KAUST Research Conference:
Hydrogen-Based Mobility and Power
Oct. 25, 2022 @ KAUST

# Chemical kinetic and flame studies for boilers and high-temperature air combustion furnaces with ammonia

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# Game-changing result – ammonia gas turbine in SIP project


41.8 kW power generation by ammonia/air gas turbine (Japan, 2015)

Kurata, et al., PCI 36 (2017) 3351-3359

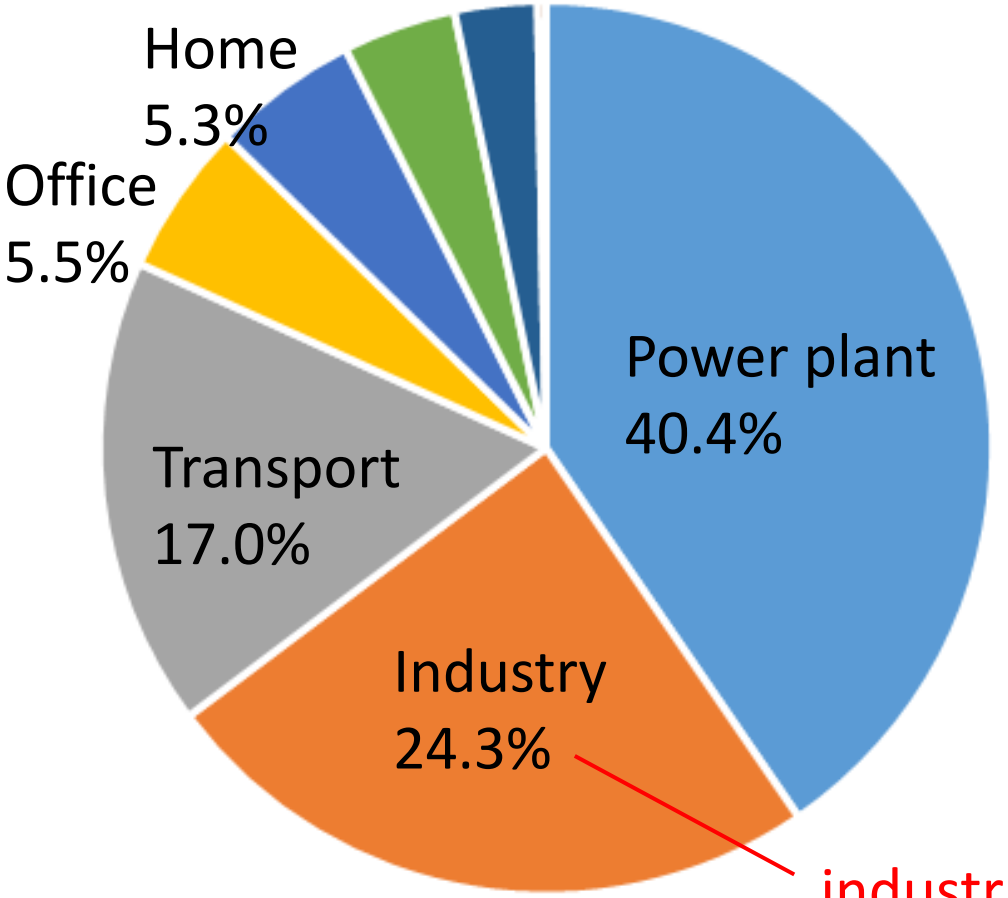
Kobayashi, et al., PCI 37 (2019) 109-133

- ✓ Heat regeneration and swirl burner
- ✓ Understanding and modelling of fundamental combustion characteristics of ammonia

**Fundamental parameters <-> Engineering parameters**

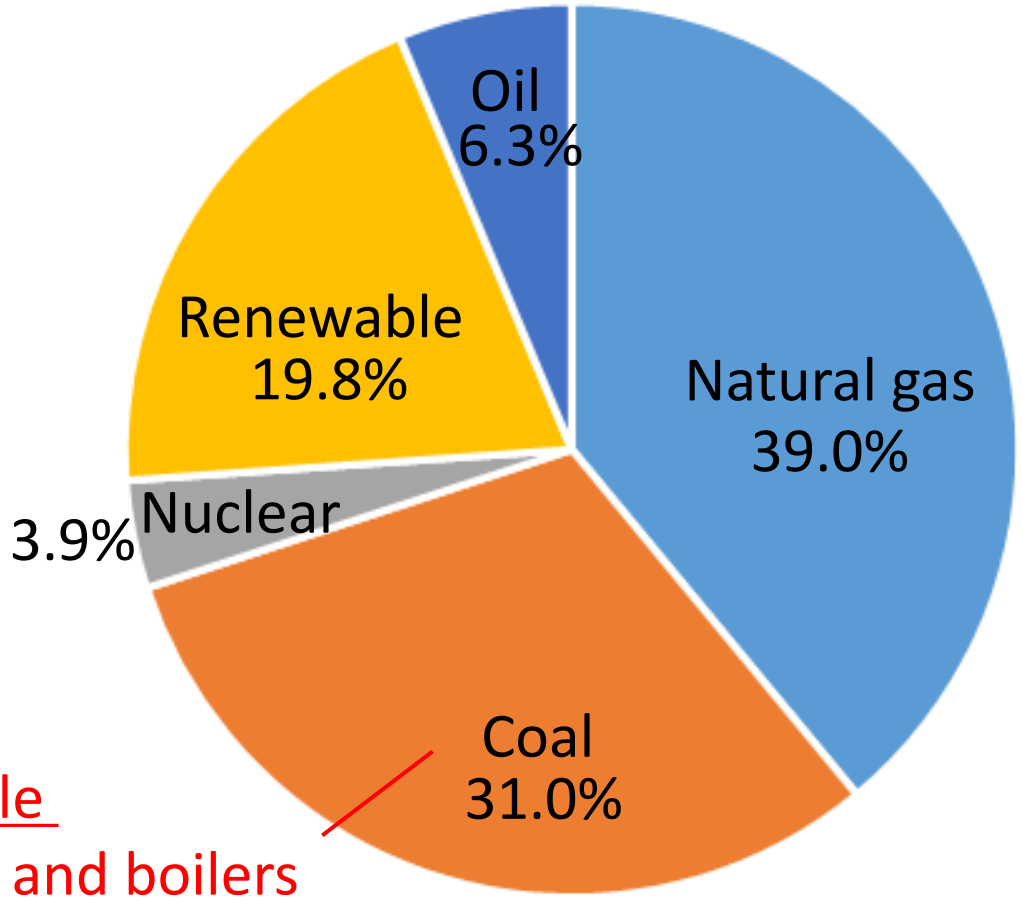
# $CO_2$ emissions and power generation

Direct $CO_2$ emission in 2020, Japan
1,044 Mt $CO_2$ in total




Large-scale
industrial furnaces and boilers

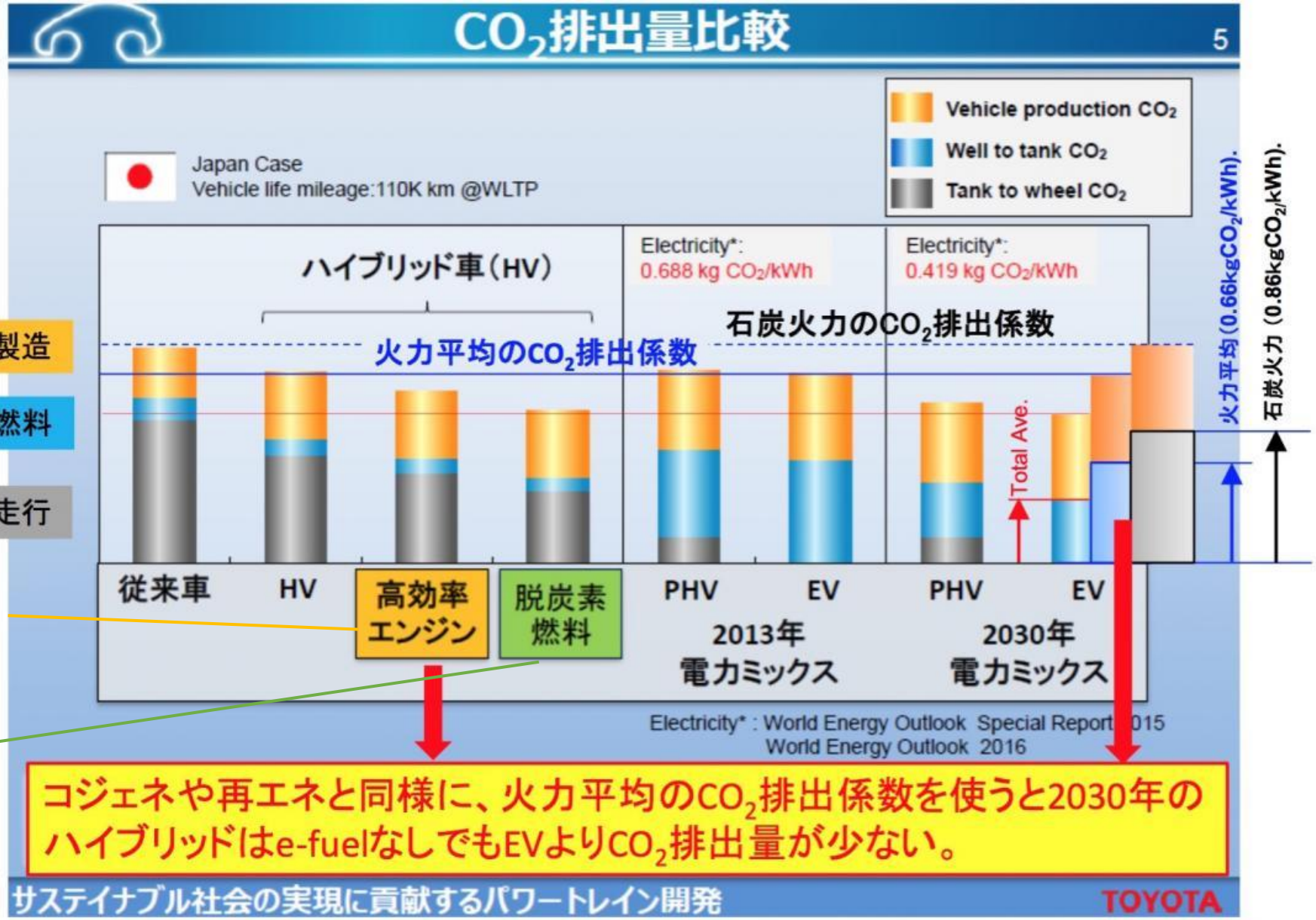
Electric power generation in 2020, Japan
10,008 PJ in total




https://www.jccca.org/download/65477?p_page=3#search

https://www.enecho.meti.go.jp/statistics/total_energy/results.html

# Lifecycle assessments of cars

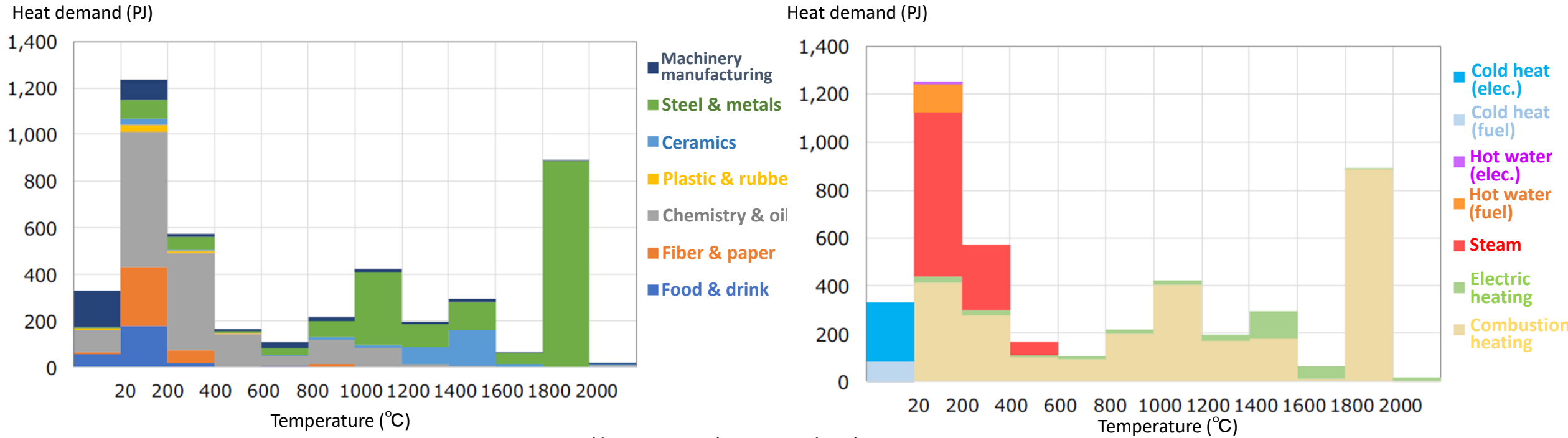



Improve thermal efficiency of engine

Introduce carbon-free fuels

https://car.motor-fan.jp/tech/10017818 「サステイナブル社会の実現に貢献するパワートレイン開発／内燃機関シンポジウム2019 」に追記

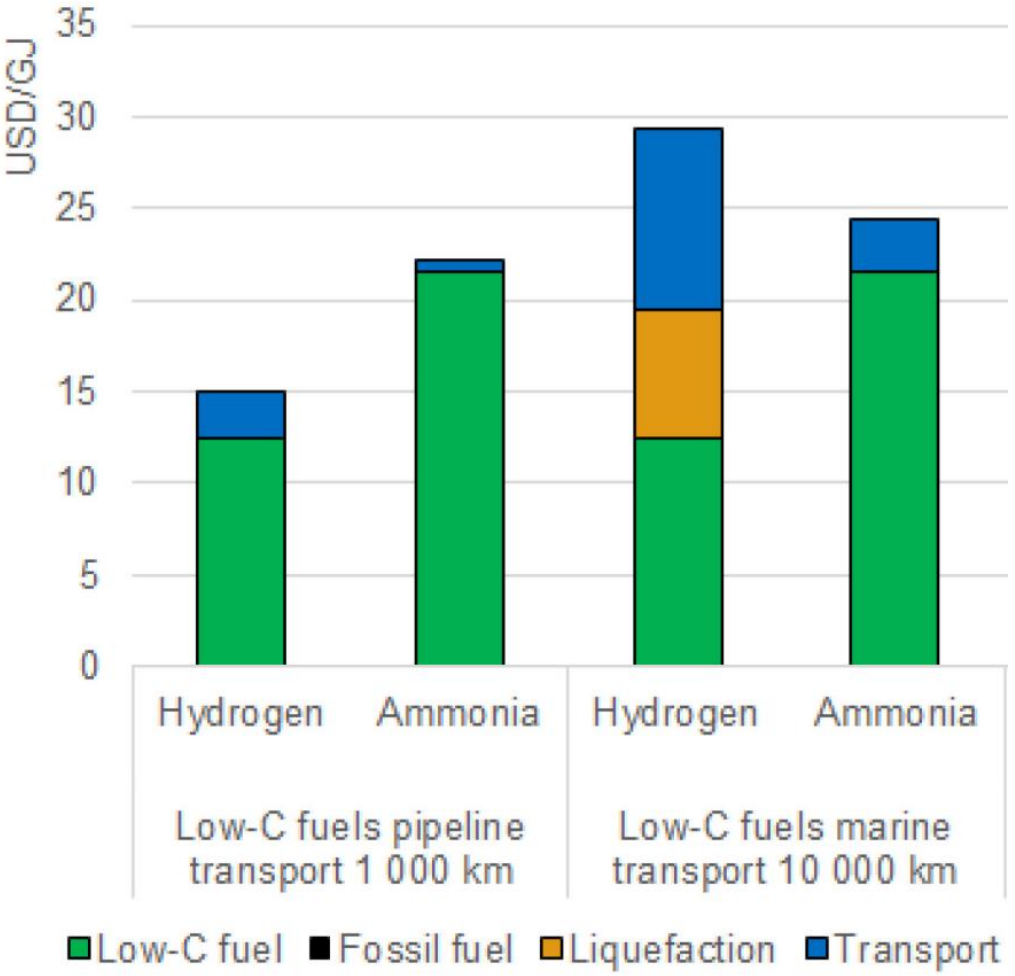
# Industrial furnaces and temperatures

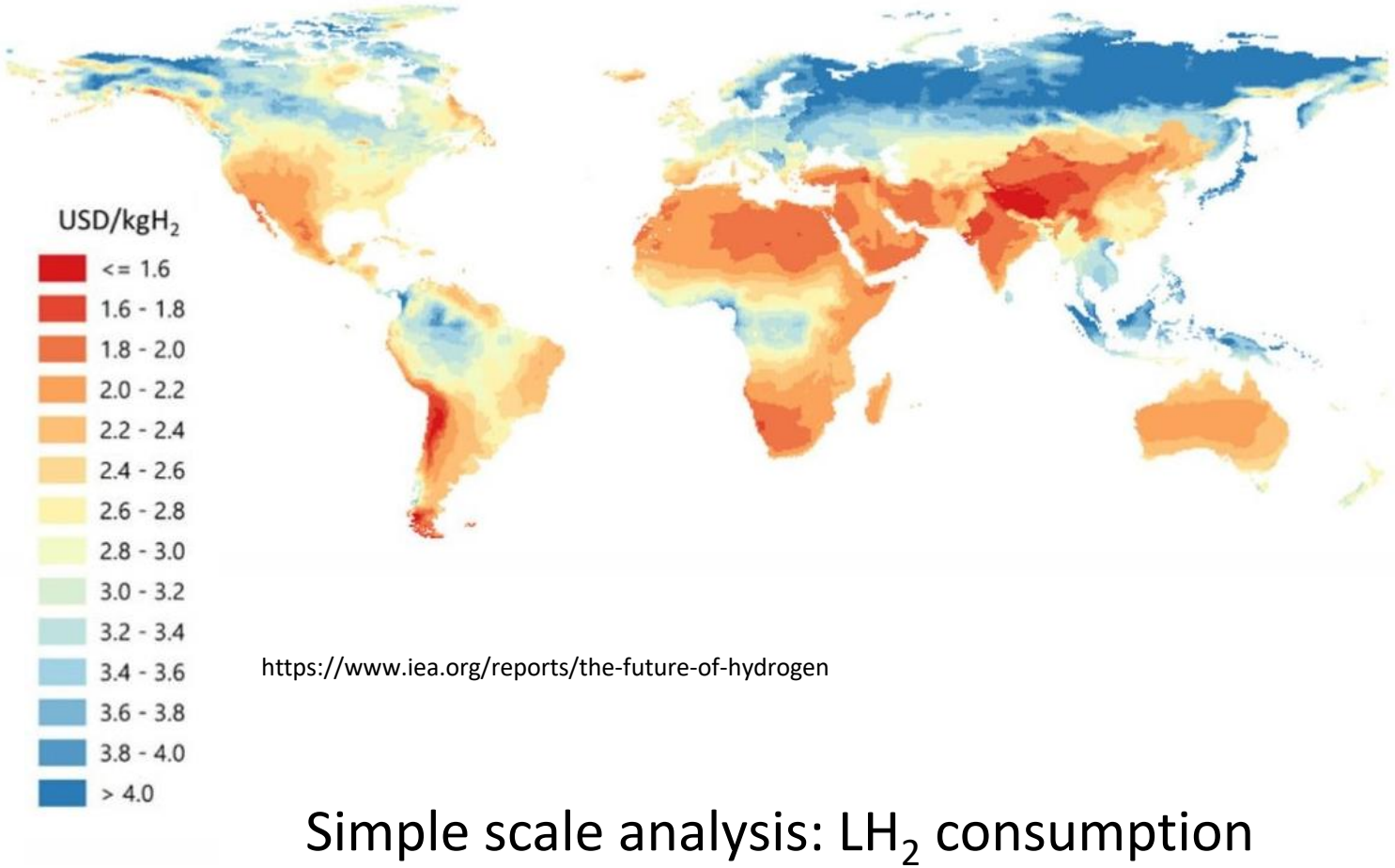



https://dl.ndl.go.jp/info:ndljp/pid/11222688

- Steel & metals and ceramics show large heat demands at high temperature
  High quality materials are important in production of vehicles
- Combustion heating is dominant for most of heat demands
  (steam would be produced as a by-product of combustion heating)

# Cost and scale of carbon-free fuels




https://www.iea.org/reports/the-future-of-hydrogen

Simple scale analysis: $LH_2$ consumption

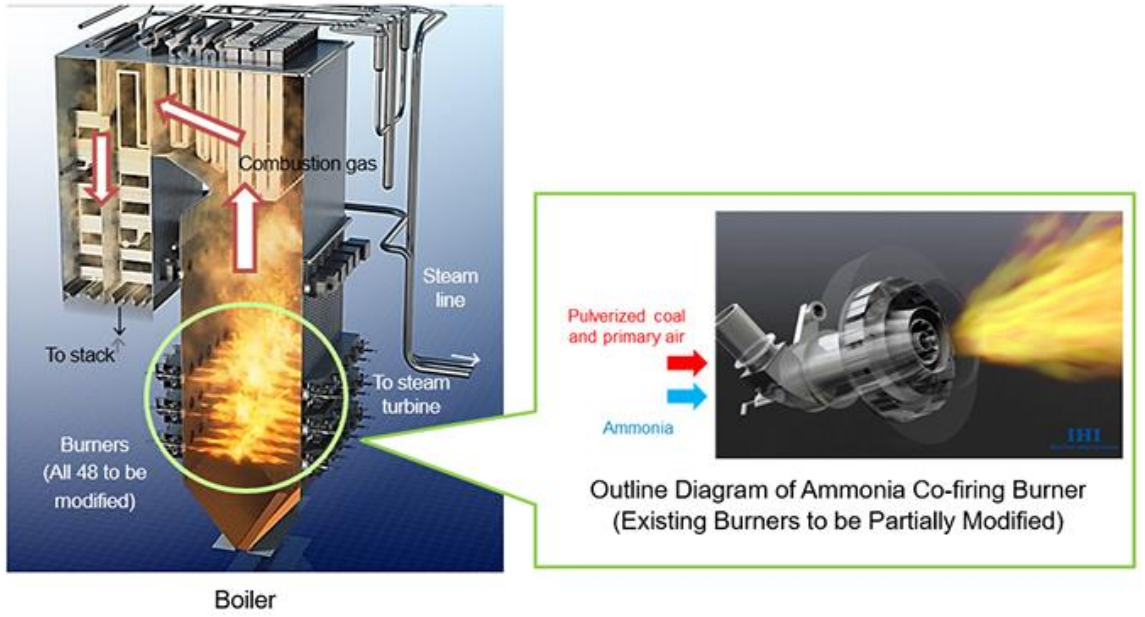
- 10 MW furnaces for 200 days operation: 20,000 $m^3$/year
- @ JAXA: 5,000 $m^3$/year

IEA, The Role of Low-Carbon Fuels in the Clean Energy Transitions of the Power Sector, 2021

# Ammonia combustion for furnaces and boilers

https://www.rozai.co.jp/business/

https://www.ihi.co.jp/en/all_news/2021/resources_energy_environment/1197406_3360.html




Furnaces: heat generation for material industries

Boilers: power and steam generation

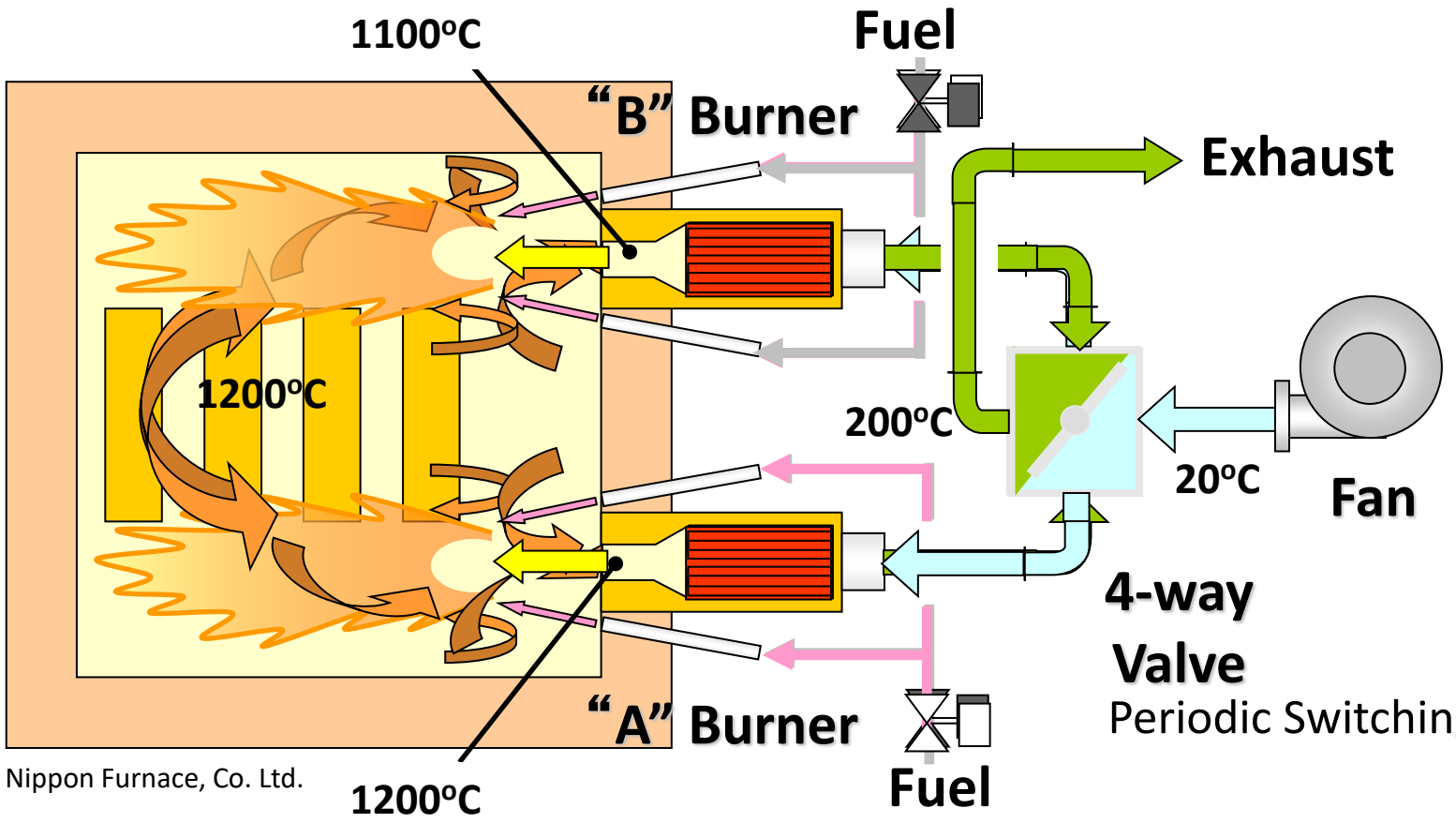
Furnaces and Boilers:

- Large $CO_2$ emission
- Huge scale (～1000 MW)
- Combustion with preheated air at atmospheric pressure
- Co-firing with HCs is still important

✓ Electric heaters
✓ Hydrogen combustion
✓ Ammonia combustion

# High-Temperature Air Combustion Technology (HiTCOT, HiTAC)

(Moderate or Intense Low-oxygen Dilution: MILD, Flameless Oxidation: FLOX)



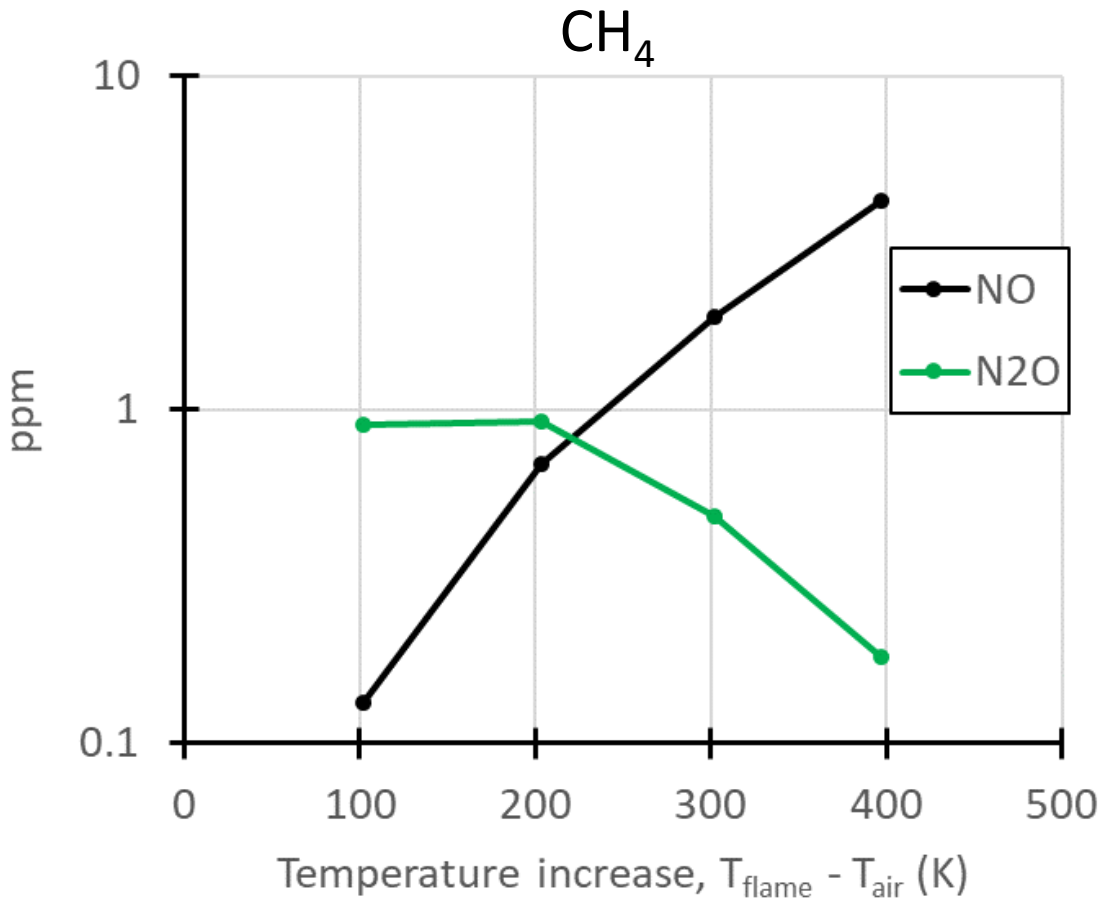

Nippon Furnace, Co. Ltd.

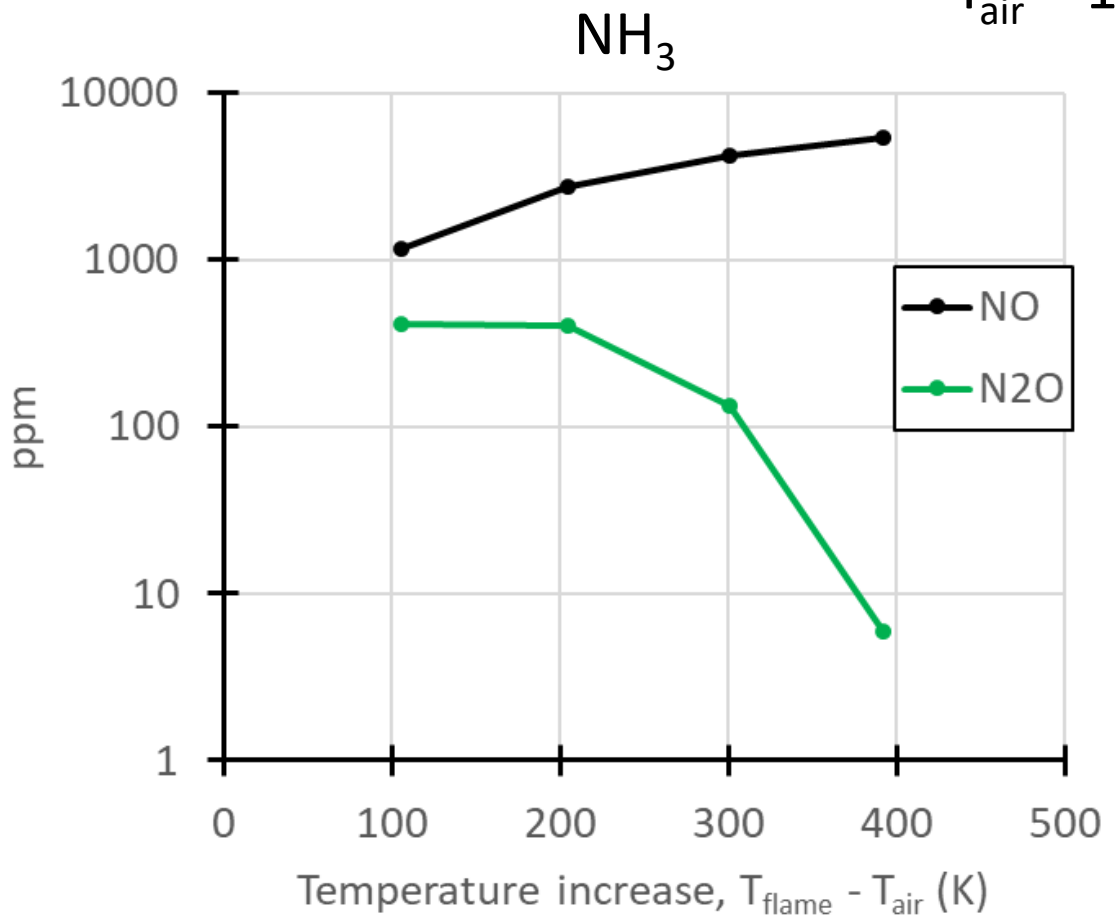
Periodic Switching in every 30 sec

- High thermal efficiency due to extensive heat recirculation
- Temperature increase at flame is very small
  -> low thermal NOx and low combustion noise

# Emission characteristics of $CH_4$ and $NH_3$ HiCOT flames

$T_{air}$ = 1300 K

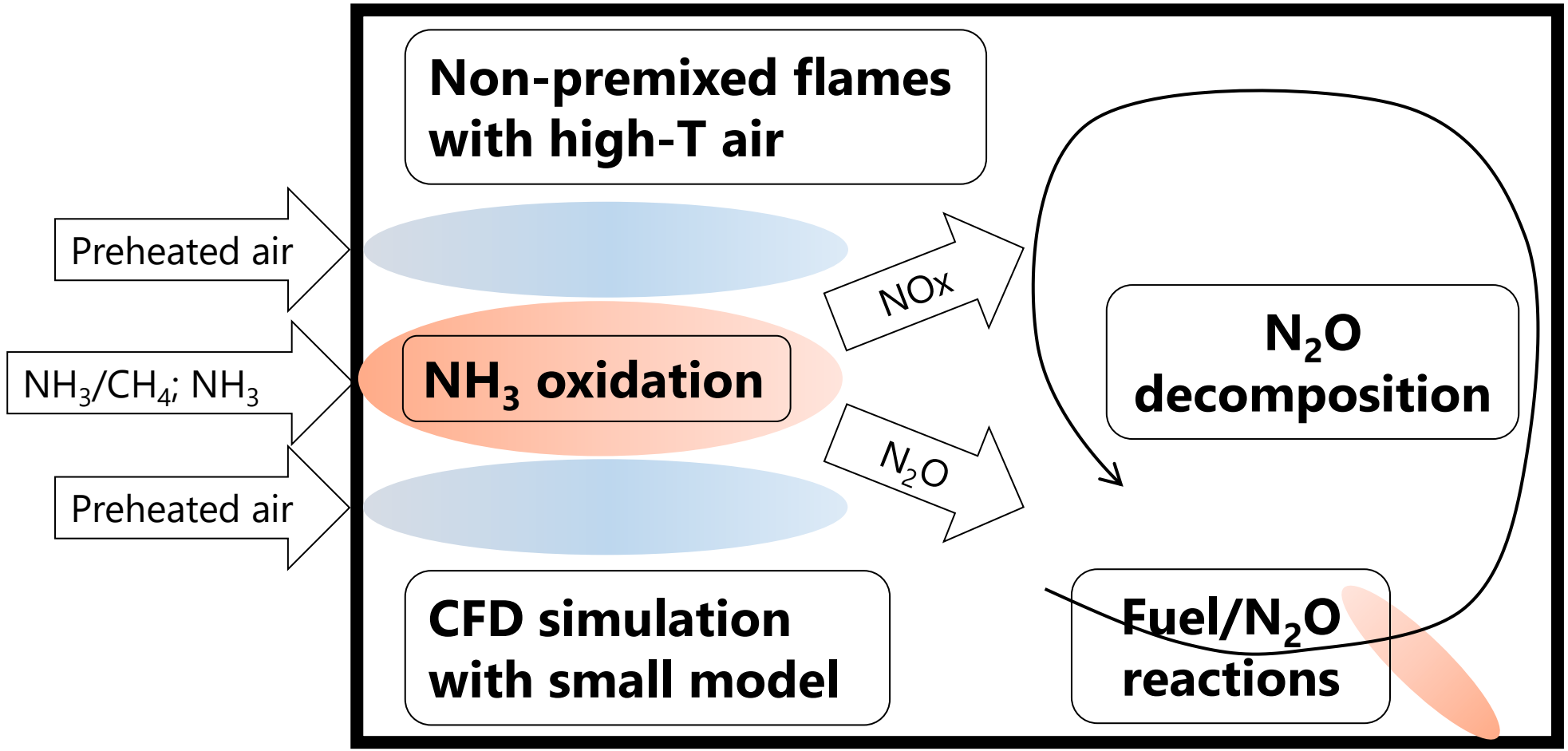



- NO can be reduced by two-staged combustion and SCR (Selective Catalytic Reduction)
- GWP (Global Warming Potential) of $N_2O$ is approximately 300 times that of $CO_2$
  -> reduction of $N_2O$ need to be considered

# Fundamental and practical

Understanding fundamental ammonia combustion characteristics and providing reliable models
-> Indicate necessary engineering parameters
(temperature, residence time, injection speed, etc.)



# Summary

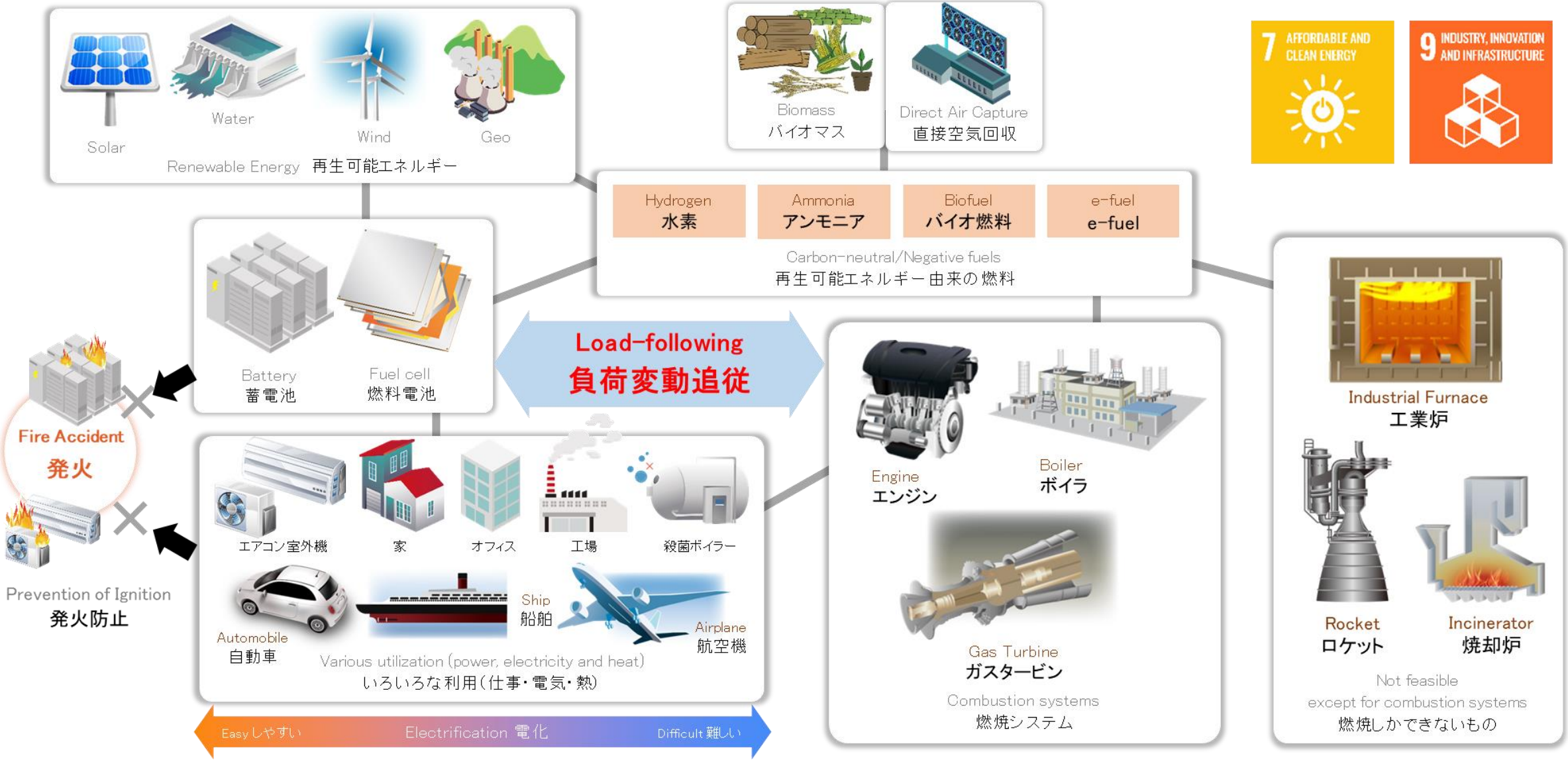
Importance of industrial furnaces in decarbonization of transport sector was introduced. Works in progress on flame and chemical kinetic studies of ammonia combustion were introduced. The studies focused on fundamentals which are important in practical applications for combustion furnaces and boilers.

- $NH_3/CH_4$ non-premixed flames with high-temperature air
- $N_2O$ pyrolysis and fuel/$N_2O$ reactions
- Generation method of small ammonia reaction model

Furnace project is under collaboration with:

- Hokkaido Univ.: ammonia jet flames with high-temperature air
- Hiroshima Univ. & Sanken Sangyo: lab-scale ammonia HiCOT furnace
- Rozai Kogyo: 1 MW ammonia HiCOT furnace

# Zero emissions and Zero fire accidents




**Understanding on combustion properties of RE-related reactants and their model predictions**

Re-related reactants: hydrocarbons(biofuel, e-fuel), ammonia, refrigerants, battery electrolytes