No．A-4-1E

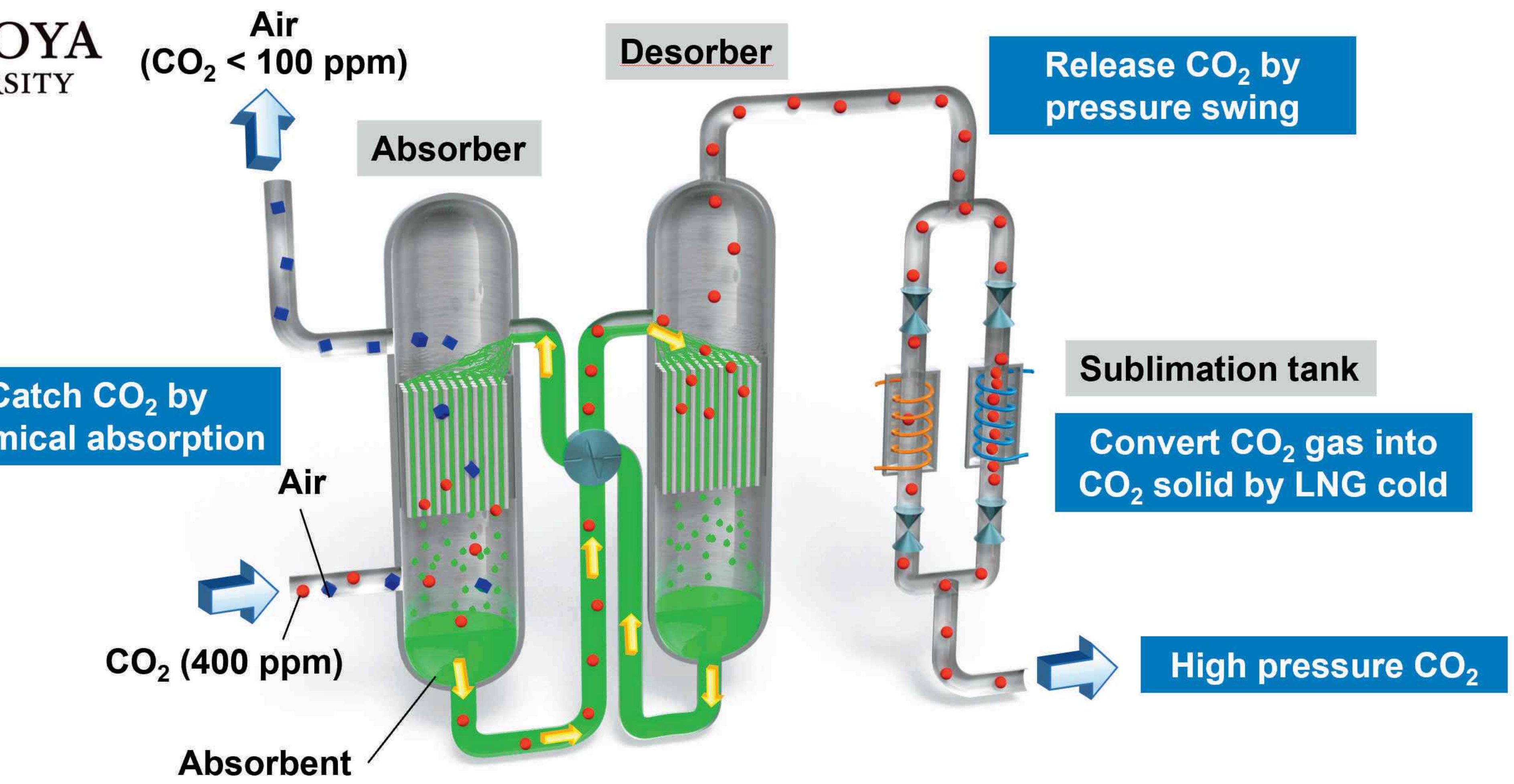
PJ： Research and Development Toward Saving Energy for Direct Air Capture With Available Cold Energy

Team： Nagoya University, TOHO GAS, Tokyo University of Science
JGC, The University of Tokyo, Chukyo University
Contact： Institute of Innovation for Future Society, Nagoya Univeristy
Koyo NORINAGA　(norinaga@nagoya-u.jp)

An alternative DAC with pressure swing amine process driven by cryogenic pumping with LNG cold

Cryo-DAC®

NAGOYA UNIVERSITY



Team

NAGOYA UNIVERSITY

- Cryo-DAC®　concept design
- High-performance amine development

TOHO GAS

- Process simulation for cost and energy analysis

TOKYO UNIVERSITY OF SCIENCE

- Material selection and analysis

JGC HOLDINGS CORPORATION

- Cryo-DAC plant design and construction

UTokyo

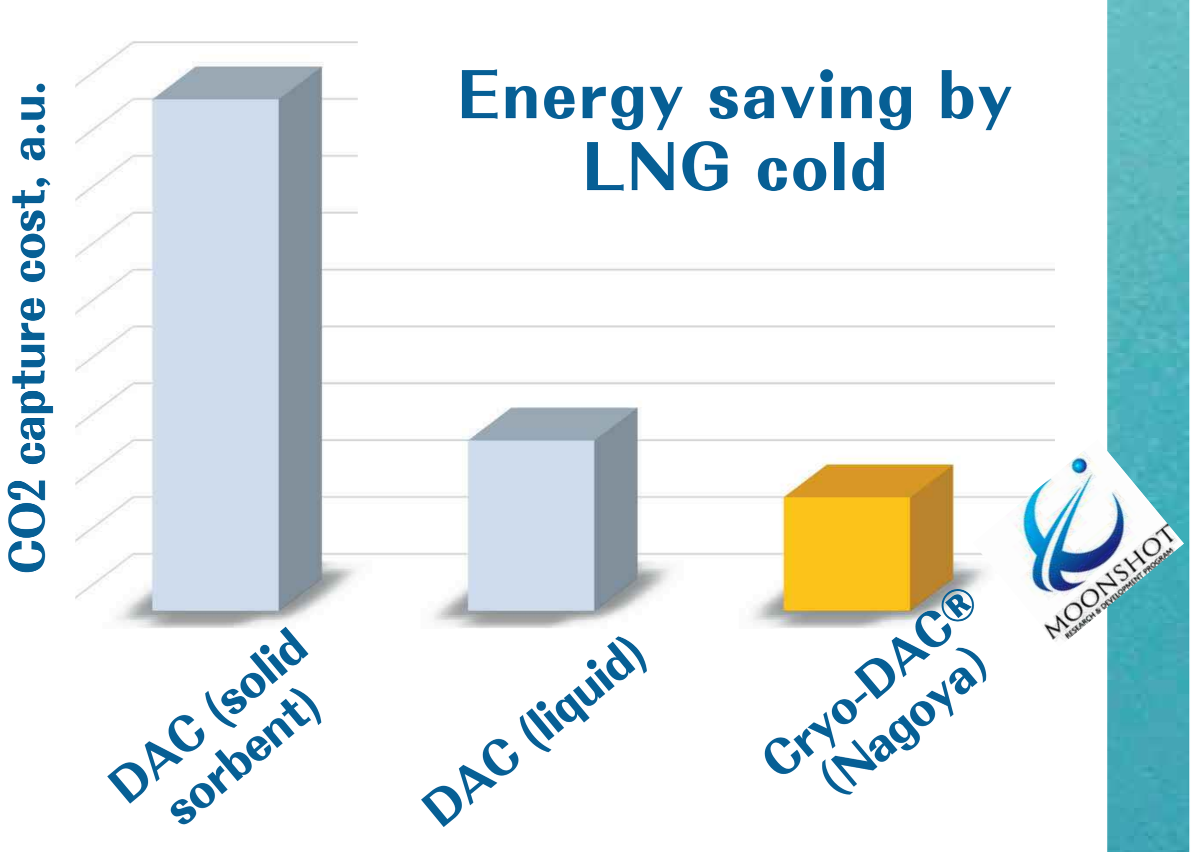
- Exergy-based process analysis
- Sensing device for stable operation

CHUKYO UNIVERSITY

- Environmental and economic analysis

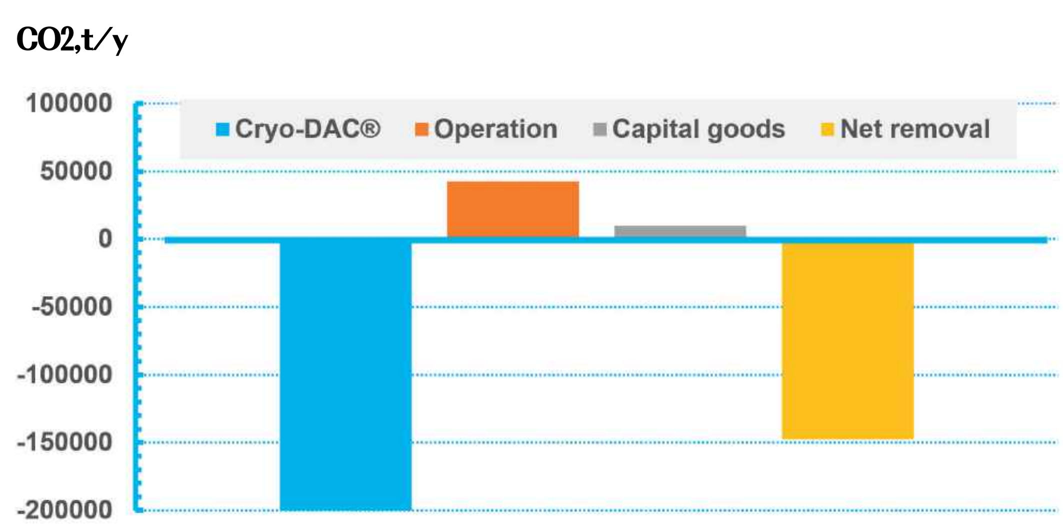
Cost

TOHO GAS



Life cycle assesment

CHUKYO UNIVERSITY



※1　CO2 emission factor :0.506 kg/kWh (2020)

※2　Aspen Economic Analyzer / National Institute for Environmental Studies 3EID database

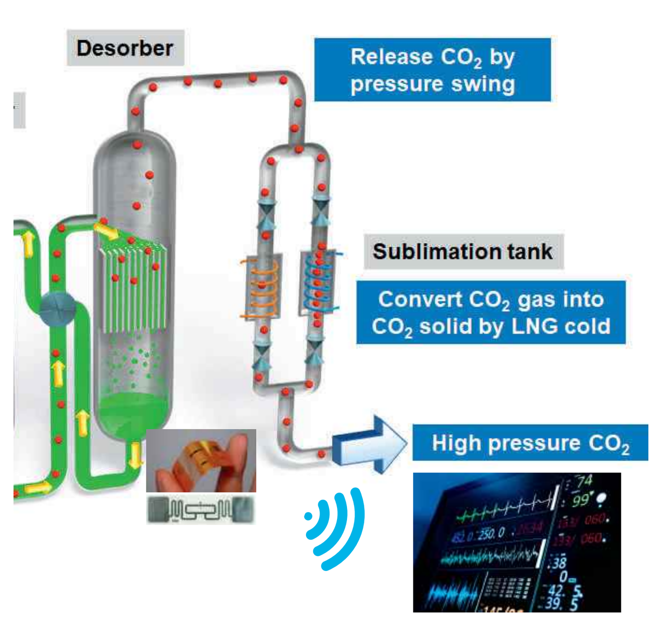
Material

TOKYO UNIVERSITY OF SCIENCE

Fatigue tests (>10　cycles, 25 years operation) in liquid nitrogen proved SUS 304 to be a candidate material for the sublimation tank

Sensor

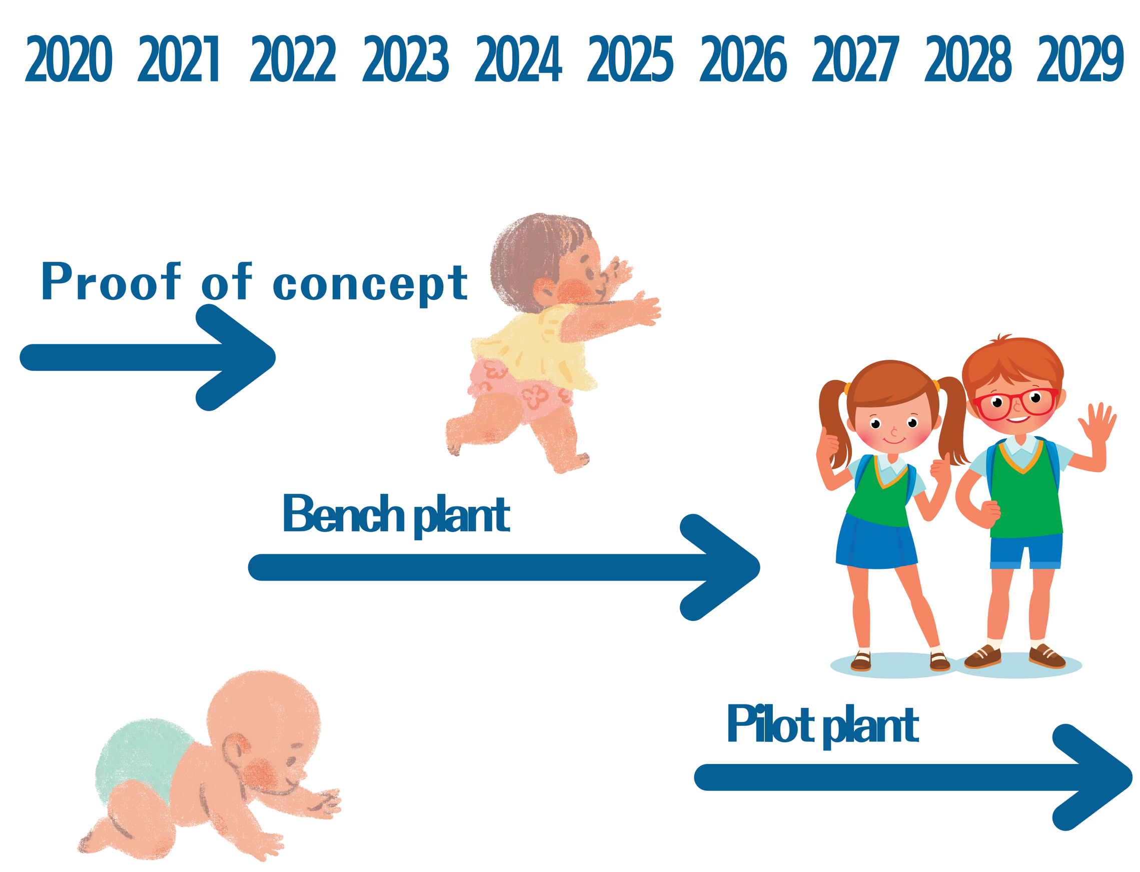
UTokyo



Integrity monitoring with wireless sensor

Roadmap

JGC HOLDINGS CORPORATION



No. A-4-2E

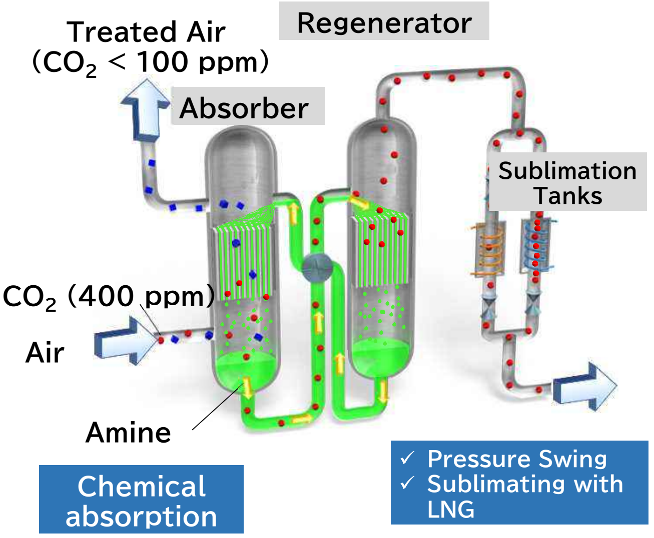
PJ : Research and Development Toward Saving Energy for Direct Air Capture With Available Cold Energy

Theme : Development of Cryo-DAC® process

Organization : Nagoya University

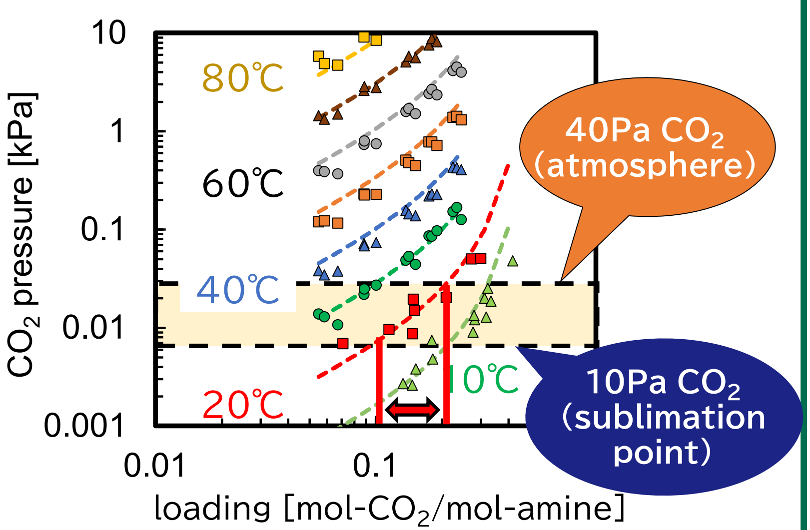
Contact : Institutes of Innovation for Future Society, Koyo NORINAGA (norinaga_at_nagoya-u.jp)

Cryogenic + DAC, Cryo-DAC®



Pressure swing absorption driven by a cryogenic pumping by LNG cold heat

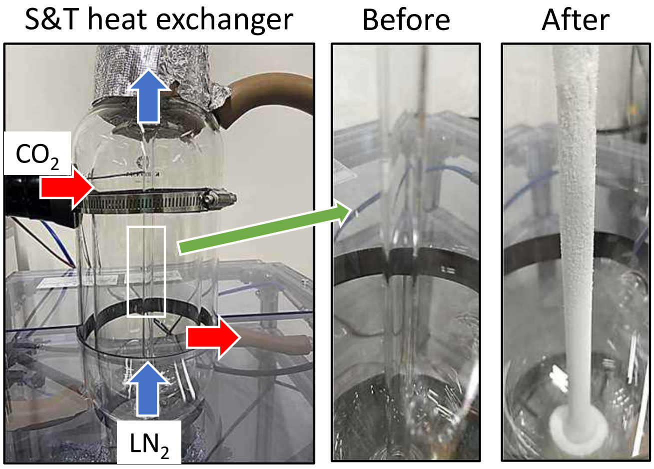
◆ NU-01, Low vapor pressure and large loading absorbent



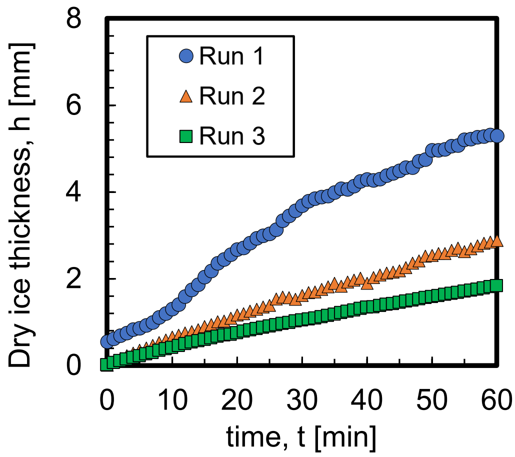
✓ Loading difference > 0.1

✓ Low vapor pressure 0.5Pa

◆ Visualization of sublimation from CO_2 gas into dry ice

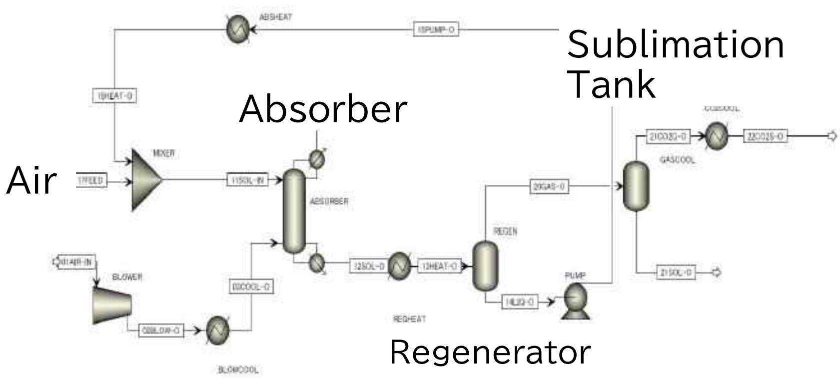


Sublimating



Sublimation rate are characterized.

◆ Process flow diagram



✓ The conceptional PFD of a bench scale Cryo-DAC® are developed.

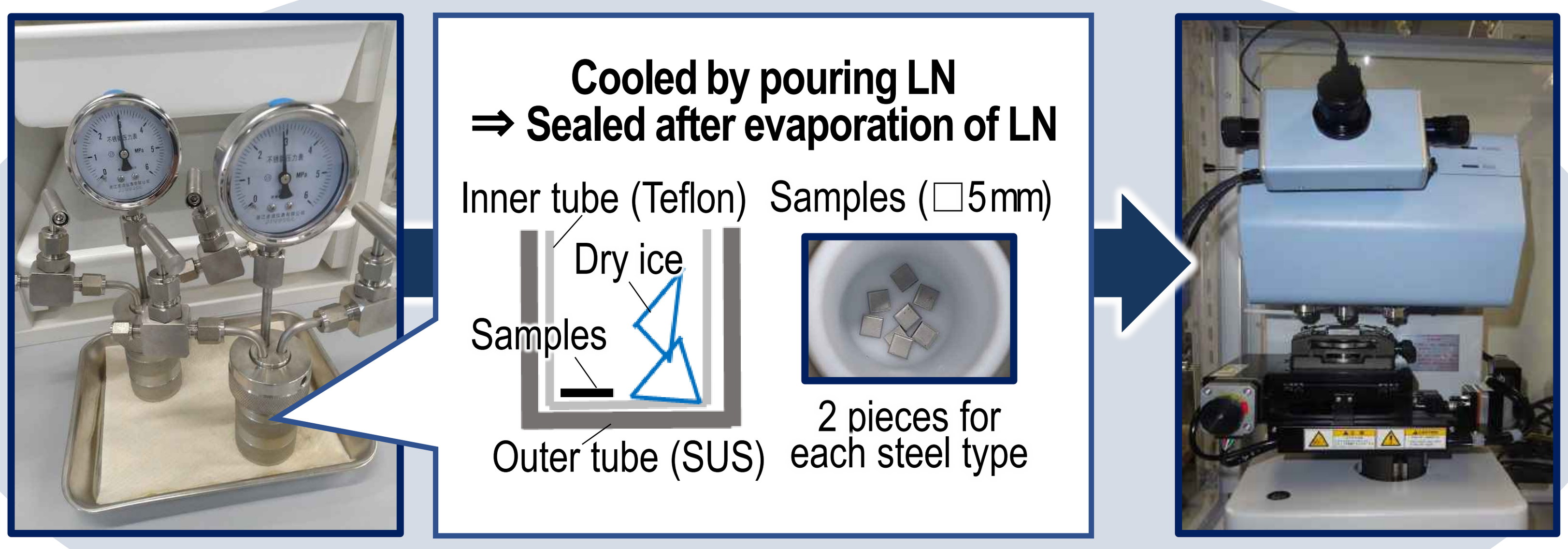
✓ The sublimation tank are designed based on a knowledge of a S&T heat exchanger.

No. A-4-3E
PJ : Research and Development Toward Saving Energy for Direct Air Capture With Available Cold Energy
Theme: Reliability evaluation of structural materials for Cryo-DAC® sublimation tanks
Organization: Tokyo University of Science
Contact: Faculty of Engineering, Tokyo University of Science. Yumi TANAKA (yutanaka@rs.tus.ac.jp)

Evaluation of the effect of temperature swing between cryogenic temperature and room temperature on steel strength in the presence of CO_2 and amines

Samples: Austenitic stainless steels resistant to cold temperatures (SUS304, 304L, 316, 316L)

■ Cold thermal shock test (CTST) was conducted in the presence of CO_2 (dry ice/CO_2 gas) in which the operation of "cooling with LN ⇔ rewarming to RT" was repeated.
⇒ Surface hardness after 1000 cyc.: SUS304≈SUS304L (+3〜+8% vs. ini.) ≫ SUS316≈SUS316L (-40〜-50%)



Cooling to -196℃ ⇄ rewarming to RT (〜1000 cyc.)

Surface hardness measurement

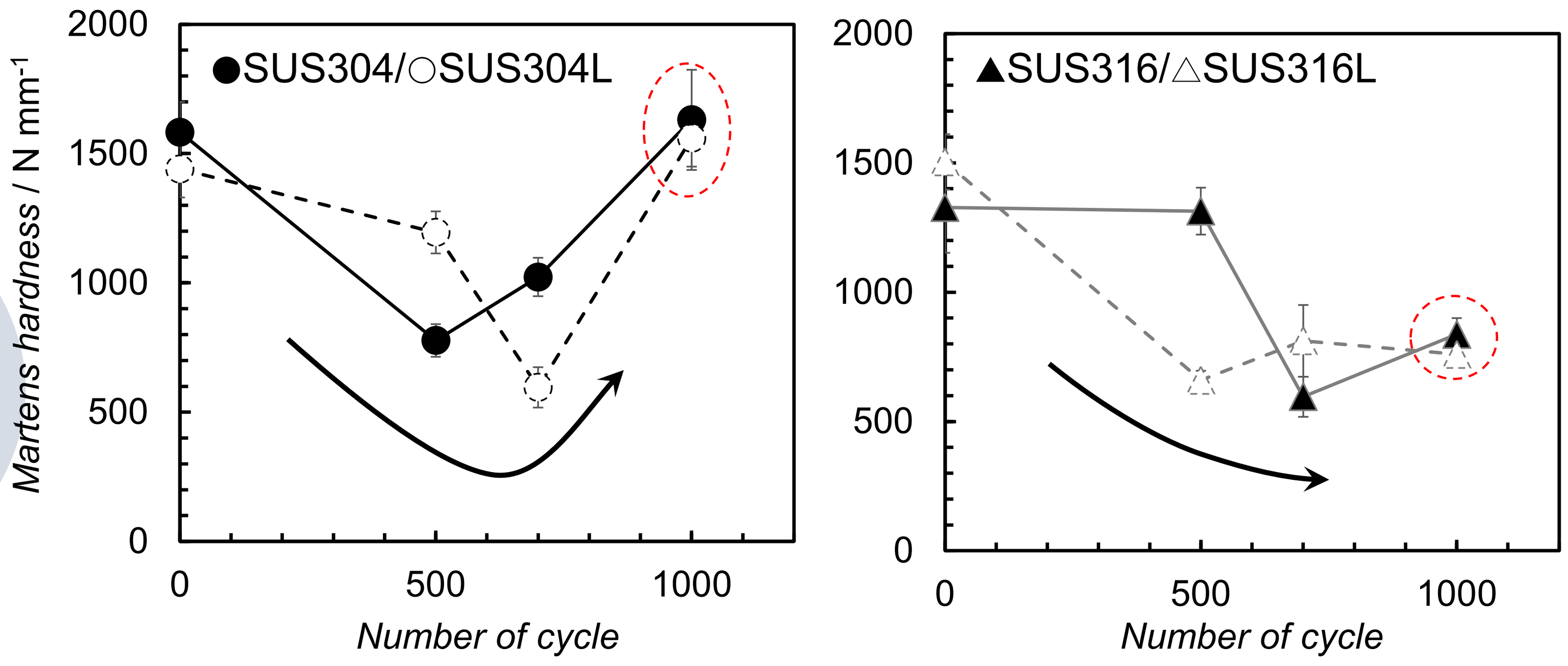


Fig.1 Change in surface hardness of steels during CTST in the presence of CO_2

■ CTST was conducted in the presence of CO_2 (dry ice/CO_2 gas) & CO_2 absorption liquid (25% aqueous solution of monoethanolamine)
⇒ Surface hardness after 1000 cyc.: Degreased significantly in all steel types (-60〜-70% vs. ini.)

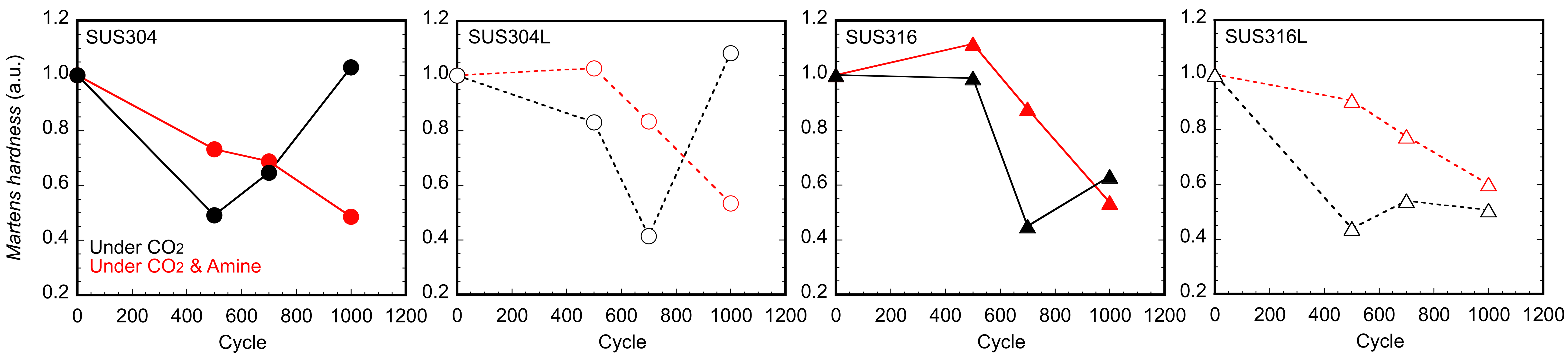


Fig. 2 Change in surface hardness of steels during CTST in the presence of CO_2/amine

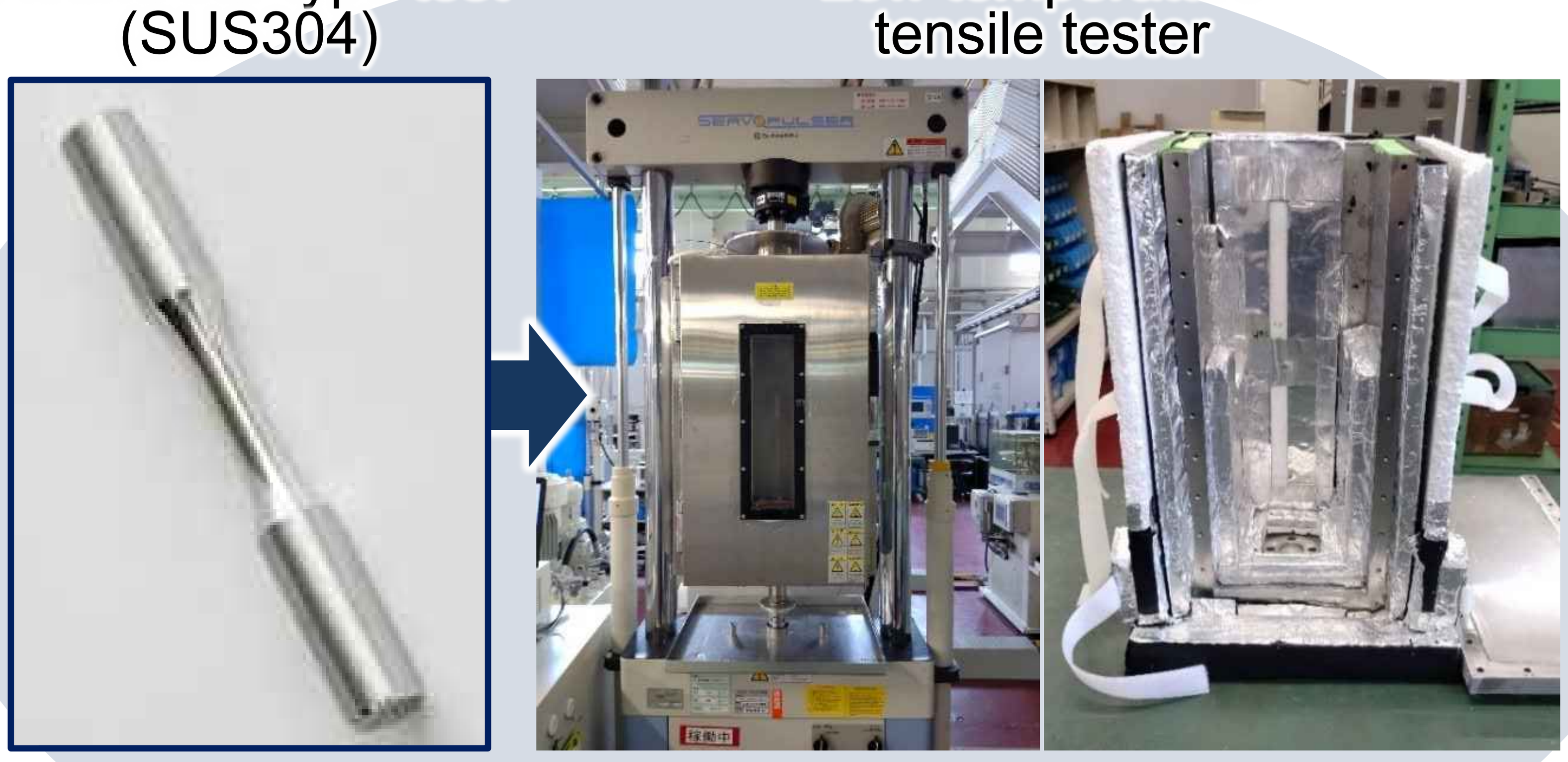
Durability evaluation of SUS304 for the operation period assumed for Cryo-DAC® (25 years: 10^7 cyc.)

Samples: SUS304 / Surface hardness change before/after CTST (〜1000 cyc.) under CO_2 = +3%

■ Tensile fatigue test (400 MPa−560 MPa, 25 Hz, 〜10^7 cyc.) was conducted at -196℃
⇒ Fatigue limit at 10^7 cyc.: 447.5 Mpa ≫ Stress fluctuation due to temp. swing from -196 ℃ to RT (10 Pa⇔4 MPa)

Round bar type test (SUS304)

Low temperature tensile tester



Stress swing: 400, 430, 465, 500, 530, 560 MPa
Temperature: -196℃ (under LN)
Swing rate & cycle: 25 Hz, 〜10^7 cyc.)

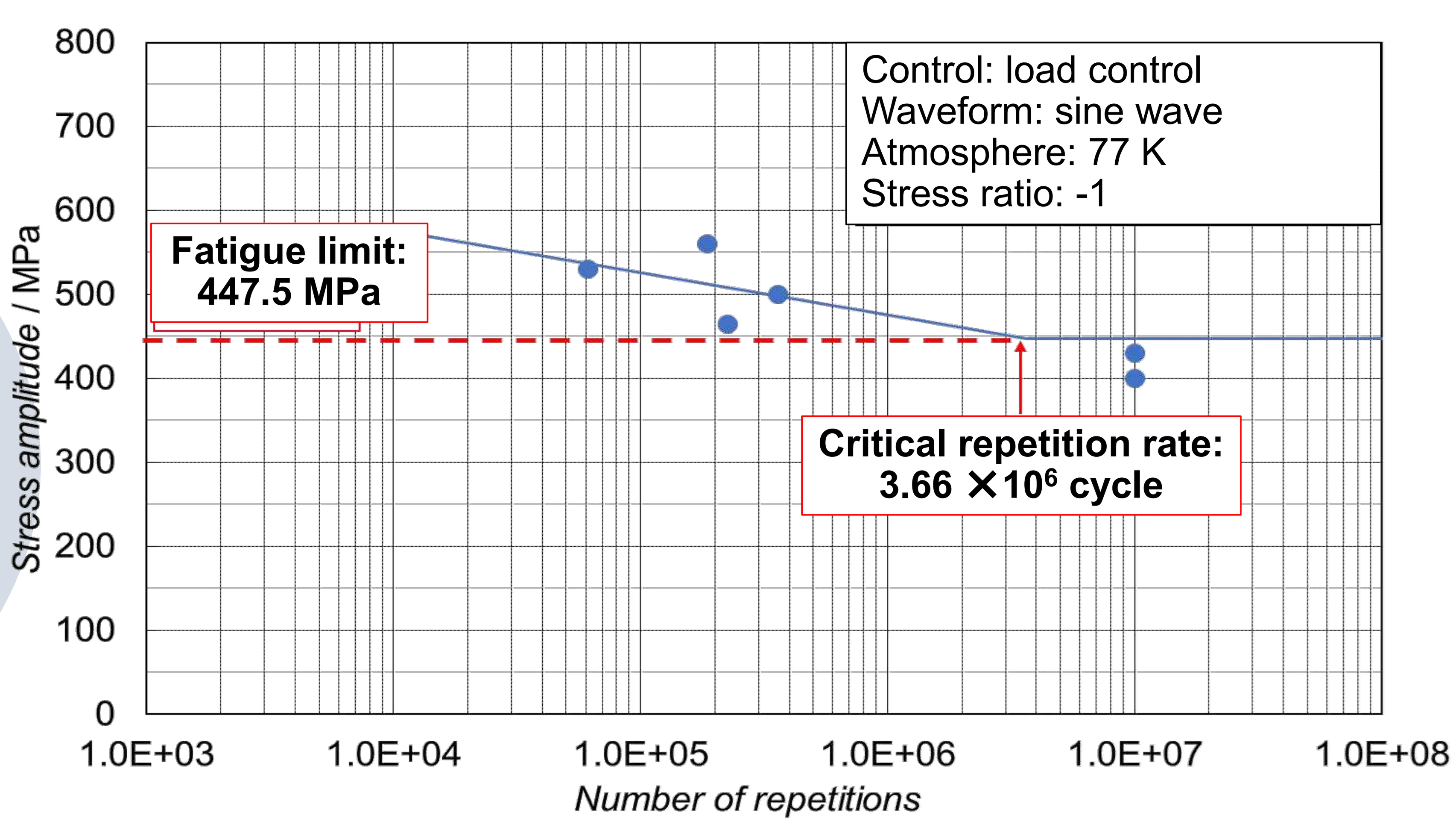


Fig. 3 S-N diagram of SUS304 under LN temperature

No. A-4-4E

PJ : Research and Development Toward Saving Energy for Direct Air Capture With Available Cold Energy

Theme: Designing the concept of Cryo-DAC® process/system

Organization: Toho Gas Co., Ltd.

Contact: Technical Research Institute, Toho Gas Co., Ltd., Soichiro MASUDA (smasuda@tohogas.co.jp)

Evaluation of energy and cost (by the University of Tokyo)

- Cryo-DAC® process has been simulated with a process simulator, Aspen Plus.
- The optimal conditions to minimize DAC cost has been investigated in a parametric study.

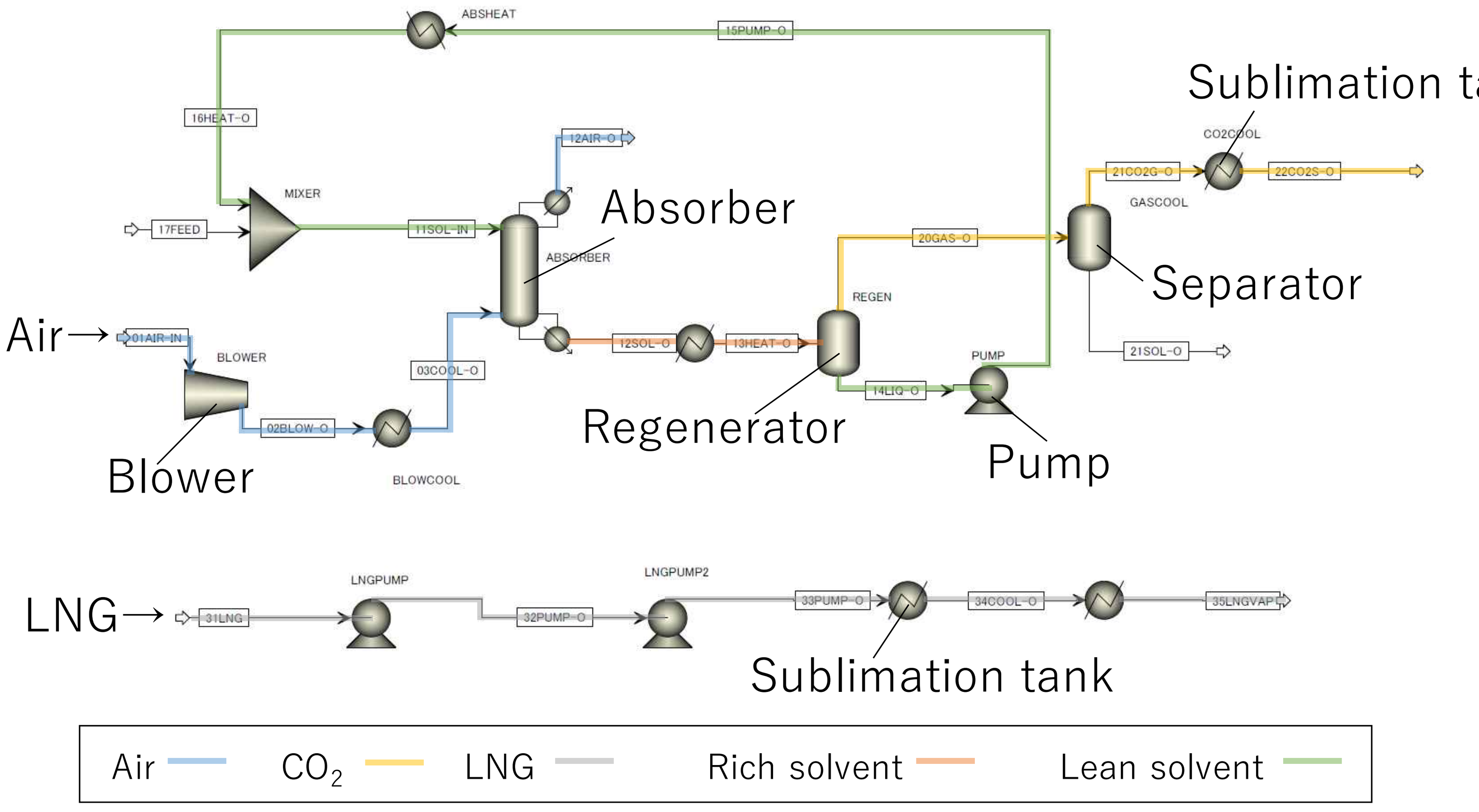


Fig. 1. Process flow diagram of Cryo-DAC®

Parameter A: Small → Large; Parameter B: small ↓ Large

55% down☺

Parameter B \ Parameter A	Small					Large
small	0.95	0.53	0.46	0.45	0.47	0.62
	0.61	0.51	0.49	0.49	0.52	0.65
	0.63	0.57	0.56	0.56	0.59	0.72
	0.68	0.64	0.63	0.63	0.65	0.78
	0.74	0.72	0.72	0.71	0.73	0.86
	0.81	0.79	0.79	0.78	0.80	0.93
Large	0.87	0.86	0.86	0.85	0.87	1.00

The cost has been relativized by setting this cost to 1

Fig. 2. Parametric study on DAC cost

Life cycle assessment (by Chukyo University)

- Life cycle CO_2 has been investigated in the system that is limited to Cryo-DAC®, the sub-system boundary B.
- Net CO_2 removal has been achieved with the current CO_2 emission factor, 0.506 kg/kWh.

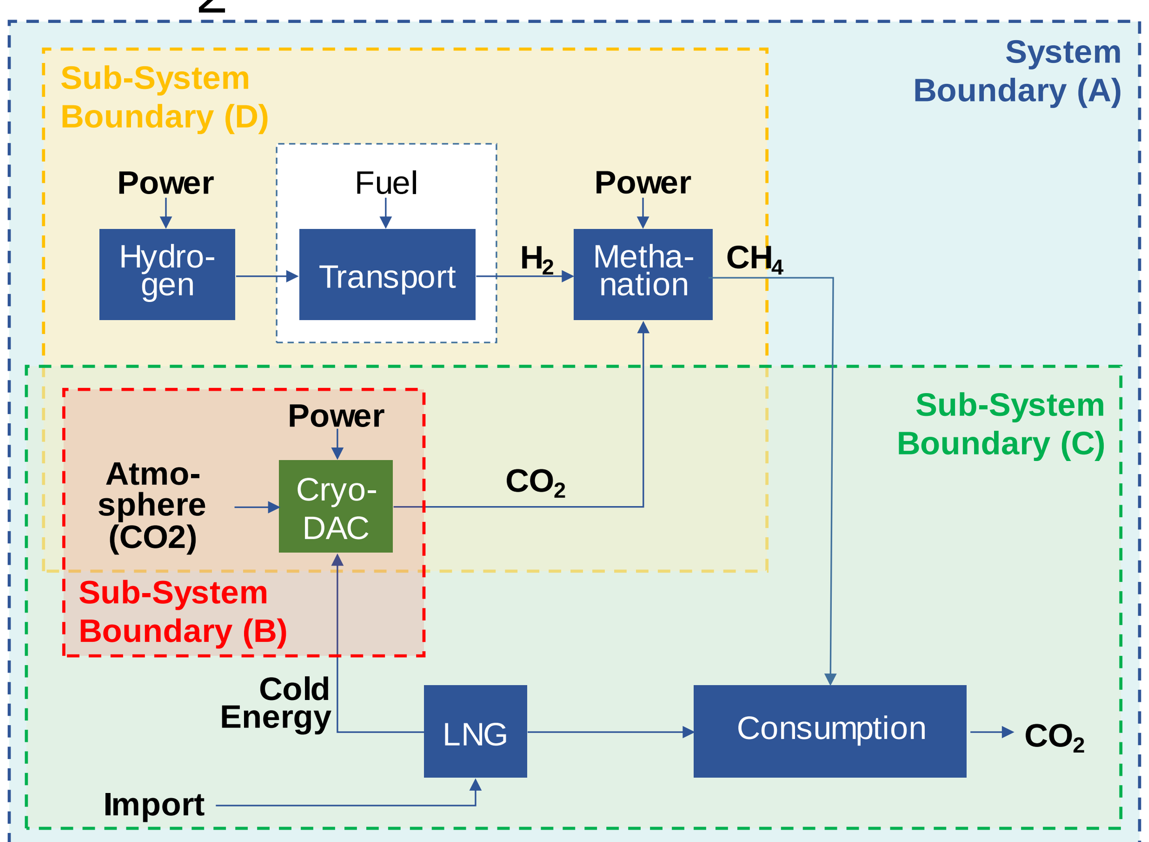
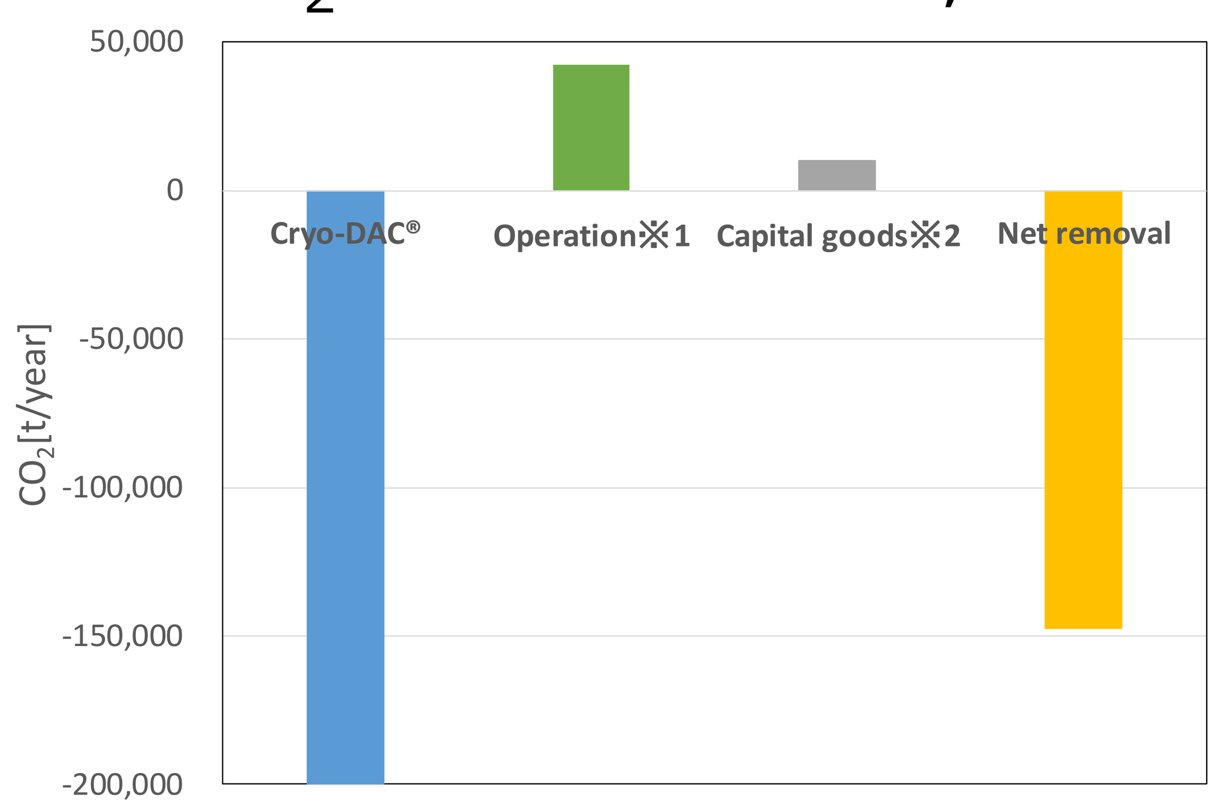


Fig. 3. The system boundary for the life cycle assessment



※1 CO_2 emission factor: 0.506kg/kWh (2020) from NEDO's guideline
※2 Aspen Process Economic Analyzer / National Institute for Environmental Studies 3EID database

Fig. 4. Result of the life cycle assessment

Development of sensing technology (by the University of Tokyo)

- The sensors that can be used at liquefied natural gas (LNG) temperature of about -160℃ have been developing to monitor the soundness of the sublimation tanks.
- The measurement of steel deformation has been achieved with micro electro mechanical systems (MEMS) strain sensors at liquid nitrogen temperature of about -190℃.

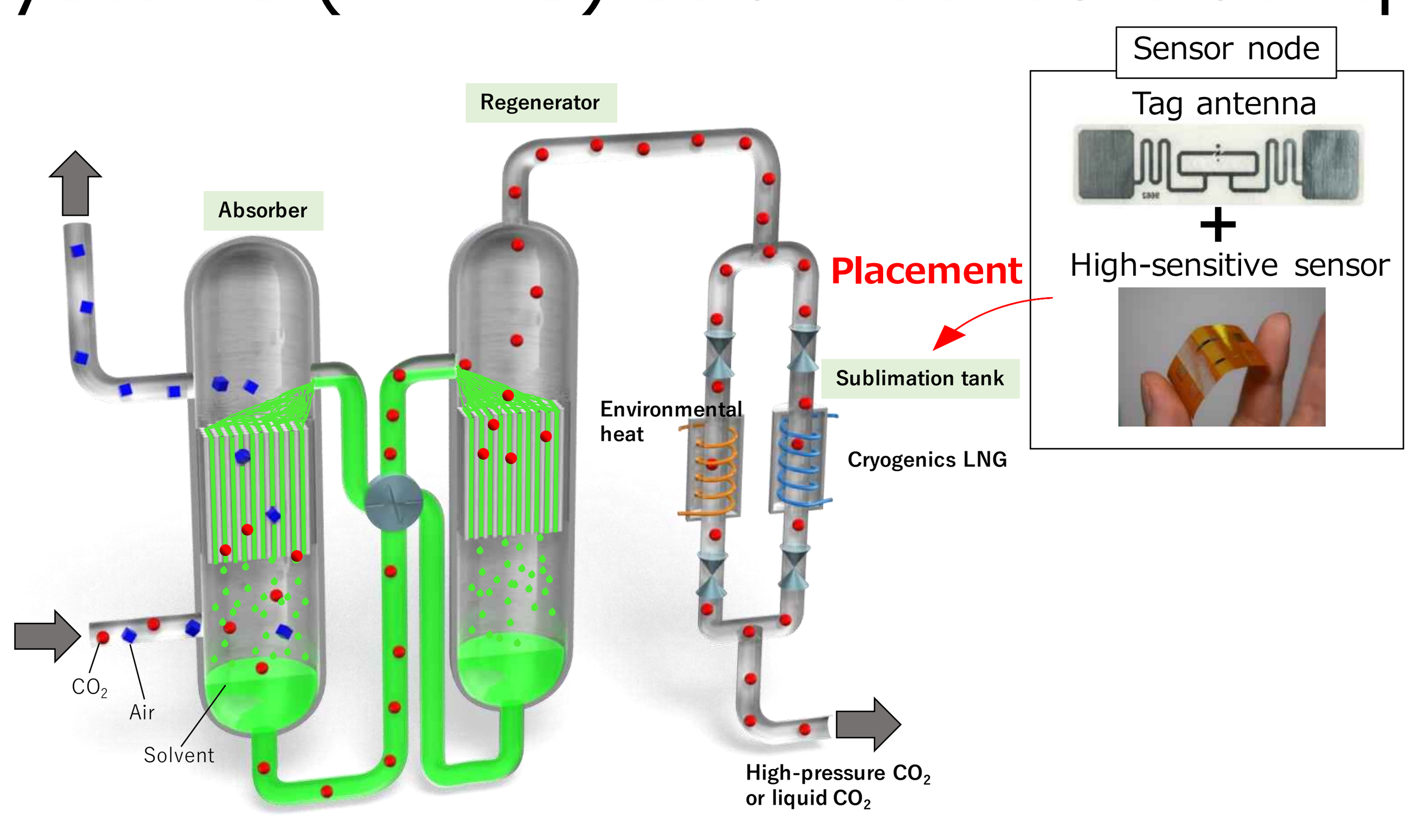
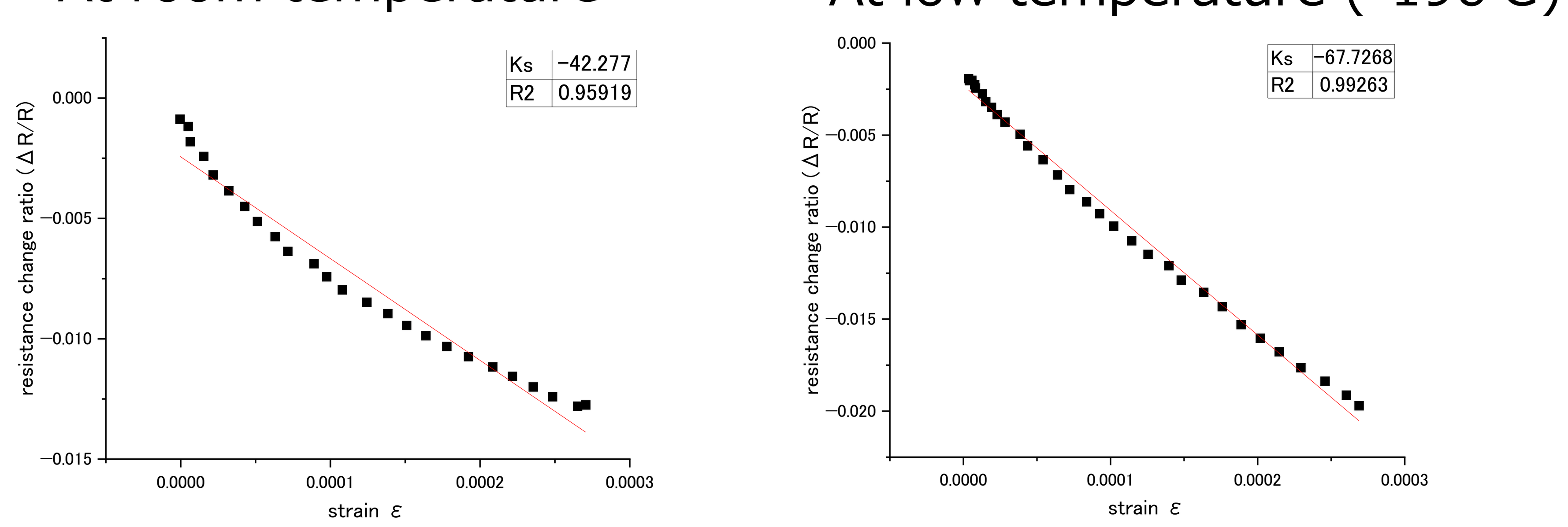


Fig. 5. Diagram depicting use of the sensors



$$K_s = \frac{\Delta R/R}{\epsilon}$$

K_s :Gauge factor R :Gauge resistance
ε :Strain ΔR :Resistance change

Fig. 6. Gauge factor of MEMS sensors