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

Nagoya University, TOHO GAS, Tokyo University of Science, JGC, The University of Tokyo, Chukyo University

PM NORINAGA, Koyo
Nagoya University

Cryo-DAC®

Our challenge

Research and Development Toward Saving Energy for Direct Air Capture **with Available Cold Energy**

YouTube JP

NEDO Moonshot Goal4/Capturing CO_2 Through Cooling and Solidification / Dr. NORINAGA Koyo

NEDO
NAGOYA UNIVERSITY
TOHO GAS
JGC HOLDINGS CORPORATION
MOONSHOT RESEARCH & DEVELOPMENT PROGRAM
THE UNIVERSITY OF TOKYO
CHUKYO UNIVERSITY
TOKYO UNIVERSITY OF SCIENCE

Cryo-DAC® our 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 JGC HOLDINGS CORPORATION

Cryo-DAC® plant design and construction

THE UNIVERSITY OF TOKYO

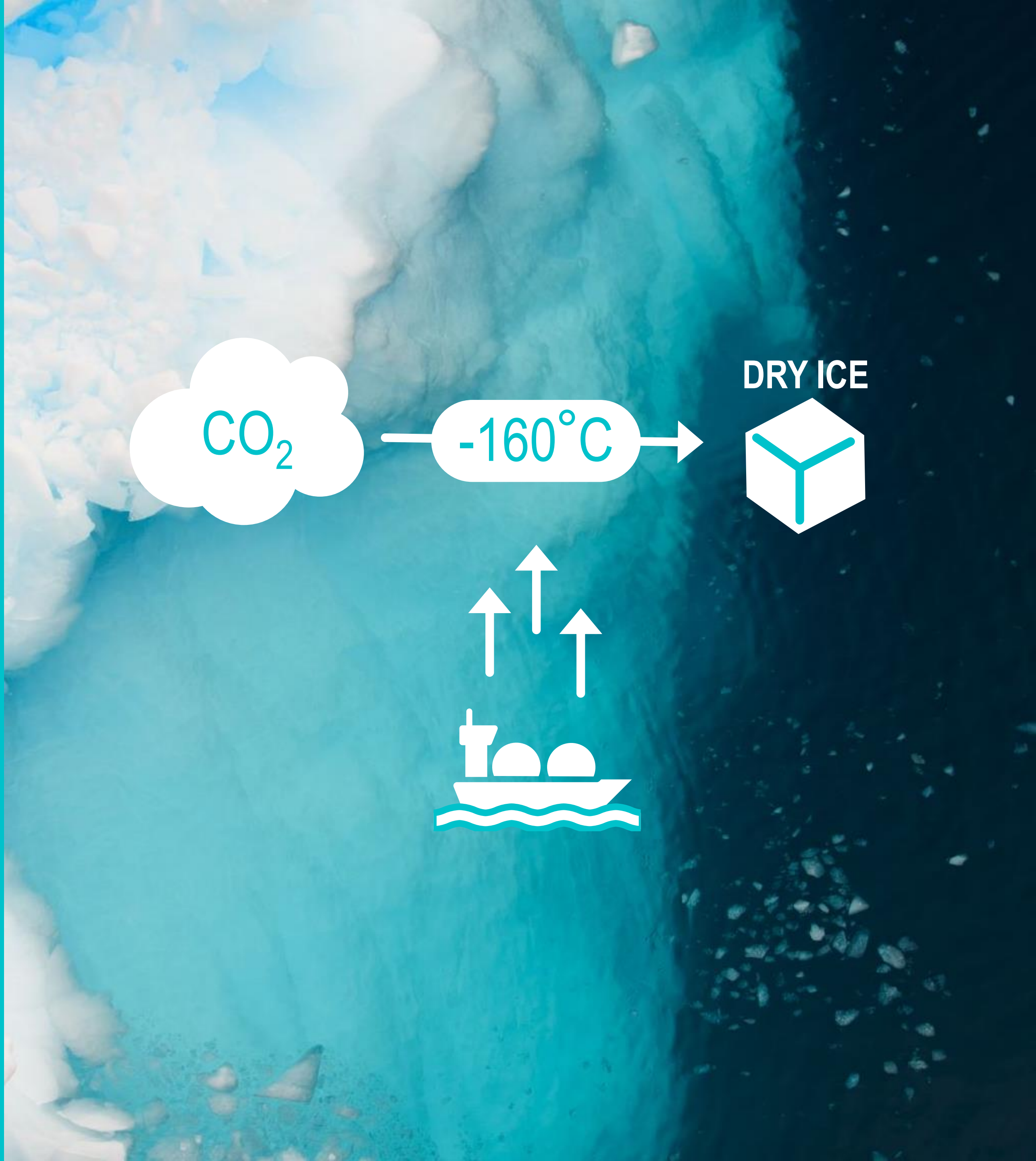
Exergy-based process analysis
Sensing device for stable operation

CHUKYO UNIVERSITY

Environmental and economic analysis

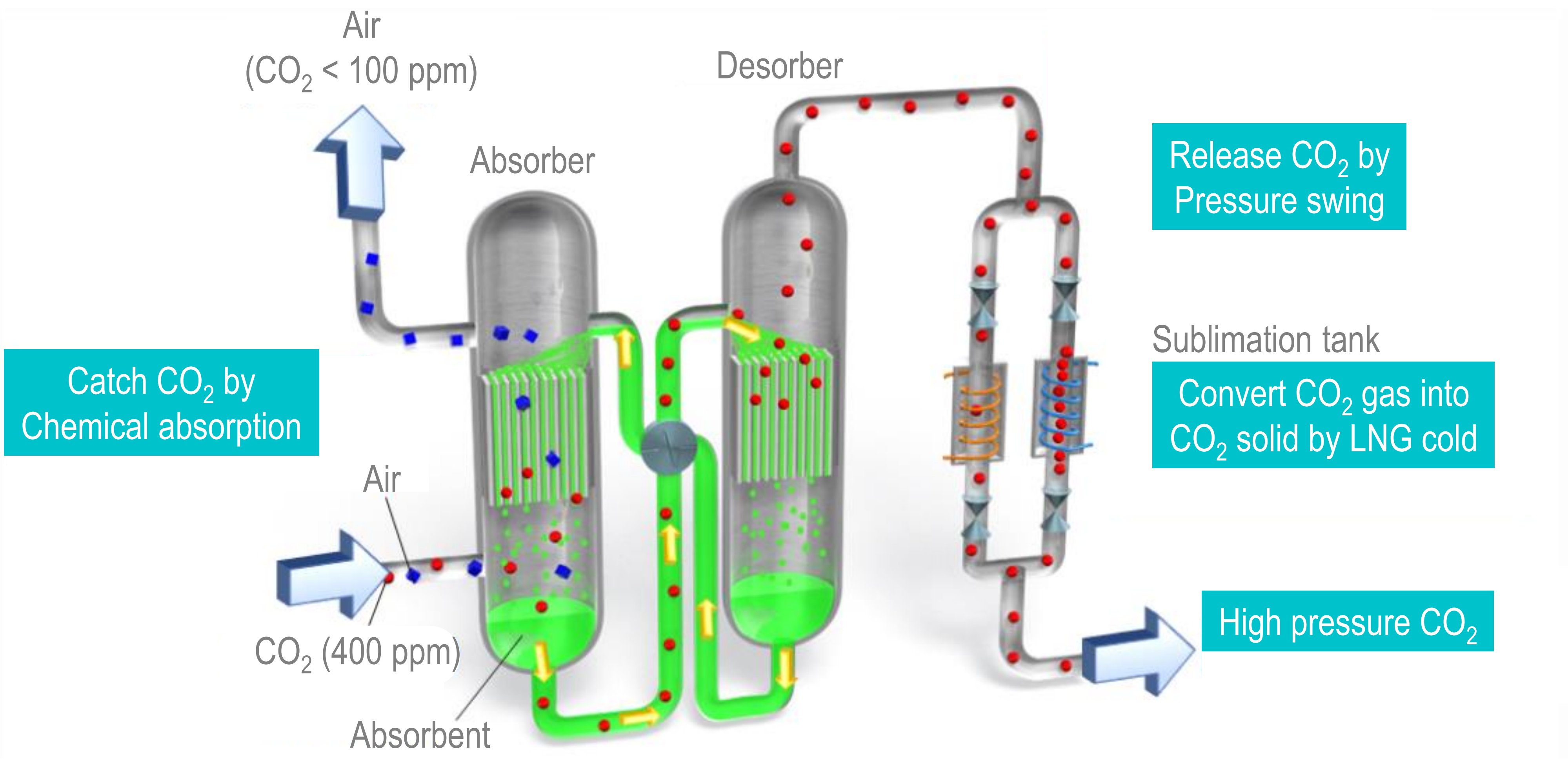
DAC with LNG coldness

Japan imports 75 millions tons of LNG in 2021

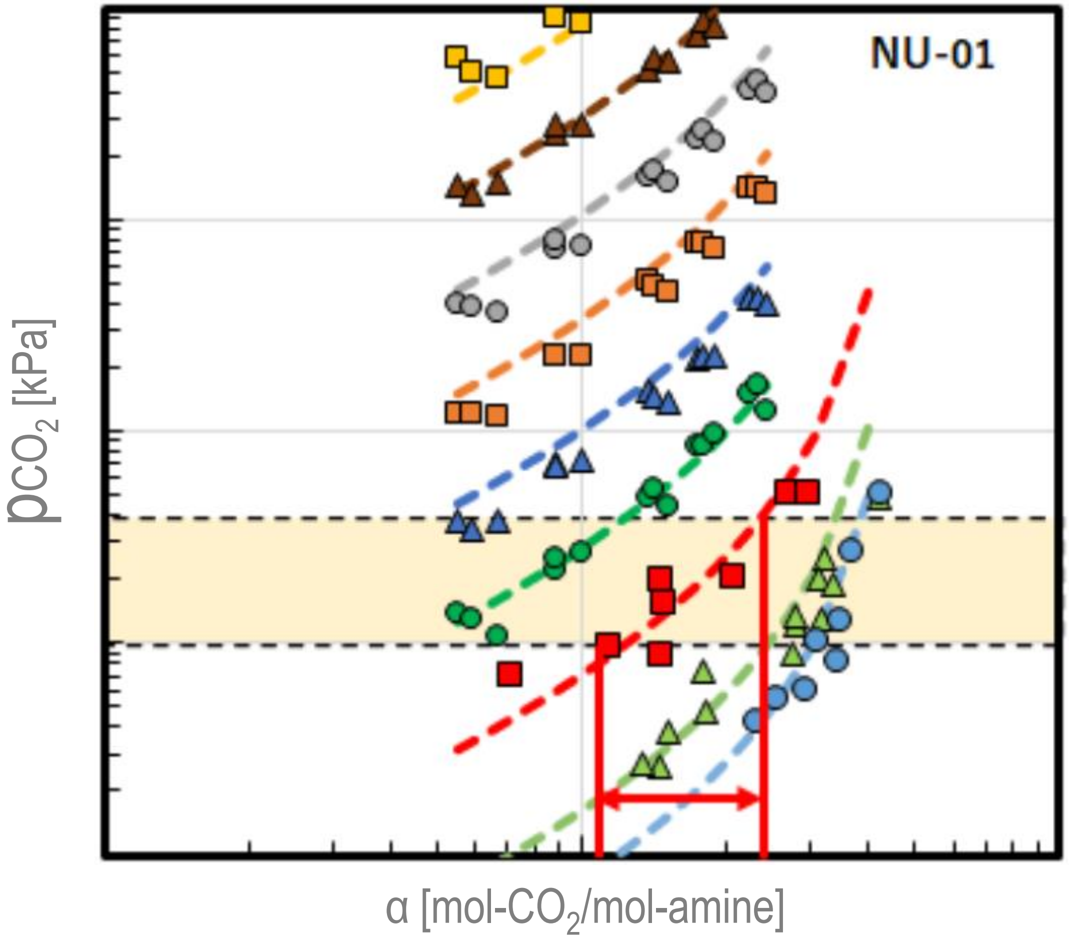


Cryo-DAC®

A pressure swing amine process driven by the cryogenic pumping with LNG cold

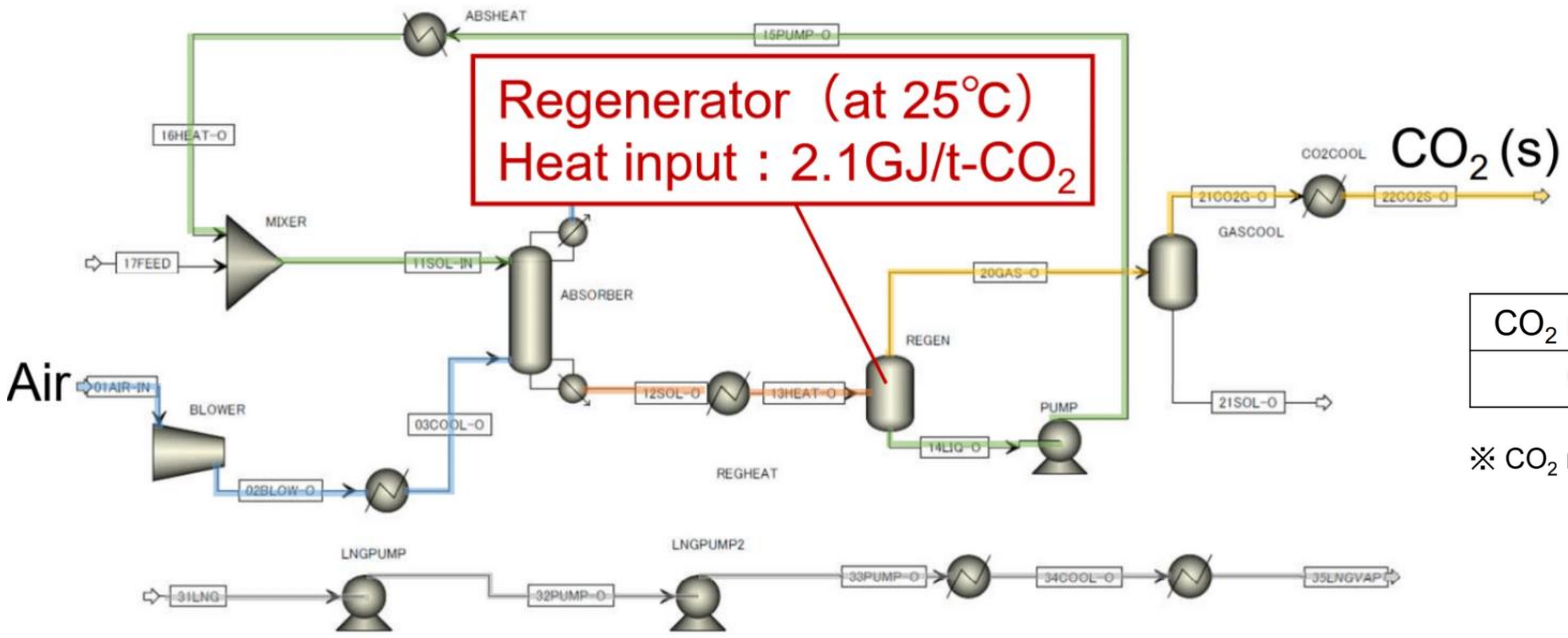


Cryo-DAC® liquid absorbent



Screening good amine/solvent mixtures
by high throughput CO_2 solubility measurements

Cryo-DAC® process simulation



CO_2 recovery ratio※	73.0 %
CO_2 purity	98.5 %

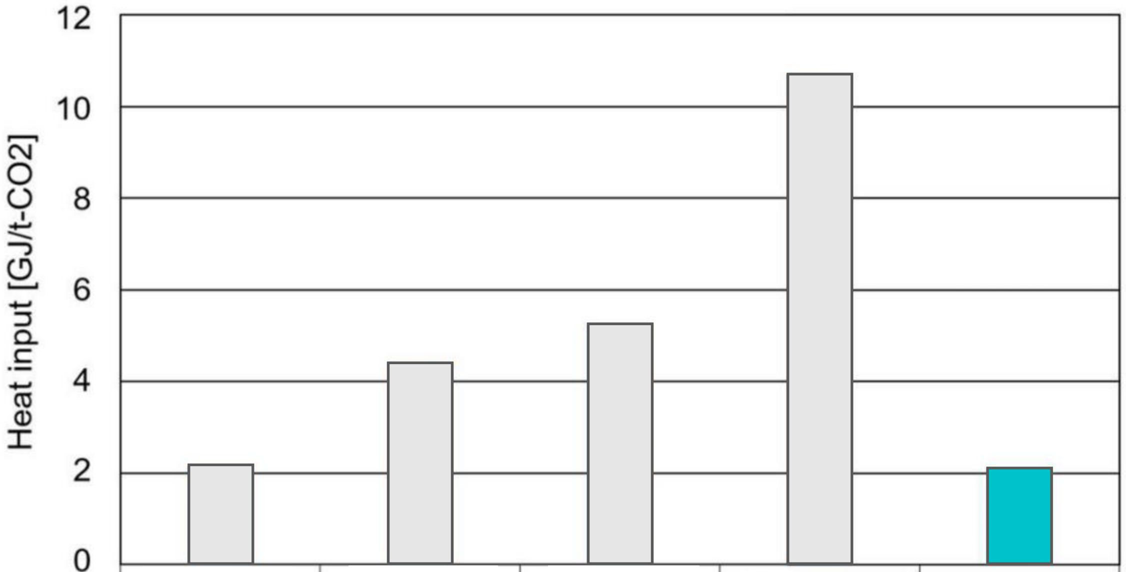
※ CO_2 recovery ratio = $\dfrac{\text{Amount of } CO_2 \text{ recovered}}{\text{Amount of } CO_2 \text{ in the feed air}}$

N120 **Energy evaluation of DAC process by chemical absorption utilizing unused cold energy of LNG**

(Toho Gas) *(Cor)Nakayama Yuki, (Cor)Kojima Misako, (Cor)Masuda Soichiro, (Cor)Tanaka Youichi, (Cor)Yabushita Masataka, (Cor)Koizumi Masahisa, (Nagoya U.) (Reg)Hirayama Mikiro, (Reg)Machida Hiroshi, (Reg)Umeda Yoshito, (Reg) **Norinaga** Koyo

SCEJ The Society of Chemical Engineers, Japan
SCEJ 87th Annual Meeting

Cryo-DAC® thermal energy requirement



	DAC A	DAC B	DAC C	DAC equipped with MEA※	This study
Regeneration temperature	100℃	85~95℃	900℃	123℃	25℃
Method	Solid sorbent		Liquid solvent		

※MEA＝ monoethanolamine

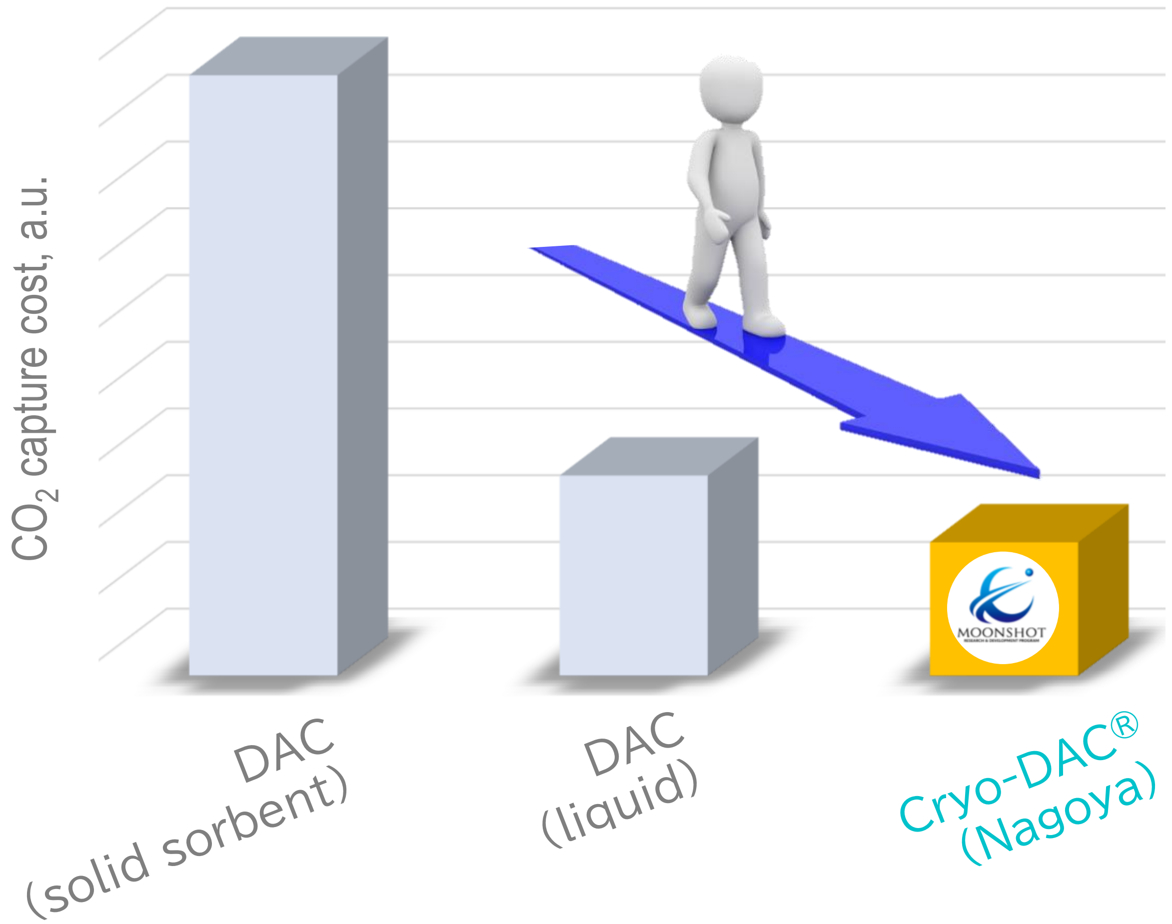
Fasihi, M et al., J. Clean. Prod., 224, 957 (2019).
Kiani, A et al., Front. Energy Res., 8, 92 (2020).

N120 **Energy evaluation of DAC process by chemical absorption utilizing unused cold energy of LNG**
(Toho Gas) *(Cor)Nakayama Yuki, (Cor)Kojima Misako, (Cor)Masuda Soichiro, (Cor)Tanaka Youichi, (Cor)Yabushita Masataka, (Cor)Koizumi Masahisa, (Nagoya U.) (Reg)Hirayama Mikiro, (Reg)Machida Hiroshi, (Reg)Umeda Yoshito, (Reg) **Norinaga** Koyo

SCEJ The Society of Chemical Engineers, Japan

SCEJ 87th Annual Meeting

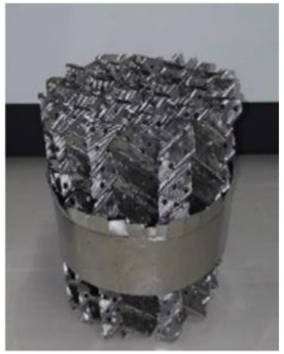
Cryo-DAC® cost (perspective)

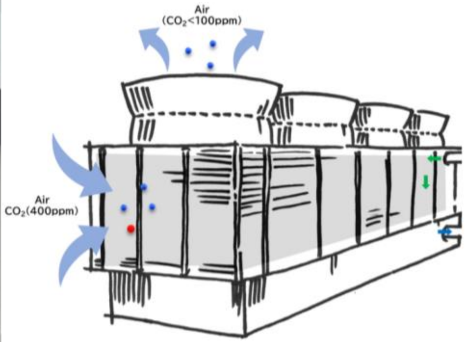


Energy saving by LNG cold can make cost reduction

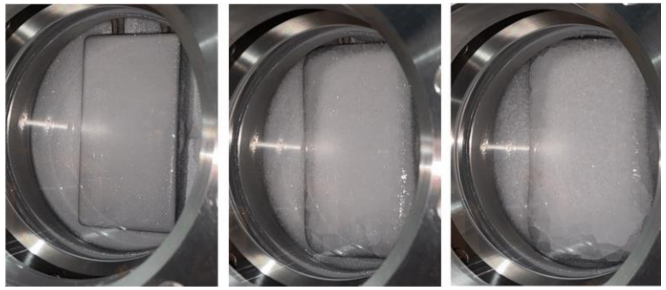
Cryo-DAC®

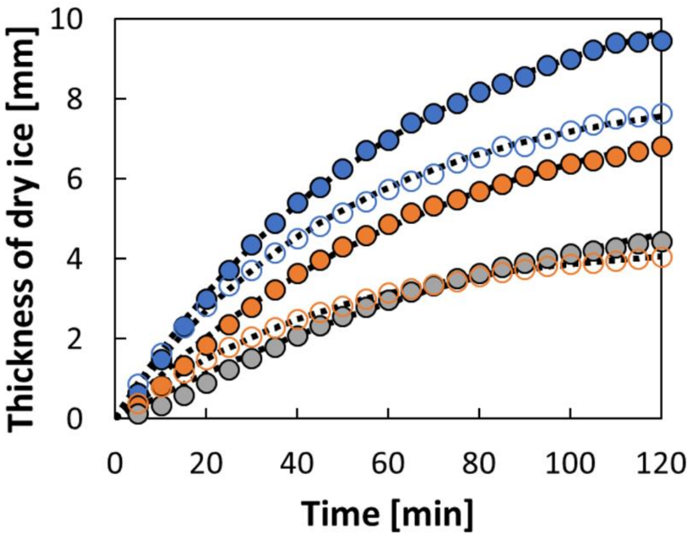
Absorber with low P drop





Kinetics of dry ice formation





Cryo-DAC® material

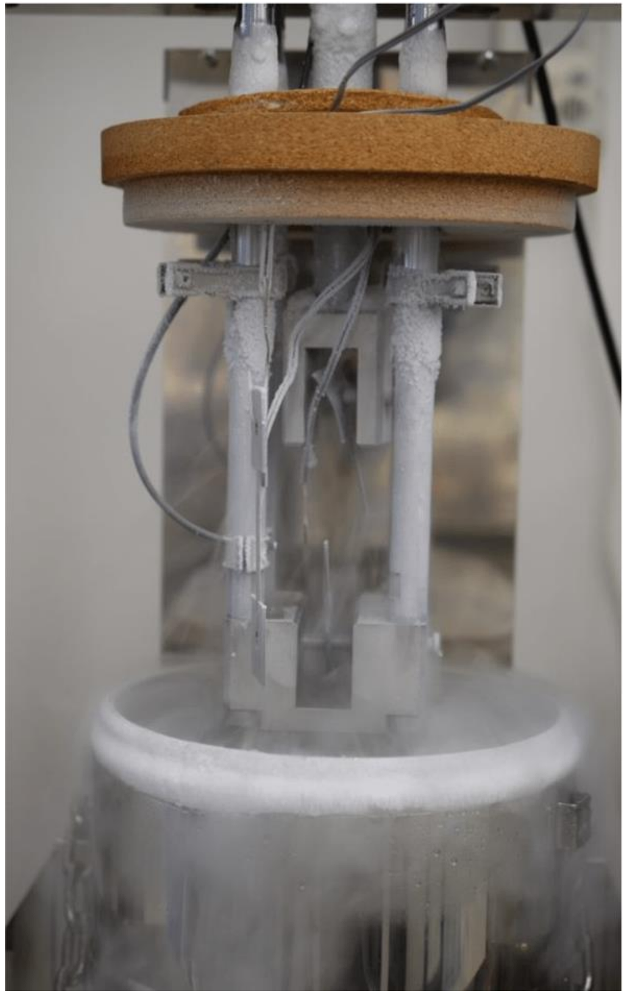
Fatigue tests (>10 cycles, 25 years operation) in liquid nitrogen

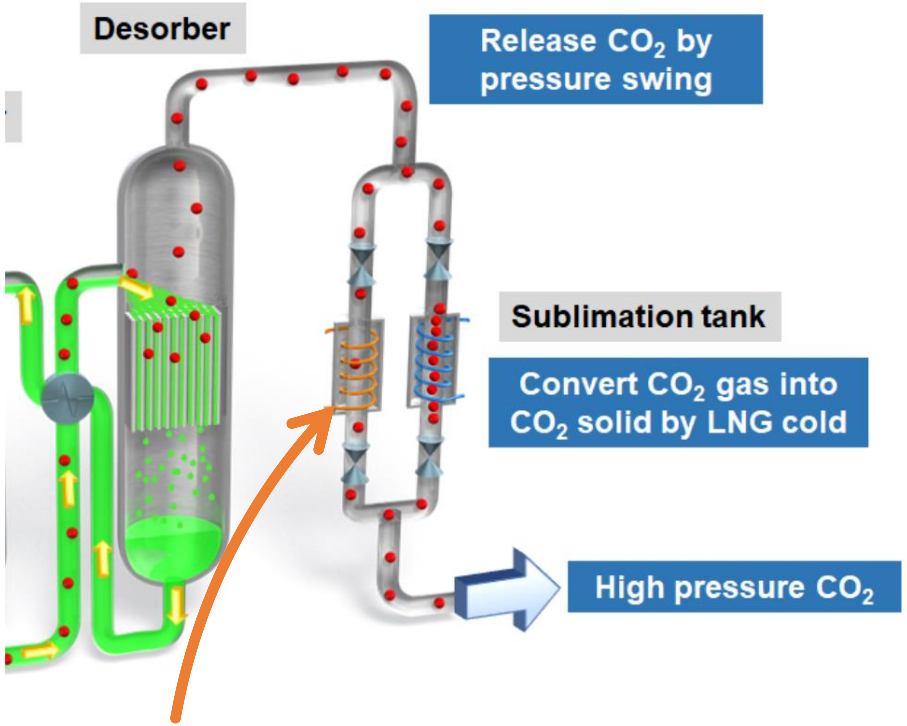
proved SUS 304 to be

a candidate material for the sublimation tank

Cryo-DAC® sensor

Integrity monitoringwith wireless sensor





Cryo-DAC® plant design

JGC HOLDINGS CORPORATION

Bench scale 1t-CO_2/y
2022 Design

2024-2025 Install & Operation at Nagoya University

(↓tentative)
Pilot scale 50t-CO_2/y
2028 Operation

Cryo-DAC® Roadmap

2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029

Start

Proof of concept

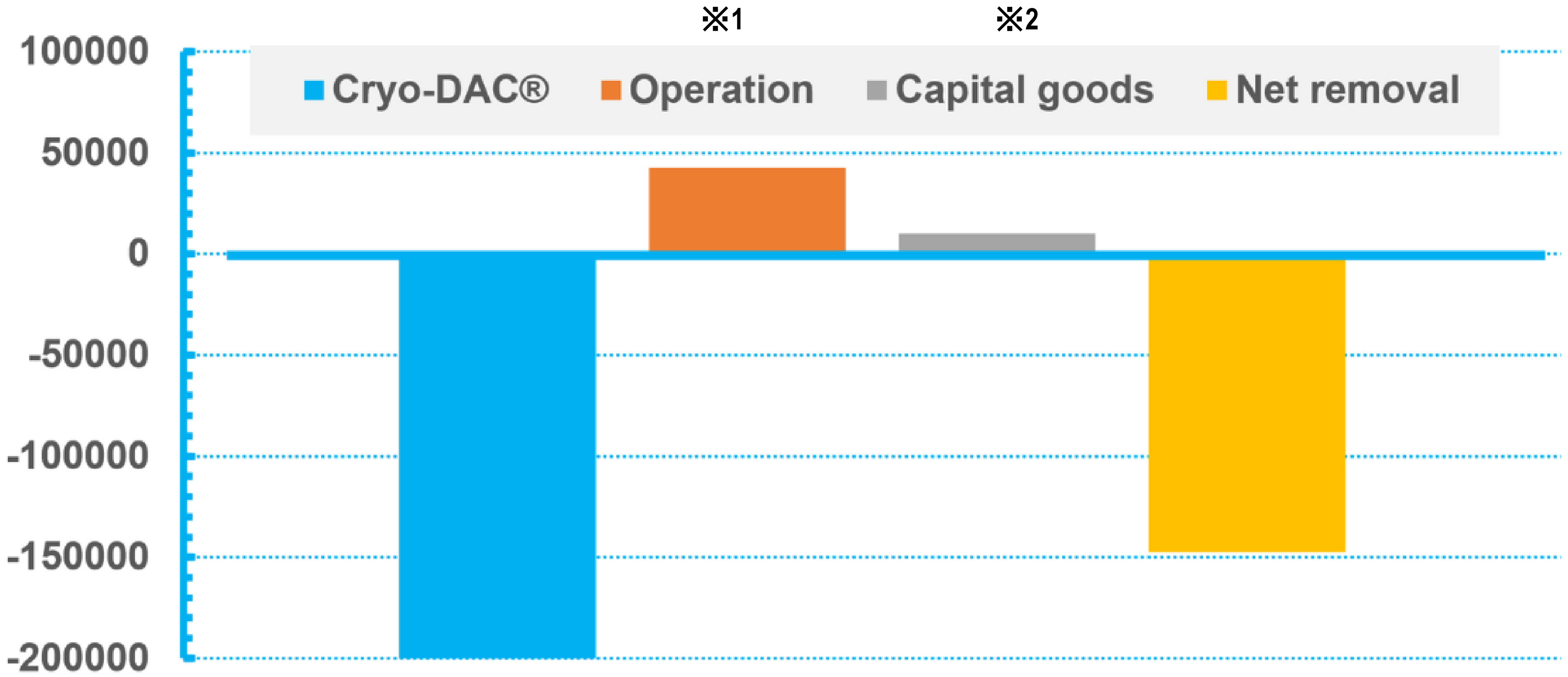
NOW

Design, construction, operation of a bench-scale plant

Design, construction, operation of a pilot-scale plant

Cryo-DAC® LCA

CHUKYO UNIVERSITY



※1 CO_2 emission factor : 0.506 kg/kWh (2020)

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

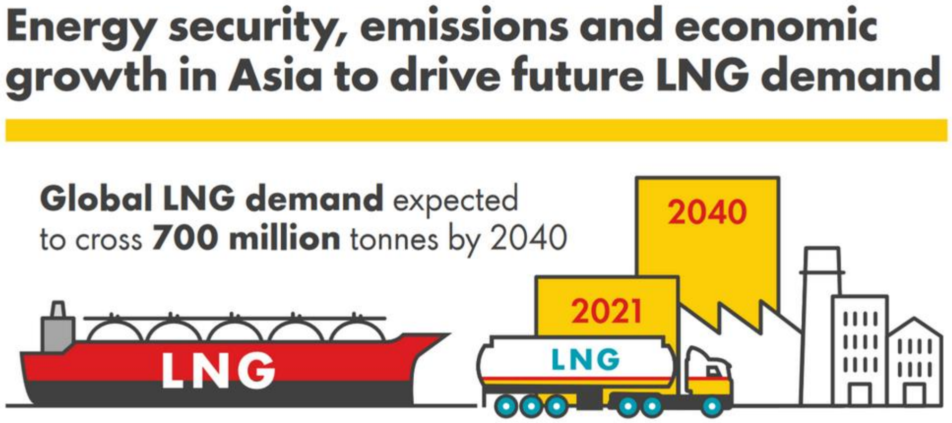
Cryo-DAC® perspectives

LNG import share % (2022)

Energy Institute Statistical Review of World Energy 2023

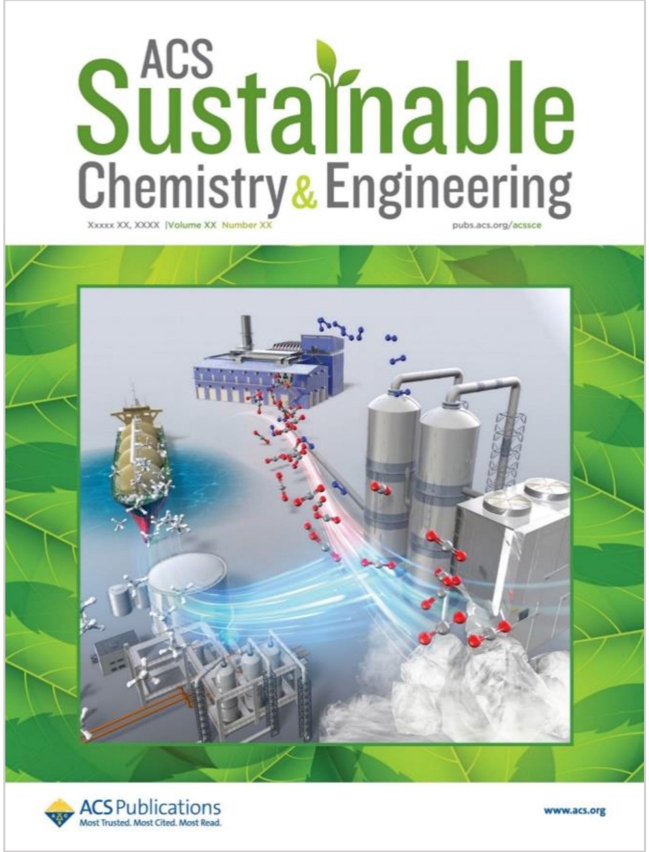
Japan	18.1
China	17.2
South Korea	11.8
India	5.2
Taiwan	5.1
Total Europe	31.4

Shell LNG Outlook 2022



LH_2 cold

CO_2 capture from LNGCC power plant



Machida et al.,
ACS Sustainable Chem. Eng. 2021,
DOI: 10.1021/acssuschemeng.1c05892).

GREENHOUSE GASES

Cold energy stored in liquefied natural gas could help capture carbon dioxide

The often-wasted energy could lower the energy required for carbon capture by cooling CO_2 into dry ice

by *XiaoZhi Lim, special to C&EN*

January 4, 2022

Liquefied natural gas (LNG), exported widely as fuel, contains significant embedded energy beyond its burnable chemical energy. The energy that was used to cool and compress it into liquid form, known as “cold energy,” is an untapped resource. Researchers have proposed using LNG’s cold energy to cool carbon dioxide (CO_2) into dry ice as part of a **carbon capture** process. In doing so, they hope to lower the energy required for carbon capture; however, it is still unclear how much energy could be saved (*ACS Sustainable Chem. Eng.* 2021, DOI: **10.1021/acssuschemeng.1c05892**).

Japan is one of the top importers of LNG, says Koyo Norinaga of Nagoya University. After the LNG arrives on tanker ships, it gets fed into the local gas pipeline network, and the coldness generated when it expands into a gas is used for refrigeration at the seaport. But

Credit: Koyo Norinaga and Hiroshi Machida

ADVERTISEMENT
ThermoFisher SCIENTIFIC
Excellence from start to finish
SureSTART vials and well plates
Learn more
thermo scientific

MOST POPULAR IN ENVIRONMENT

As nuclear waste piles up, scientists seek the best long-term storage

Featured in C&EN news

Cryo-DAC® 7 goals

Direct Air Capture with Liquid Sorbent and LNG Cold

1. Develop good sorbents
2. Pursue an efficient use of LNG coldness
3. Find suitable materials for construction
4. Develop sensing device for stable operation
5. Design & construct bench / pilot / commercial plants
6. Draw scenarios pleasing to our society
7. Offer a unique DAC to the world

NEDO
MOONSHOT RESEARCH & DEVELOPMENT PROGRAM
NAGOYA UNIVERSITY
TOHO GAS
THE UNIVERSITY OF TOKYO
CHUKYO UNIVERSITY
JGC HOLDINGS CORPORATION
TOKYO UNIVERSITY OF SCIENCE

Cryo-DAC®

Cryo-DAC®

https://cryodac.my.canva.site/home