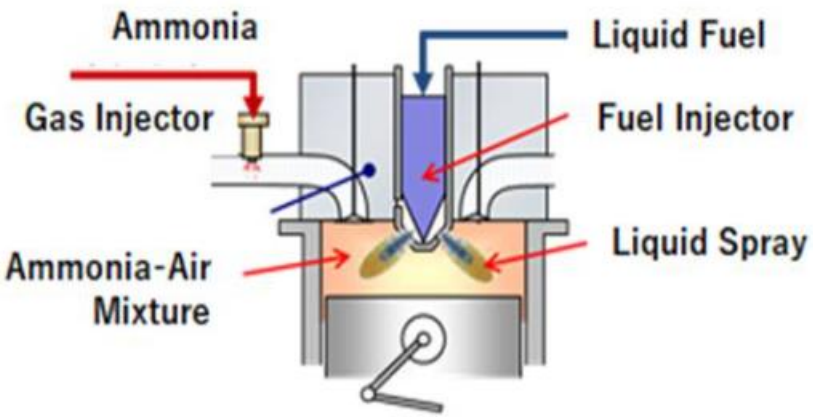
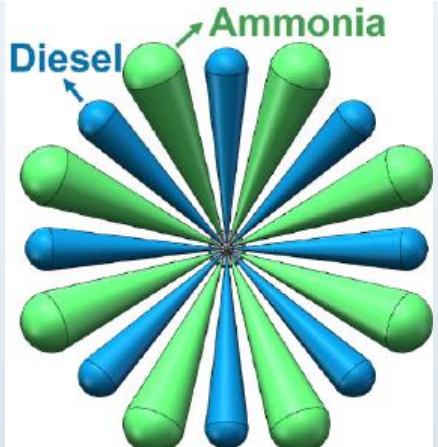
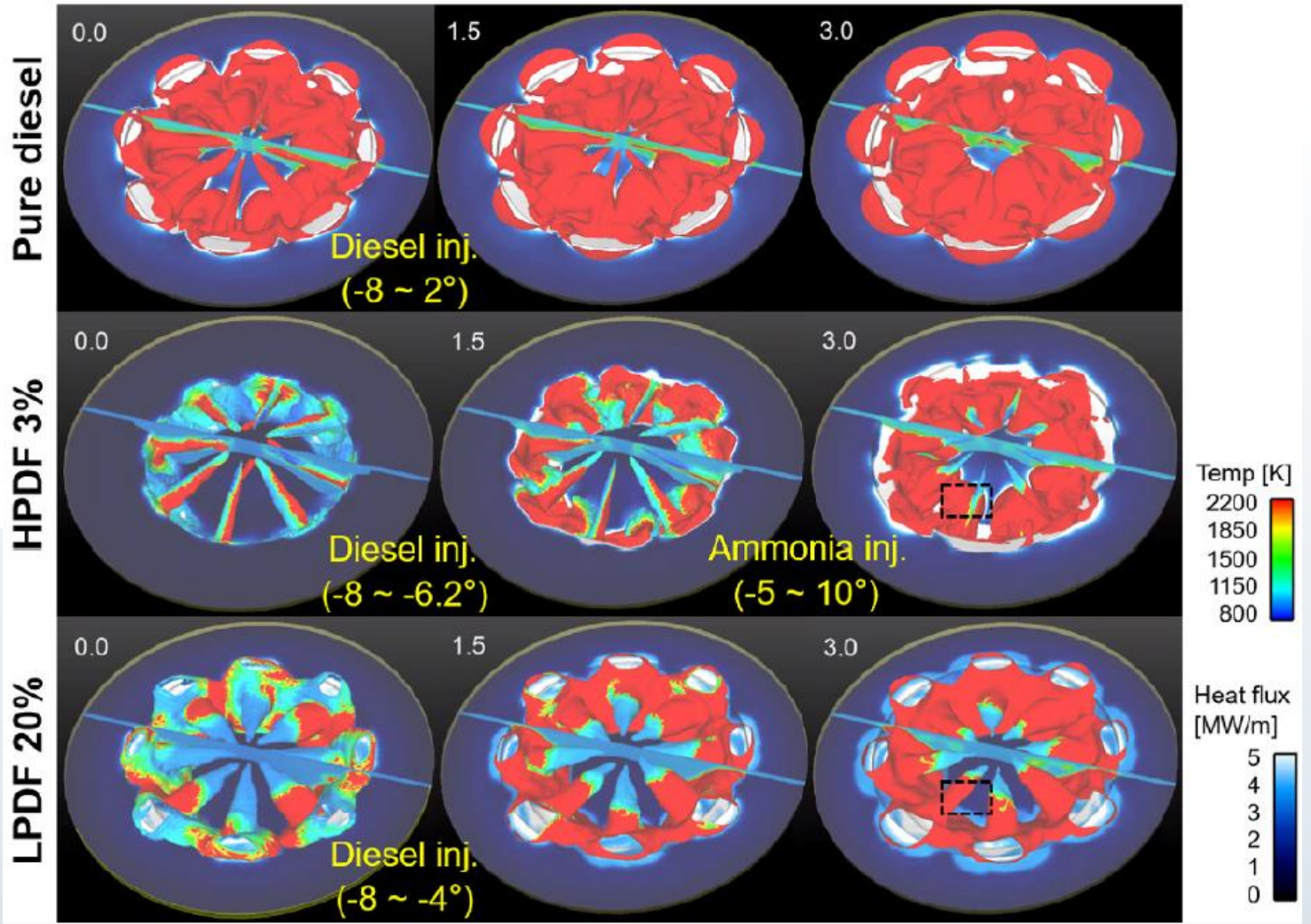
Pilot diesel ignition ammonia engines

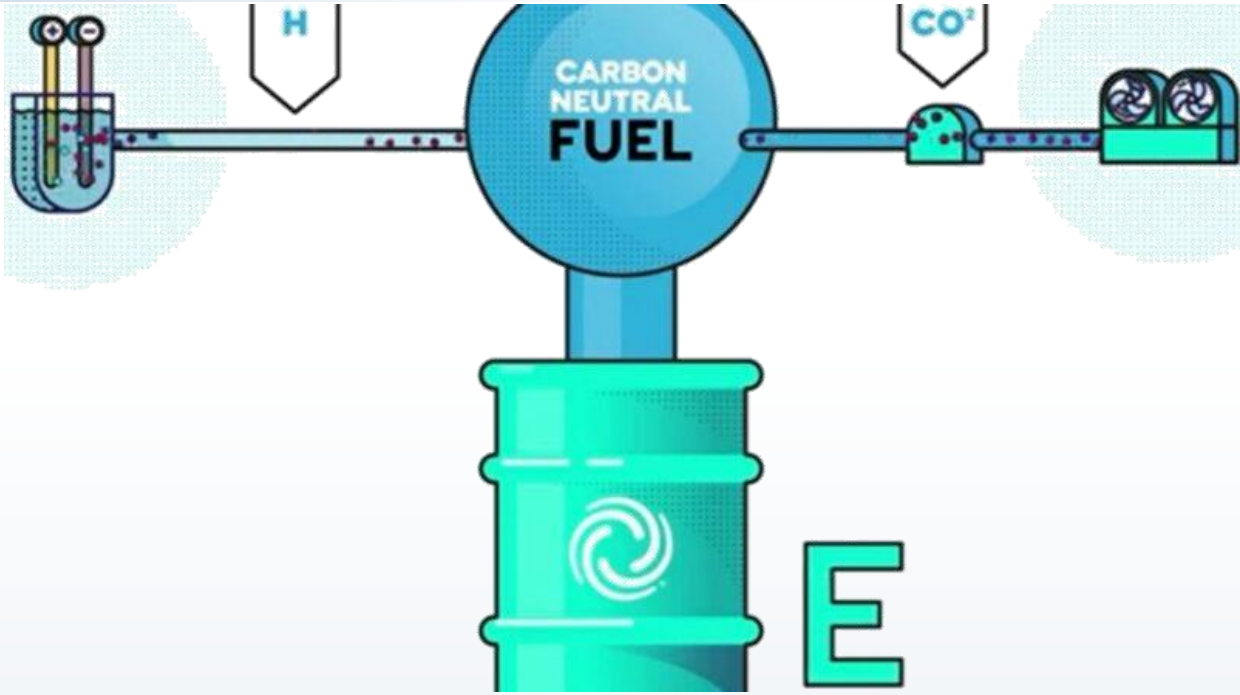
- Ammonia direct injection?







5. Future research directions



- Efficiency enhancement
- Co-optimization of fuels and engines
- Powertrain hybridization
- The application of carbon-neural fuels
  - ✓ Hydrogen
  - ✓ Synthetic fuels: made by chemically hydrogenating carbon dioxide
  - ✓ Biofuels
  - ✓ E-fuel

6. Summary

- NG SI engine: stoichiometric for vehicles, lean for stationary applications
- NG/diesel dual fuel engine: to avoid low load conditions because of methane slip
- Ammonia SI engines: stoichiometric operation, hydrogen addition
- Ammonia/diesel dual fuel engine: combustion strategy optimization to reduce NH3/N2O

7. Acknowledgement

- Program SEEEP High Level Summer School
- Zhejiang University