再生可能エネルギーによるエネルギーミックスの大幅な改善
～100g/kWhの可能性を探る～
まちづくり共同研究成果発表会

【共同研究メンバー】
グループ① 上田・横山（NTTアーバンソリューションズ総合研究所）
平井（NTTアーバンソリューションズ）
安達（シェルター）
寺澤（アジア航測）
小久保（高砂熱学工業）
澤井（三井住友建設）
八塩（大林組）
グループ② 吉岡（KEK,岩手大学,岩手県立大学）
滝沢（近藤設備）
寺澤（アジア航測）

謝辞：佐貫、小貫（東北大）、晴山（岩手県庁）

1．グリーンILC（運転中のCO2排出量）についてCERNと2040年日本の電力事情を比較すると日本は極端に「悪い（10倍以上多く排出する）」
- そのことだけでILC in JapanがJustify（正当化）されないかもしれない

2． ILC in Japan（in Tohoku)のグリーン化の見通しについて根拠のある指針を作成したい
- 2040年の「電力 in Iwate」をベースにすればILCをCO2排出量が**100g/kWh以下**の電力で運転できる可能性がある
- その分について排熱回収を含むカーボンクレジットによりオフセットしてゼロエミッション運転実現の可能性がある（本・報告には含まない）

3．建設期間に排出するカーボンを長期運転期間に割り振ってゼロエミッションを目指す（上田発表参照）

70th ICFA Advanced Beam Dynamics Workshop
on High Luminosity Circular e+e– Colliders

eeFACT 2025

Research Activities Aimed at Decarbonizing the Life Cycle of Accelerator Facilities

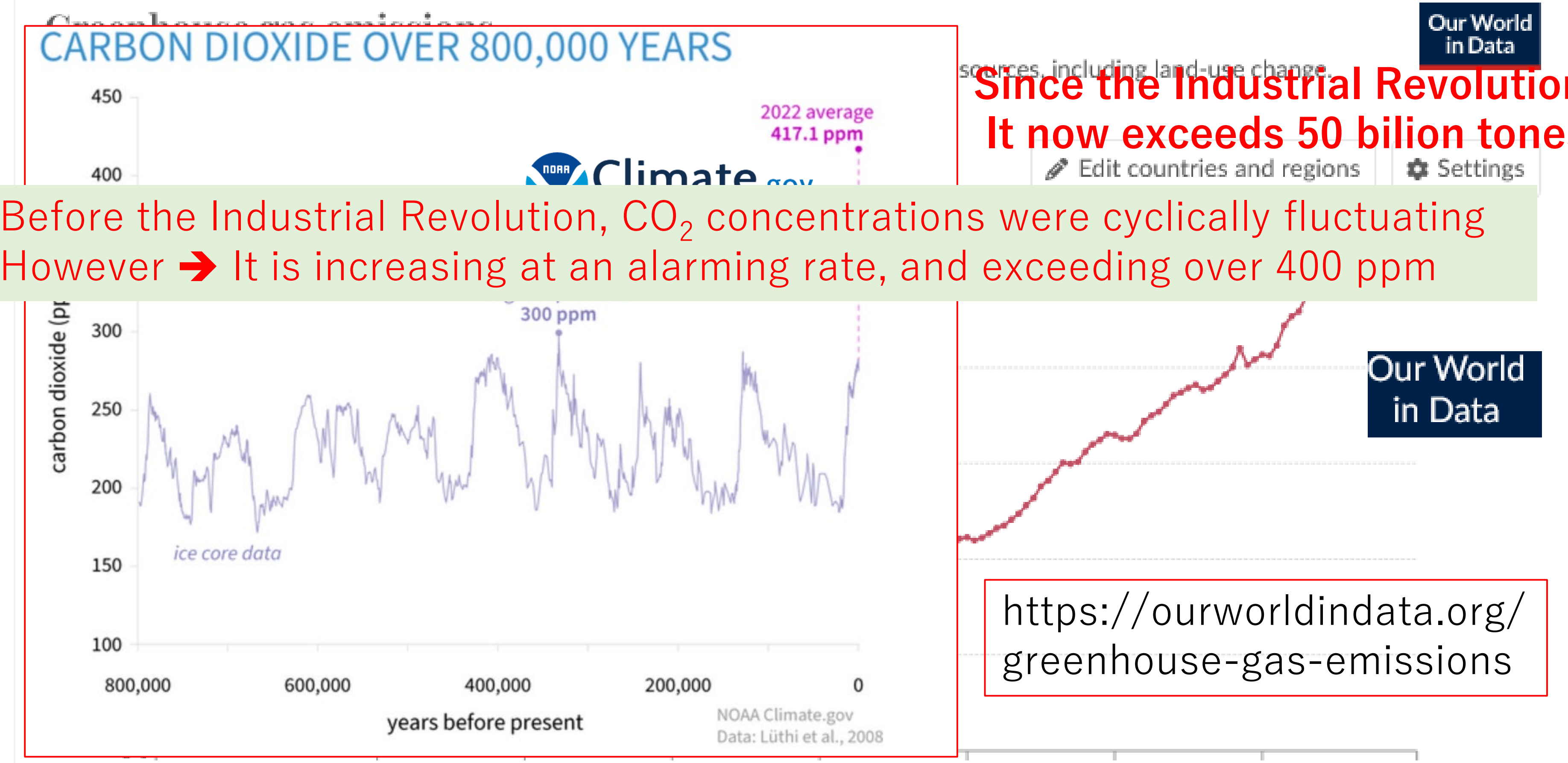
March 3 - 7, 2025

Tsukuba International Congress Center (EPOCHAL),
Tsukuba, Japan

Masakazu Yoshioka (Iwate University)

Abstract

- There is no doubt that global warming is accelerating due to greenhouse gas emissions from human activities.
- All industries are now required to work toward achieving carbon neutrality by 2050. Accelerator facilities are no exception.
- In particular, life cycle assessment, including construction, operation, and decommissioning periods, is necessary to achieve carbon neutrality.
- Researchers around the world who are planning large accelerators are actively addressing this issue.
- For example, during the construction period, the decarbonization of steel products and concrete used there must be considered.
- During the operation period, the electricity used should be as low carbon emission as possible.
- This presentation will describe global trends and the Japanese situation regarding this activity, based on the authors' recent work on the case for an ILC to be located in Japan.



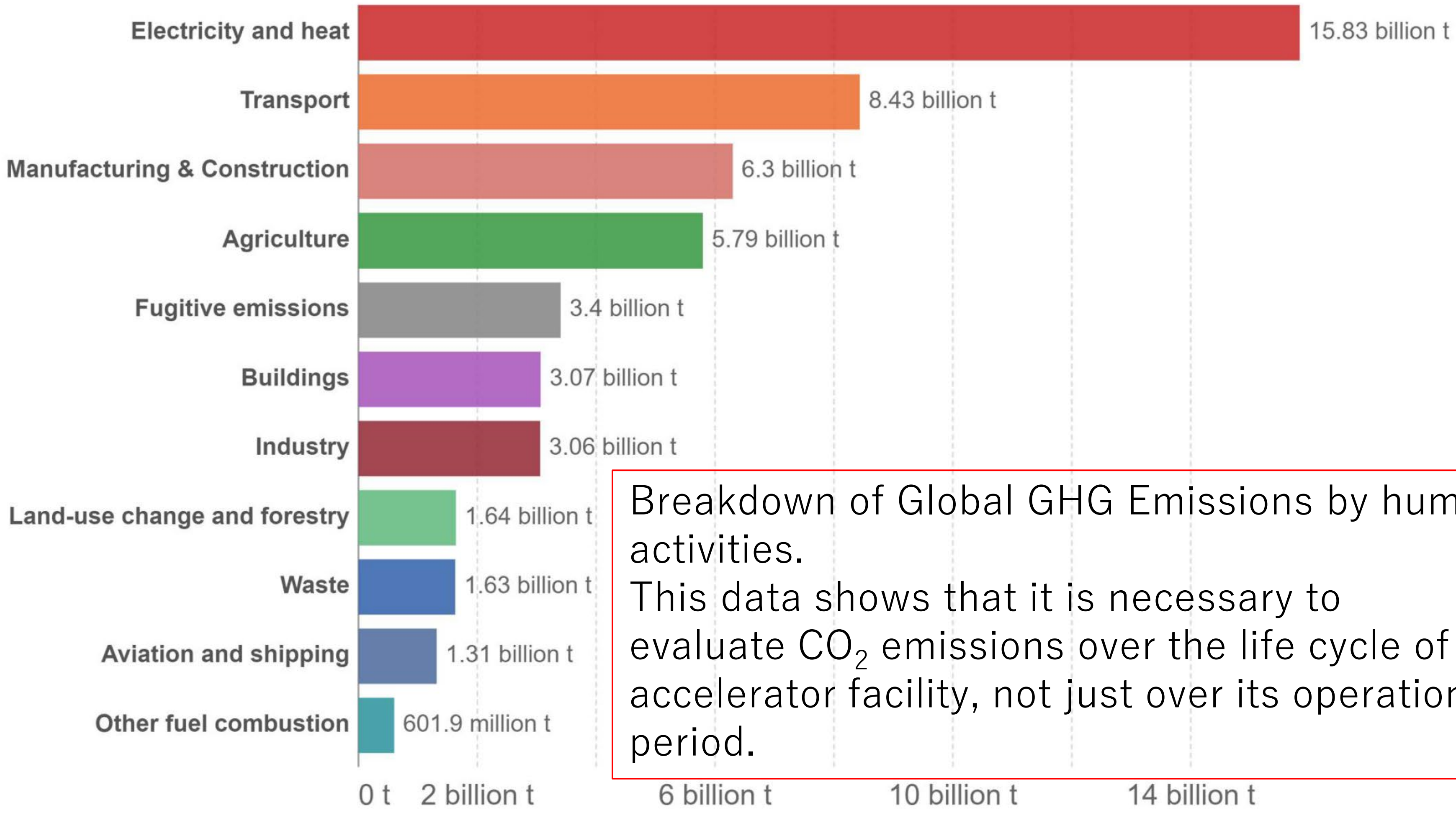
Since the Industrial Revolution.
It now exceeds 50 bilion tones.

Before the Industrial Revolution, CO_2 concentrations were cyclically fluctuating
However ➔ It is increasing at an alarming rate, and exceeding over 400 ppm

https://ourworldindata.org/greenhouse-gas-emissions

Let me clarify my understandings.

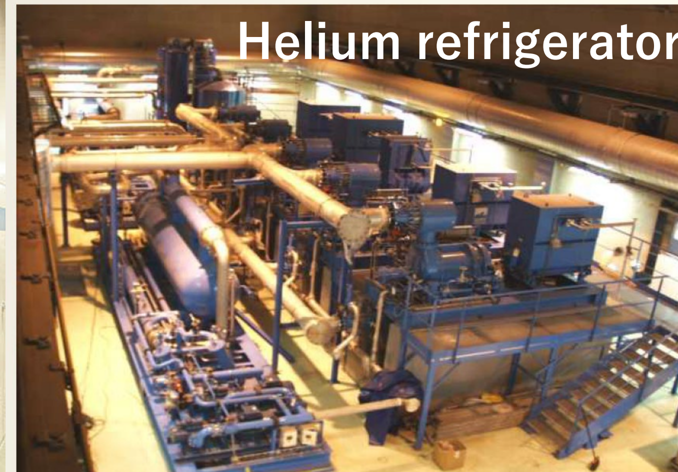
- The Earth is currently warming due to cyclic variations in the precession of the Earth's orbital and rotational axes (Milankovitch cycle) and natural cycles such as biogenesis and eruptive activity.
- Anthropogenic emissions of global greenhouse gases are accelerating this trend.
- The rate of warming is so rapid that changes can occur within a short human lifetime, and scientists must work to halt it.
- Accelerator facilities are no exception and should be taken seriously, including those of you in this hall.

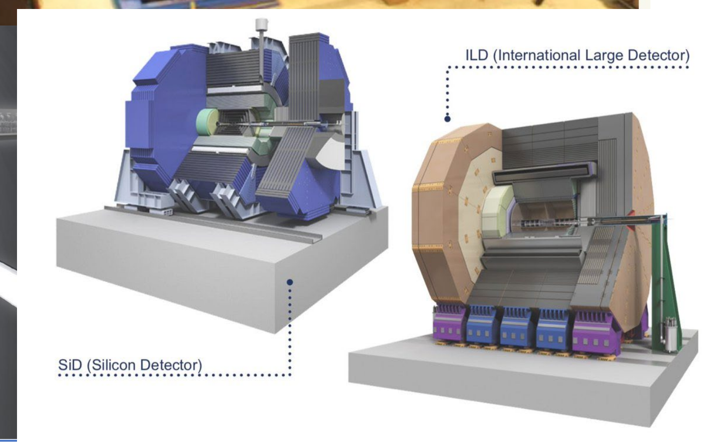


Breakdown of Global GHG Emissions by human activities.
This data shows that it is necessary to evaluate CO_2 emissions over the life cycle of an accelerator facility, not just over its operational period.

Our World in Data based on Climate Analysis Indicators Tool (CAIT) 2019 (Adapted)

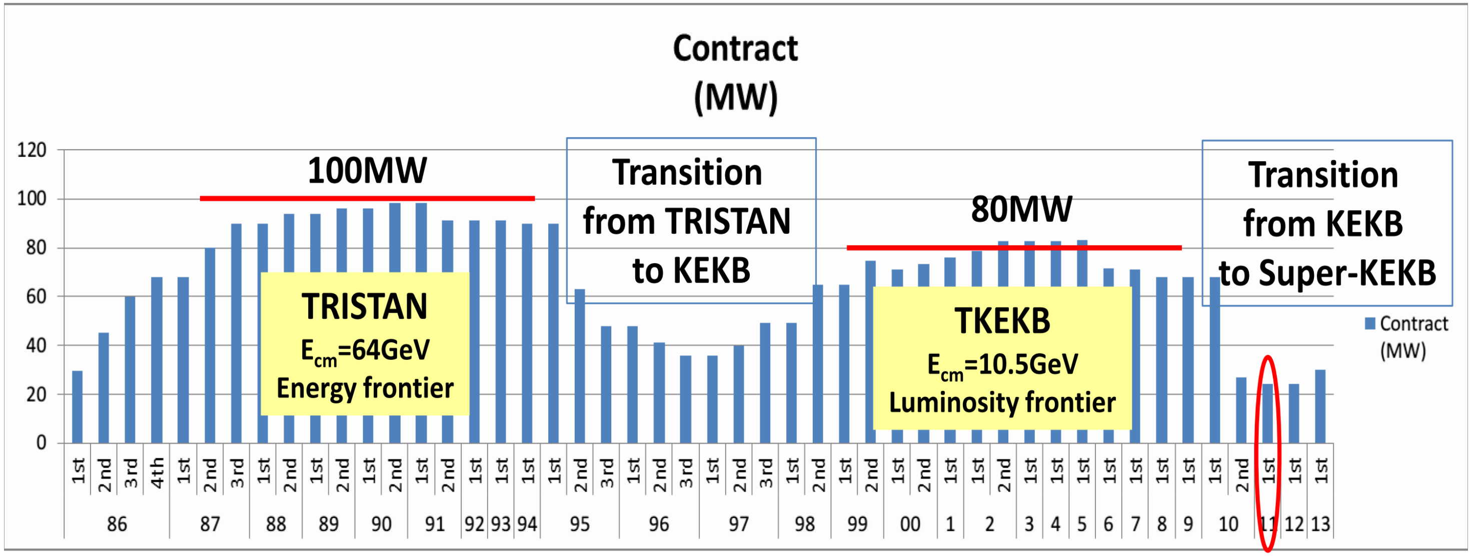
Presentation by Suzanne Evans of ARUP, WSFA2023 in Morioka



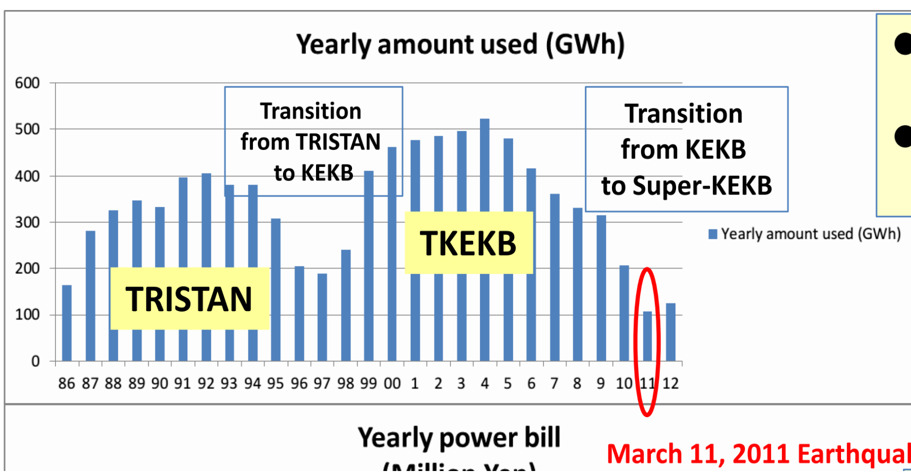


- Accelerators are electric power-loading facilities and their construction uses a lot of concrete and steal. CO_2 emissions for the production of 1 ton of blast furnace iron amount to 2 tons, and 0.7 tons for the production of 1 ton of cement.
- Reducing life-cycle global GHG emissions from construction to decommissioning of accelerator facilities is an important issue.

These figures show data from when I was in charge of power contracts at KEK during TRISTAN and KEKB operation. Old but helpful to understand.



March 11, 2011 Earthquake



- **Contract (Peak Power Demand):**
  TRISTAN = 1.15 KEKB
- **Yearly amount usage:**
  TRISTAN = 0.8 KEKB

Energy-oriented TRISTAN has greater peak power than KEKB, but luminosity-oriented KEKB has greater annual power use than TRISTAN

	Peak(MW)	TWh/year	Feature
TRISTAN	100MW	0.4	Energy Frontier 64 GeV in 1986
KEKB	80MW	0.5	Luminosity Frontier (Factory Machine at 10.5 GeV) 2.11 E34 /cm^2/s in 2009
ILC	130MW	0.7	Energy and Luminosity Frontier 250 GeV (Higgs Factory) 2.7 E34 /cm2/s with 5 Hz operation and pol. e^-

- This table shows how energy-efficient the ILC based on a superconducting accelerator is. Beam energy is 4 times higher than TRISTAN, but only 30% more electric power
- Super-KEKB, currently in operation at KEK, is also an eco-friendly design (nanobeam scheme) and achieves more than twice the luminosity at half the current of KEKB.

Accelerator researchers should make the following efforts to achieve sustainable accelerator facilities. And all efforts will be made in cooperation with industry and the community.

- Improve power efficiency and performance of accelerator components.

- Ensure that power used by accelerators is from sustainable sources whenever possible. To this end, we will help increase the amount of sustainable electricity in the region.

- Recovering as much of the waste heat energy emitted from the accelerator facilities as possible and making it available for local use. To this end, we should create regional energy management projects using waste heat.

- Help increase the amount of green carbon (CO_2 absorption by forests), blue carbon (CO_2 absorption by seaweed), and white carbon (CO_2 fixation by increasing the number of wooden buildings) in the region to increase CO_2 . absorption.

Much information was exchanged at the Workshop on Sustainability of Future Accelerators held in Morioka in September 2023. Here are some highlights from the workshop.

① CO_2 emitted when generating 1 kWh of electricity in each country or region of the world.

② In particular, the situation in Nordic countries has already achieved almost carbon neutrality.

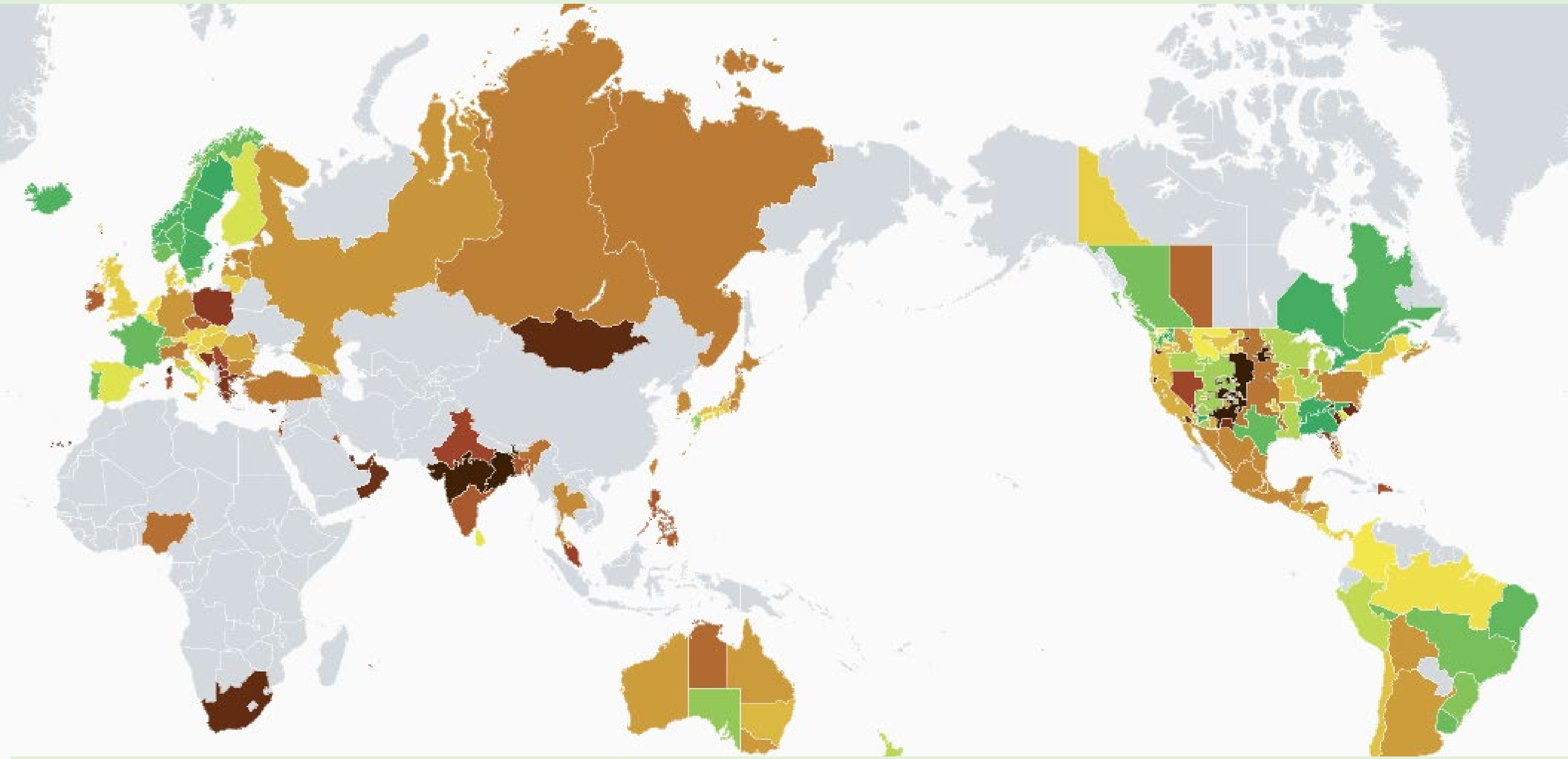
③ CERN’s sustainability strategy.

④ Japan's strategy to achieve carbon neutrality by 2050.

https://app.electricitymaps.com/zone/

This site was taught by Steiner Stapnes

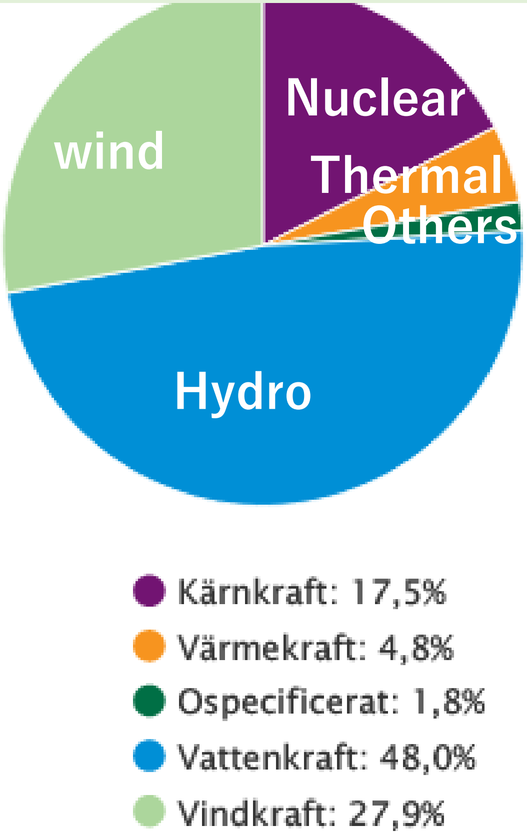
① World Map of CO_2 Emissions/kWh: The greener the better, the darker the worse
Data not AVAILABLE for gray countries or regions. Data displayed in real time.



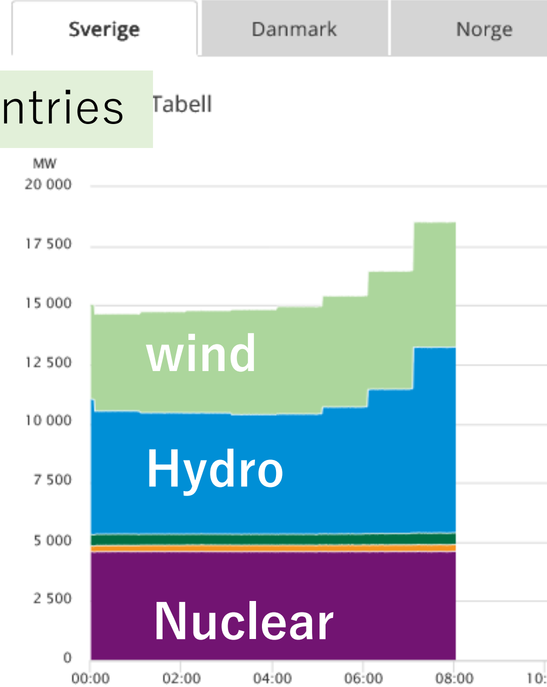
This information is very helpful in understanding the global situation, so please take a look!

Kraftfördelning klockan 09:11

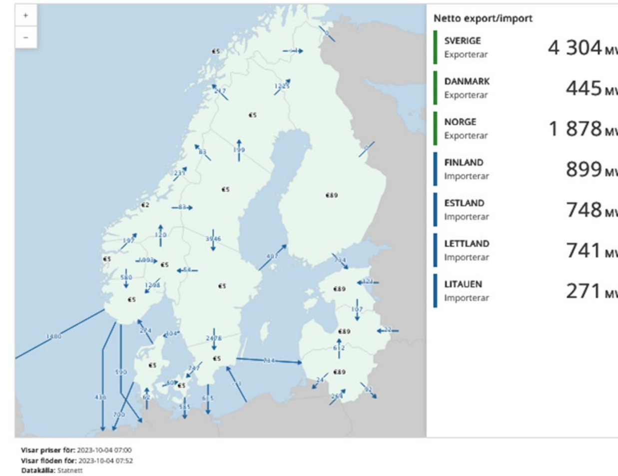
② The situation in Nordic countries



Electricity composition at a given moment in time in seven Nordic countries



- Changes in electricity demand over time and the amount of electricity generation that follows.
- When electricity demand increases in the morning, wind and hydroelectric power generation follows.
- Nuclear power is the base power source



- Power mix varies by country.
  - Denmark 90% wind,
  - Norway 90% hydro,
  - Finland 51% nuclear.
- The power grid is controlled across borders to achieve the best energy mix
- Thermal power is less than 5%, renewable energy 75.9%, nuclear 17.5%
- **Nordic countries are a good model for achieving carbon neutrality in 2050**

This information was given to us by Anders Sunesson (ESS Institute) from Sweden

③ CERN's sustainability strategy.

Linear colliders

Sustainability studies for LCs
Life Cycle Assessments

Steinar Stapnes

EAJADE WP4: Morioka 27.9.2023

Sustainability during operation

- Operation costs dominated by energy (and personnel, not discussed in the following)
- Reducing power use, and costs of power, will be crucial. Other consumables (gas, liquids, travels …) during operation need to be well justified. Align to future energy markets, green and more renewables, make sure we can be flexible customer and deal with grid stability/quality.
- Carbon footprint related to energy source, relatively low already for CERN (helped by nuclear power), expected to become significantly lower towards 2050 when future accelerators are foreseen to become operational (in Europe, US and Japan).
- Provided we can run on green mixtures (PPA example at CERN, also (hopefully) built fully into the green ILC concept) we can also contractually chose green options. LCs are very suited for this (variable power load).

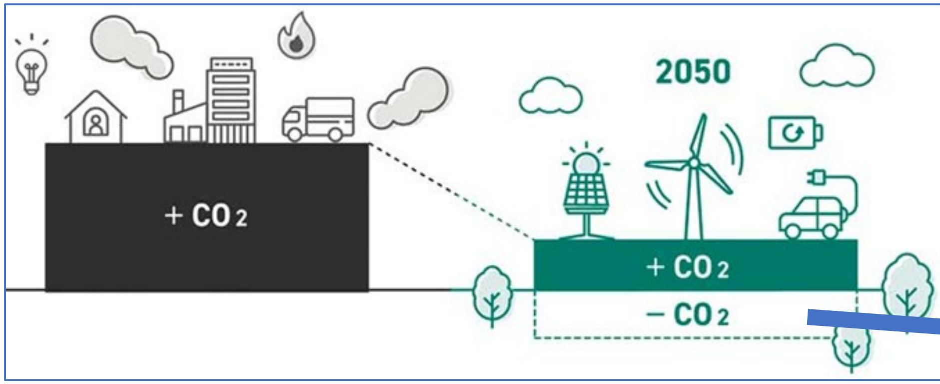
A rough estimate, assuming ~50% nuclear and ~50% renewables (as wind/sun/hydro):

1 TWh annually equals ~12.5 ktons CO2 equiv. annually

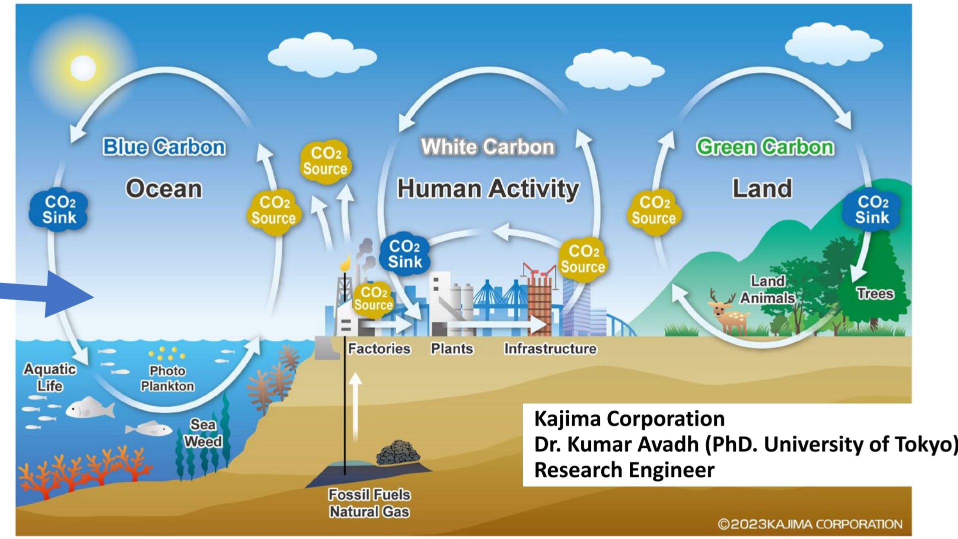
(note: this is factor ~3 below the current French summer month average)

- **In this presentation, CO_2e/kWh = 5g for nuclear power and 20g/kWh for renewable electricity.**
- **Since CERN plans to use 50% nuclear and 50% renewable energy for electricity, CO_2e/1TWh = 12.5 kton (12.5 g/kWh) when 1 TWh (1 billion kWh) is used per year**

④ Japan's strategy to achieve carbon neutrality by 2050.



Carbon Cycle



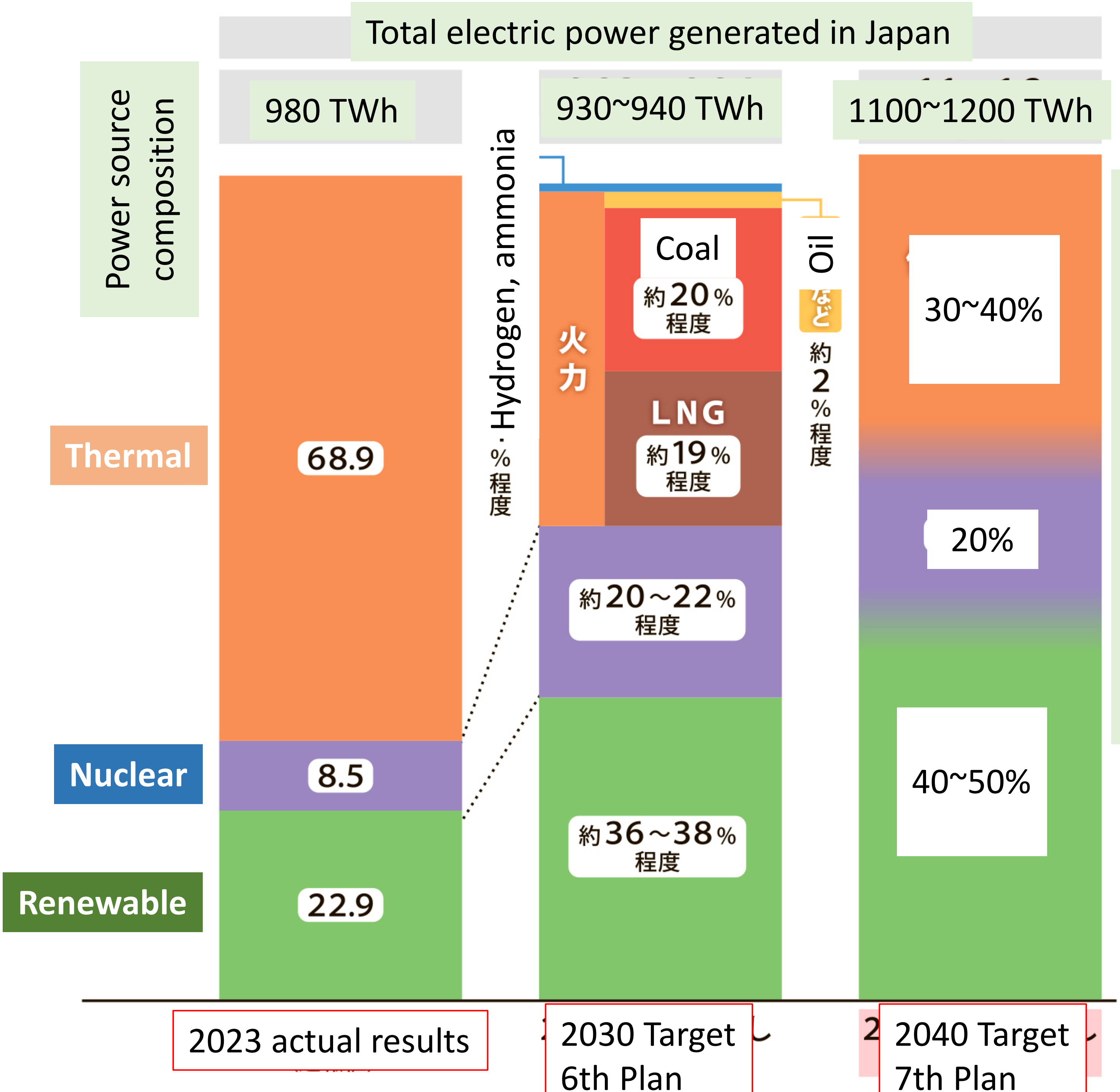
- Japan is an island nation and must be a closed scenario in one country.
- Japan will strive to reduce CO_2 emissions as much as possible by 2050.
- On the other hand, it will be difficult to achieve complete fossil fuel phase-out, and an “offset” scenario with abundant renewable biomass will be adopted.

Next, I will discuss the carbon neutral strategy for the ILC to be located in the Kitakami Highlands in northeastern Japan.

① First, I will discuss Japan's 7th Basic Energy Policy, which was approved by the Cabinet in February 2025.

② Next, I describe the situation in Iwate Prefecture, where the ILC candidate site is located, which is blessed with renewable energy.

③ Finally, we propose a zero-carbon strategy for the ILC if it is located in the Kitakami Highlands.



① Japan's 7th Basic Energy Plan. It was approved by the Cabinet in February 2025.

Goal:

to achieve up to 40~50% renewable

reduce fossil fuels to 30~40%.

Let's estimate the CO_2 emitted by the power source structure in the 7th Basic Energy Plan

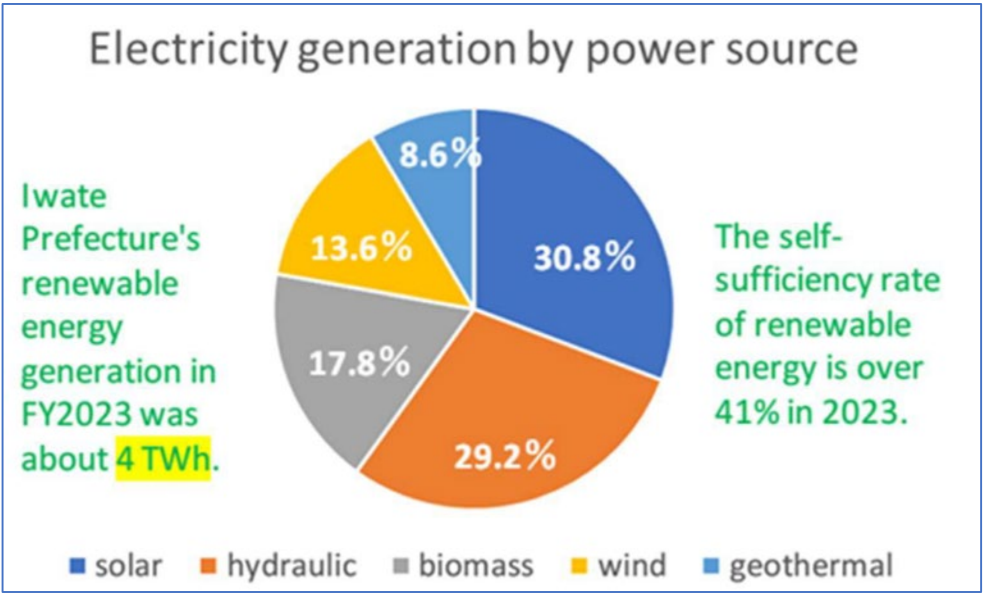
I assume following CO_2 emission intensity by power source
(this is a working hypothesis for this time, and of course these figures must be verified)

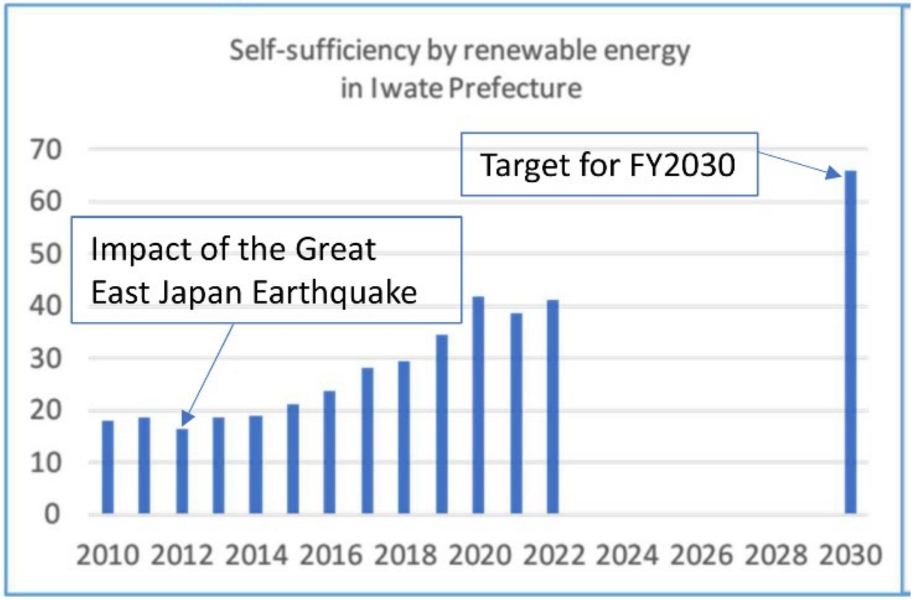
- Thermal 340g/kWh
- Nuclear 5g/kWh
- Renewable energy 20g/kWh

Power source type ↓	CO2 emission g/kWh	Power source composition ratio (Best case %)	Power source composition ratio (Worst case%)	CO2 emissions when 1 TWh is used (Best case, k -ton)	CO2 emissions when 1 TWh is used (Worsr case, k-ton)
Thermal power	340	30	40	102	136
Nuclear power	5	20	20	1	1
Renewable Energy	20	50	40	10	8
Total		100	100	113	145

CERN's plan for CO_2 emissions for 1 TWh/year is 12.5 k-ton.
On the other hand, the 7th Basic Energy Plan of Japan is 113~15 k-ton.
In order to reduce this value, we will rework the scenario on the next page.

Consideration is based on the electricity situation in Iwate Prefecture, not the target for Japan as a whole.
These graphs are based on “Iwate Prefecture's Renewable Energy Electricity Status (2023) and Target for 2030” prepared by the Iwate Prefecture Environmental Living Department in September 2023



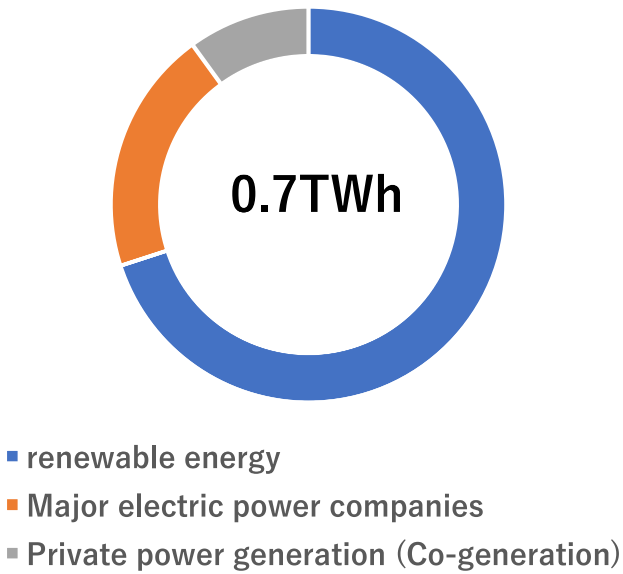


Since Iwate Prefecture is still actively increasing renewable energy, the 66% renewable energy target for 2030 will be achievable.

Next, I estimate the amount of CO_2 emitted by the ILC in 2040, assuming that the ILC is located in the Kitakami Highlands and that the ILC's electricity mix is as follows

- **70%** Renewable energy power producers in Iwate Prefecture
  - CO_2 emissions are assumed to be **20 g/kWh**
- **20%** Major electric power companies
  - CO_2 emissions are assumed to be **113-145 g/kWh** as per the 7th Basic Energy Plan
- **10%** Private power generation (Co-generation)
  - Conventional LNG-fired power generation cogeneration **145g/kWh**

ILC Power source composition



This assumption of power supply composition is **my personal idea and has no authority**.
The actual power supply configuration should be determined by the ILC Lab, taking into consideration the following three points：

- Power system redundancy
- Cost of power
- Sustainability

Conclusion: Assuming that the annual power consumption of the ILC is 0.7 TWh, the annual CO_2 emissions are less than 60 k-ton/0.7TWh when operating with the above power configuration.

Assuming 0.7 TWh of ILC annual power	Power source ratio (%)	Electricity consumption by power source TWh	CO2 emission g/kWh	CO2 emission k-ton
Local renewable electricity	70	0.49	20	9.8
LNG cogeneration	10	0.07	415	29.05
The 7th Basic Energy Plan	20	0.14	113~145	15.82~20.3
Total	100	0.7		54.67~59.12

Presentation by Suzanne Evans of ARUP, WSFA2023 in Morioka

Life Cycle Assessment

Comparative environmental footprint for future linear colliders CLIC and ILC

Contents | LCA approach | **A1-A5 assessment** | Benchmarking | Sensitivities & reduction opportunities | Conclusions | ARUP

A1-A5 GWP Results

System | Sub-system | Components | Sub-components

A1-A5 absolute GWP

The absolute A1-A5 GWP results are listed below and are reported to 3 significant figures:

CLIC Drive Beam (built in 3 stages):

380GeV 127,000 tCO_2e
1.5TeV 169,000 tCO_2e
3TeV 205,000 tCO_2e

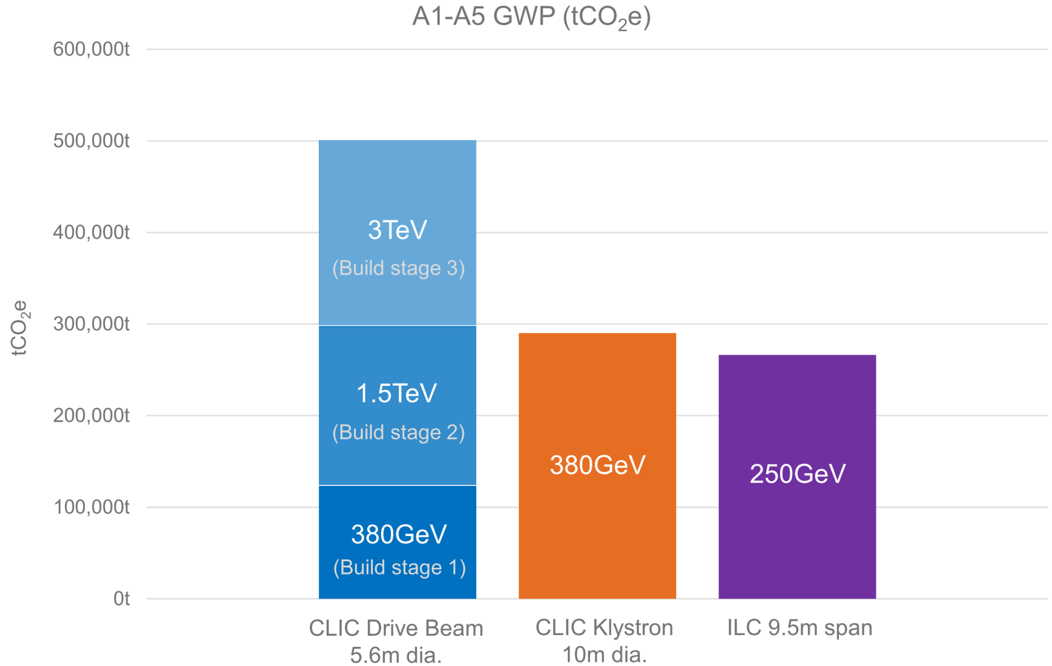
Total CLIC Drive Beam 3TeV: 501,000 tCO_2e

CLIC Klystron:

380GeV 290,000 tCO_2e

ILC:

250GeV 266,000 tCO_2e



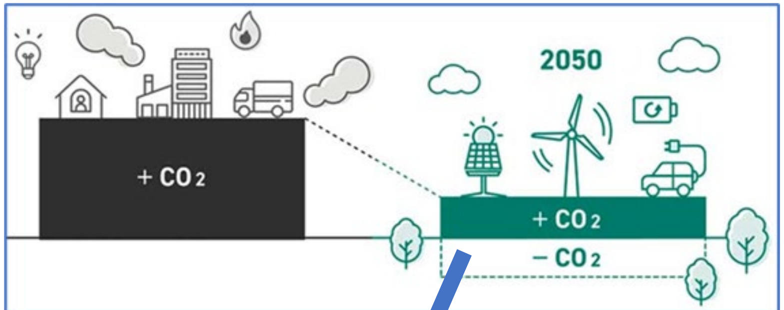
- Suzanne's work is extremely important because it provides a methodology for LCA of CO_2 emissions from accelerator construction, in which she has already mentioned the choice of steel and cement materials with the lowest possible CO_2 emissions.
- In my presentation today I will not go into details, but only use the conclusion of the ILC **(266 k-tons of CO_2 emissions).**

Rounded numerical targets:

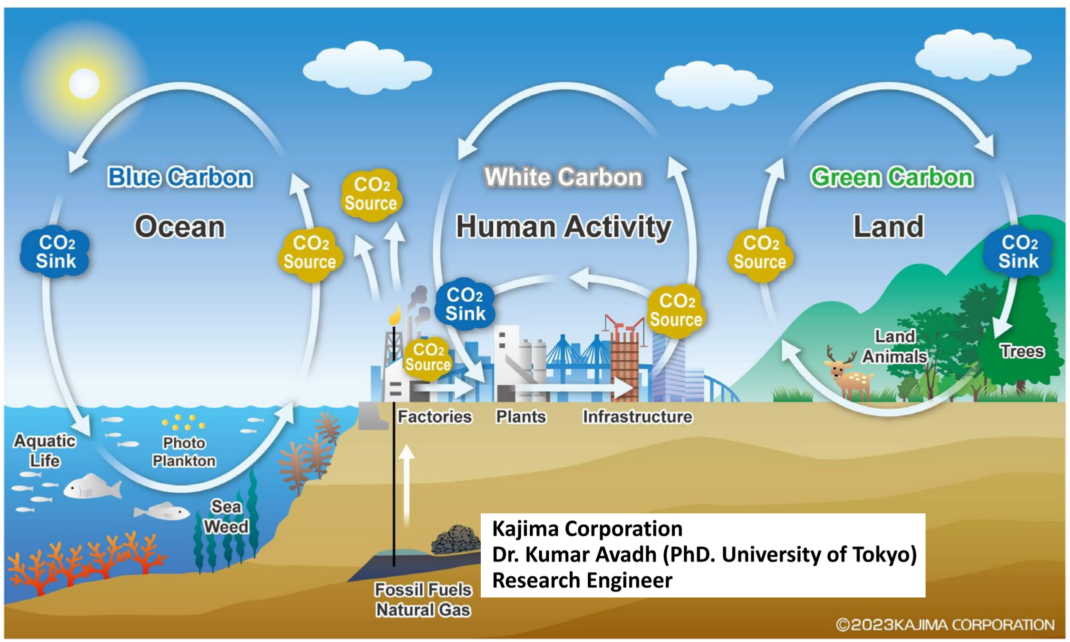
construction period ➔ Less than 30 k-tons/year
operation period ➔ Less than 60 k-tons/year

The challenge is to offset these numbers with carbon credits in accordance with Japanese policy.

Again, Japan's strategy is to reduce CO_2 emissions while simultaneously increasing and ultimately offsetting CO_2 absorption.



Carbon Cycle



Negative CO_2 emission

1. Green Carbon: CO_2 absorption by forests
2. Blue Carbon: CO_2 absorption by coastal seaweed
3. White Carbon: Long-term fixation of CO_2 by wooden buildings

By the time the ILC starts operation in 2040, we would like to be able to credit these CO_2 absorptions.

Waste heat utilization business using HASClay will be described in next pages, in detail.

- As a final topic, I would like to discuss a study on the commercialization of waste heat recovery from accelerator facilities.
- We have established an industry-government-academia joint research system led by East Japan Mechanical & Electric Development Co (HKK).
- I will explain using part of HKK's presentation at LCWS2024 in July last year.

LCWS 2024

Industry : Sustainability Session

Commercialization and fundamental research of waste heat recovery technology using adsorption heat storage materials

Higashi-nihon **K**iden**K**aihatsu Co.,Ltd.(**HKK**)

Yuichi Kouno

1

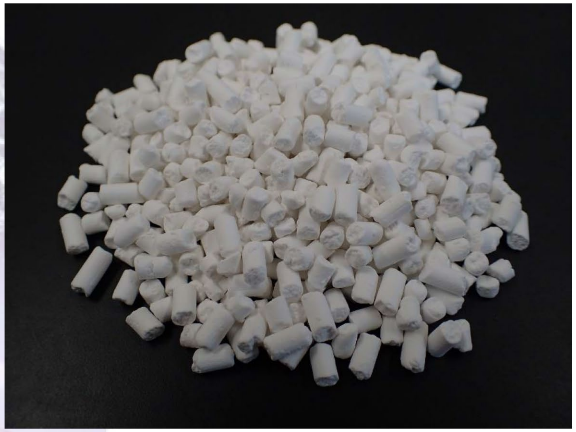
- HASClay is a super-porous material (specific surface property is more than 500m^2/g).
- It can store heat by sending hot air (50~100°C)through the wet material to expel adsorbed water molecules.
- Conversely, if moist air is sent to a material in a dry state, water vapor is adsorbed and hot air with low humidity comes out.
- The dry state can store 560 MJ/m^3 of energy.

What's HASClay ?

HASClay® is an inorganic adsorbent material composed of a composite of amorphous hydroxyl aluminum silicate (HAS) and low-crystallinity clay.

HASClay® has the ability to store heat with the principle of energy transfer by water vapor desorption.

- In particular, it has an excellent storage capacity for low-grade heat (<100 ˚C).
- It is capable of repeating the heat storage and dissipation cycle over and over again.
- By sealing the container and blocking moisture, the heat energy can be stored semi-permanently and will not ignite or deteriorate, making it safe to store.
- Off-line transport allows exhaust heat from ILC and factories to be used effectively in a wide range of fields.

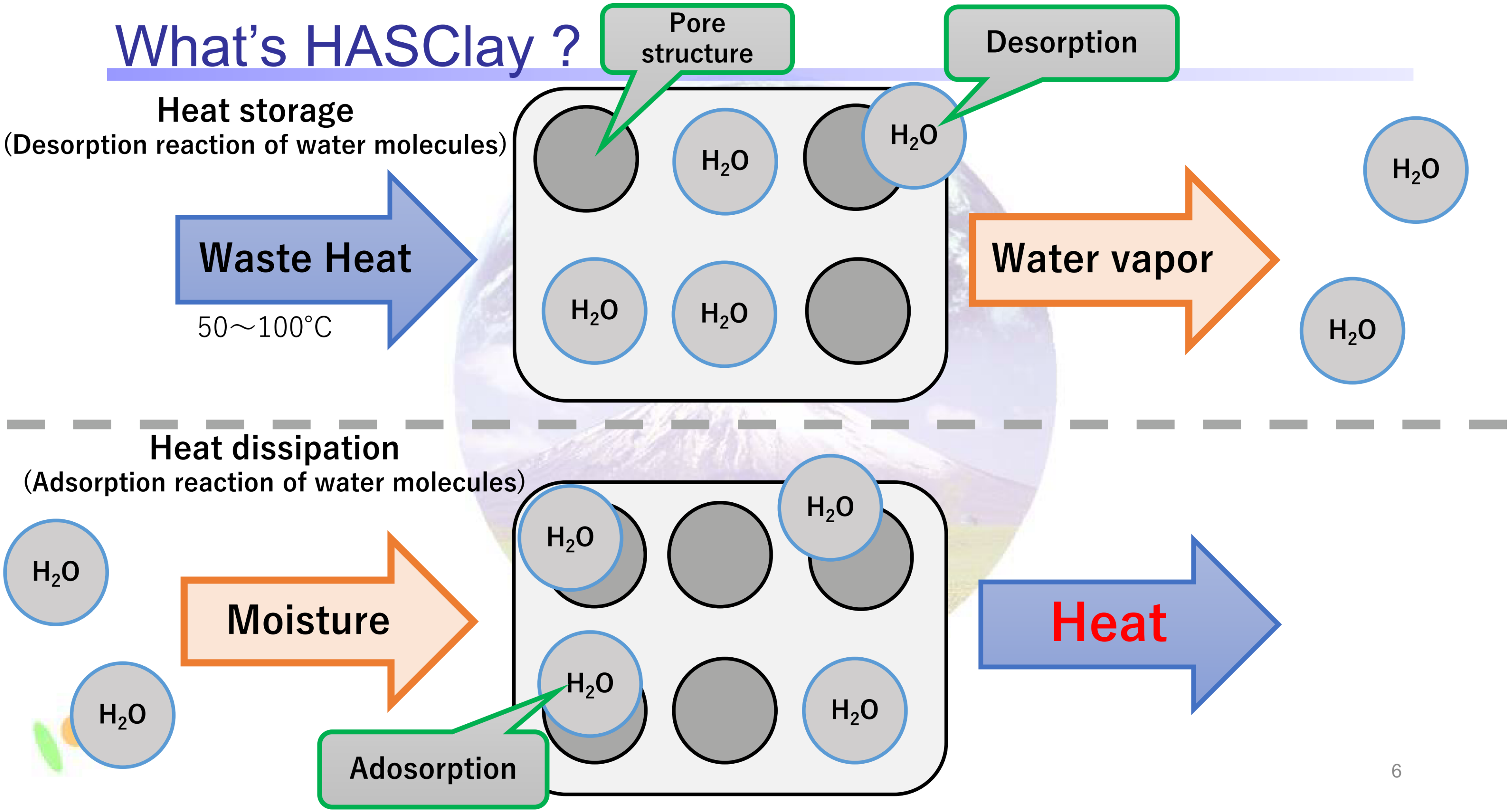


The appearance of HASClay®

Performance of various adsorbents

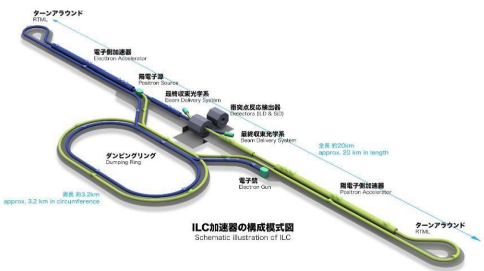
Adsorbent	Heat storage ability	Heat storage capacity(kJ/L)
HASclay	**40 ˚C or more**	**567**
Modified zeolite	80 ˚C or more	439

- This is the illustration of the heat storage process (above) and the heat dissipation process (below)
- It is suitable for low-grade waste heat recovery below 100°C.



- Assuming the cooling towers are installed at five ground stations, the heat release per station is $4X10^{11}$ joules.
- The HASClay required to recover 20% of that thermal energy is 400 tons.
- A realistic design of this magnitude is possible.

How to use HASClay in ILC



Schematic illustration of ILC
Source: KEK Homepage

- **Power :**
  120 [MW] = $1x10^{13}$ [J/day]
- **Waste heat recovery target :**
  20[%] = $2x10^{12}$ [J]
- **Number of cooling tower :**
  5 towers → $4x10^{11}$ [J] @ tower
- **Heat storage capacity of HASClay :**
  500 [MJ]@1m^3 → Heat storage time : 8.5 [hour]
- **Required amount of HASClay :**
  800 [m^3] = 400 [tons]

- An air-cooled cooling tower is installed as a preliminary step to a closed water-cooled cooling tower to generate a rising air flow without using power to dry HASClay.
- We are planning a facility for waste heat recovery and utilization in agriculture, forestry, and fisheries using factory waste heat and hot spring waste heat using this method.

How to use HASClay in ILC

©Ray.Hori/KEK

120[MW]
$1x10^{13}$ [J/day]

Waste heat 60℃

Heat Storage Device
30[m]x30[m]
=900[m²]

Closed water cooling Tower

HASClay
800[m³]=400[ton]

Heat recovery
$4x10^{11}$[J]

Mesh

Image of
HASClay Special Container
(Airflow through inside)

To delivery area

When laying 1[m³] of HASClay per 1[m²]

Heat storage capacity per Heat storage device
= 500[MJ] @1m³x 900[m²] = 4.5×10^{11}[J]

Heat recovery : 4×10^{11}[J]
Waste heat recovery target : 20[%]
→ Considered promissing

8

Green ILC Summary

- Once the ILC lab is established, further efforts should be made to improve energy-saving technologies.
- Meanwhile, we, the group of communities with candidate sites, will continue our efforts to achieve sustainable communities by the time construction of the “ILC in Japan” begins.
- To this end, we will make efforts to deepen cooperation between the ILC and local primary industries (agriculture, forestry, and fisheries).
- Research on the commercialization of ILC waste heat recovery technology is progressing well, and within a few years it should be possible to recover the waste heat from factories and the many hot springs in Iwate Prefecture and build a regional thermal energy circulation system. Once the ILC is operational, waste heat recovery from the ILC will also be incorporated into this project.

ご清聴ありがとうございます

Thank you for your attention