Tune

09

DECEMBER
2021

Tohoku University Research News of Engineering

Direct is the Future

- Capturing CO_2 directly from Atmosphere -

Department of Chemical Engineering, Tohoku University
Professor
Yasuhiro FUKUSHIMA

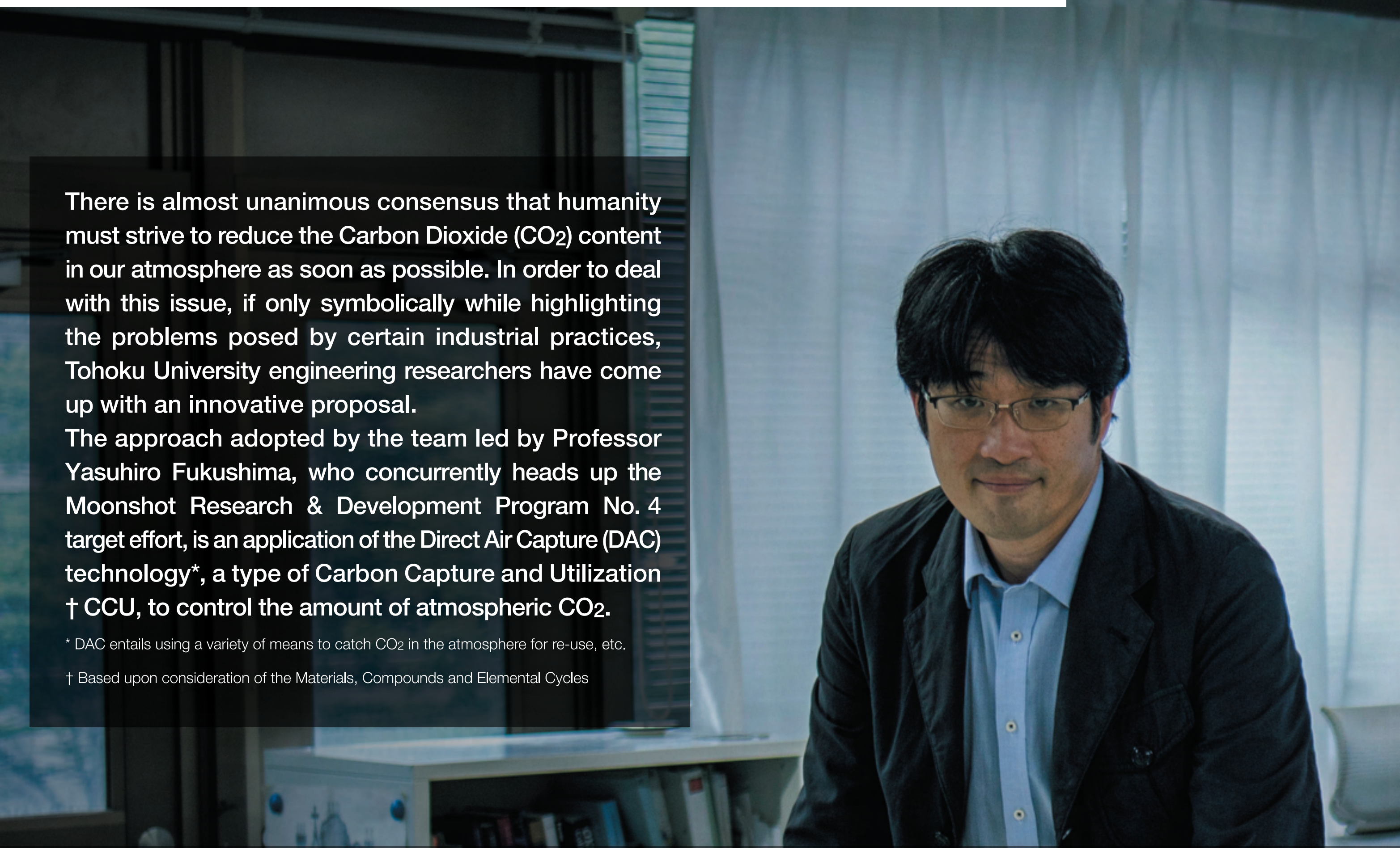
Ranking & Data
TOHOKU UNIVERSITY

TOHOKU
UNIVERSITY

Direct is the Future

- Capturing CO_2 directly from Atmosphere -

Text by Stophe POMEROY / Photographs by Hayato IKEGAMI



There is almost unanimous consensus that humanity must strive to reduce the Carbon Dioxide (CO_2) content in our atmosphere as soon as possible. In order to deal with this issue, if only symbolically while highlighting the problems posed by certain industrial practices, Tohoku University engineering researchers have come up with an innovative proposal.
The approach adopted by the team led by Professor Yasuhiro Fukushima, who concurrently heads up the Moonshot Research & Development Program No. 4 target effort, is an application of the Direct Air Capture (DAC) technology*, a type of Carbon Capture and Utilization † CCU, to control the amount of atmospheric CO_2.

* DAC entails using a variety of means to catch CO_2 in the atmosphere for re-use, etc.

† Based upon consideration of the Materials, Compounds and Elemental Cycles

Grand Strategy Design

Moonshot Targets

Foreseeing Problems

Stophe Pomeroy (S.P.): *Dr. Fukushima, you are a Project Manager of a prominent thrust related to global warming, as part of the "Big Tech" endeavor, the Moonshot Program. This is a national program organized by the Council for Science, Technology and Innovation under auspices of the Cabinet Office, together with several ministries of the Japanese government. I realize that you are not at liberty to disclose certain details due to Intellectual Property and other such agreements, but could you outline your activities for us?*

Professor Yasuhiro Fukushima (Y.F.): Certainly! In general, the technologies designated as the Moonshot targets hold promise and seen exerting a major impact on our society as well as for the entire planet. We can expect paradigm shifts to happen that will improve our global lot.
The "quad-C"** consortium, in addition to myself and others at Tohoku University, is comprised of researchers from an energy-business startup and from Osaka City University, organized primarily by a former colleague at our department in Sendai.
In the main, the Tohoku University-backed proposal by our team centers on utilization of CO_2 in the air, through use of the Direct Air Capture (DAC) technology, although this carbon content in the air is rather marginal, percentagewise.
However, quad-C is taking the chemical materials-based approach, grounded in physical/chemical sciences rather than life sciences.
As for our forte now, the Chemical Engineering aspect... our school's engineering program is one of only two in Japan, the other being out West run under an integral syllabus similar to us at Kyoto University... has a comprehensive educational set-up with an undergraduate/graduate tack available.
The Moonshot Program hopes to apply Japanese technology in helping balance the global carbon ledger. Ultimately, we plan on bringing forth and then disseminating widely the innovative modules that aim to lower the concentration of CO_2 in the atmosphere through use of gas absorbent materials.

** "quad-C" stands for Combined Carbon Capture and Conversion (quad-C) process

S.P.: *You mention the current status of Chemical Engineering as a discipline in Japan; I knew the late Sir Harry Kroto quite well, whenever he visited Japan he expressed concerns about the apparent decline in Chemical Engineering education here..*

Y.F.: Ah, as an Industrial Journalist, you do find that alarming. But as you seem to be aware, the Japanese chemical industry has been faced with reduced demand from the petrochemical sector in recent decades. Along with this trend, there have been rapid changes in higher education related to Chemical Engineering.
However, there is more to applications of Chemical Engineering knowledge than as used in petrochemicals, our current research field being just one. We hope our research and development efforts honed in on our Moonshot targets will act as a catalyst in helping Japan to catch up in replenishing our human resources base.
We in Japan can scrutinize - and fortunately for us the Moonshot Program provides public money to do so - energy conservation and waste-handling measures, from food loss to plastic refuse, that must be dealt with by our human resource capacity now.

The Dangers Present

S.P.: *I hear also that other universities have a Moonshot endeavor taking a separate CCUS approach, but your team I understand is aiming to yield innovative results for adoption by industry.*

Y.F.: Our focus is on development of technologies to recover CO_2, with that then being converted into valuable materials, such as polyurethane, polycarbonate, urea, some other derivatives useful as pharmaceuticals, not to mention in lithium-ion battery materials, among others. Synthesis of these materials require chemicals like phosgene and toxic reagents of the ilk, treated in high temperature and pressure, in the present method. CO_2 can replace these reagents and potentially work at a milder condition. Indeed, this motivates chemical industries, aside the carbon emission reduction pressures nowadays.

S.P.: *In realizing your focal points what are your plans?*

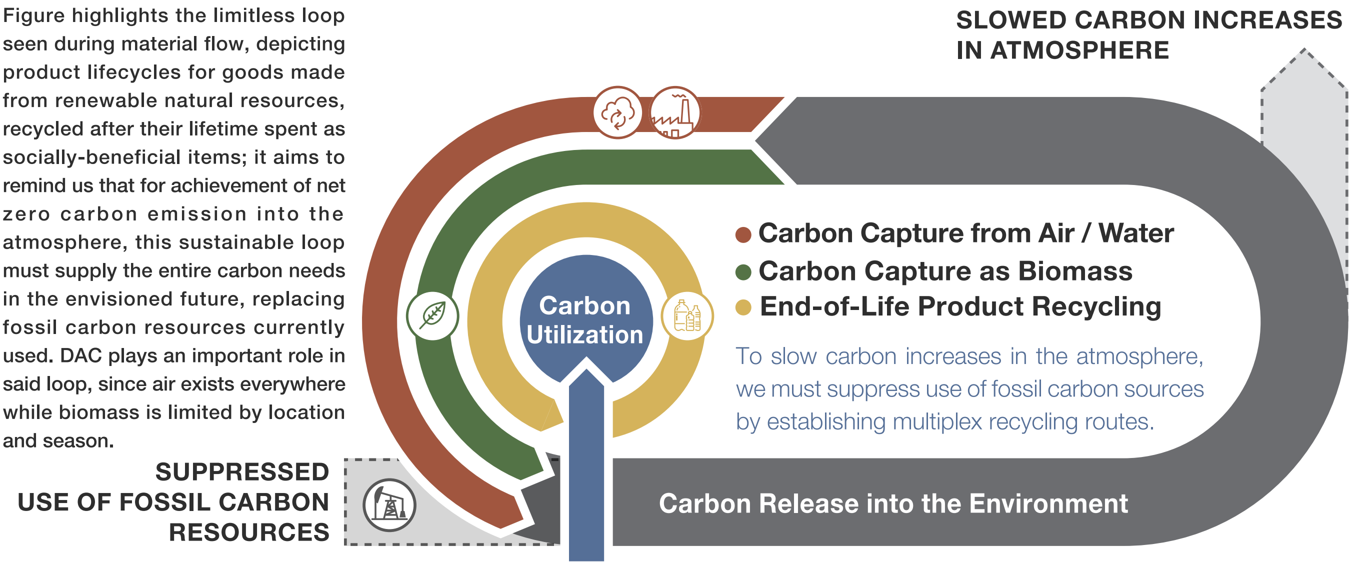
Y.F.: We have two prongs. First, we are using an energy-saving conversion route. Chemical substances that I mentioned before contain a structure called carbonyl. The advantage of employing a route that allows CO_2 to be used as a carbonyl source is that, by use of an appropriate catalyst, CO_2 can be incorporated into the chemical structure without the need for a carbon reduction process. This amounts to a high energy saving.
Second, to obtain CO_2 - which exists in the atmosphere at a concentration of only about 0.04% - a huge amount of air needs to be blown into the converter. A high recovery rate of CO_2 from the introduced air at very high flowrates is the key to saving energy, which will be carbon-free while being extremely limited in the future.
We are approaching this challenge by upgrading membrane separation technology that was originally developed for space applications. In addition, we seek to eliminate energy requirement for CO_2 recovery from absorbents by using the new quad-C process configuration realized by Dual Function Materials (DFMs).
To compass the development of multiple items including the reactors, membrane, sorbents, separation methods, etc., the target performance for the respective items should be flexibly rearranged so that we can accelerate the pace of approaching commercialization. My profession is actually in the system performance managing method applying a birds-eye-view, combined with chemical process modeling and simulation techniques. Atmosphere is not the most ideal gas to recover CO_2, concentrationwise. But in the carbon neutral future, flue gas with high CO_2 concentration will no longer be available. So, CO_2 in the air will be one of the future sources of carbon for our industries. It requires a lot of good imagination to accept this concept, as it is so much a different one that do not lie on the extension of the previously taken course of innovation in the chemicals industry.

S.P.: *I see... As your formulaic expressions "on the air" shown on this issues indicate?*

Y.F.: Our first target is to produce a urea derivative by bringing the ethylene diamine that chemically absorbed CO_2 into contact with the catalyst (CeO_2). The knowledge on sorption and the reaction of various DFMs and CO_2 obtained in this work, together with the new simulation and evaluation techniques we develop, will expand the range of carbonyl compounds that can be produced from CO_2 with biomass and recycled End-of-Life products.

CCU, Carbon dioxide Capture and Utilization

Figure highlights the limitless loop seen during material flow, depicting product lifecycles for goods made from renewable natural resources, recycled after their lifetime spent as socially-beneficial items; it aims to remind us that for achievement of net zero carbon emission into the atmosphere, this sustainable loop must supply the entire carbon needs in the envisioned future, replacing fossil carbon resources currently used. DAC plays an important role in said loop, since air exists everywhere while biomass is limited by location and season.



Yasuhiro FUKUSHIMA,

Professor,
Department of Chemical Engineering,
Tohoku University

1997 Bachelor's Degree, 1999 Master's Degree, and 2002 Ph.D., The University of Tokyo; 2002-2004 Research Associate, The University of Tokyo 2004-2010 Assistant Professor, 2010-2014 Associate Professor, National Cheng Kung University, Taiwan; 2014-2020 Associate Professor, 2020- Professor, Tohoku University. 2020- Project Manager of the Moonshot Research and Development Program Member of the Board of Directors, Institute of Life Cycle Assessment, Japan.

Ranking & Data

TOHOKU UNIVERSITY

University Ranking

1

THE
Japan University Rankings 2021

23

QS Asia
QS Asia University Rankings 2021

82

QS
QS World University Rankings 2022

QS — QS World University Rankings by Subject 2021

65
Natural Science - Materials Science

52
Engineering & Technology - Mechanical

57
Engineering & Technology - Chemical

ARWU

ShanghaiRanking's Global Ranking of Academic Subjects 2021

9
Metallurgical Engineering

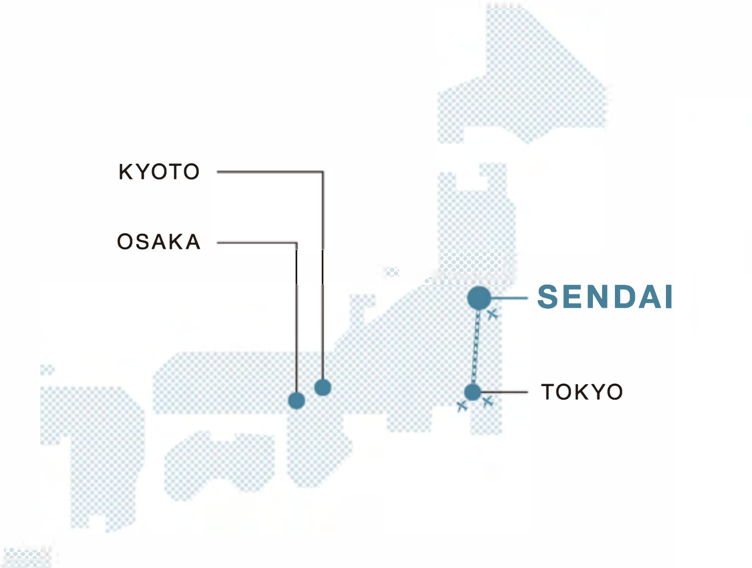
Statistics 2021

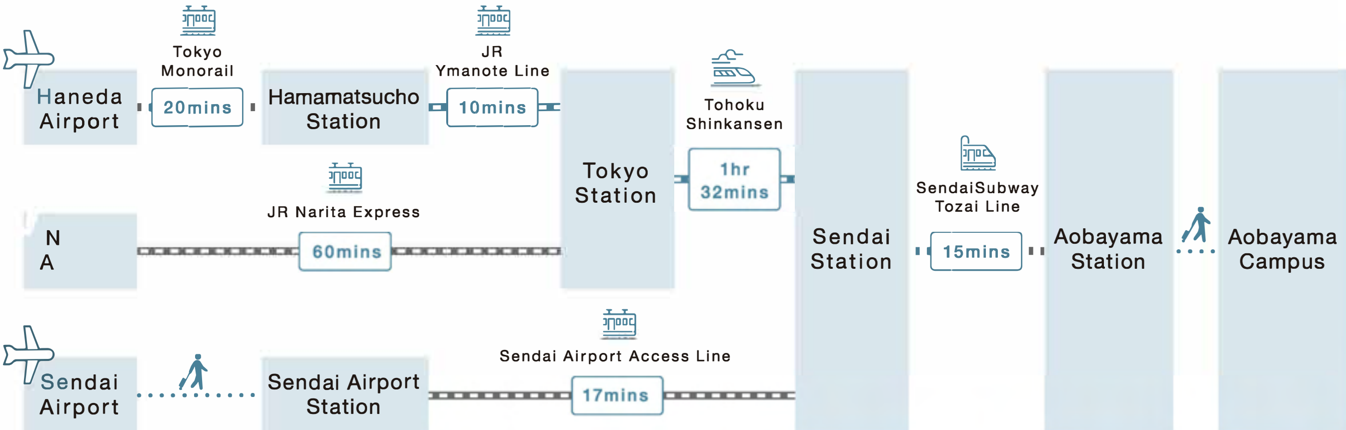
	Tohoku University	School of Engineering
STUDENTS-TO-FACULTY RATIO	1 : 6	1 : 9
NUMBER OF FACULTY	3,168	641
NUMBER OF INTERNATIONAL STUDENTS	2,044	543
UNDERGRADS	10,695	3,475
GRAD STUDENTS (MS)	4,261	1,502
GRAD STUDENTS (PhD)	2,709	521

Sendai, the home city of Tohoku University

SENDAI At a Glance

Average Temp.	12	℃
Preci itation	1241	mm
Sunshine	1843	hours





TOHOKU UNIVERSITY

Tohoku University Research News of Engineering

Office of Research Strategy,School of Engineering, Tohoku University

E-mail : eng-ken@grp.tohoku.ac.jp Tel/Fax : +81-22-795-5807
Address : 6-6 Aramaki, Aoba-ku Sendai 980-8579, Japan
Url : http://tune.eng.tohoku.ac.jp/

Tohoku University Research News of Engineering (Tune) is an annual publication of School of Engineering (SoE), Tohoku University, Sendai, Japan. Each Tune volume provides the scientific community with the latest research results of SoE on a selected topic.