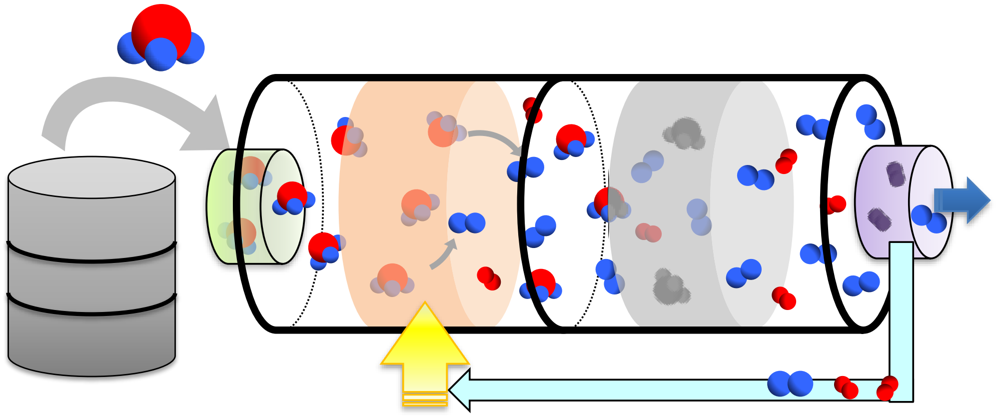
Ammonia As a Hydrogen Carrier for PEM Fuel Cells



18 AIChE Annual Meeting in Pittsburgh, PA, October 28-November 2, 2018,
Wednesday, October, 31, 2018 f rom 9:45 - 10:00 David L. Lawrence
Convention Center, 317

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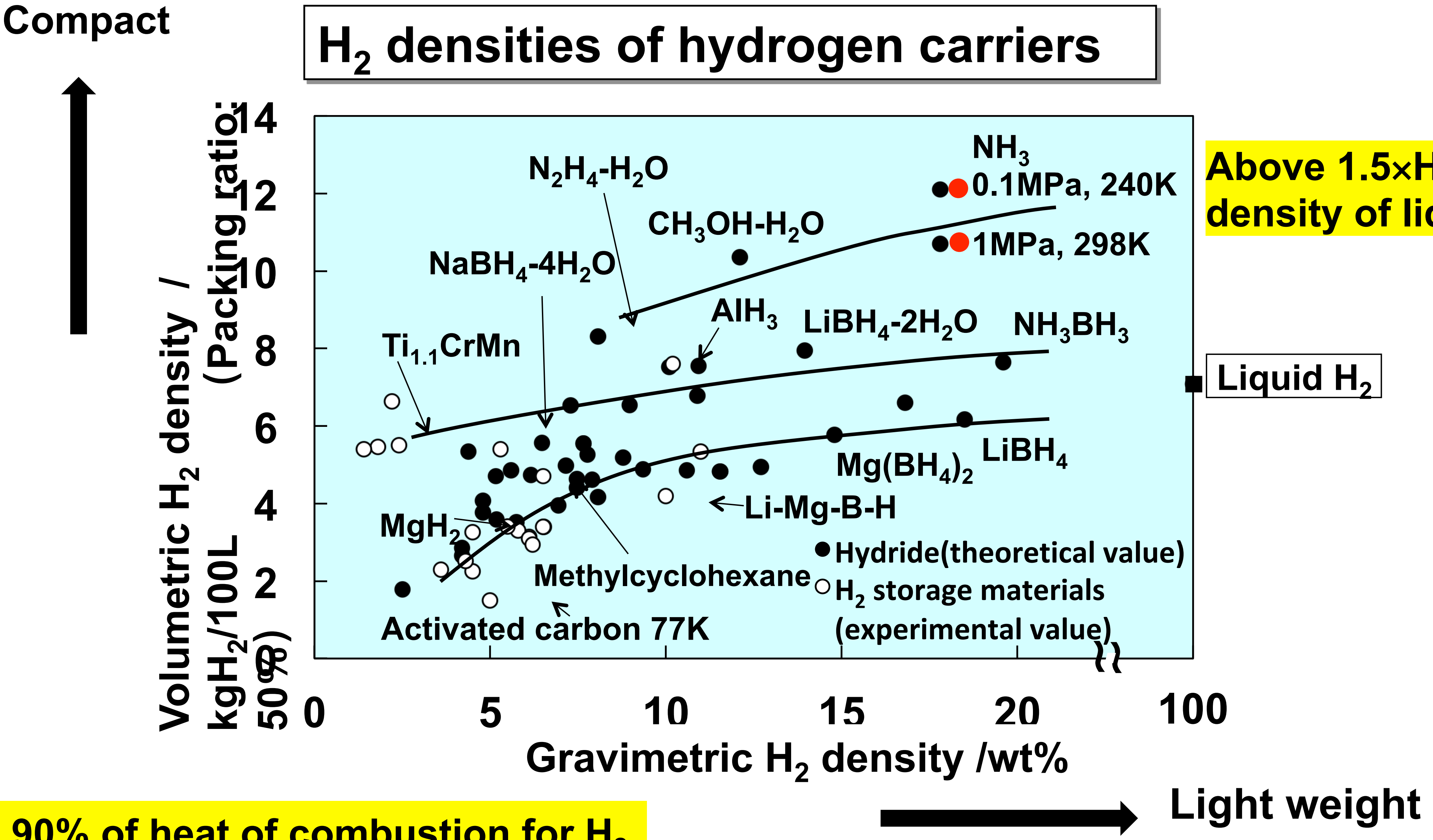
1. Research on hydrogen carriers (1999～2018)



Above 1.5×H_2 density of liquid H_2

90% of heat of combustion for H_2

2. Basic technology for hydrogen station utilizing ammonia

Excellent storage capacity and high heat of combustion

Hydrogen station utilizing ammonia: Key issue

Specification of hydrogen fuel for FCV (ISO 14687-2:2012)

Species	Concentration
Purity of H_2	99.97%
N_2, Ar	100ppm
Ammonia	0.1ppm

History of this research (press release, July, 19 2016)

Component technologies to produce high-purity hydrogen from ammonia (NH_3 <0.1ppm, N_2 <1ppm, H_2 >99.98%)

(1)NH_3 decomposition catalyst (Ru/MgO, Ru: 3wt%) and 1Nm^3/h-scale simulated shell and tube cracker: Low heat transfer performance

(2)NH_3 storage material (zeolite) and 1Nm^3/h-scale remover: NH_3 <0.1ppm

(3) 1Nm^3/h-scale H_2 purifier (two-tower-type): Purification efficiency of 70%

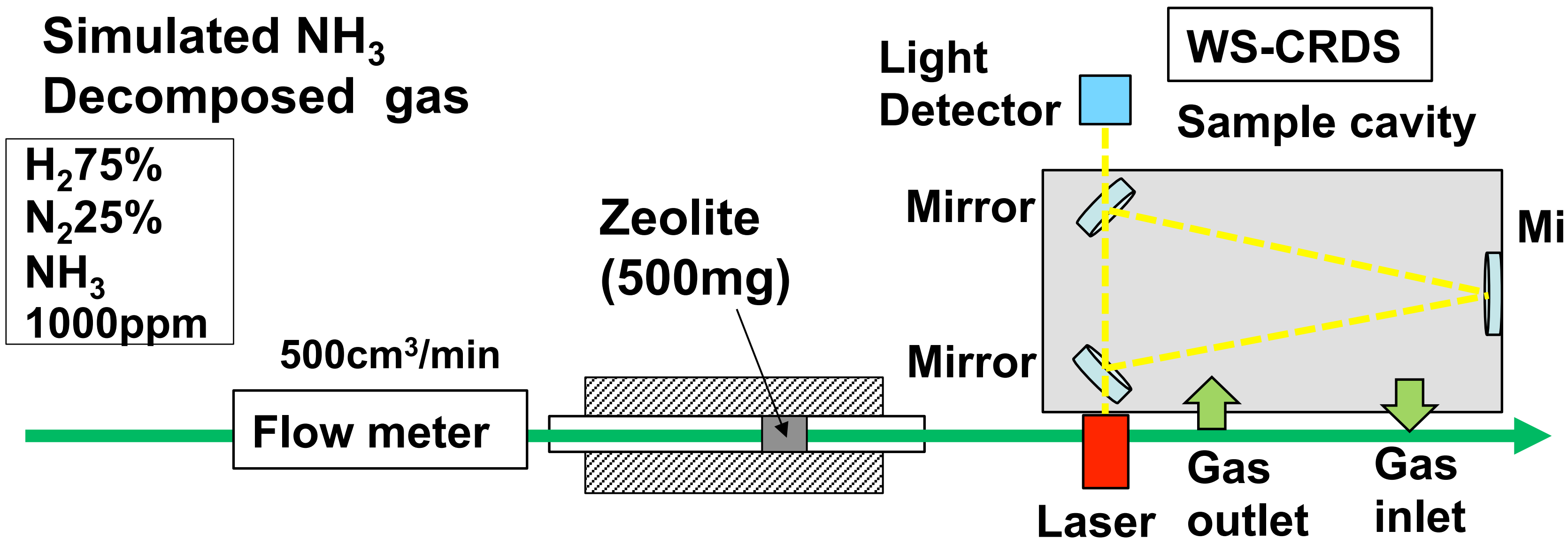
Purpose of this research

1. Component technologies to detect ammonia concentration smaller than 0.1 ppm
2. Component technologies to improve purification efficiency and H_2 conversion efficiency without emission of CO_2

(1) NH_3 storage materials and remover

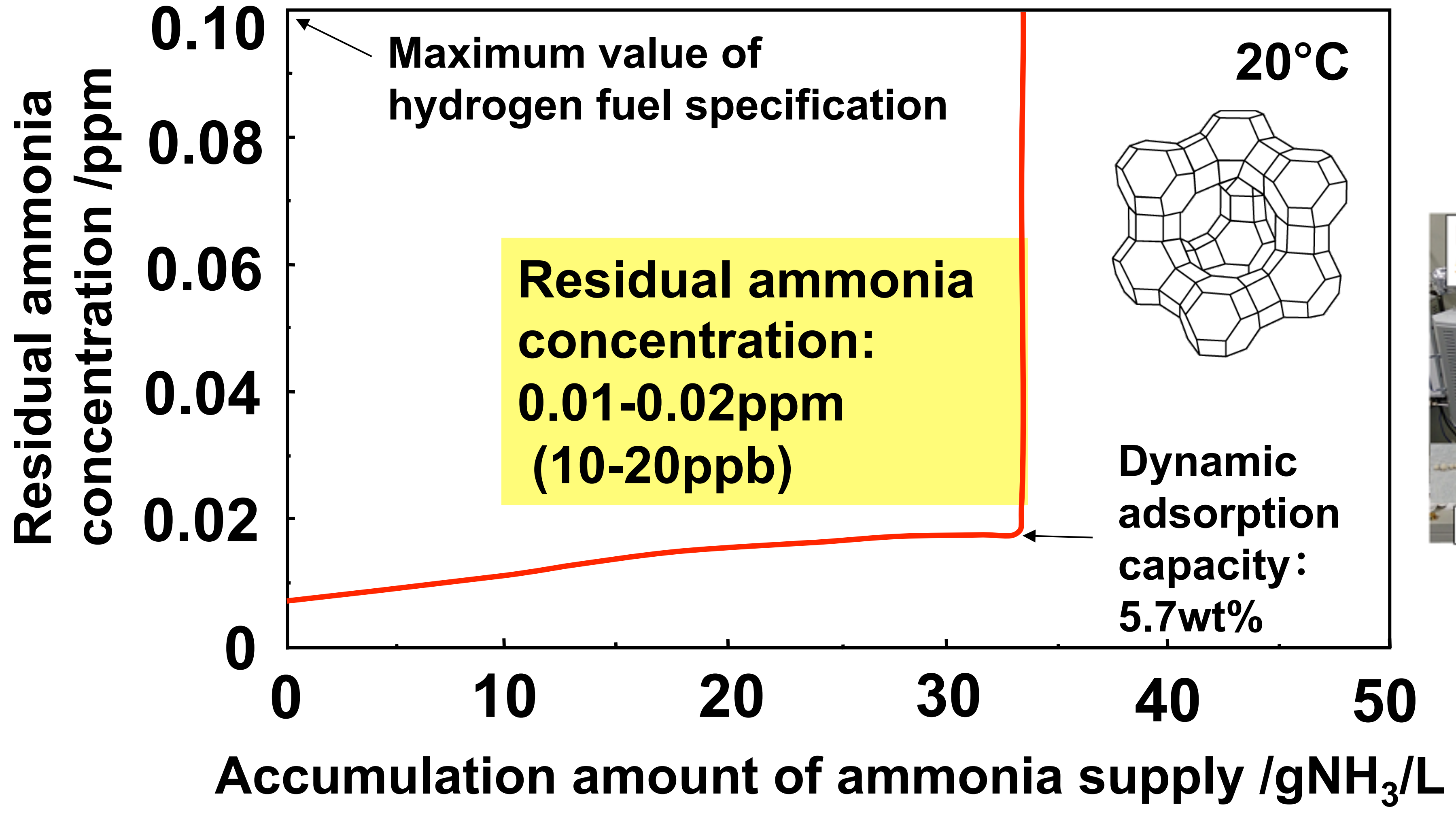
Zeolite: High adsorption power, flow channel, recyclable by heating

Conceptive picture of specially designed breakthrough testing apparatus

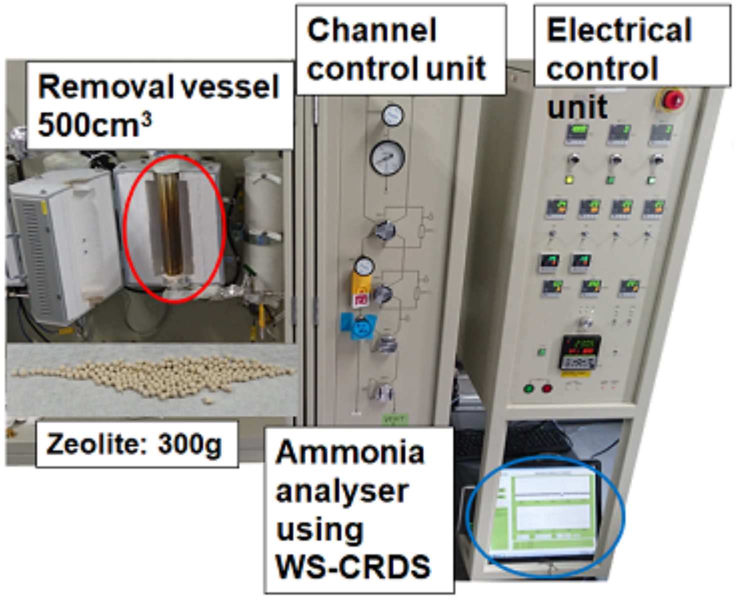


Exit NH_3 concentration: Cavity ring-down spectroscopy is a reliable technique to measure trace ammonia in gases even at ppb level.

Residual ammonia concentration passed through zeolite packed column

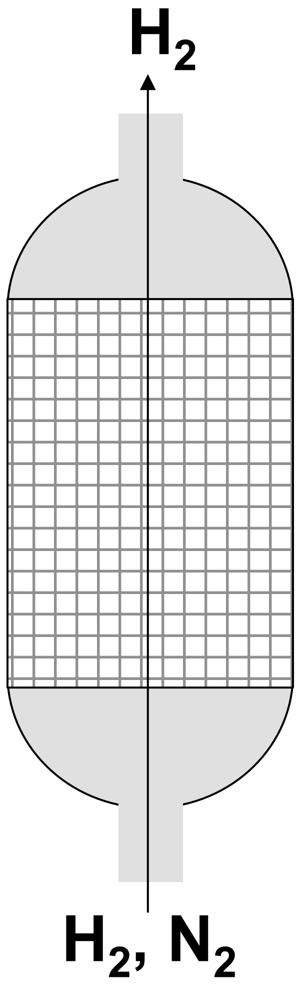


Ammonia remover ($1Nm^3$/h-scale)

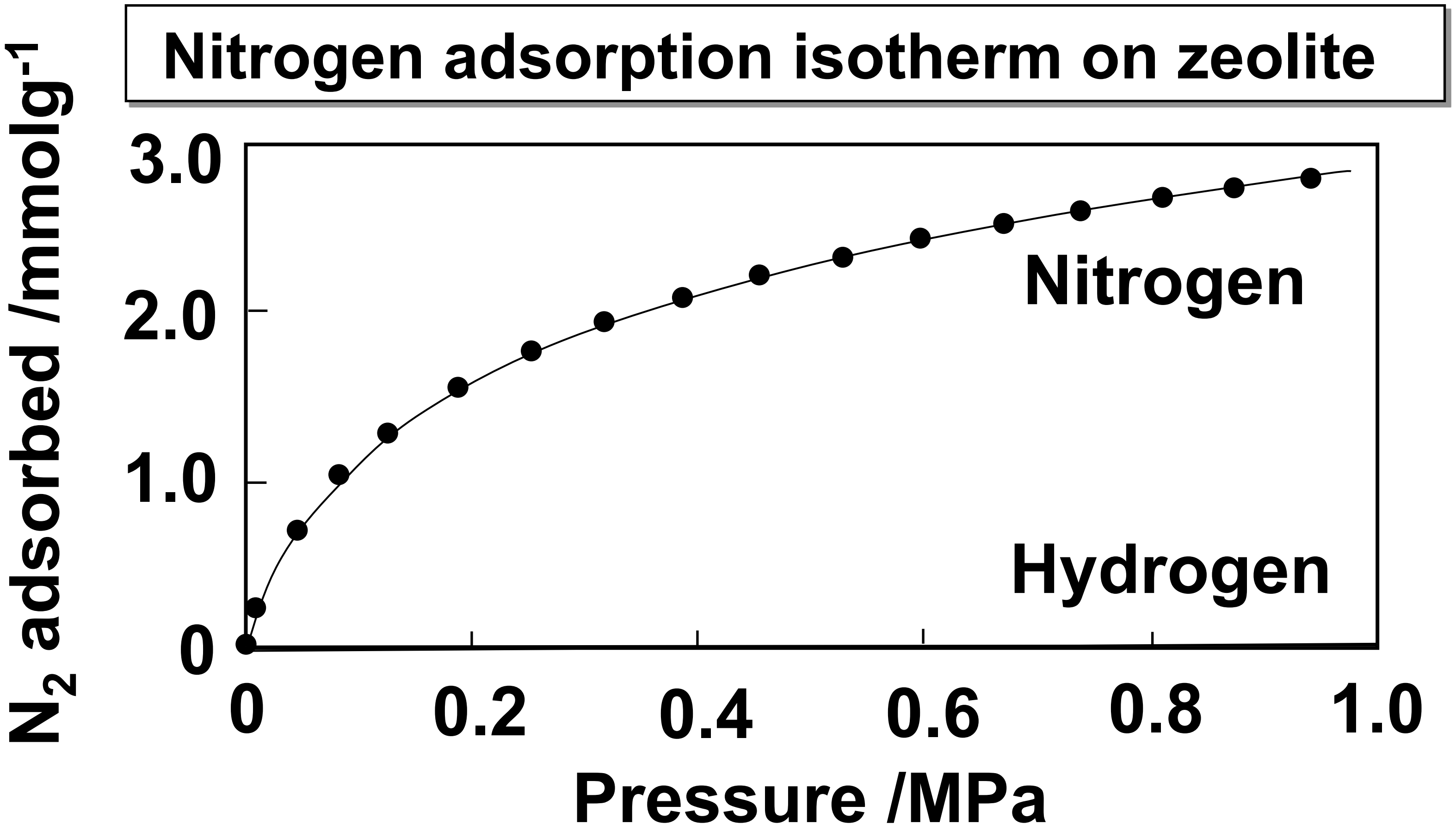


NH_3 concentration: Sufficient satisfaction of hydrogen fuel specification

(2) H_2 purifier with off-gas supply unit



Pressure swing adsorption (PSA)



Nitrogen is adsorbed on the surface of the zeolite and hydrogen passes through the zeolite

Residual nitrogen concentration: Below 1ppm

Purification efficiency (two-tower-type) : 70%← gas pulsation

Overview of 1Nm^3/h-scale H_2 purifier (four-tower-type)

Mixture of hydrogen and nitrogen

H_2 1.5Nm^3/h
N_2 0.5Nm^3/h

High purity hydrogen

Purity >99.98%
H_2 1.35Nm^3/h
N_2<1ppm

Off-gas
H_2 0.15 Nm^3/h
N_2 0.5Nm^3/h

Off-gas supply unit

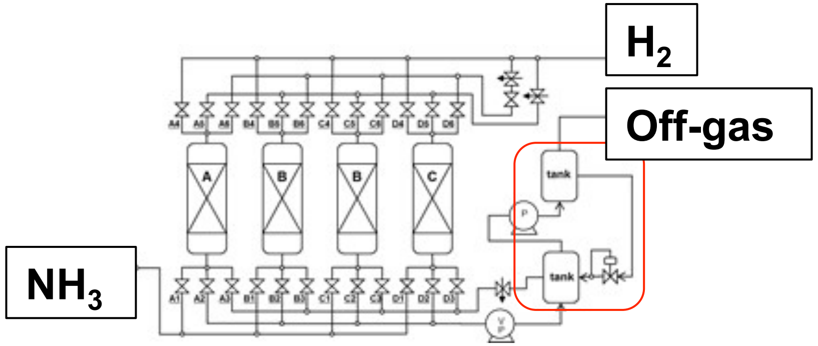
Purification efficiency: 70%(two-tower-type)→ 90%(four-tower-type)
Hydrogen production rate: 1.3times (four-tower-type)
Off-gas(10%): Heat source for ammonia decomposition
Scale-up from 1Nm^3/h to 10Nm^3/h

Overview of 10Nm^3/h-scale H_2 purifier (four-tower-type)

H_2 15Nm^3/h
N_2 5Nm^3/h

Purity of H_2
>99.98%

H_2 13.5Nm^3/h
N_2<1ppm

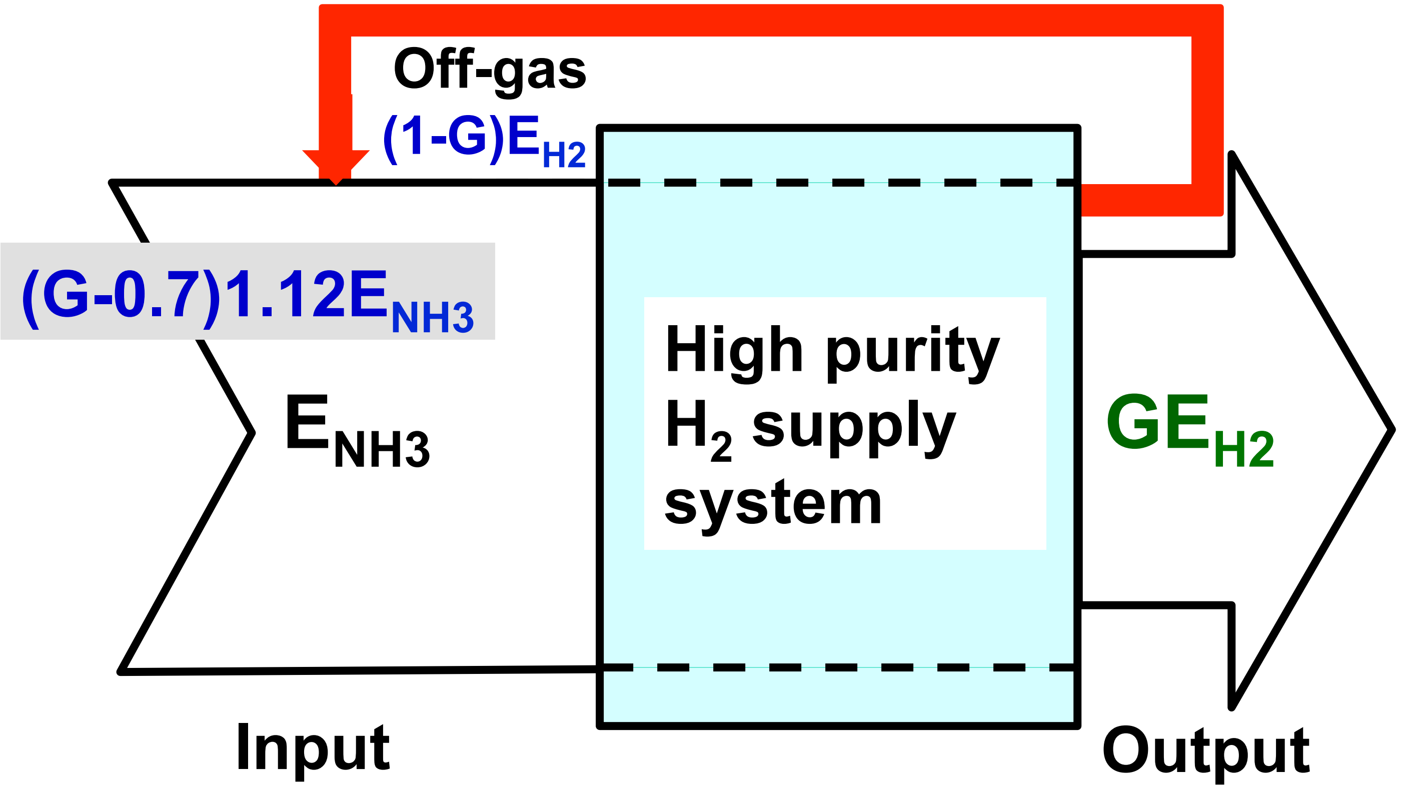


Off-gas
H_2 1.5 Nm^3/h
N_2 5Nm^3/h

Heat source for
ammonia
decomposition

We have a prospect for production of 300-1000Nm^3/h H_2 purifier.

Energy balance of ammonia decomposition and high purity H_2 supply system



$$e_c = \frac{GE_{H2}}{E_{NH3} + (G-0.7)1.12E_{NH3}}$$

E_{NH3}: Heat of combustion for ammonia, 17.1MJ/(1Nm^3/hNH_3)

$(G-0.7)1.12E_{NH3}$: Additional heat of decomposition

G: Hydrogen purification efficiency

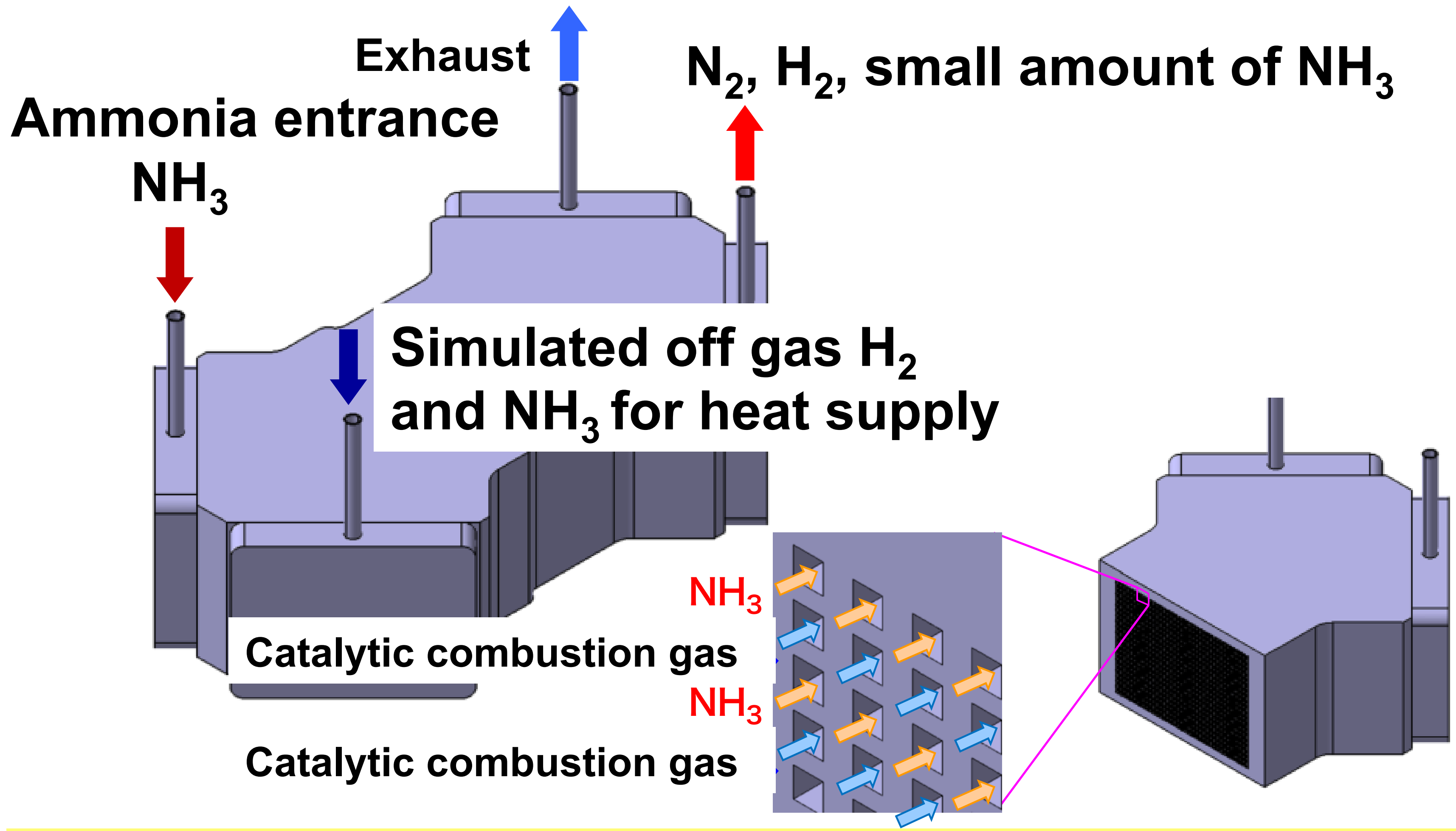
E_{H2}: Heat of combustion for hydrogen 19.2MJ/(1.5Nm^3/hH_2)

Calculated hydrogen conversion efficiency: 82%(G=0.9) >78%(G=0.7)

(3) NH_3 cracker with heat supply unit

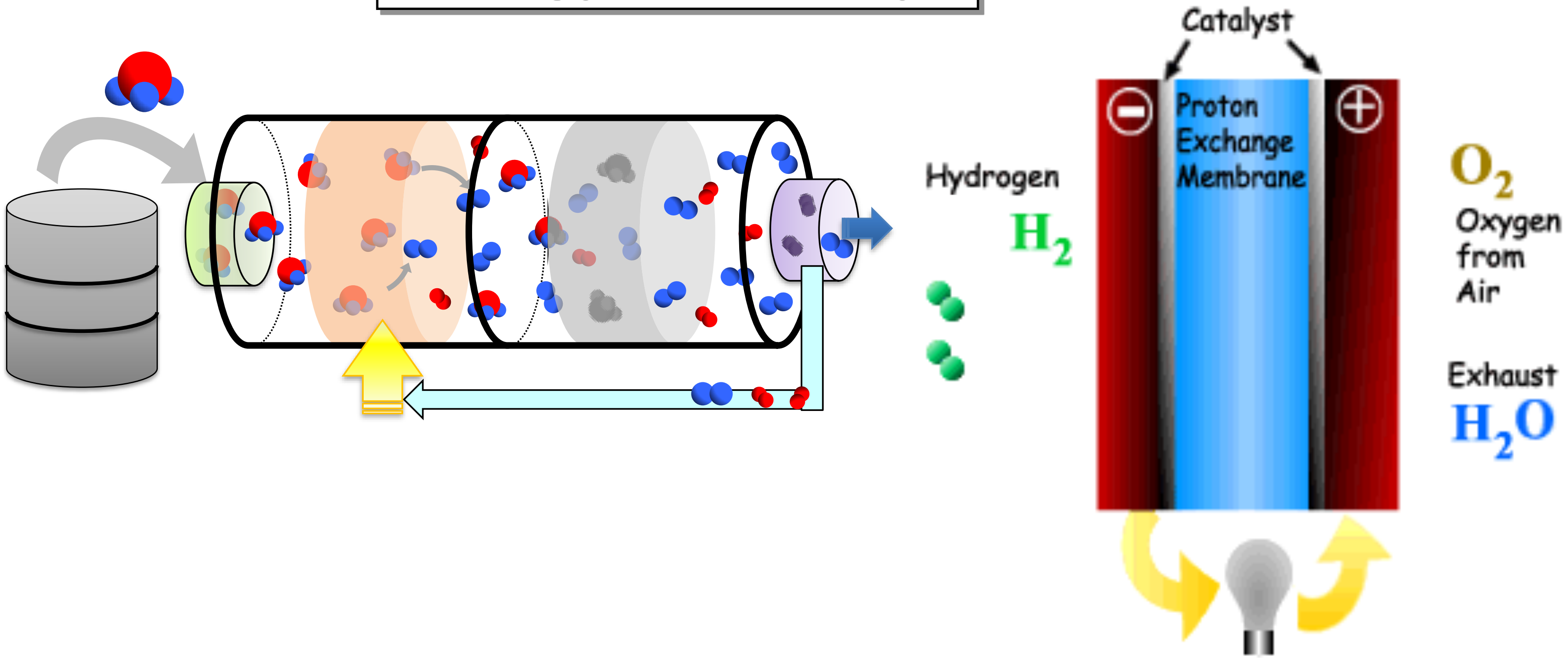
Micro-channel: High heat transfer performance compared with shell and tube

Micro-channel cracker(1Nm^3/h-scale) with heat supply unit



Residual ammonia concentration is 1500-2000ppm at 550°C and 10000h^{-1}.

Energy efficiency



Hydrogen conversion efficiency(e_c): 80%

Power generation efficiency(e_g): 60%

Energy efficiency($e_c \times e_g$): About 50%

3. Summary

(1) We have developed component technologies to detect ammonia concentration below 0.1ppm.

(2) We have developed 10Nm^3/h-scale high efficiency H_2 purifier.

(3) Hydrogen purification efficiency (hydrogen recovery rate) was 90% and production amount was 1.3times of the conventional purifier.

(4) Hydrogen conversion efficiency using micro-channel cracker was 80% and similar to the calculated value (82%).

Acknowledgements

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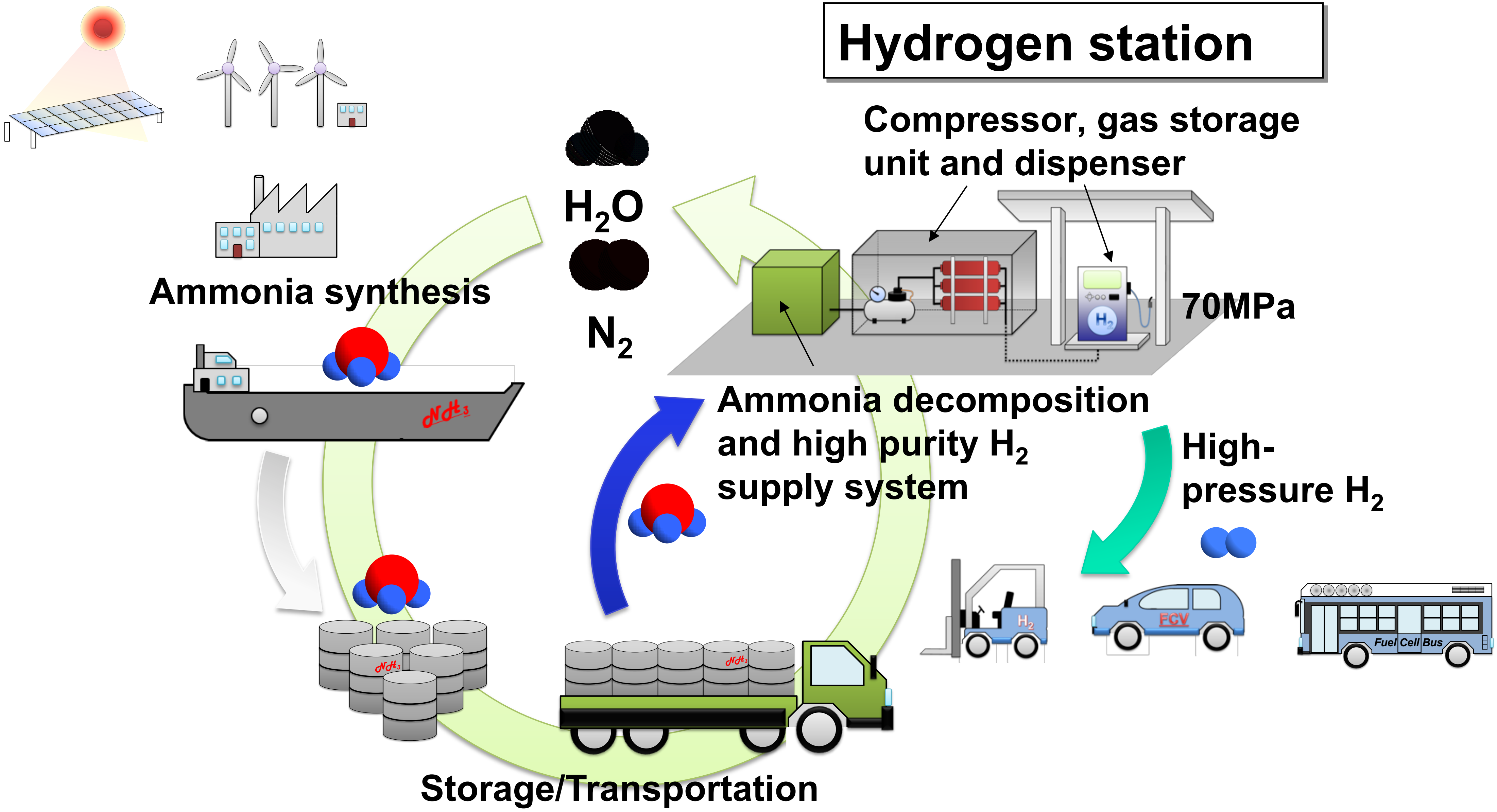

Thank you for your attention.