Overview
on the sustainability of future accelerators
Masakazu Yoshioka

My Profile

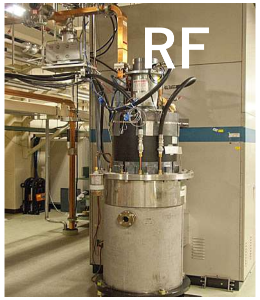
- Born in 1946
- Studied physics at Kyoto University
- Engaged in large accelerator construction and technology development at the University of Tokyo (13 years) and KEK (23 years)
- Then, moved my base of activities to Iwate Prefecture, where the ILC candidate site is located, to realize ILC in Japan from 2016
- Currently Professor Emeritus at KEK and Visiting Professor at Iwate University and Iwate Prefectural University

Table of Contents

1. The need for **life cycle assessment** of accelerator facilities.
2. Responsibility of accelerator researchers to reduce the energy consumption of accelerators from the **accelerator design stage**.
3. The causes of greenhouse gas emissions **during construction of accelerator facilities** must be understood.
4. The main cause of CO2 emissions during accelerator operation is **electricity consumption**.
5. **The electric power composition of the region** where the accelerator facility is located should be understood, and operation using **green power** should be realized.
6. Low-grade waste heat emitted from accelerator **should be recovered** as much as possible and returned to society.
7. **Collaborate with local communities** to reduce CO2 emissions in the areas where accelerator facilities are located.

Today, based on my nearly 50 years of experience with accelerators, I will talk about the sustainability of accelerator facilities, an issue of today, with some stories from the past!

(1) **LCA:** Future accelerators must be assessed for sustainability during their **life cycle**, including construction, operation, and decommissioning, to meet the global goal of carbon neutrality by 2050.



From construction to operational phase

- Stopping global warming is an urgent task for the entire human.
- To achieve this goal, we should aim to reduce greenhouse gas emissions to practically zero by 2050.
- Currently, the concept of **Life Cycle Assessment** is based on **all industries,** such as (for example) automobiles, metal production, cement production, civil engineering and construction, agriculture, forestry, and fisheries, etc.
- **Accelerators are no exception**, and their CO2 emissions should be assessed on a life cycle basis.

LCA is being done in every industry.

OPEN ACCESS PEER-REVIEWED CHAPTER

Life Cycle Assessment of Ordinary Portland Cement (OPC) Using both Problem Oriented (Midpoint) Approach and Damage Oriented Approach (Endpoint)

WRITTEN BY

Busola D. Olagunju and Oludolapo A. Olanrewaju

Submitted: 15 April 2021 , Reviewed: 14 May 2021 , Published: 09 July 2021

DOI: 10.5772/intechopen.98398

OICA

Application of LCA
in the automotive industry

UNECE GRPE
Workshop on Life Cycle Assessment
2022-05-31

LIFE-CYCLE ANALYSIS -

A CHALLENGE FOR FORESTRY

AND FOREST INDUSTRY

Proceedings of the International Workshop organised by the European Forest Institute and the Federal Research Centre for Forestry and Forest Products

3-5 May 1995
Hamburg, Germany

Edited by Arno Frühwald and Birger Solberg

Sarah B. Boyd

Life-Cycle Assessment of Semiconductors

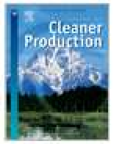
Foreword by Arpad Horvath

Springer

ELSEVIER

Journal of Cleaner Production

Volume 130, 1 September 2016, Pages 195-201



The environmental impacts of iron and steel industry: a life cycle assessment study

Gulnur Maden Olmez [a], Filiz B. Dilek [a], Tanju Karanfil [b], Ulku Yetis [a]

Even in the primary industry (this is the case of forestry)

I learned about the systematic activities of LCA for accelerator facilities from the presentation of **Suzanne Evans of ARUP** at LCWS2023 (SLAC) and WSFA2023 (Morioka, Japan).

According to Suzanne Evans of ARUP, CO_2 emissions during ILC construction will be 266 kilotons.

- **A methodology for calculating life cycle CO_2 emissions has been discussed.**
- **The CLIC and ILC cases were evaluated in detail.**
- **Future reductions are also proposed.**

ARUP

Life Cycle A

Comparative environme

Final Report

July 2023

CERN KEK-JAPAN

ARUP

Life Cycle Assessment

Comparative environmental footprint for future linear colliders CLIC and ILC

The International Workshop on Sustainability in Future Accelerators 2023 | 26/09/2023

ARUP: *Suzanne Evans, *Jin Sasaki, Ben Castle, Yung Loo, Heleni Pantelidou, Marin Tanaka
CERN: John Osborne, Steinar Stapnes, Benno List, Liam Bromiley
KEK: Nobuhiro Terunuma, Akira Yamamoto, Tomoyuki Sanuki
(*presenters: suzanne.evans@arup.com, jin.sasaki@arup.com)

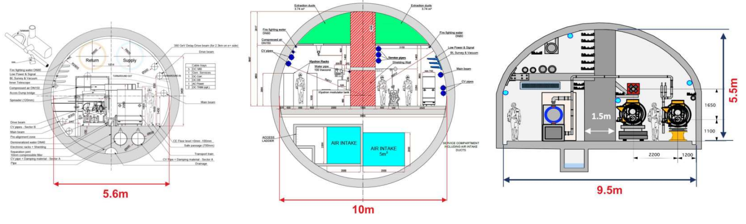
ARUP

Linear Collider Options

1. CLIC Drive Beam 5.6m internal dia. Geneva. (380GeV, 1.5TeV, 3TeV)

2. CLIC Klystron 10m internal dia. Geneva. (380GeV)

3. ILC Arched 9.5m span. Tohoku region, Japan. (250GeV)



Reference: CLIC Drive Beam tunnel cross section, 2018 | Reference: CLIC Klystron tunnel cross section, 2018 | Reference: Tohoku ILC Civil Engineering Plan, 2020

7

ARUP

2030 Baseline assumptions

LCA Modules		CLIC Drive Beam	CLIC Klystron	ILC
A1-A3	Materials	Concrete (CEMI) & Steel (80% recycled)		
A4	Transport of materials to site	Concrete: Local by road (50km) Steel: European by road (1500km)		Concrete: Local by road (50km) Steel: National by road (300km)
A5	Material wasted in construction	Concrete insitu: 5% Precast concrete: 1% Steel reinforcement: 5%		
A5	Transport of disposal materials off site	Concrete and steel recycling: 30km by road Concrete and steel landfill: 30km by road Spoil: 20km by road *Assumed that 90% of EoL construction materials are recycled or repurposed and 10% is in landfill.*		
A5	Construction process	Tunnel Boring Machine (TBM)		Drill & Blast
A5	Electricity mix 2021/2022	Fossil: 12% Non-fossil: 88%		Fossil: 71% Non-fossil: 29%

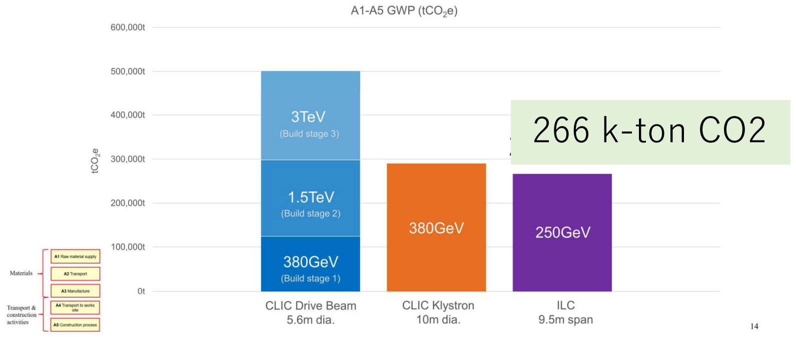
11

System | Sub-system | Components | Sub-components

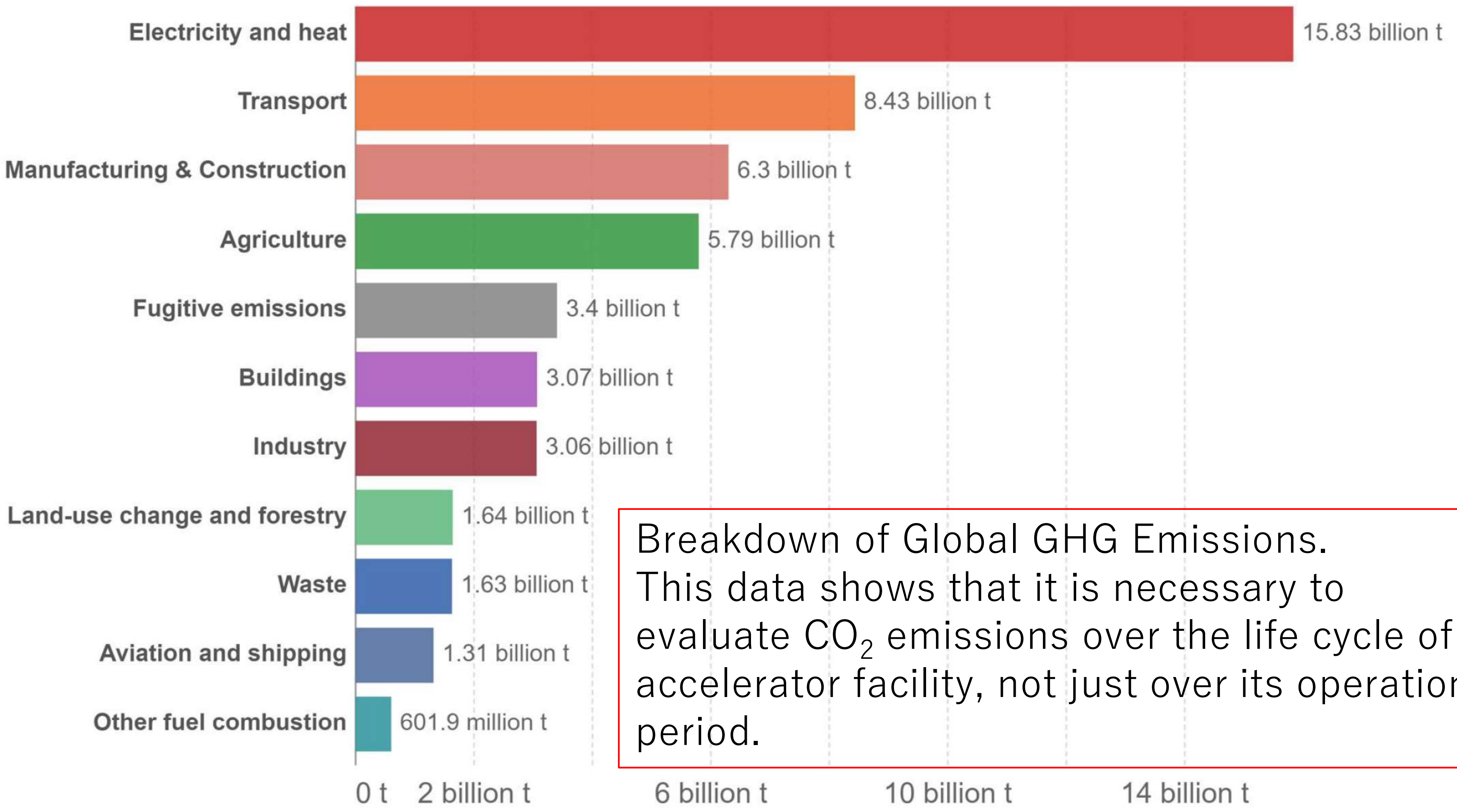
ARUP

A1-A5 Results

Global Warming Potential, GWP (tCO_2e)



14



Breakdown of Global GHG Emissions.
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)

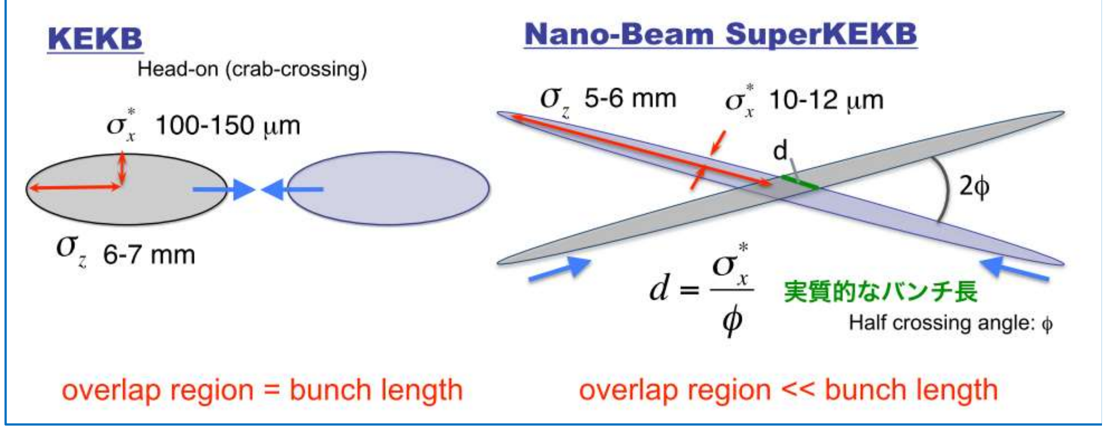
Presentation by Suzanne Evans of ARUP, WSFA2023 in Morioka

(2) Accelerator scientists should strive **to achieve performance with less electric power in the optical design phase** of accelerators, and to **improve power efficiency of accelerator components.**

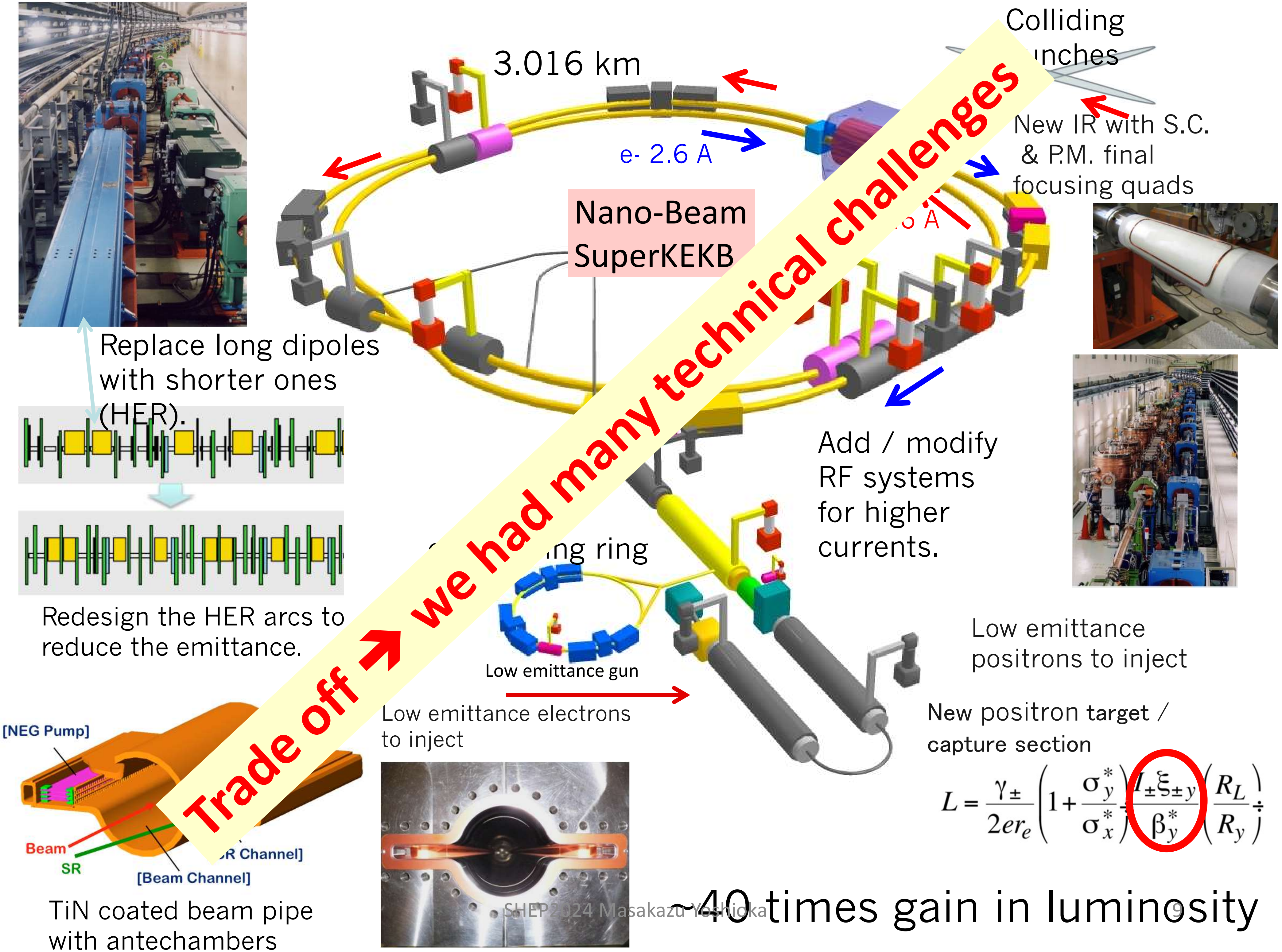
Three typical efforts are listed below

Effort example 1: Efforts in the optical design phase ➔ Nano-beam scheme of Super KEKB
Optical design to increase beam collision performance with the lowest possible power consumption ➔ The nanobeam scheme is a method to reduce the hourglass effect at the beam collision point by increasing the beam-crossing angle, thereby narrowing the vertical beta function at the collision point.

Super-KEKB is an eco-friendly accelerator that has already achieved twice the luminosity of its predecessor KEKB with half the beam current.



In other general terms, efforts are being made to maximize the beam performance per power consumption at the accelerator design stage.


Colliding bunches
3.016 km
e- 2.6 A
3.6 A
New IR with S.C. & P.M. final focusing quads
Nano-Beam SuperKEKB
Replace long dipoles with shorter ones (HER).
Redesign the HER arcs to reduce the emittance.
Add / modify RF systems for higher currents.
damping ring
Low emittance gun
Low emittance electrons to inject
Low emittance positrons to inject
New positron target / capture section
[NEG Pump]
Beam
SR
[SR Channel]
[Beam Channel]
TiN coated beam pipe with antechambers
$L = \frac{\gamma_\pm}{2er_e}\left(1+\frac{\sigma_y^*}{\sigma_x^*}\right)\left(\frac{I_\pm\xi_{\pm y}}{\beta_y^*}\right)\left(\frac{R_L}{R_y}\right)$
~40 times gain in luminosity
Trade off → we had many technical challenges

Comparison of Parameters

	KEKB Achieved : with crab	SuperKEKB High-Current	SuperKEKB Nano-Beam
Energy (GeV) (LER/HER)	3.5/8.0	3.5/8.0	4.0/7.0
β_y^* (mm)	5.9/5.9	3/6	0.27/0.30
ε_x (nm)	18/24	24/18	3.2/4.6
σ_y(mm)	0.94	0.85/0.73	0.048/0.062
ξ_y	0.129/0.090	0.2/0.3	0.09/0.08
σ_z (mm)	~ 7	5/3	6/5
I_{beam} (A)	1.64/1.19	9.4/4.1	3.6/2.6
$N_{bunches}$	1584	5000	2500
Luminosity (10^{34} cm^{-2} s^{-1})	2.11	~40	80
Total Electric Power (MW)	~ 50	~ 100	~ 75
Luminosity/AC power	0.042	0.04	1.07

During the design phase of Super KEKB, two schemes were discussed, a high-current scheme and a nano-beam scheme, and the nano-beam scheme was selected as an eco-friendly accelerator.

Effort example 2: Base technology choice for accelerators to reduce power consumption ➔Superconducting accelerators

Many of the recent accelerators such as ILC, SNS (ORNL Spallation Neutron Source), Euro-XFEL, etc. are based on superconducting linacs with low power consumption.

Although this is an old document from 21 years ago for ILC technology choice, it is still valid today: TRC report in 2003 for LC technology choice

E_{CM} = 500GeV	TESLA	JLC-C	JLC-X/NLC	CLIC
Total site AC power (MW)	140	233	243	175
Design Luminosity $10^{33}cm^{-2}s^{-1}$	34.0	14.1	25.0	21.0
Luminosity/AC power	0.243	0.061	0.103	0.120

Superconducting linac is the most eco-friendly accelerator

Effort example 3: Improve reliability of accelerator components to reduce failure rates (MTBF), and shorten recovery time (MTTR) ➔ Reduce accelerator idling time and wasteful power consumption

R: **r**eliability
A: **a**vailability
M: **m**aintainability

RAM (reliability, availability, and ease of maintenance) must be considered in the optical design of accelerators and in the technology choice of accelerator components

MTTR: **m**ean **t**ime **t**o **r**epair (or **r**ecover)
MTBF: **m**ean **t**ime **b**etween **f**ailures

$$A = 1 - (MTTR/MTBF)$$

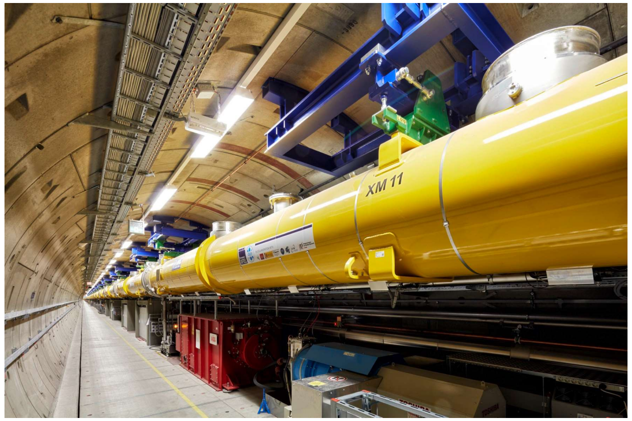
20th Int. Conf. on RF Superconductivity SRF2021, East Lansing, MI, USA JACoW Publishing
ISBN: 978-3-95450-233-2 ISSN: 2673-5504 doi:10.18429/JACoW-SRF2021-MOOFAV06

FOUR YEARS OF SUCCESSFUL OPERATION OF THE EUROPEAN XFEL

J. Branlard*, S. Choroba, M. Grecki, S. Köpke, D. Kostin, D. Nölle,
V. Vogel, N. Walker, S. Wiesenberg,
DESY, Hamburg, Germany

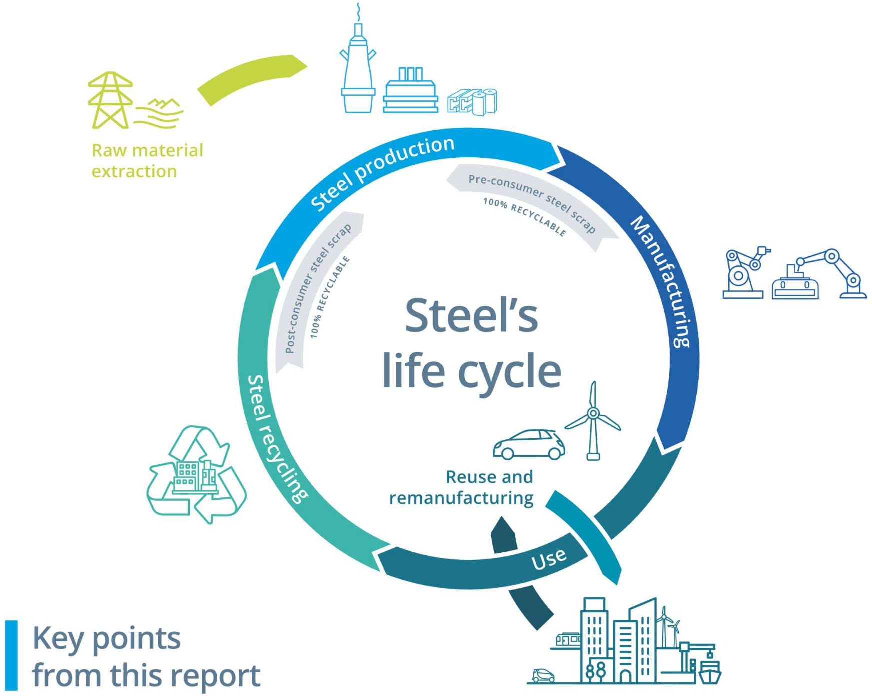
Table 2: Machine Availability over 7 (5) Weeks of Operation at Reduced (Maximum) Voltage

	unit	reduced-V	max-V	total
availability	%	98.7	95.6	97.9
total operation time	days	90.4	34.8	125.2
number of events		124	176	300
total down time	hrs	27.9	36.9	64.7
trips	hrs	13.5	26.6	40.1
linac off (access)	hrs	10.7	7.6	18.3
ramp up/down	hrs	1.8	1.7	3.5
development	hrs	0.8	0.8	1.9



In my working experience, accelerator operators are always striving to reduce idling time and bring **Availability** close to 100%.

(3) Furthermore, we should understand **CO2 emissions during the manufacturing** of concrete, steel frame, and reinforcing bars, which are the key factors of CO2 emissions during construction, and we should cooperate in efforts with industries to reduce these emissions.

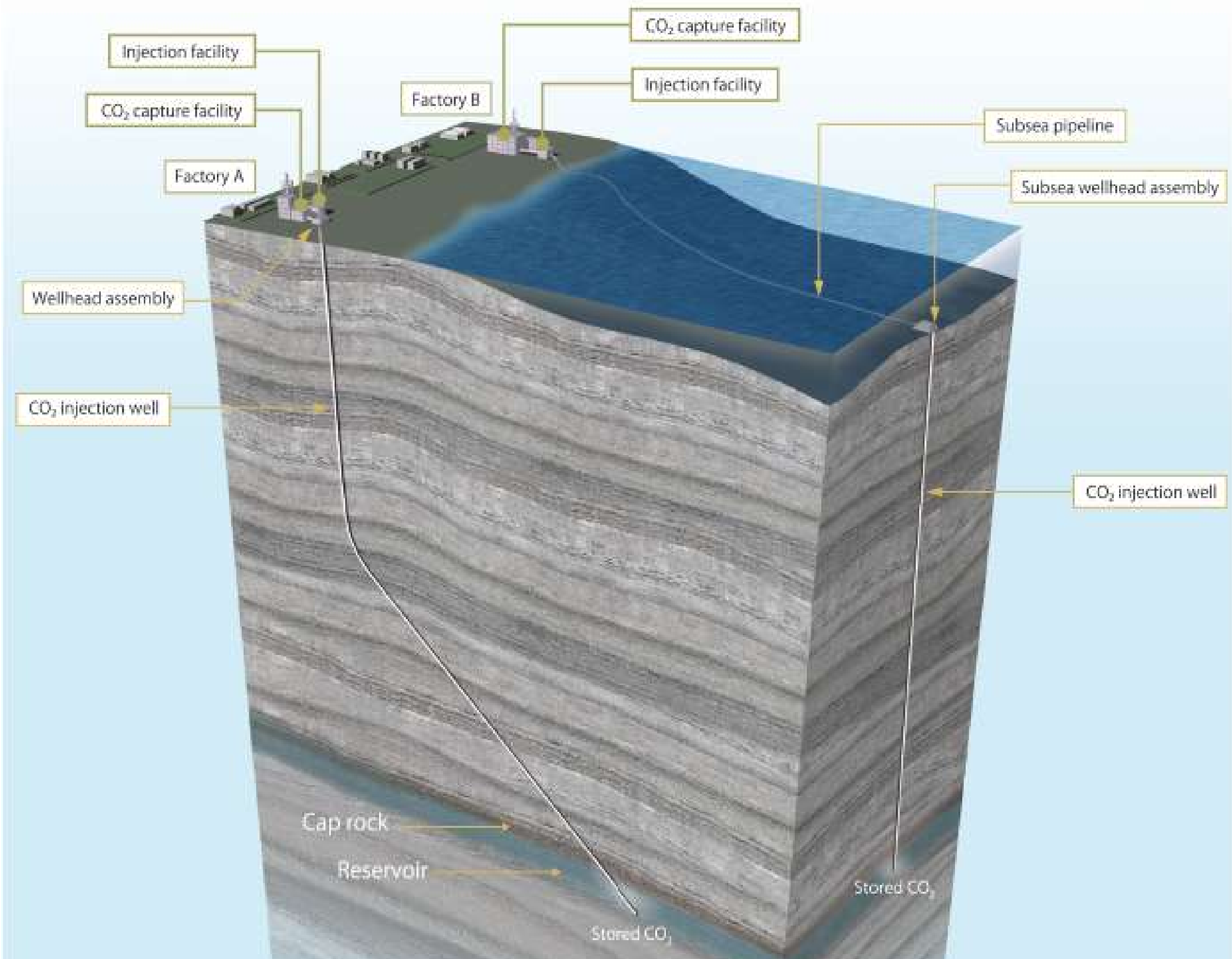


- Efforts are being made in the steel industry to introduce hydrogen reduction instead of relying on coke for reduction reactions.
- In addition, efforts are being made to increase the recycling rate of iron and to utilize electric furnaces.
- However, it is not easy to achieve zero CO2 emissions because the hydrogen reduction reaction is an endothermic reaction and recycled iron contains impurities.

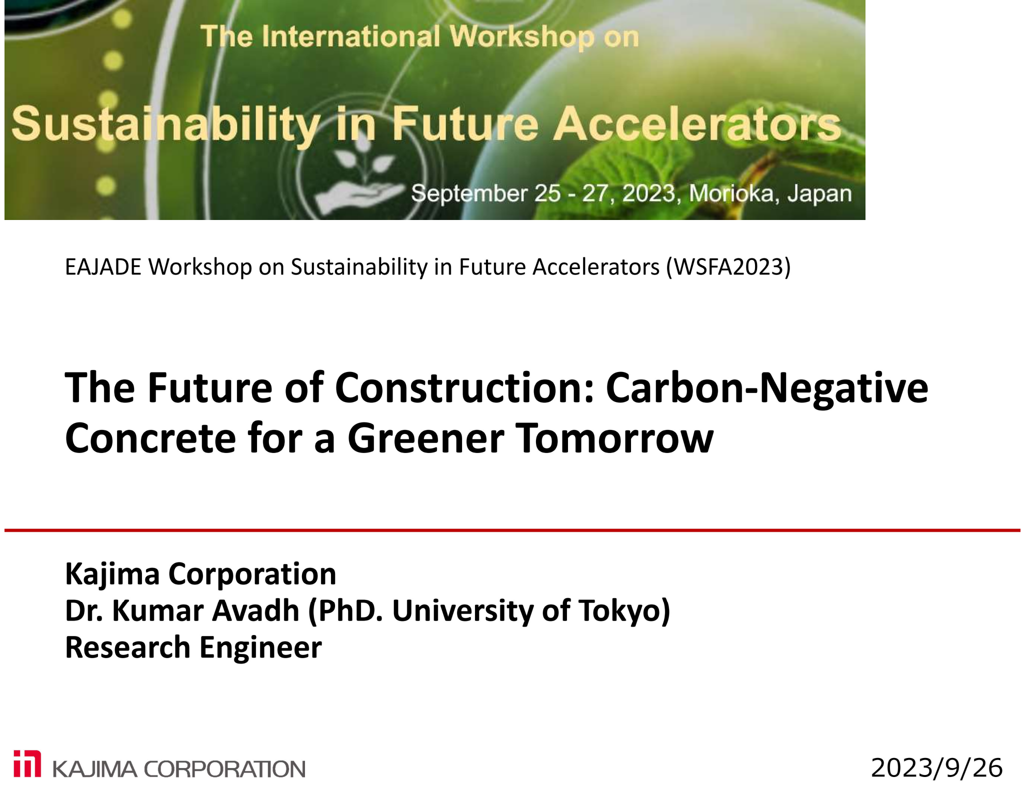
- Technology has already been developed to separate and compress the remaining CO2 emissions and seal it in deep underground for a long period of time.

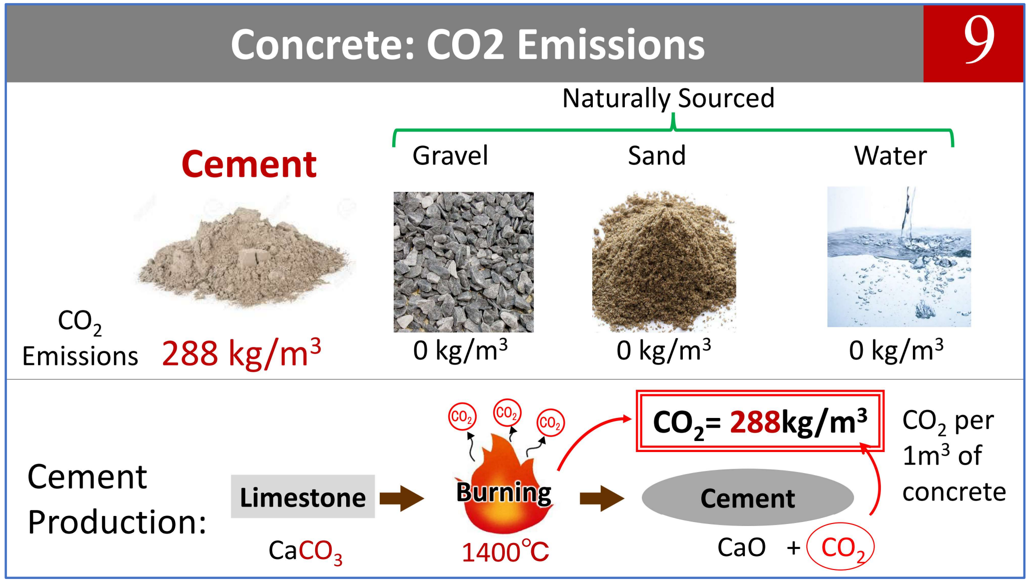
June 5, 2024 @ Tomakomai city in Hokkaido

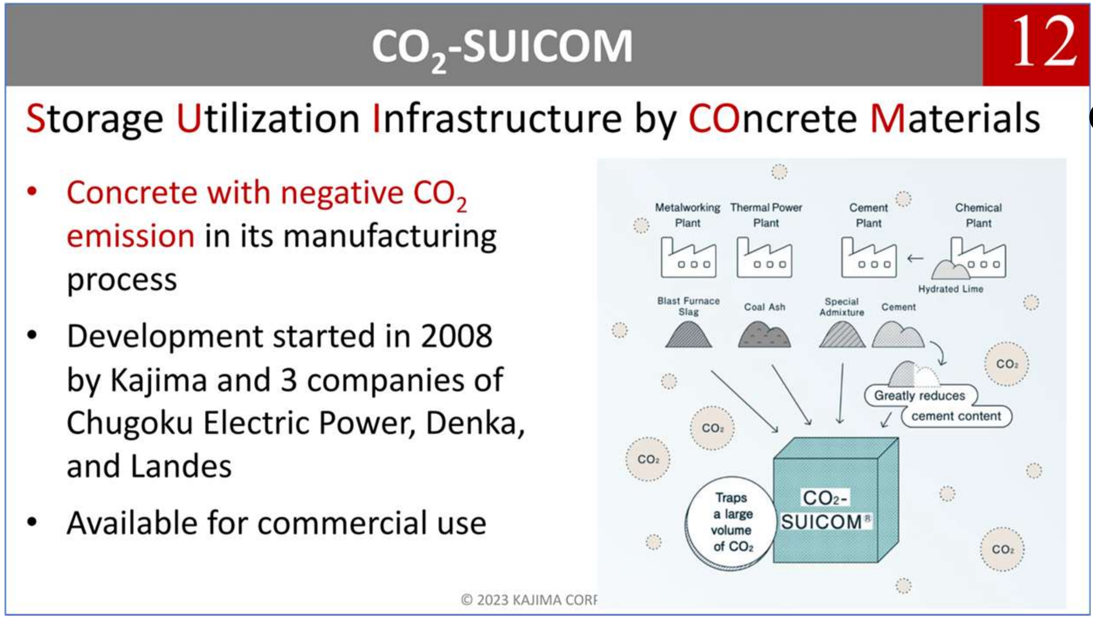
CO_2 Capture		CO_2 Transport		CO_2 Injection/Storage
High-purity CO_2 is captured from gas emitted from thermal power plants, factories, etc.	➡	Captured CO_2 is transported to injection facility (dedicated pipeline, transport ship, etc.).	➡	CO_2 is injected and stored in geological formations at depths greater than 1,000 m.



- Industrial trials of CCS are being conducted around the world, and it has already been established as an elemental technology.
- Japan, an earthquake-prone and volcanic country with four colliding plates, has achieved 300 k-ton of deep underground storage, which is almost at the practical stage.







- Cement, like steelmaking, also emits CO2 in the manufacturing process.
- However, Japanese cement manufacturers and general contraction companies are now working to develop cement that reduces CO2 emissions and traps CO2.

The International Workshop on

Sustainability in Future Accelerators

September 25 - 27, 2023, Morioka, Japan

Linear colliders

Sustainability studies for LCs

Life Cycle Assessments

Steiner Stapnes (CERN)

Steinar Stapnes

EAJADE WP4: Morioka 27.9.2023

(4) The main source of CO_2 emissions during accelerator operation is the electricity generated in the region where the accelerator is located.

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 CO_2 equiv. annually

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

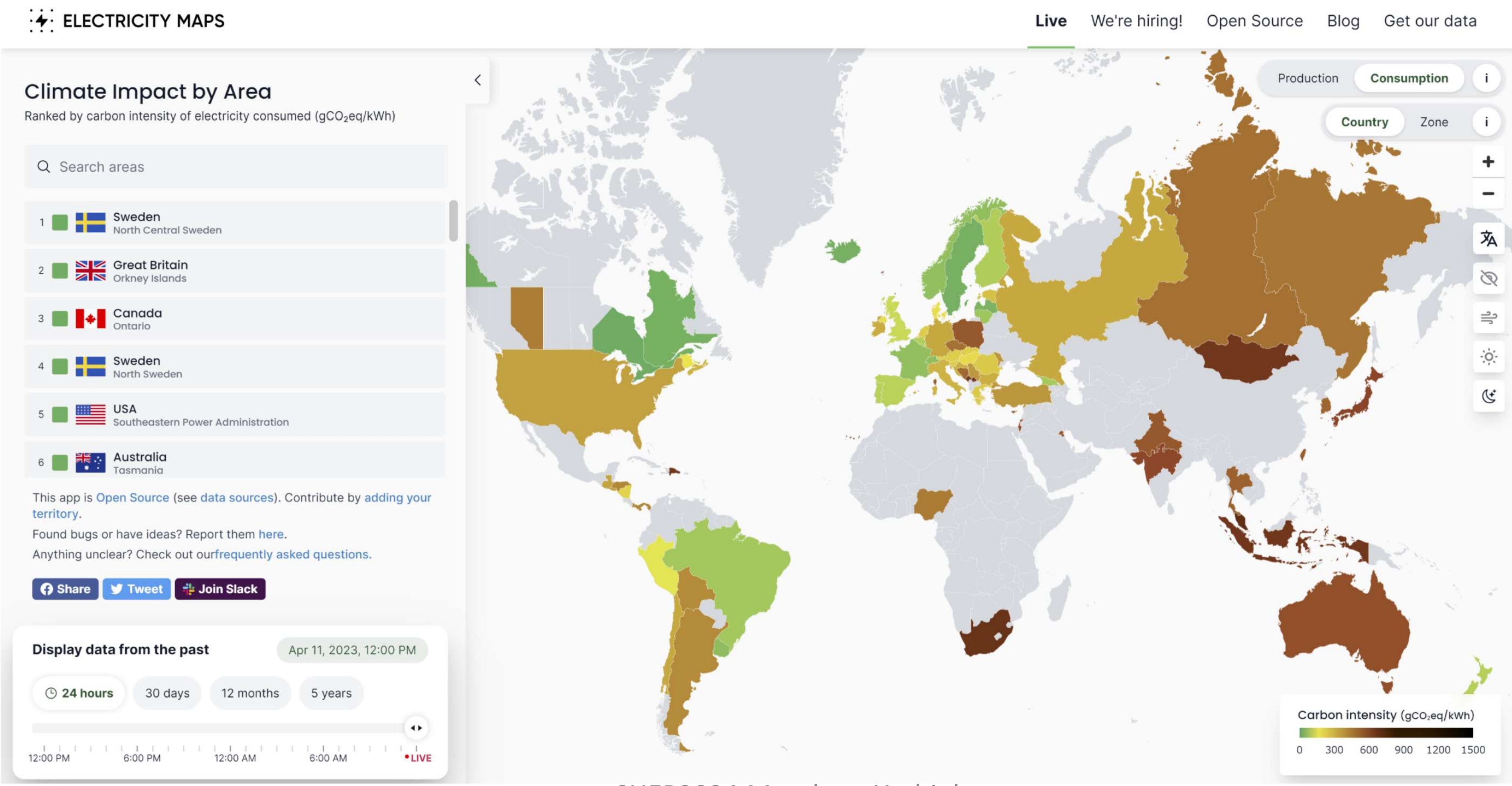
27/09/23 Steinar Stapnes 17

(5) We should understand the power composition of the region and ensure that accelerator operations are powered by “green (sustainable) power”.

This map is extremely useful and should be used by all!

Developed by the team led by Olivier Corradi

I'm a statistician, data scientist and entrepreneur focussed on finding scalable solutions to climate change. I created and founded Electricity Maps early 2016, where I now dedicate most of my time as CEO.



https://app.electricitymaps.com/

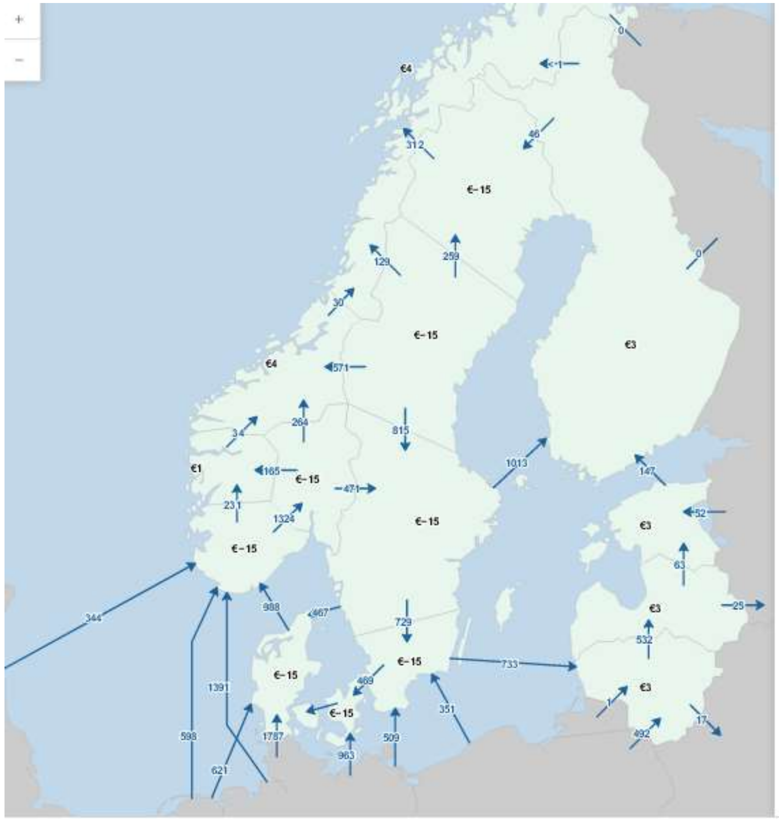
SVENSKA KRAFTNÄT

Svenska kraftnät, P.O. Box 1200, SE-172 24 Sundbyberg

Phone: +46 10-475 80 00
E-mail: registrator@svk.se
Org.nr: 202100-4284

https://www.svk.se/om-kraftsystemet/kontrollrummet/

This site is also an excellent source of information on the current electricity supply and demand situation in the seven Nordic countries at a glance.



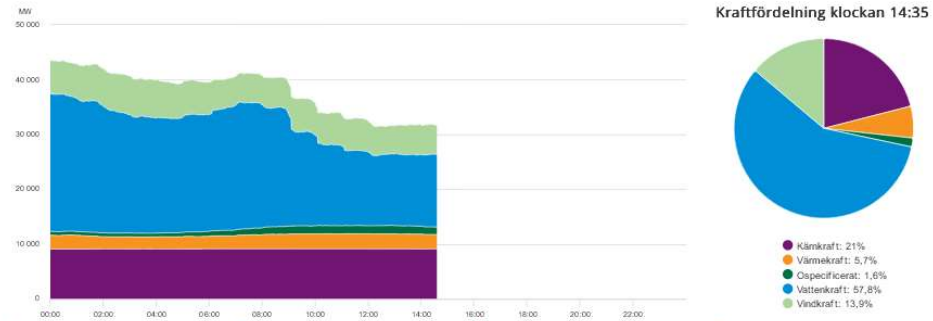
Netto export/import

SVERIGE	Exporterar	2 316 MW
DANMARK	Importerar	3 319 MW
NORGE	Importerar	3 862 MW
FINLAND	Importerar	1 114 MW
ESTLAND	Exporterar	32 MW
LETTLAND	Importerar	443 MW
LITAUEN	Importerar	677 MW

Datum 2024-06-08

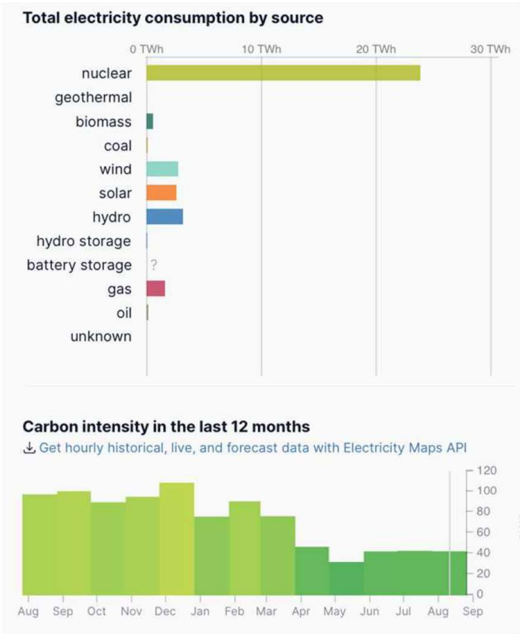
Sverige | Danmark | Norge | Finland | Estland | Lettland | Litauen | Totalt

Graf | Tabell



KÄRNKRAFT 9 107 MW	VÄRMEKRAFT 2 643 MW	OSPECIFICERAT 1 359 MW	VATTENKRAFT 13 243 MW
VINDKRAFT 5 312 MW	TOTAL PRODUKTION 31 662 MW	TOTAL FÖRBRUKNING 38 803 MW	NETTO IMPORT 7 141 MW

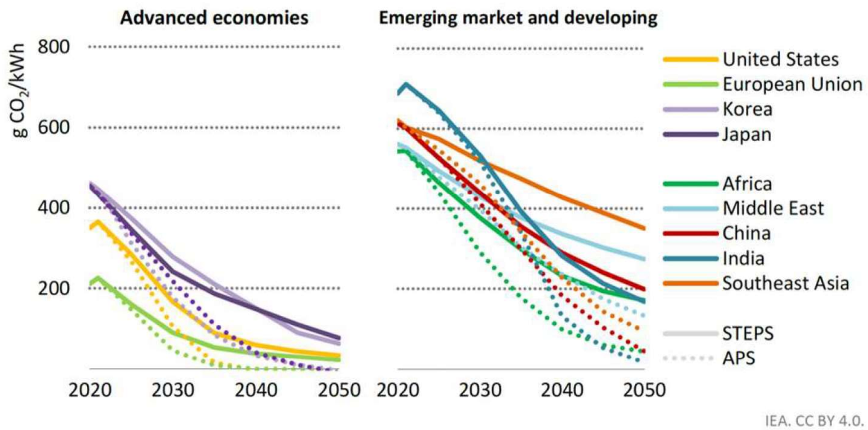
From energy to CO2 – in 2040-50



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

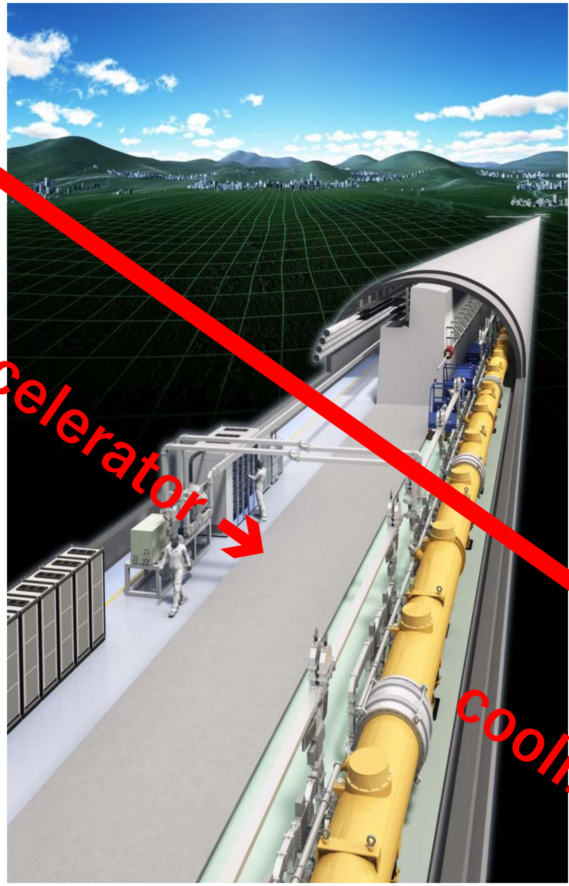
Contains also g/kWh per source

Figure 6.14 ▷ **Average CO_2 intensity of electricity generation for selected regions by scenario, 2020-2050**



CO_2 intensity of electricity generation varies widely today, but all regions see a decline in future years and many have declared net zero emissions ambitions by around 2050

(6) The low-grade waste heat emitted from accelerators should also be recovered as much as possible and returned to society.



Cooling water temperature is below 100° C in the cooling tower stage, making it unsuitable for recovering thermal energy

WSFA2023
Sustainability Session Ⅱ：Green ILC & Japanese Industry

Commercialization of Low-Grade waste heat recovery

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

1

What's HASClay ?

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

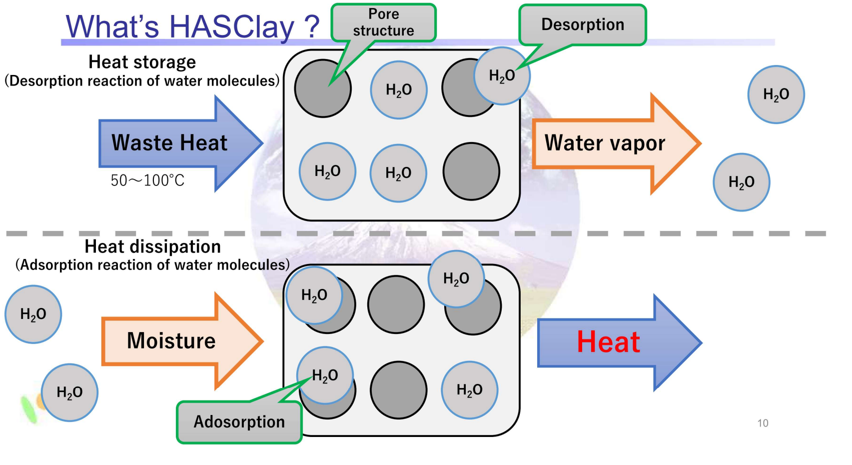
HASClay® has the ability to store heat with the principle of energy transfer by water vapor desorption.

- 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.

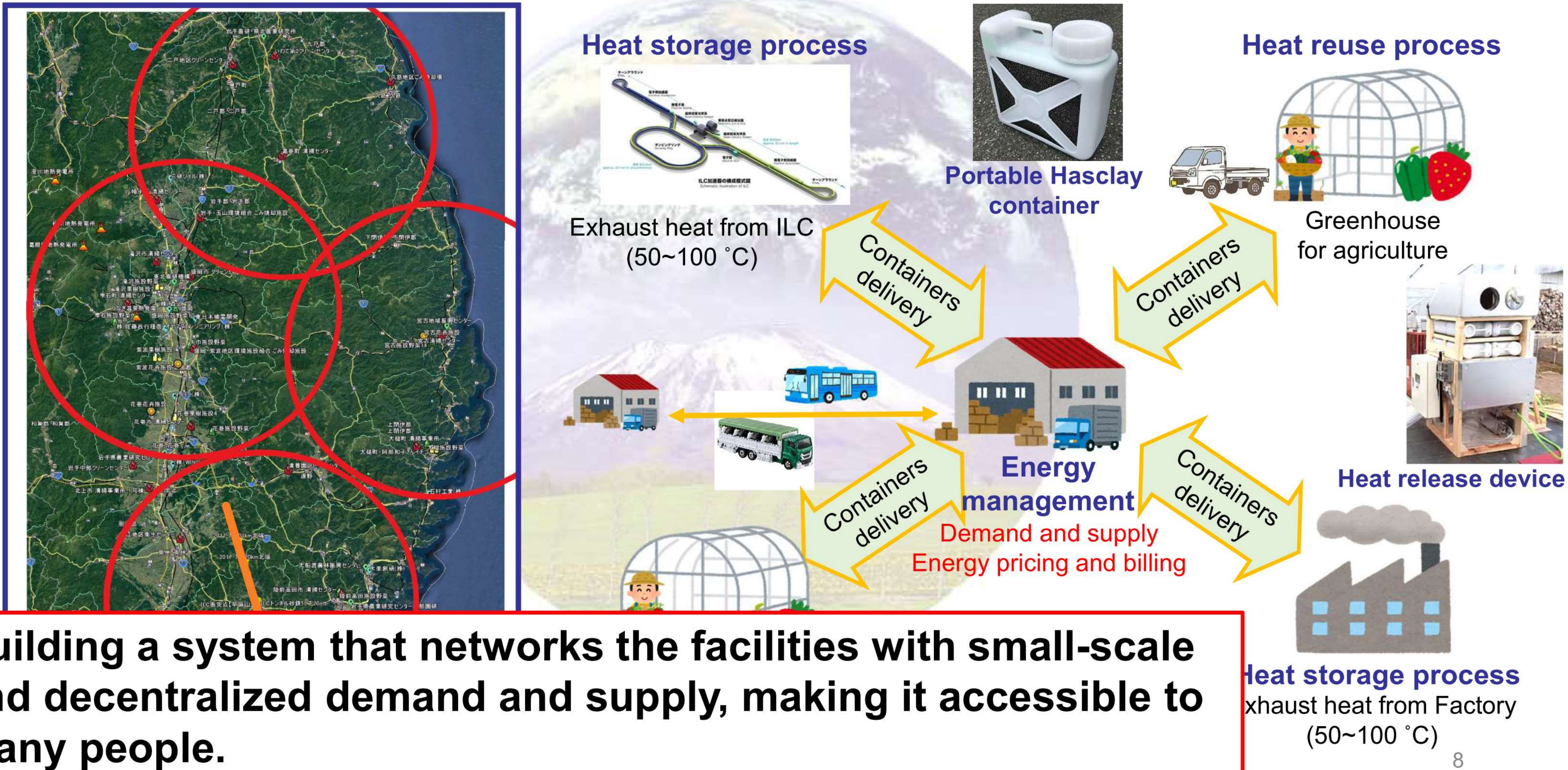
The appearance of HASClay®

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



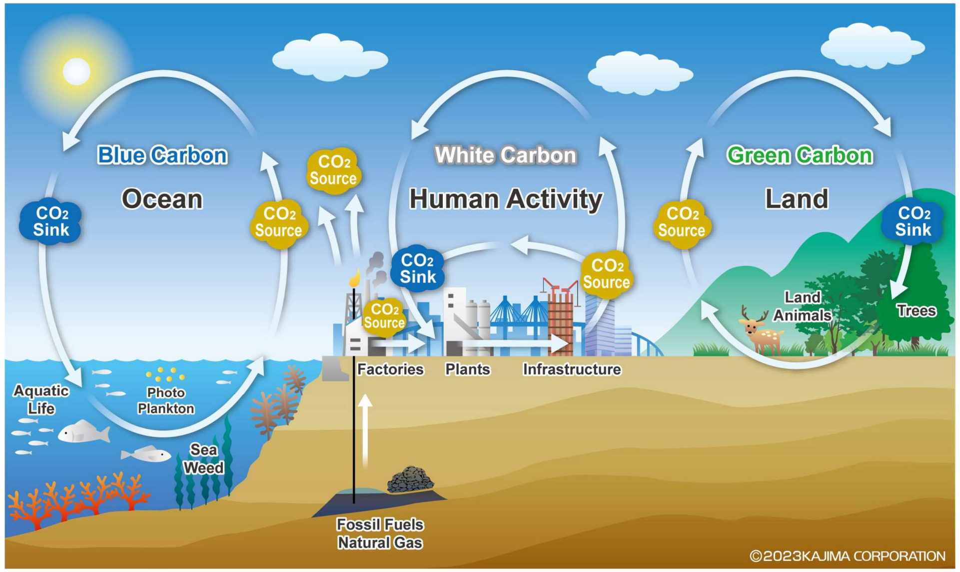
Off-line Waste Heat Circulation Model



Building a system that networks the facilities with small-scale and decentralized demand and supply, making it accessible to many people.

(7) In addition, to reduce CO2 emissions in the entire region where the accelerator is located, efforts should be made to increase **CO2 absorption** throughout the agriculture, forestry, fisheries, and livestock industries, as well as to increase long-term CO2 fixation by incorporating more wooden structures in local housing and large public buildings, including accelerator-related facilities.

Carbon Cycle



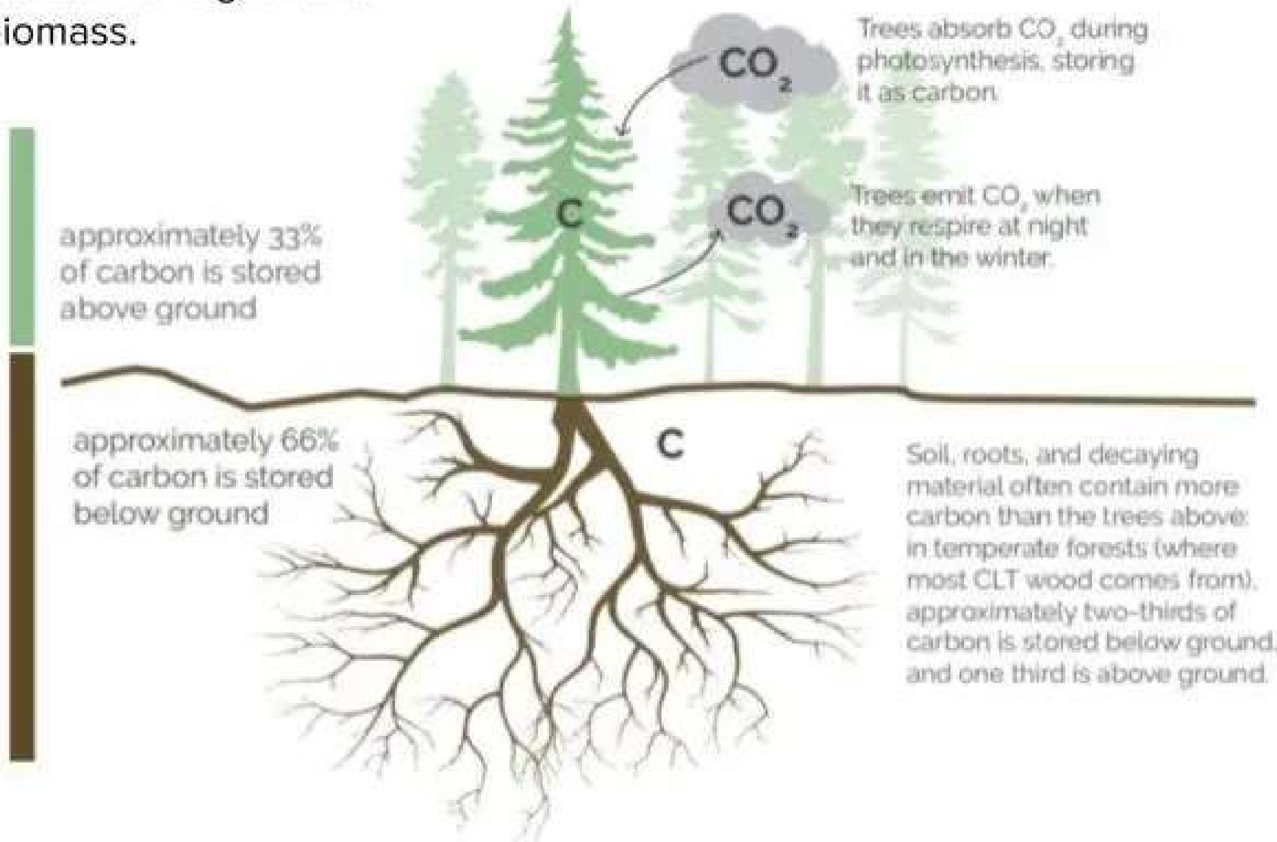
- Before the Industrial Revolution, CO2 emitted by human activities and CO2 absorbed and accumulated by the natural world were in balance.
- CO2 is stored in forests, soil, oceans, and atmosphere.
- After the Industrial Revolution, that balance has been lost, and the concentration of CO2 in the atmosphere is increasing.
- Furthermore, human activities have also damaged the ability of nature to absorb and store CO2, in other words, they are causing double damage to nature.

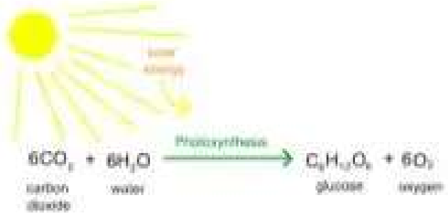
An Oregon State University and University of Oregon Collaboration

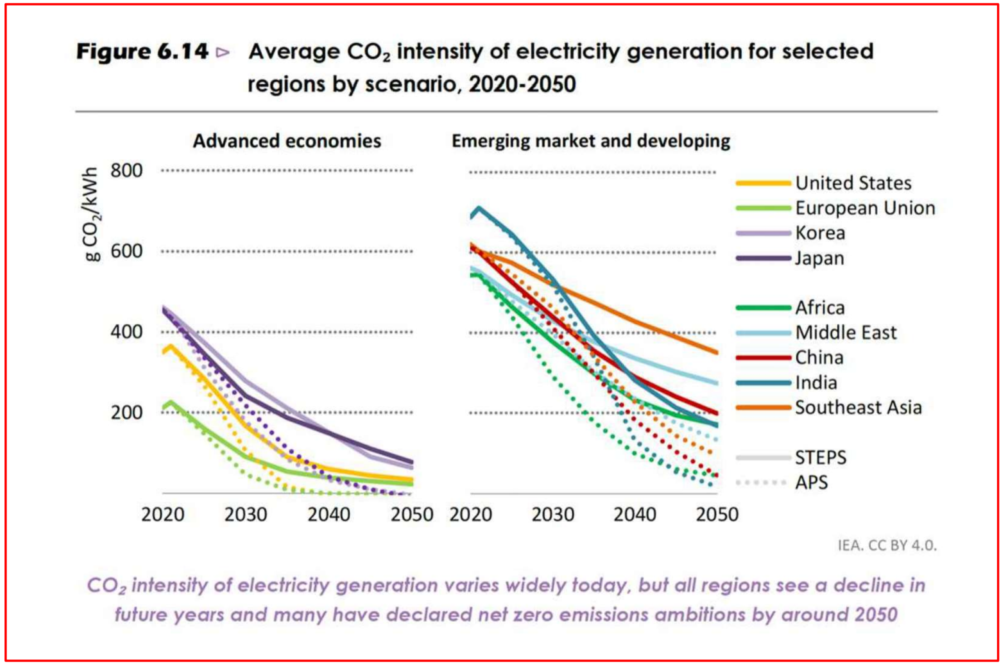
I borrowed this slide because it is an excellent demonstration of how CO2 is fixed in forests and soils.

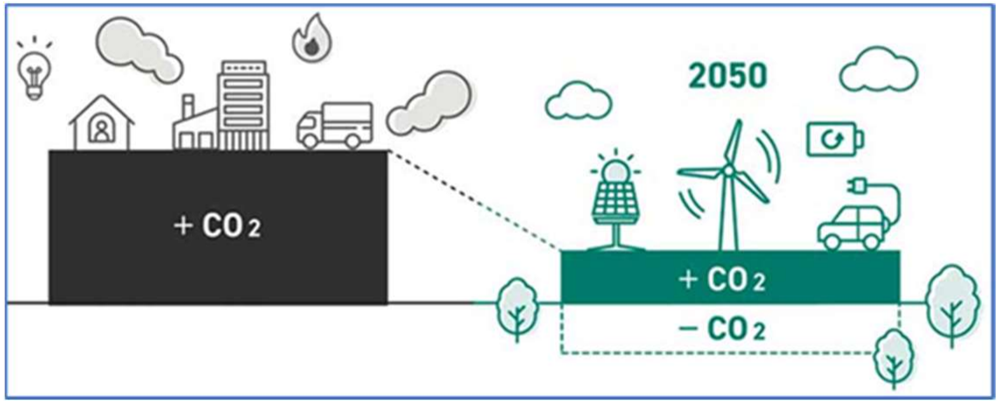
What is Biogenic Carbon?

Biogenic Carbon is carbon stored in the growth of biomass.





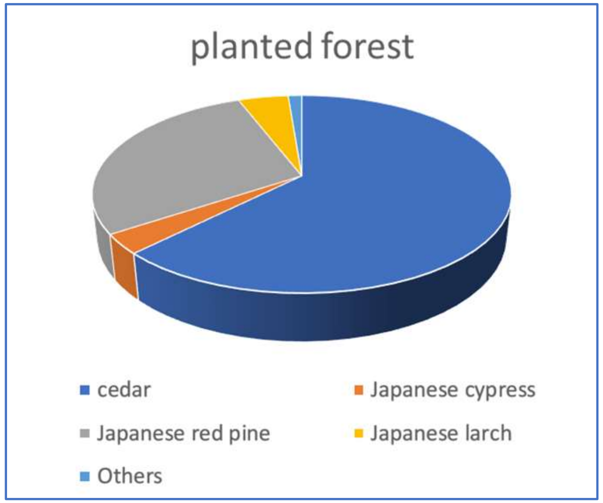


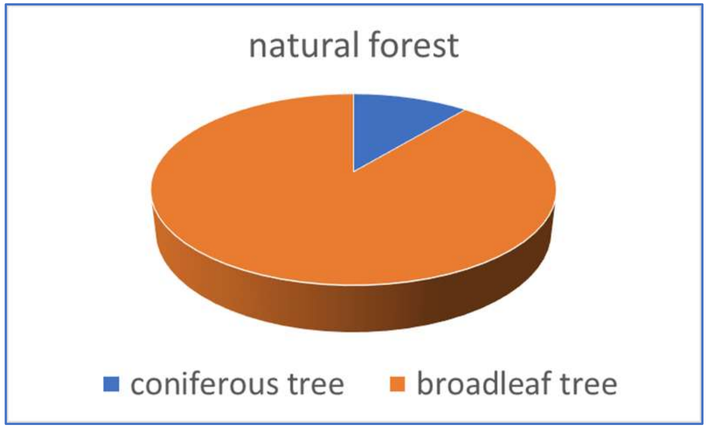


Scenario for Japan
Reduce CO2 emissions while at the same time increasing CO2 absorption/storage to ultimately offset CO2 emissions

- Again, let's look at the graph of CO2 emissions per kWh of electricity generated from Steiner's slide on page 19.
- Even in areas with excellent renewable energy rates, CO2 emissions cannot be reduced completely to zero!
- In an island country like Japan, it is sometimes unavoidable that some CO2 emissions will remain.
- As I have mentioned above, I believe that we should strive to reduce CO2 emissions and increase green carbon, blue carbon, and white carbon (negative emissions) at the same time, as well as effectively commercialize CCS.

We calculated the CO2 absorbed by the forests of Ichinoseki City, Iwate Prefecture, where the ILC candidate site is located.





47% Planted Forest: 31465 ha
53% Natural Forest: 34895 ha
Total 66363 ha

In planted forests, cedar is the most abundant species, followed by red pine.

Natural forests are mostly broadleaf tree.

Estimation by Hiroshi Kikuchi, advisor to the Ichinoseki City Agricultural Land and Forestry Department:

- The entire Ichinoseki forest absorbs 303.53 kilotons of CO_2 per year.
- The average annual CO_2 absorption per unit area is 4.57 t/year/ha.

It should be mentioned that the Ichinoseki forest will absorb more CO2 every year than the CO2 emitted during the construction of the ILC (266 k-ton) over a 10-year period.
The power of nature is that great!

Summary

- **Why Global Warming is Accelerating**
  - Before the Industrial Revolution, CO_2 emitted by human activities and CO_2 absorbed and accumulated by the natural world were **in balance**.
  - CO_2 is stored in forests, soil, oceans, and atmosphere.
  - After the Industrial Revolution, that **balance has been lost**, and the concentration of CO_2 in the atmosphere is increasing.
  - Furthermore, human activities have also **damaged the ability of nature to absorb and store CO_2**, in other words, they are causing double damage to nature.
- **What HEP Researchers Should Do**
  - To save energy in the accelerator and other research facilities and give back to society the technology developed for this purpose.
  - Recover thermal energy emitted from accelerators and research facilities and return it to society.
- **Efforts to be made in cooperation with the local community**
  - To cooperate in increasing the renewable energy rate of local electricity and to operate research facilities with green electricity as much as possible.
  - Understanding and, where possible, cooperating with efforts by steel, cement, and other GHG emitting companies to reduce their emissions (including CCS/CCUS).
  - Cooperate with local efforts to restore forests (green carbon) and oceans (blue carbon), which are inherent to the natural environment.

ILC: an amazing energy transformer

FROM eV TO TeV:

Finally, I dedicate this presentation to the **late Denis Perret-Gallix (LAPP/IN2P3.CNRS)** who inspired me to start my research activities for the Green ILC. This slide is the cover of his talk at the 2nd Energy for Sustainable Sciences, CERN Oct 2013.

Thank you very much for your kind attention.

THE GREEN ILC