Sustainability

Some considerations

Thomas Schörner
FH Sustainability Forum
19 February 2024, DESY

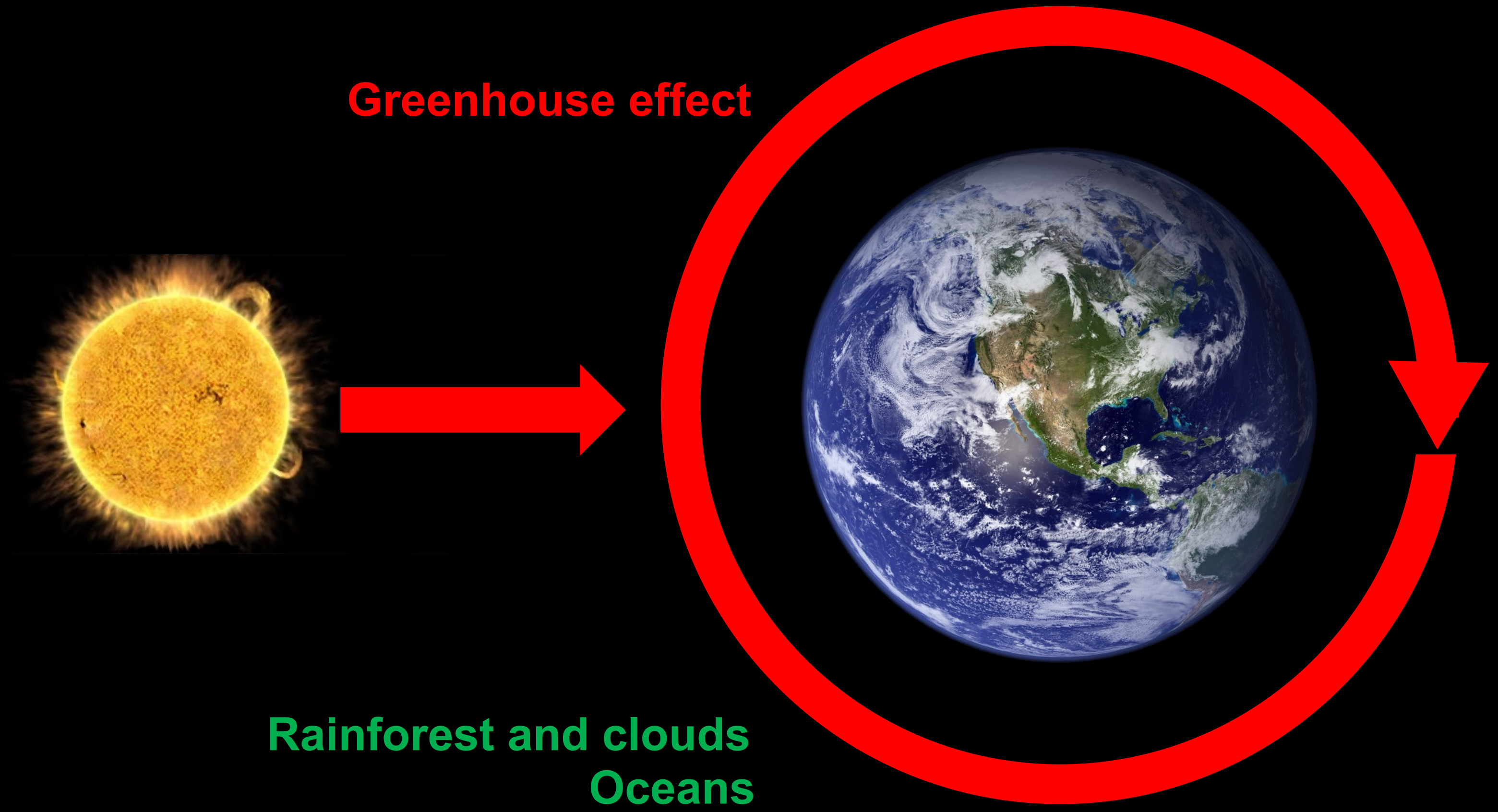
With lots of material borrowed from
M. Düren, B. List, S. Stapnes and others

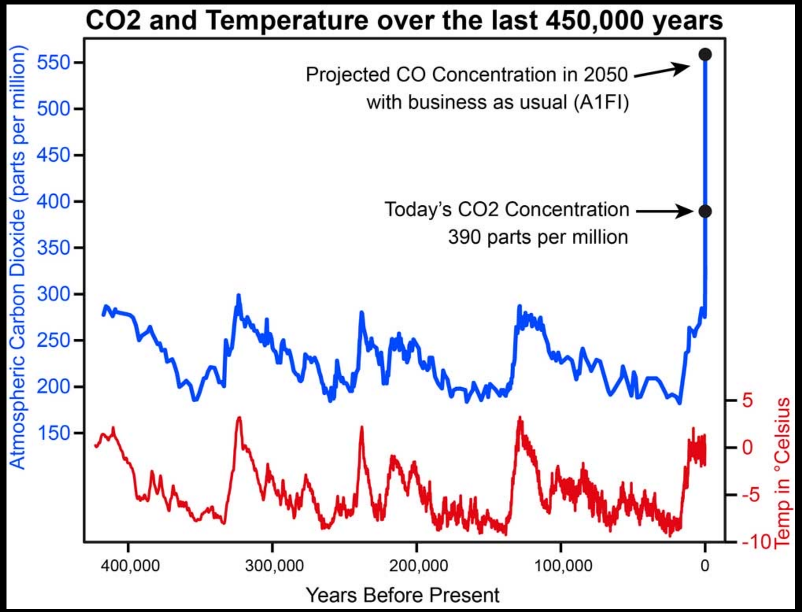
HELMHOLTZ

Sustainability

System Earth

A stabilised feedback loop (physics + biology + planetary distortions)



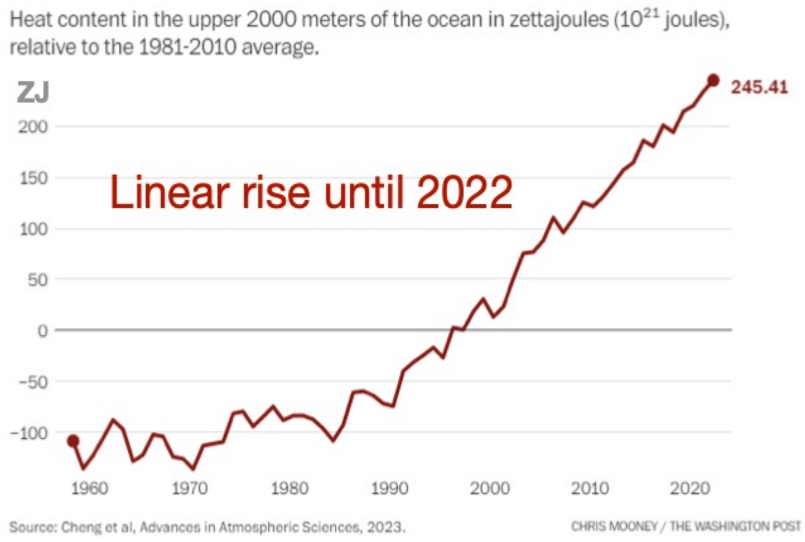


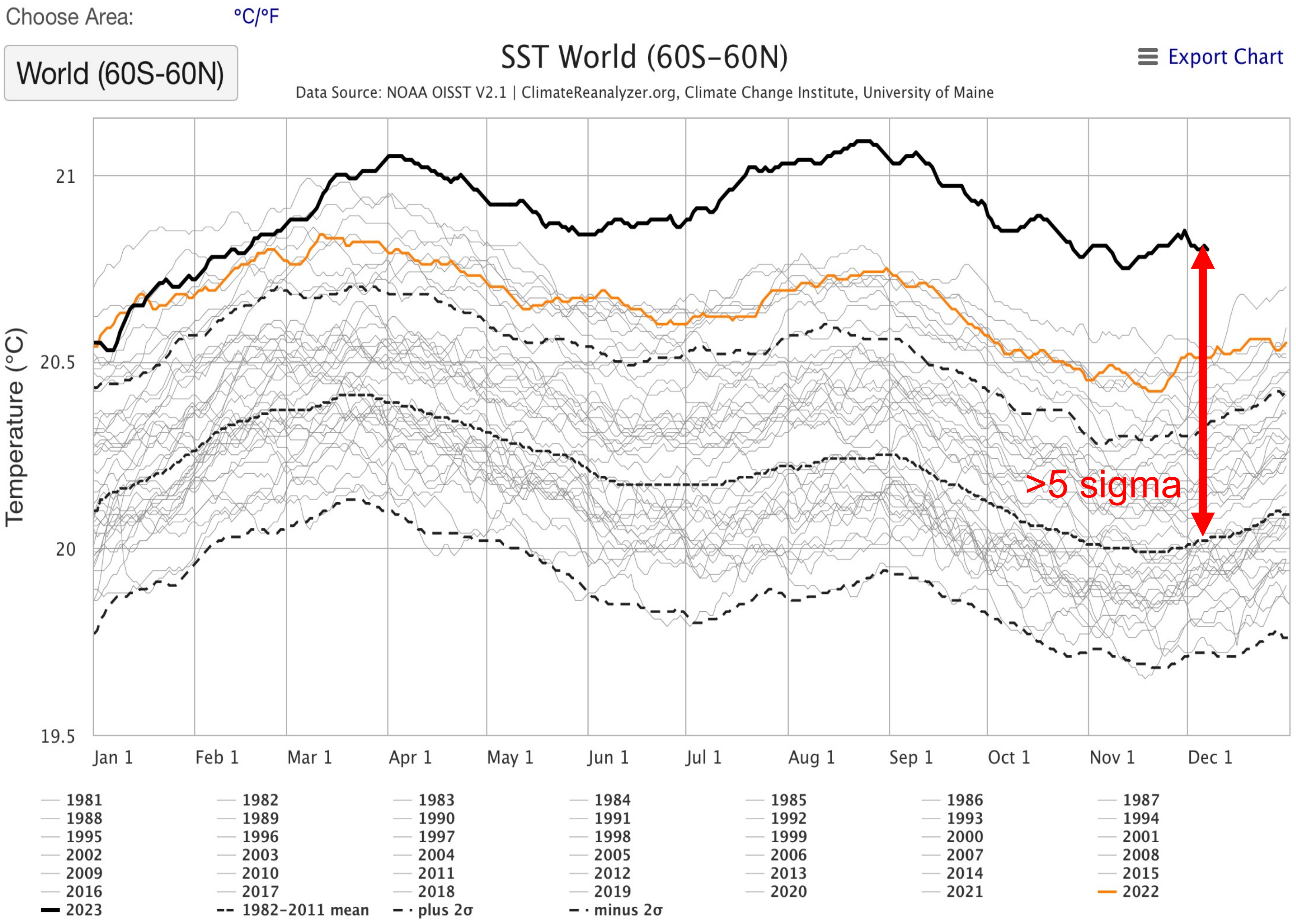
https://climatereanalyzer.org/clim/sst_daily/

Singular Events

Global sea surface temperature

Heat stored in upper ocean layers since the year 2000:
250 Zetta Joule or 70 billion GWh

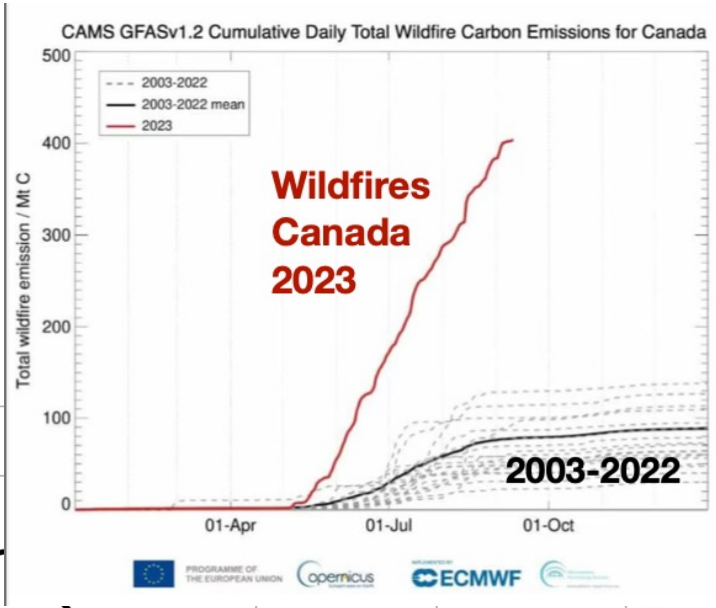


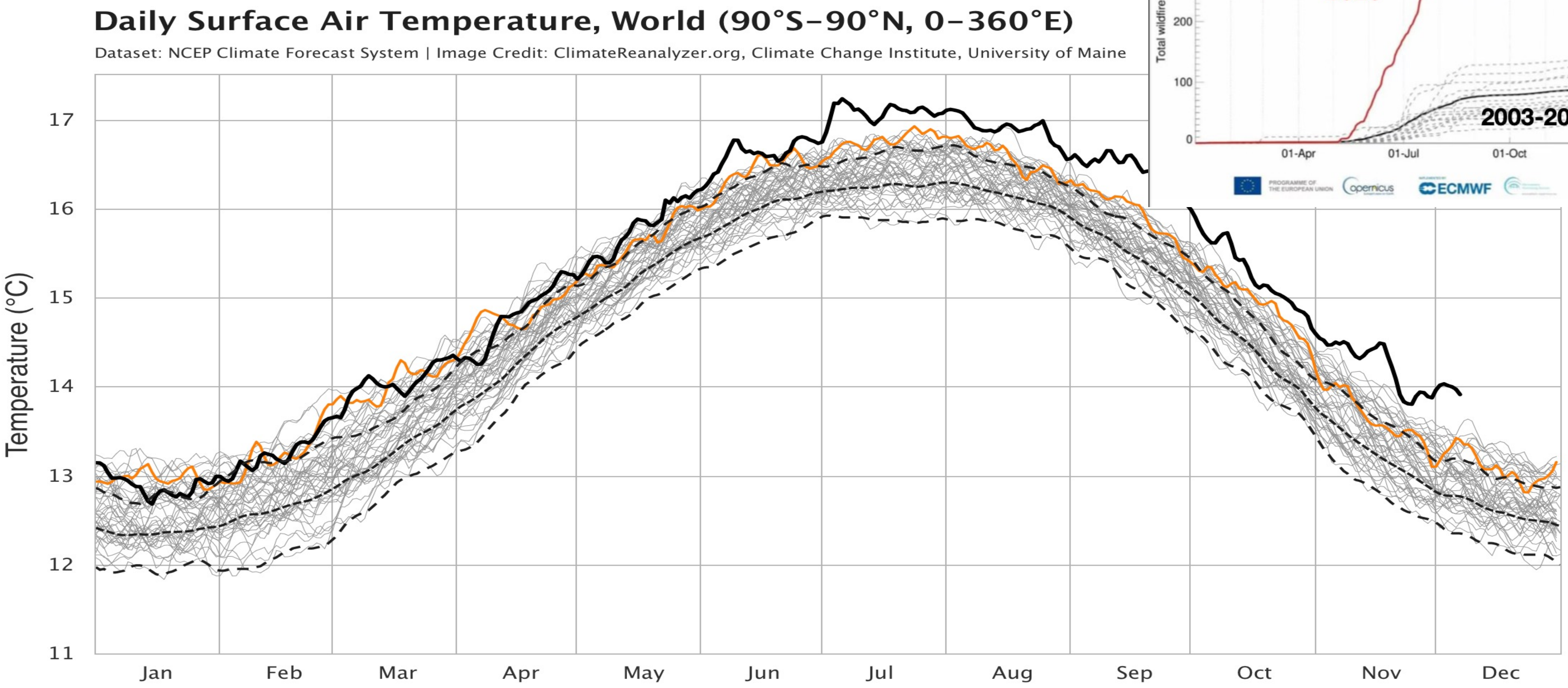


Singular Events

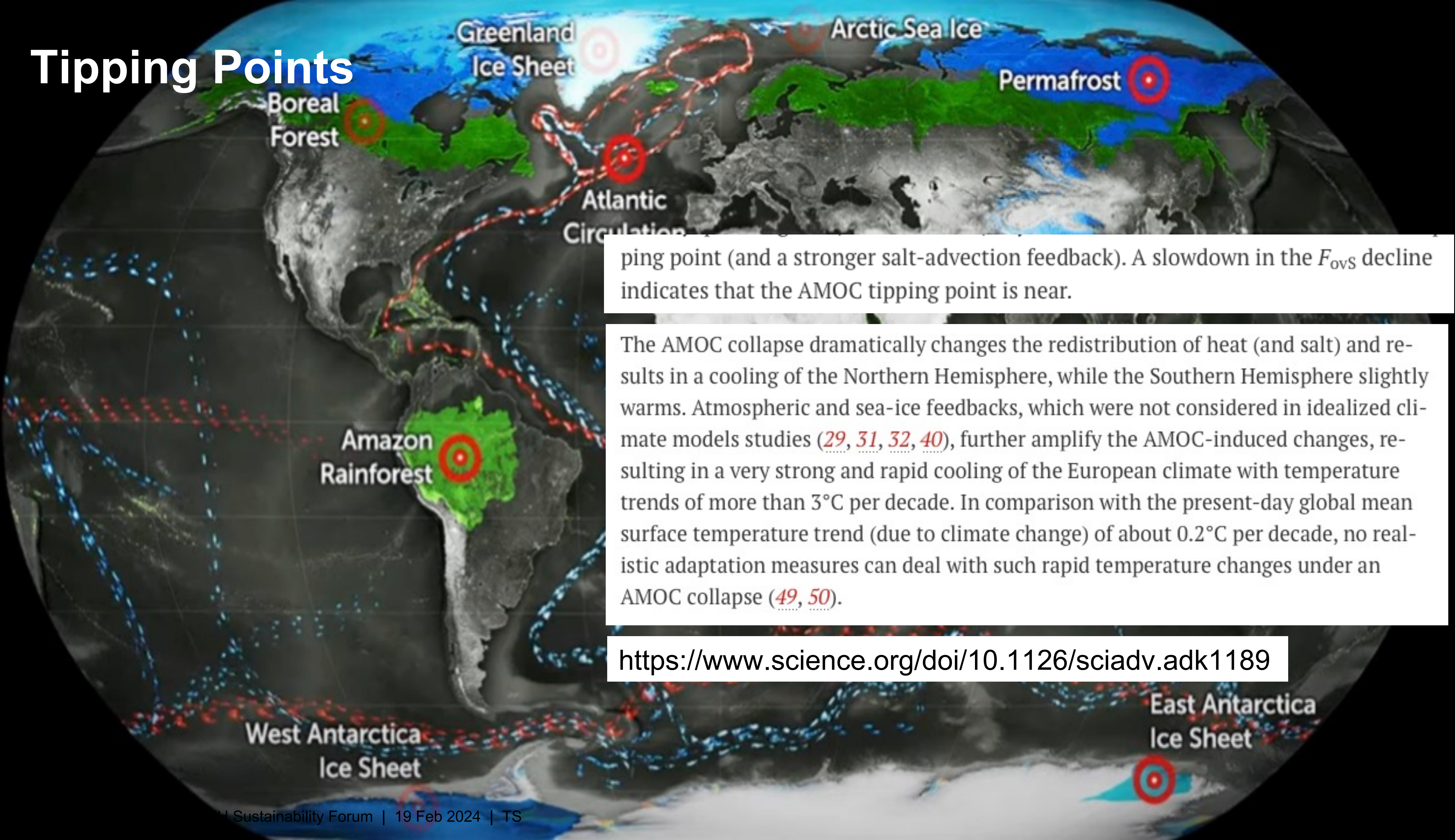
Global 2m land temperature

Many wildfires, floods and draught over the entire planet.





Tipping Points



ping point (and a stronger salt-advection feedback). A slowdown in the F_{ovS} decline indicates that the AMOC tipping point is near.

The AMOC collapse dramatically changes the redistribution of heat (and salt) and results in a cooling of the Northern Hemisphere, while the Southern Hemisphere slightly warms. Atmospheric and sea-ice feedbacks, which were not considered in idealized climate models studies (*29*, *31*, *32*, *40*), further amplify the AMOC-induced changes, resulting in a very strong and rapid cooling of the European climate with temperature trends of more than 3°C per decade. In comparison with the present-day global mean surface temperature trend (due to climate change) of about 0.2°C per decade, no realistic adaptation measures can deal with such rapid temperature changes under an AMOC collapse (*49*, *50*).

https://www.science.org/doi/10.1126/sciadv.adk1189

Nachhaltigkeit in der Teilchenphysik

Will our civilisation survive the next 30 years?

NEUE WEGE. SEIT 1607.

JUSTUS-LIEBIG-UNIVERSITÄT GIESSEN

Prof. Dr. Michael Düren

II. Phys. Institut der JLU Giessen

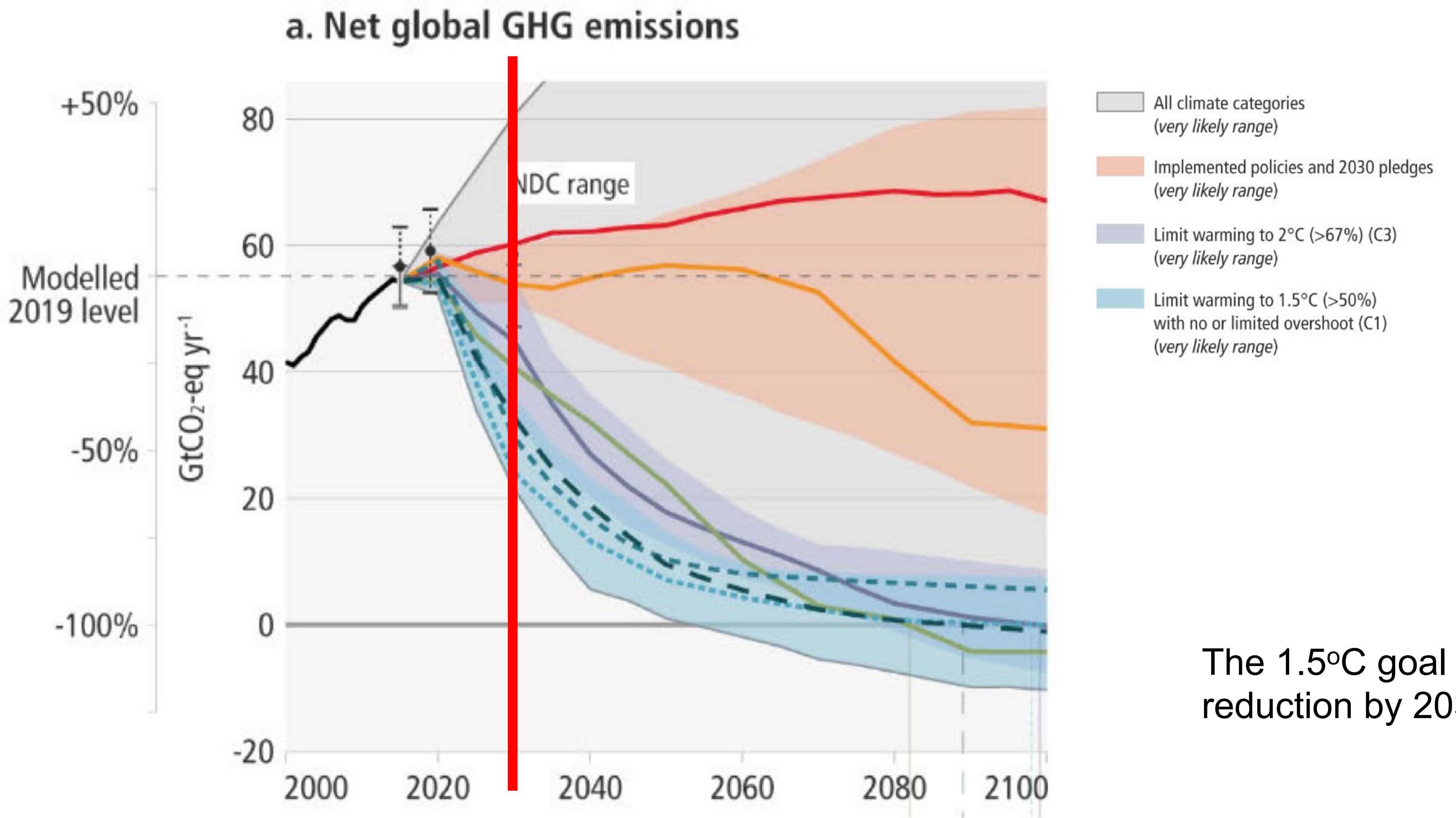
Zentrum für internationale Entwicklungs- und Umweltforschung

Arbeitskreis Energie der DPG

24.11.23

Personally, I think:
The next 10 years will be a step by step breakdown of our civilisation

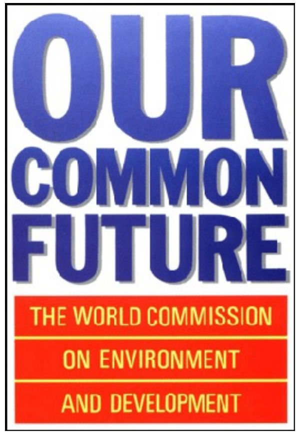
Global GHG Emissions



The 1.5°C goal requires CO2 eq. reduction by 2030 by ~50%,

Sustainability: What It Is…

Cover of the "Brundtland Report" 1987

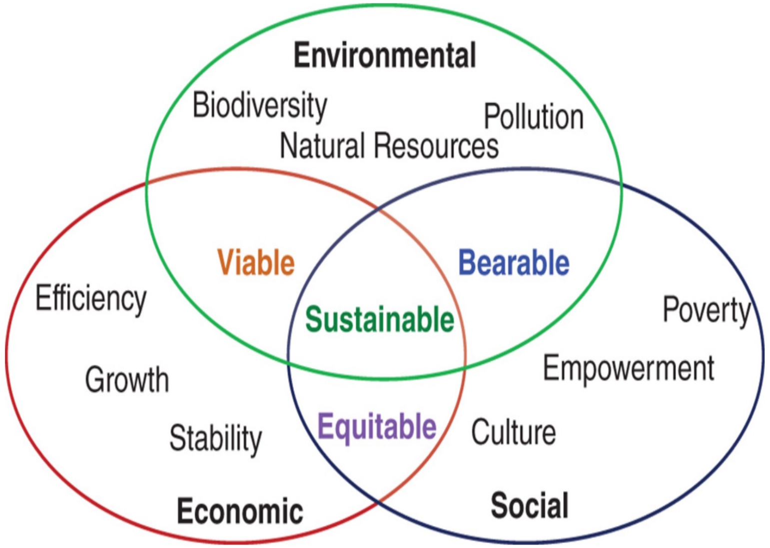


Development that meets the ***needs of current generations without compromising the ability of future generations*** *to meet their needs and aspirations*. (WCED, 1987)

WCED (World Commission for Environment and Development) (1987) *Our Common Future*, Oxford University Press, Oxford.

Gro Harlem Brundlandt at WEF 1989

R.Y. Surampalli et al. (eds), Sustainability. Wiley 2020.



Three aspects:

- environmental
- economical
- social

Carbon footprint:

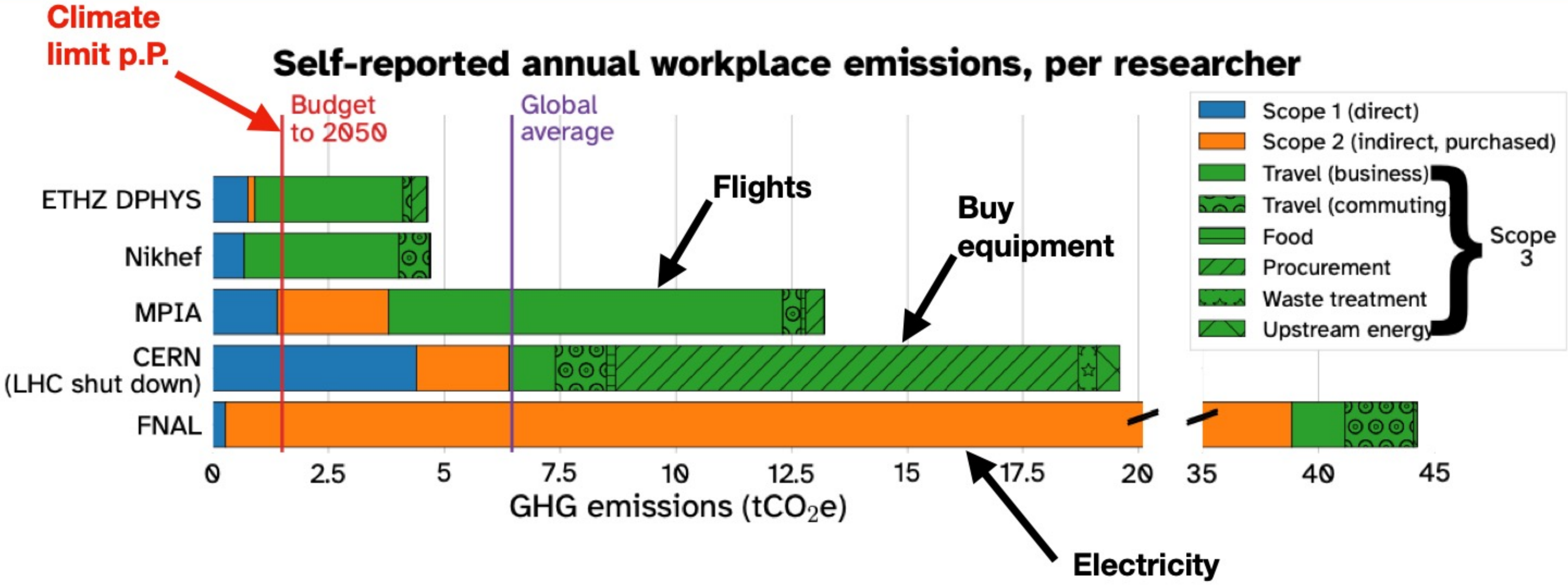
Scope 1 = direct emission (e.g. fossil heating)

Scope 2 = indirect emission (electricity)

Scope 3 = purchase materials, services, …

The Individual

HECAP+ paper: Environmental sustainability in basic research

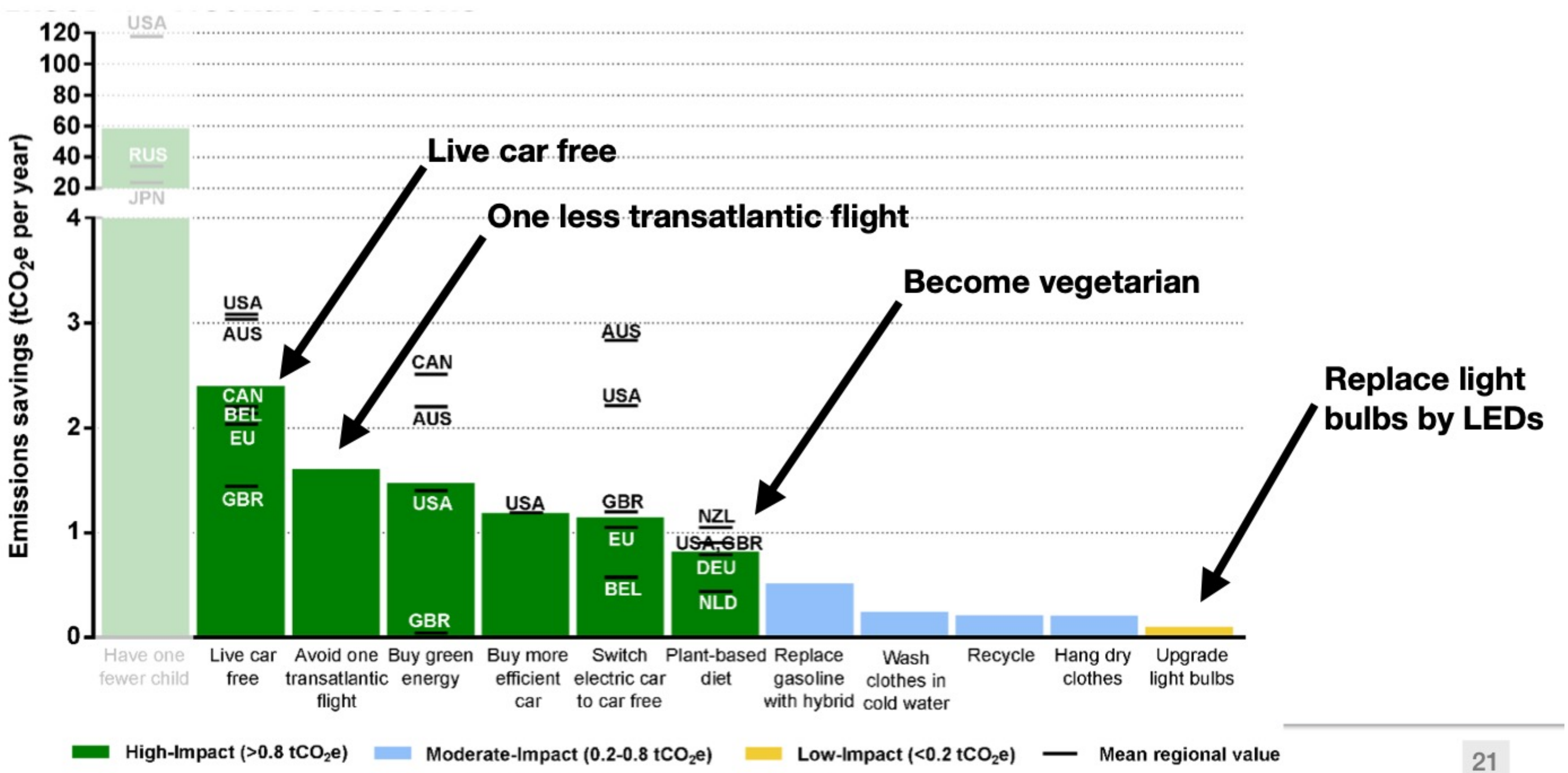


Physicist’s emissions

Personal Emissions

(Plot deleted from HECAP+ paper v2 as it can easily be misinterpreted)

M. Düren / HECAP+



Michael Düren, Univ. Giessen

Figure from https://doi.org/10.1088/1748-9326/aa7541

Beyond The Individual

Approaches to Improve Sustainability

Our infrastructures are resource-hungry; sustainability adds new cost measures

Overall system design (and choice)

- Compact (short) accelerator → high gradient, high fields
- Energy efficient → low losses (wall-plug to beam)
- Effective → small beam sizes, maximise lumi
- Energy recovery concepts
- Civil engineering, landscaping, community integration

Subsystem and component design, e.g.

- High-efficiency cavities and klystrons
- Permanent magnets, HTS magnets
- Heat-recovery in tunnel linings
- Responsible sourcing and material choices

Sustainable operation concepts

- Recycle energy (heat recovery)
- Adapt to regenerative power availability
- Exploit energy buffering potential
- Recover low-grade energy (heat)

Lifecycle thinking

https://www.nist.gov/el/systems-integration-division-73400/lifecycle-graphic

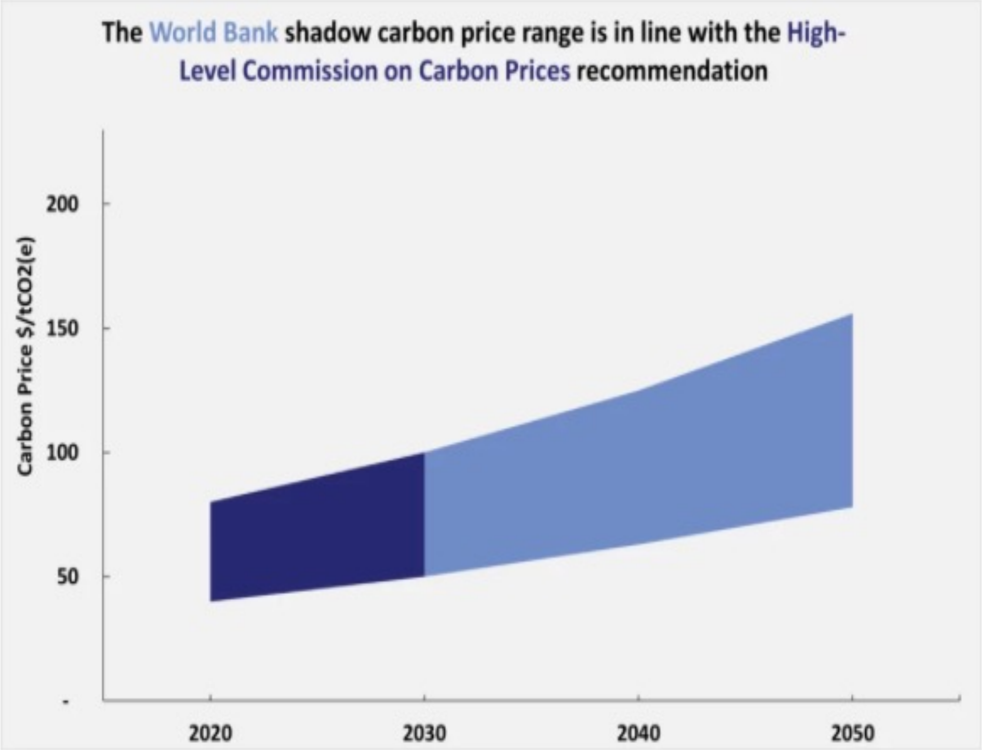
A Word on Shadow Prices

Shadow Prices Definition

Poor man's working definition: price of an article or commodity in a perfect market (internalising all costs).

Shadow Prices Today

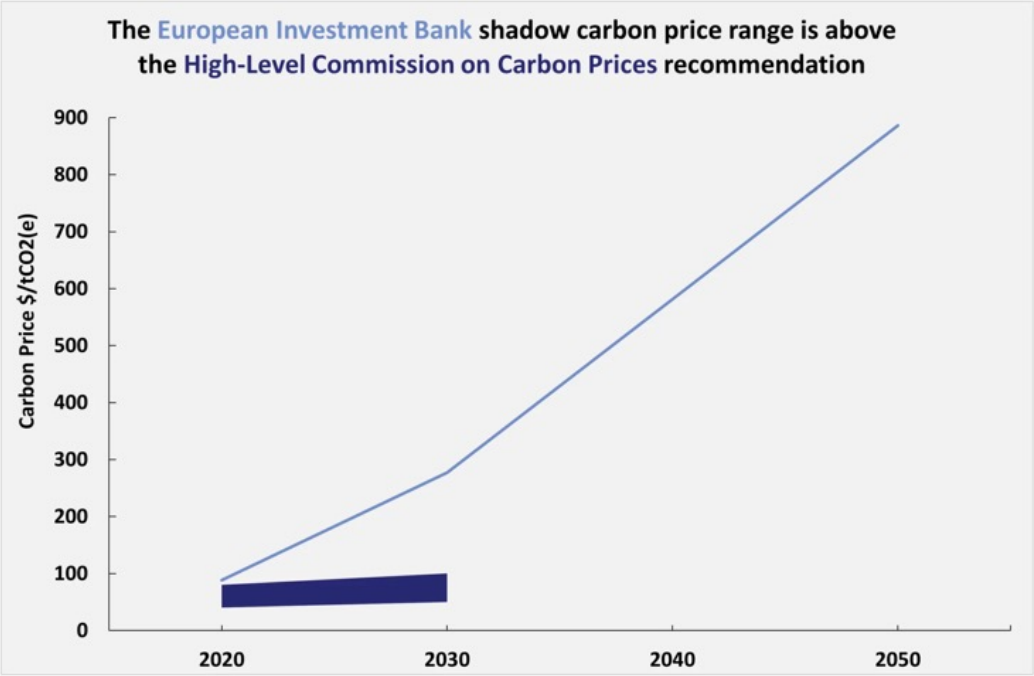
The graph below shows how the level of carbon pricing at the bank compared with those of the High-Level Commission on Carbon Prices (HLCCP). The HLCCP prices only extend to 2030.



Source: World Bank (2017) Shadow price of carbon in economic analysis

Recommendation: The World Bank Group should apply a carbon price scenario to assess alignment with limiting warming to below 1.5°C, alongside the other MDBs.

The graph below shows how the level of carbon pricing at the bank compares with those of the High-Level Commission on Carbon Prices (HLCCP). The HLCCP prices only extend to 2030.

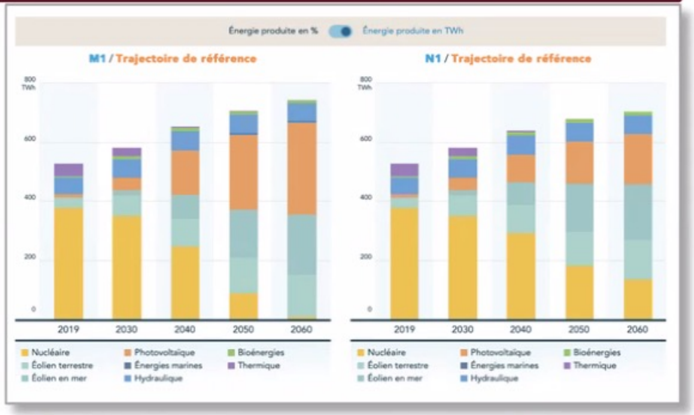


Source: European Investment Bank (2020) **EIB climate bank roadmap**. Prices were in 2016 Euros and converted using 2016 exchange rate from **OECD**

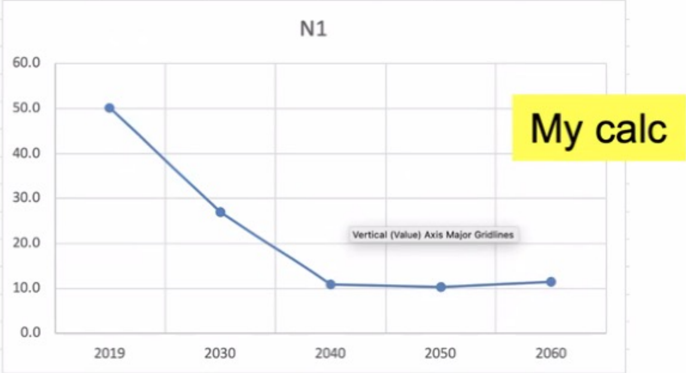
Shadow Prices and CERN?

RTE Study

- RTE (https://www.rte-france.com): réseau de transport d'électricité français - the French grid operator
- Study provides detailed scenarios with many variations for development of French electricity mix up to 2050
- Enough data to calculate CO2 emission factors
  -> plan: consolidate this to have meaningful reference numbers
- Broadly in agreement with our "12.5 g/kWh"



https://rte-futursenergetiques2050.com



12 | 2/15/24 | Benno List

CERN: 1.3 TWh/a

German mix today: 434 g/kWh
Europe mix today: 260 g/kWh
France mix today: 50 g/kWh

Realistic shadow price:
1000 Euro / t Co2eq

So today:
1.3 TWh/a * 260 g/kWh * 1000 Euro/t
= 400 million Euro / year

The Morioka Workshop

EAJADE
WSFA
2023

EAJADE
Europe-America-Japan Accelerator Development Exchange Programme

Summary of the WSFA2023 “EAJADE Workshop on the Sustainability of Future Accelerators”

HELMHOLTZ

EAJADE

Europe-America-Japan Accelerator Development Exchange Programme

EAJADE (Europe–America–Japan Accelerator Development and Exchange programme) is a training, education and staff exchange network in the field of accelerator research for high-energy elementary particle physics (HEP). More precisely, it is a "Marie Sklodowska-Curie Action" in the framework of the European "Horizon Europe" programme, focusing on staff exchange between (and within) Europe and other world regions.

The recent update of the European Strategy for Particle Physics emphasizes the need for a "Higgs factory" — a high-energy lepton collider able to scrutinize the Higgs boson and its interactions with other elementary particles and to use it as a window towards potential "new physics". A Higgs factory is both a precision instrument for detailed studies of the Higgs-boson and a discovery machine for potentially completely new physics.

Four Higgs factory proposals are being considered: the Chinese Electron–Positron Collider in China (CEPC), the Compact Linear Collider (CLIC) and the Future Circular Collider (FCC-ee), both at CERN, and the International Linear Collider (ILC) in Japan. All proposals require wide international collaboration for their implementation, and 5-15 years of design refinements, technical developments and prototyping/pre-series before construction can start. More information about the projects can be found at the project web sites[1]. The exchanges proposed in EAJADE cover primarily FCC-ee, CLIC and ILC where there are large European communities, even though there is overlap with the technical challenges that also need to be addressed with CEPC and a much more limited European participation in CEPC studies.

EAJADE Institutions

Beneficiaries (sending) and associate partners (receiving)

Beneficiaries in the EU

- CEA (E. Cenni), CERN (S. Stapnes), CNRS (P. Bambade), CSIC/IFIC (J. Fuster), DESY (T. Schörner), INFN (L. Monaco), U Hamburg (M. Wenskat)

Associate academic partners

- Canada: U Victoria
- Japan: KEK, U Tokyo, U Tohoku
- USA: LBNL, BNL, FNAL, Cornell, JLAB, SLAC

Associate non-academic partners (in EU)

- CPI TMD (UK), INEUSTAR (Spain), ZANON (Italy), ScandiNova (Sweden), Research Instruments (Germany)

Somewhat of a grey zone: U Oxford

- After Brexit and with pending Northern Ireland discussions – unclear status of UK in Horizon etc.: Can U Oxford be beneficiary or not?
- UK promise to replace EU funds from national budget.
- Decision expected (according to EU PO) in late August / early September.

Work Packages

Work package no.	Work package title	Activity type	Number of person-months involved per secondment	Lead benefi-ciary	Start month	End month
1	R&D&I at currently operating state-of-the-art facilities	Research, training	143	CNRS	1	48
2	State-of-the-art high-gradient, high-efficiency, reduced-cost radio-frequency structures and power sources	Research, training	68	INFN	1	48
3	Special technologies, devices and systems performance	Research, training	74	CERN	1	48
4	Sustainable technologies for scientific facilities	Research, Training	12	CEA	1	48
5	Investigation of potential early applications of novel and advanced technologies for colliders	Research, training	52	DESY	1	48
6	Management, dissemination, training, knowledge transfer, and communication	Management, training, dissemination, communication	4	DESY	1	48

2014

E-JADE

Europe -Japan Accelerator
Development Exchange Programme

2023

EAJADE

Europe-America-Japan Accelerator
Development Exchange Programme

EAJADE Work Package 4 (1)

Work package 4	Sustainability			Start/end month		1/48	
Work package title	Sustainable technologies for scientific facilities						
Lead beneficiary	CEA						
Participating organisation short name**	CEA	CERN	DESY	CNRS	INFN		
Total person-months per participating organisation:	4	2	2	2	2		

Objectives:

- Advance technology of critical accelerator components towards more sustainability in terms of energy efficiency during manufacturing and operation and in terms of resource conservation by avoidance of harmful, toxic or otherwise unsustainable raw materials or production methods.
- Advance overall design of accelerator facilities towards better sustainability by use of sustainable energy sources, adaption of power consumption to energy availability, evaluation of energy storage potentials, re-use of waste heat, reduction or re-use of waste materials during construction and operation.
- Investigate civil engineering solutions to sustainability issues of accelerator facilities, in particular concerning construction and operation of extensive tunnels and underground caverns, and management of electricity, water, heat.
- Foster an integrated approach to sustainability by bringing together experts from engineering disciplines (mechanical, electrical, civil engineering), physicists, social and economic sciences to develop concepts for sustainable accelerators.

EAJADE Work Package 4 (2)

Description of work and role of specific beneficiaries/associated partners:

Task 4.1 High-efficiency and sustainable SC cavities (CNRS, 2 person-months, with task 4.2): Advancement of superconducting cavity surface treatments with the goal to achieve the highest possible Q quality factors for low cryogenic losses; investigation of sustainable cavity production methods by reduction of electropolishing steps through improved heat treatment, and use of niobium raw materials with relaxed requirements on grain size and Ti content that allow more sustainable production methods. Furthermore, CEA and CNRS will collaborate with Cornell, KEK and Tohoku in the development and tests of new surface treatments for sc cavities. Also energy recovery schemes with smart RF loads will be studied.

Task 4.2 High-efficiency radio frequency power amplifiers (CNRS, 1 person-month): Investigate possibilities to improve the efficiency of radio frequency (rf) power generation by use of solid-state amplifiers to replace traditional klystrons.

Task 4.3 Energy Recovery Linacs (INFN, 2 person-months): Improve the overall energy efficiency through the implementation of novel schemes as the Energy Recovery Linacs capable of minimizing the overall AC plug power required without impacting accelerator performances. Japan hosts a leading facility in this scenario with its cERL at KEK, a compact and successful Energy-Recovery demonstrator, and we intend to join cERL team in order to deepen our understanding of operative issues and physics behind this emerging concept. INFN LASA expects this effort to largely benefit from the structured exchanges foreseen through EAJADE and moreover to be a valuable context to evaluate the possible applicability of such a machine layout to future generation of HEP colliders.

Task 4.4 Power Modulation (DESY, CERN, 2 person-months, interdisciplinary): Investigate means to make accelerators more suitable as consumers of regenerative energy sources (in particular solar and wind) by adjusting power consumption to RES energy availability. This includes e.g. operating modes with reduced power consumption, identification of internal energy buffering potentials. Improve the calculation package for power consumption in particle colliders (staging and operation scenarios)

Task 4.5 Smart Tunneling (CERN, 1 person-month, interdisciplinary): Investigate technologies to make construction and operation of accelerator tunnels more sustainable, by environmentally friendly construction methods and technological measures such as direct cooling / heat recovery from tunnel walls.

Task 4.6 Green ILC (CEA, 4 person-months, interdisciplinary): Together with the local experts in Japan, conduct a case study for energy generation, distribution and storage for a green field accelerator site in Japan, with a focus on use of renewable energies and sustainable technologies (e.g. high temperature superconductor at liquid nitrogen temperature use for power transmission).

Description of deliverables:

4.1 *SustAccSession* (month 36): Organisation of a series of dedicated sessions on sustainable accelerator design and technologies at workshops on ILC, CLIC and FCC-ee

4.2 *SustAccRep* (month 48): Summary report on sustainability efforts in the context of a "green" accelerator

Outline of the Workshop

Four blocks (presented here in different order than in workshop)

- Large-scale research facilities and sustainability / life cycle assessments (LCA)
- Sustainable accelerator technologies
- Horizon-Europe and national sustainability-supporting programmes
- Green ILC and local industries

Visit to Geothermal Power Plant in Hachimantai-city

- Novel (small) production plant (7.5 MW power generation capacity) → local electricity to power 15000 homes

3 production wells (300 C @ 2 km depth, 150C @ surface; 10% eff. depents on T, P)

Only 20 such plants are needed to power ILC

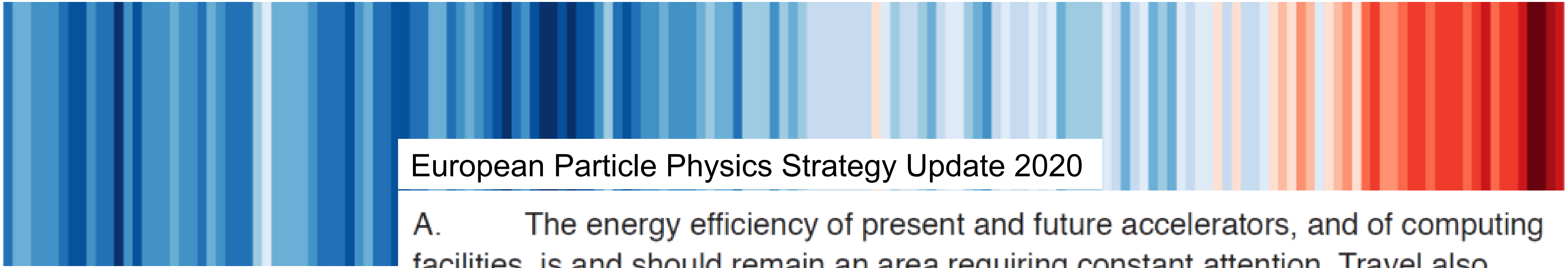
THANK YOU
to Organizers!

Large-Scale Infrastructures
Construction, Operation, Lifecycle Assessment

- Objective Assessment of Sustainability Aspects of
  New Large Infrastructures: B. Heinemann

- Experience from ESS on Green Facilities: A. Sunesson
- PETRA IV and Sustainability: A. Klumpp (cancelled)
- A Life Cycle Assessment of the CLIC and ILC Linear
  Collider Feasibility Studies: S. Evans
- The ISIS-II Neutron And Muon Source Life Cycle Assessment:
  An Introduction: H. Wakeling
- The HElmholtz LInear ACcelerator HELIAC : W. Barth
- CERN Accelerates Sustainability: R. Losito
- Optimisation of the FCC Power Consumption and Next Steps
  for Sustainability Studies¶: J.-P. Burnet
- A Sustainability Roadmap for C3: B. Bullard
- A Sustainability Outlook for CLIC / ILC: S. Stapnes

Sustainability: Assessment of New Large Infrastructures



European Particle Physics Strategy Update 2020

A. The energy efficiency of present and future accelerators, and of computing facilities, is and should remain an area requiring constant attention. Travel also represents an environmental challenge, due to the international nature of the field. ***The environmental impact of particle physics activities should continue to be carefully studied and minimised. A detailed plan for the minimisation of environmental impact and for the saving and re-use of energy should be part of the approval process for any major project. Alternatives to travel should be explored and encouraged.***

Jim Clarke, Beate Heineman

EAJADE Workshop on Susta

HELMHOLTZ

DESY.

Establishing a Working Group on “Sustainability Assessment of Accelerators”

- The LDG decided last week to form a new working group that will develop guidelines and a minimum set of key indicators pertaining to the methodology and scope of the reporting of sustainability aspects for future HEP projects
  - LDG = European Lab Directors Group, chaired by Dave Newbold
- This group will effectively define for all new infrastructure proposals what they should quantify and report upon so that fair comparisons can be made between these proposals
- Having clear and common indicators will ensure that projects are not accused of cherry picking only their most favourable sustainability numbers

Charge to the Working Group (I)

This working group is asked to develop guidelines and a minimum set of key indicators pertaining to the methodology and scope of the reporting of sustainability aspects for future HEP projects:

- Define key indicators to be reported, such as peak (or instantaneous?), lifetime- and performance specific (per luminosity) energy consumption, lifetime- and specific Global Warming Potential (GWP) including the contribution of construction. These figures should be supplemented by margins of uncertainty and possibly an assessment of the potential for improvement.
- Define the methodology and assumptions to be applied, to allow a transparent determination and comparison of these key figures across the proposals. The maturity of a proposal should be determined, for example early concept phase, CDR, TDR or TRL levels.
- Identify other high level environmental impacts that may be relevant for all or specific collider proposals.
- In general, best practices determining the GWP for large projects in Europe should be followed.

- Other aspects to be added if necessary
- Final report by end of 2024 – in time to serve as input to european strategy update?

ICFA Sustainability Panel (T. Roser)

icfa.hep.net/panels/ → ICFA Panel on Sustainable Accelerators and Colliders

ICFA Panel on Sustainable Accelerators and Colliders

Chair: Thomas Roser, BNL, USA

roser@bnl.gov

Mandate:

Assess and promote developments on energy efficient and sustainable accelerator concepts, technologies, and strategies for operation, and assess and promote the use of accelerators for the development of Carbon-neutral energy sources. The panel will formulate recommendations on R&D and support ICFA with networking across the laboratories and communications. The membership will ensure a broad regional participation and coverage of accelerator technologies and concepts, relevant in the context of energy consumption and production.

Bracket Lifecycle (and “System”) Thinking

Lifecycle Thinking

Quantifying the entire environmental impact

Quantifying total damage by **endpoint** indicators (e.g. damage to human health) possible but difficult

”**Midpoint** indicators” allow to asses impact on environment in a quantitative way:

- Greenhouse Warming Potential (GWP) – kg CO2 eqiv
- Ozone Depletion Potential (ODP) – kg CFC-11 equiv
- Ecotoxicity – kg 1,4-DCB equiv

“Not enough to look at operation power and guess the CO2 from this power in ~2050 in your favourite country”

M.A.J. Huijbregts et al., Int. J. Life Cycle Ass. **22** (2017) 138, DOI:10.1007/s11367-016-1246-y

Midpoint Indicators

ReCiPe Midpoint (H) 2016 Impact Categories

Midpoint Impact Categories	Abbr.	Unit
Global warming	GWP	kg CO_2 eq
Stratospheric ozone depletion	ODP	kg CFC-11 eq
Ionizing radiation	IRP	kBq Co-60 eq
Fine particulate matter formation	PMFP	kg PM2.5 eq
Ozone formation, Human health	HOFP	kg NOx eq
Ozone formation, Terrestrial ecosystems	EOFP	kg NOx eq
Terrestrial acidification	TAP	kg SO_2 eq
Freshwater eutrophication	FEP	kg P eq
Marine eutrophication	MEP	kg N eq
Terrestrial ecotoxicity	TETP	kg 1,4-DCB
Freshwater ecotoxicity	FETP	kg 1,4-DCB
Marine ecotoxicity	METP	kg 1,4-DCB
Human carcinogenic toxicity	HTPc	kg 1,4-DCB
Human non-carcinogenic toxicity	HTPnc	kg 1,4-DCB
Land use	LOP	m^2a crop eq
Mineral resource scarcity	SOP	kg Cu eq
Fossil resource scarcity	FFP	kg oil eq
Water consumption	WCP	m^3

Reference: ReCiPe Midpoint (H) 2016

Lifecycle Thinking

The whole life from cradle to grave matters

Consider the whole lifecycle and its impact:

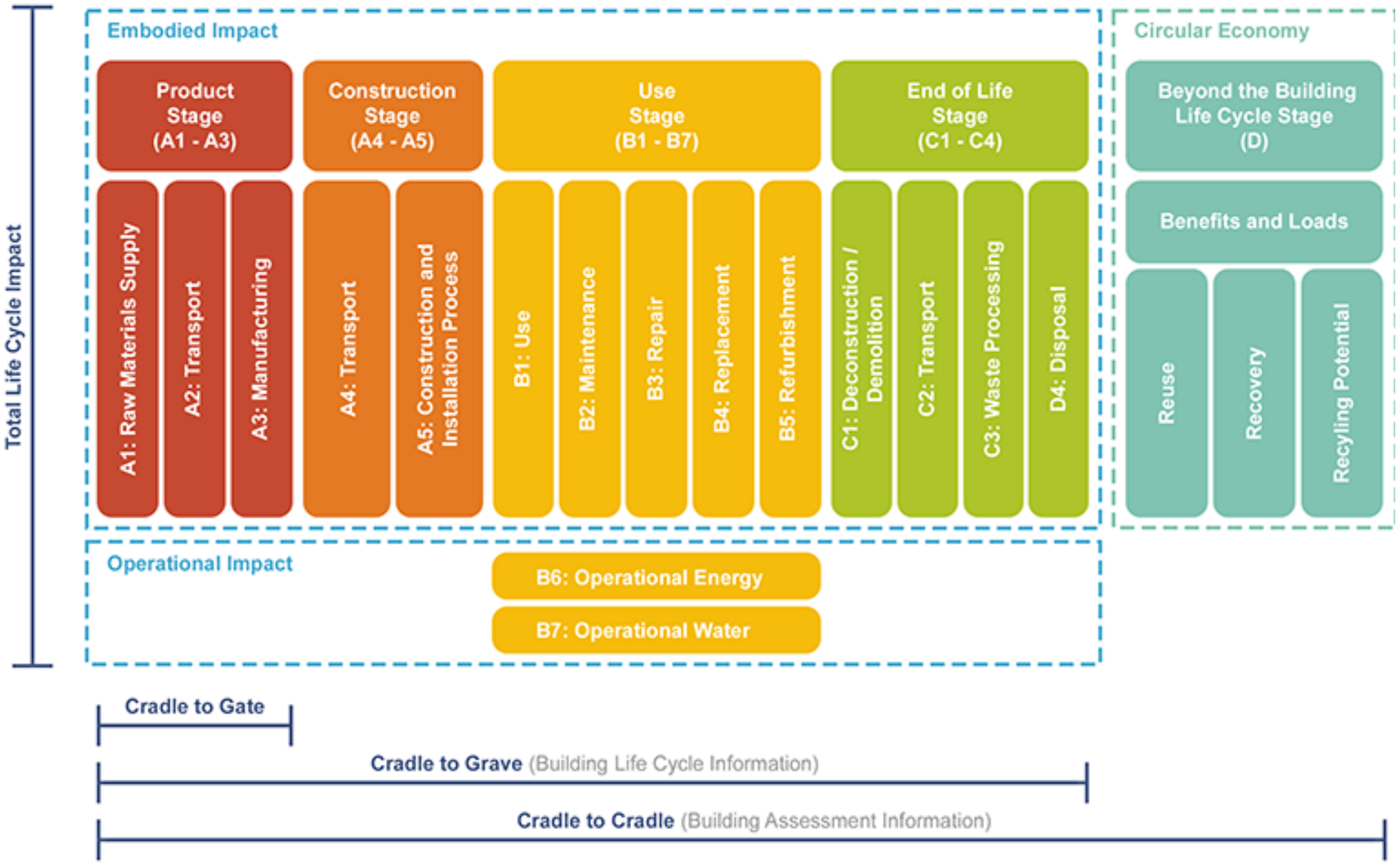
- Raw material extraction
- Manufacture, Transport & Installation
- Operation
- Disposal

➔ Already challenging for a pair of jeans, much more for a complete accelerator

Difficult for complex facilities. Requires scope definition: what's in, what's out?

- What is the complete project to consider? Baseline? Upgrades?
- How to attribute environmental cost to different project stages / future upgrades?
- How to treat impact of **future** consumables (material, energy)?
- Avoid **burden shifting**: Moving problems elsewhere

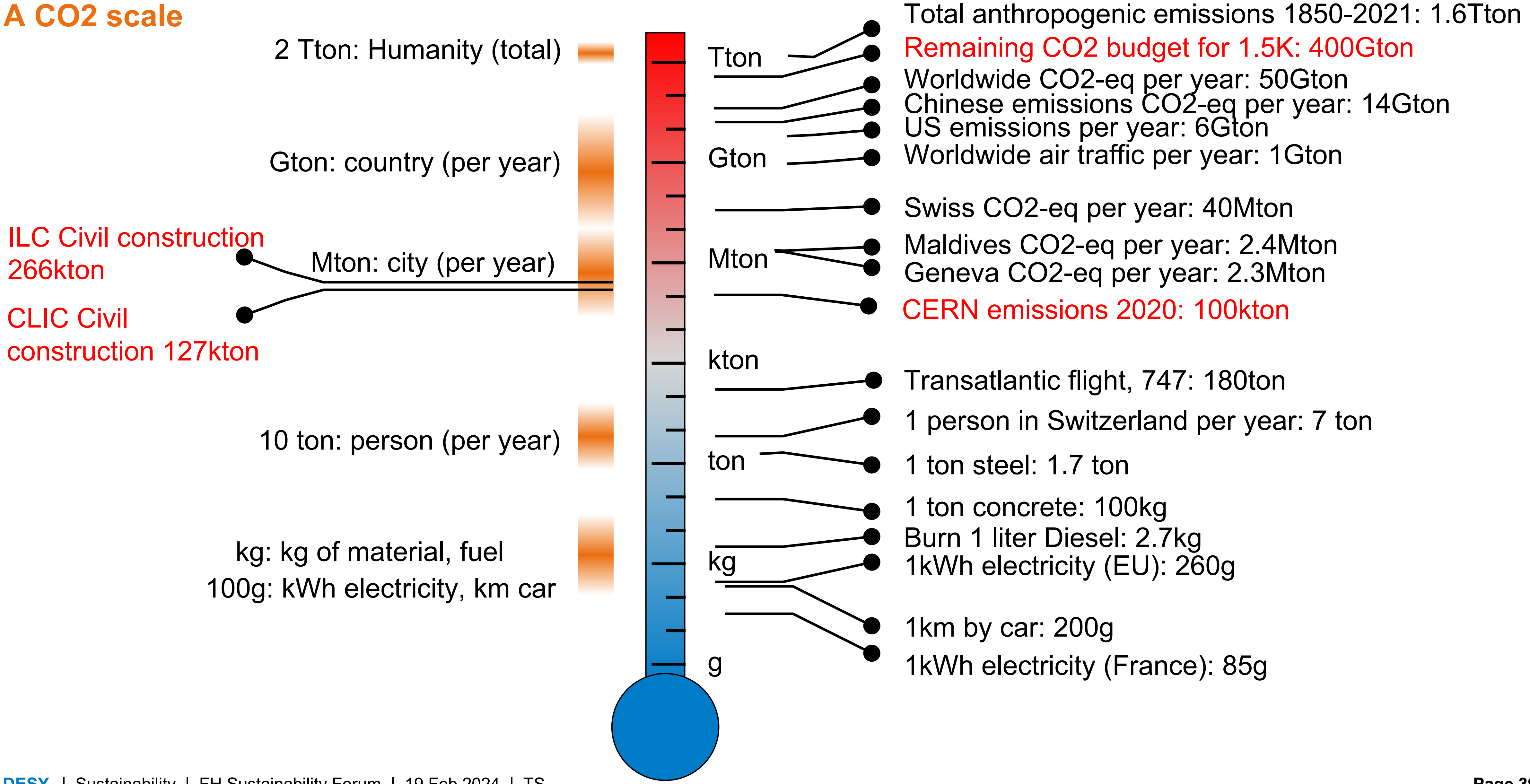
Lifecycle stages according to EN 15978



https://browningday.com/news/lca-stages-matter-when-tracking-embodied-carbon/
https://www.buildingenclosureonline.com/blogs/14-the-be-blog/post/89547-lca-stages-matter-when-tracking-embodied-carbon

How much is it?

A CO2 scale



Facility choice, design, operation

From costs and power to sustainability and life cycle assessments

1. Reduce power/energy (hand in hand with cost optimisation)
2. Operation energy use means carbon –> use the minimum energy, of the right type and at the right time, compensate
3. Life Cycle Assessments

Machine Choice

… and running scenarios

Machine choice and minimizing running power (also major cost driver)

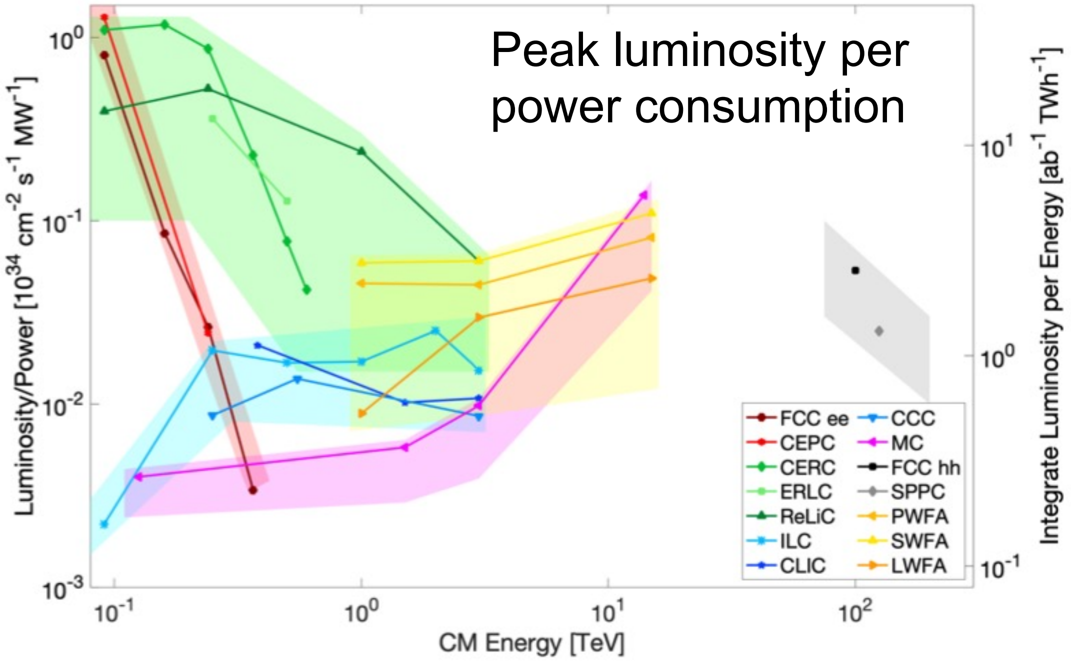
Power at 250-380 GeV in the 100-150 MW range for may projects, reaching ~500 MW at 3 TeV for CLIC
With standard running scenario this corresponds to 0.6-0.8 TWh annually. (CERN currently consumes ~1.2 TWh/a)

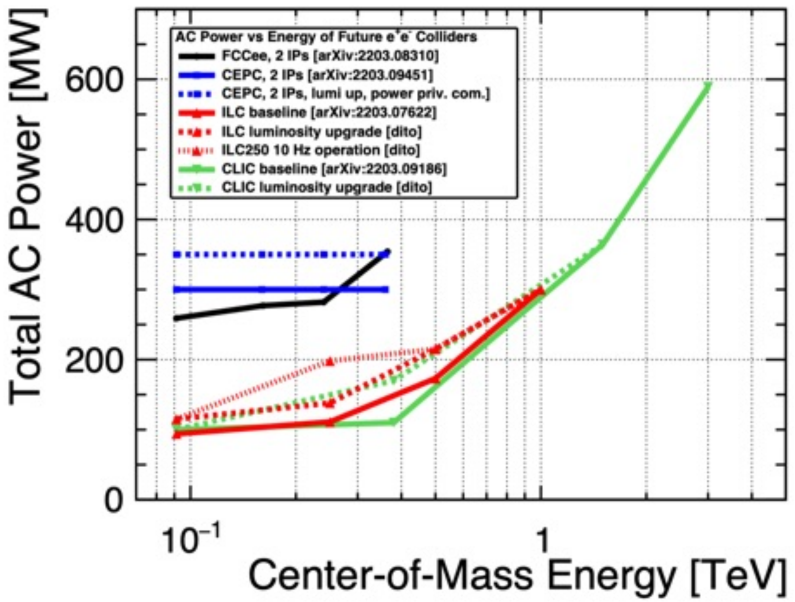
Typically, we optimize energy reach and luminosities (experimental conditions) with respect to cost and power (maybe also facility size and schedule)

Need to include environmental impact and sustainability (we are learning what this means)

- Sustainability in a wider sense adds new construction and operation optimization criteria:

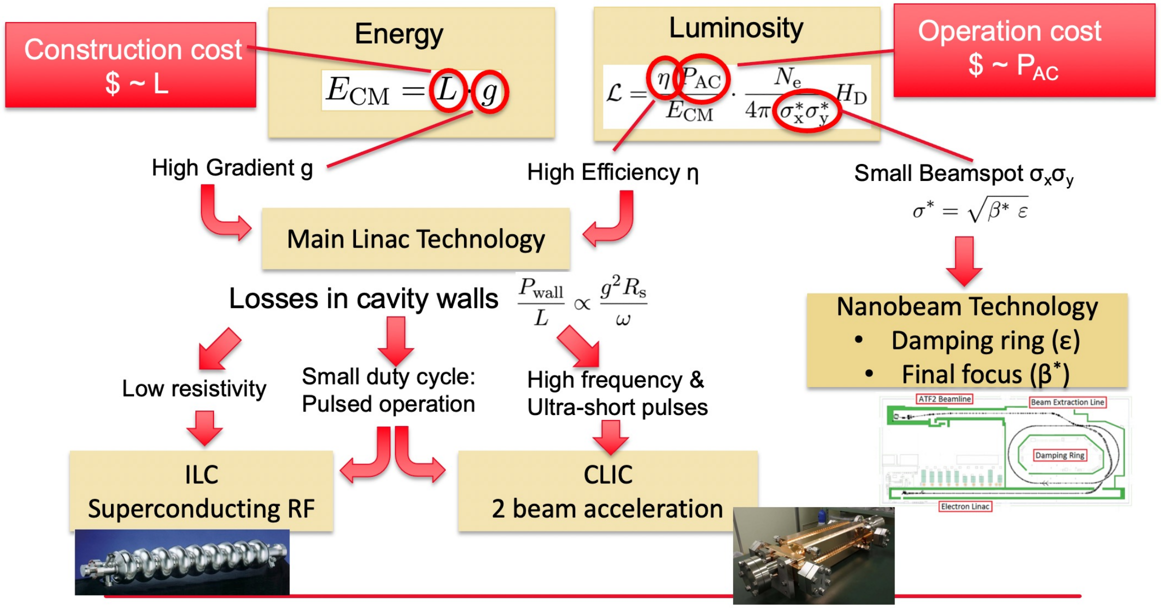
Keep in mind: This is not only more constraints but also a new opportunity for R&D, new ideas, collaboration

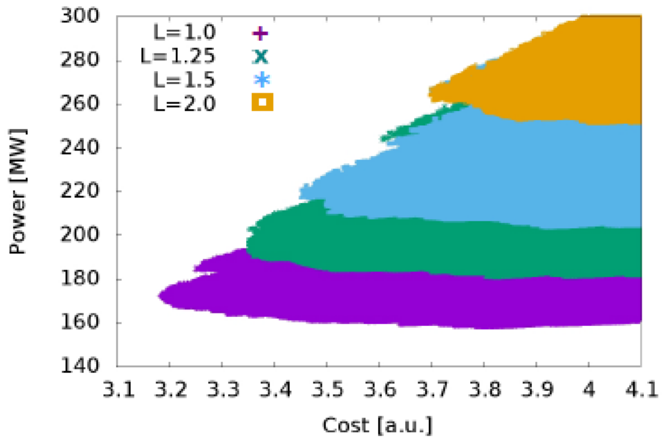




Overall System Design

Making the overall system as sustainable as possible requires a Lifecycle Approach





Parameter optimization at CLIC

BL: https://indico.cern.ch/event/981823/contributions/4328846/

Challenge: Achieve target **energy** and **luminosity** with least possible amount of **resources**

Conserve resources for construction:

- compact -> high acceleration gradient

Conserve resources in operation:

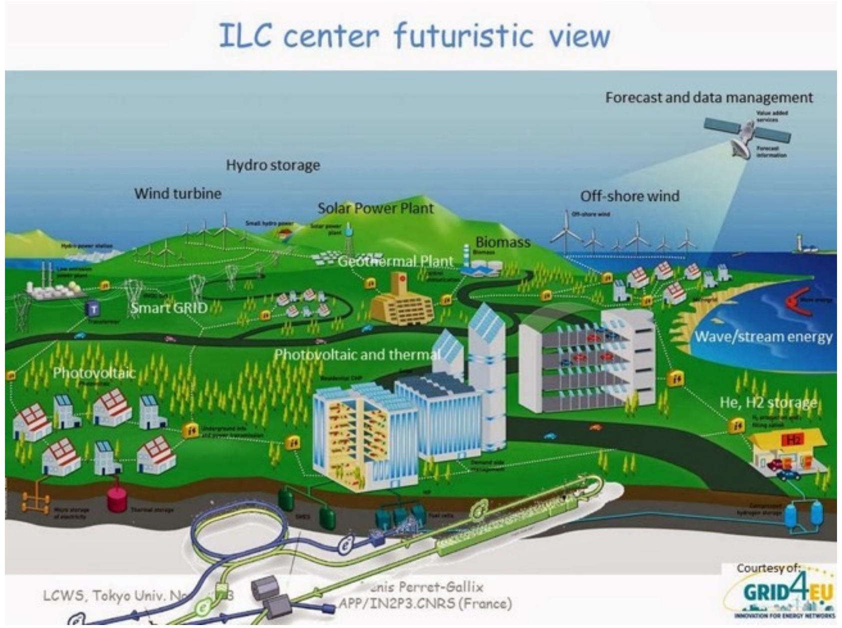
- Energy-efficiency (limit losses in cavity walls):
  superconducting RF – ILC
  high frequency & ultra-short pulses: CLIC
- Effectiveness: maximum luminosity per charge
  -> nanobeam technology

ILC and CLIC:

- different solutions to the efficiency problem
- Final power consumption similar

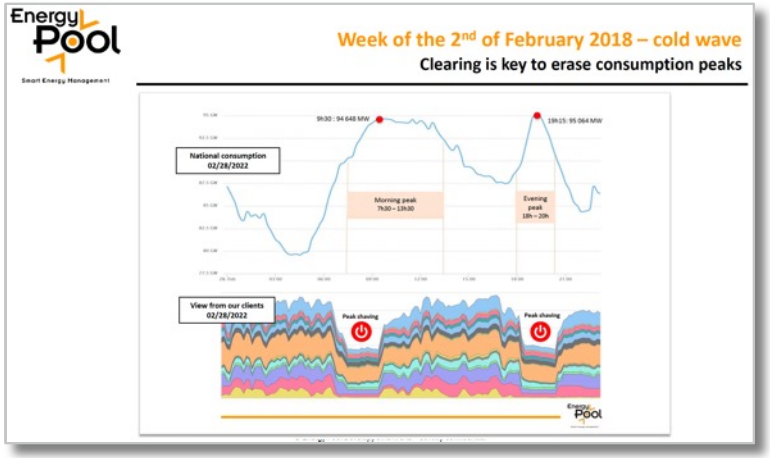
Inherent tension between invest and operation requires a quantitative approach: Lifecycle Assessment

Green ILC



Running on renewables and when energy is cheap

Demand-side flexibility

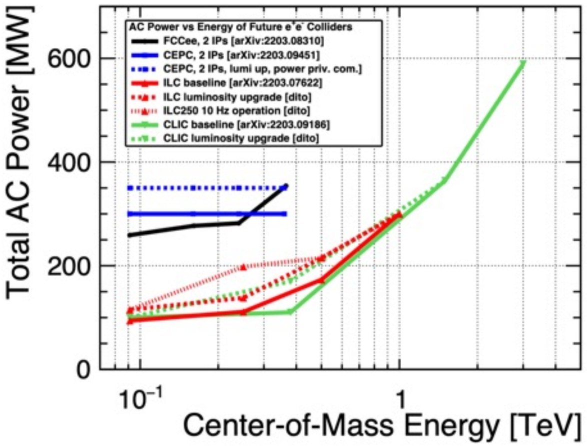


C. Gaunand, B. Remenyi: *Introduction to Demand Side Flexibility*
ESSRI Workshop 2022 https://indico.esrf.fr/event/2/contributions/94/

Two studies in 2017:

- Supply the annual electricity demand of the CLIC-380 by installing local wind and PV generators (this could be e.g. achieved by 330 MW-peak PV and 220 MW-peak wind generators) at a cost of slightly more than 10% of the CLIC 380 GeV cost.
  - Study done for 200 MW, in reality only ~110 MW are needed
- Self-sufficiency during all times can not be reached but 54% of the time CLIC could run independently from public electricity supply with the portfolio simulated.

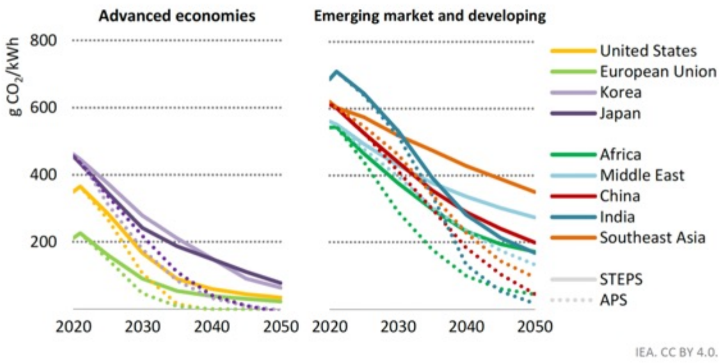
Machine choice and minimizing running power (also major cost driver)



Electricity contract design (e.g. renewables, long-term etc.)

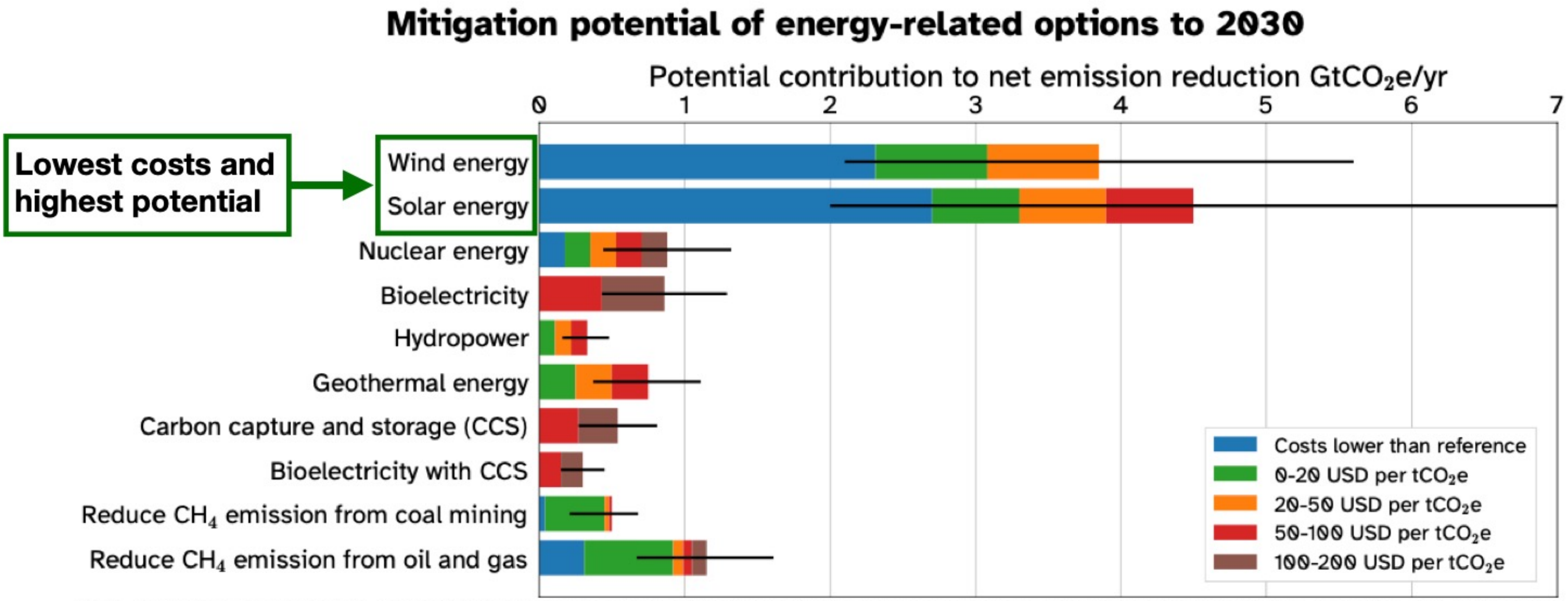
And note CO2 / kWh will go down globallly

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

Electricity

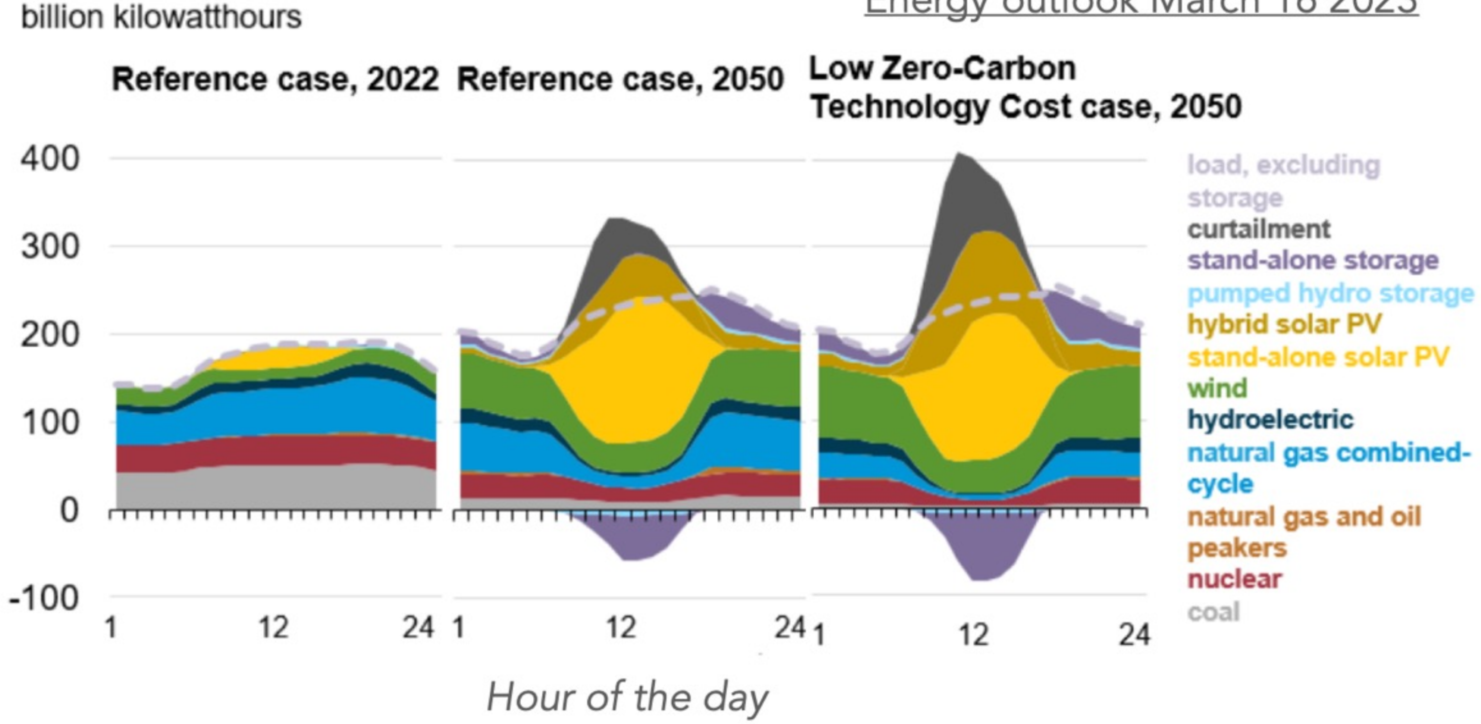


Costs calculated with respect to conventional power generation; mitigation potential assessed with respect to current policy reference scenarios. For all measures save emissions reductions, the cost categories are indicative, and estimates depend heavily on factors such as geographical location, resource availability and regional circumstances. Relative potentials and costs will vary across countries and in the longer term.

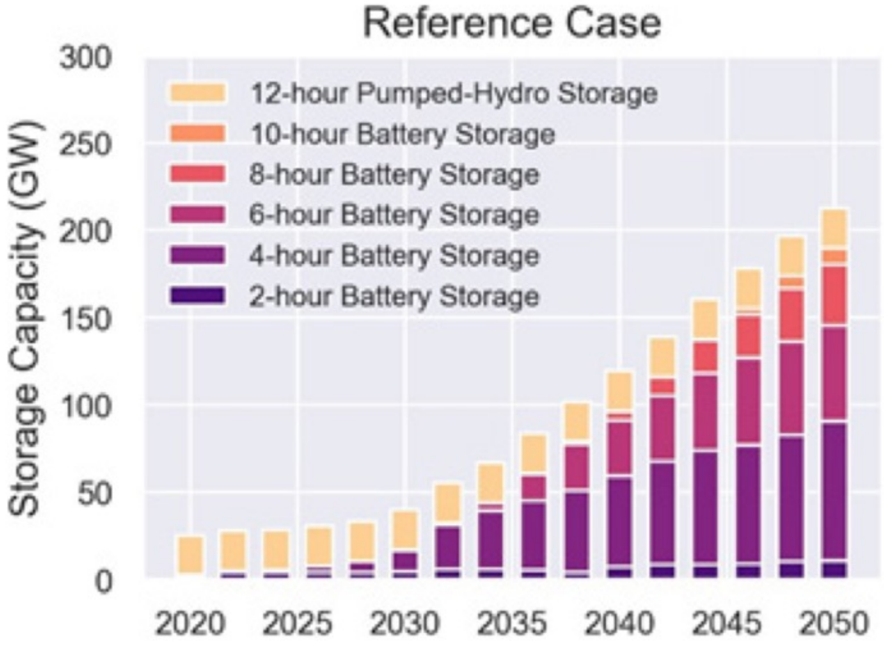
Operations emissions

Solar and wind are established technologies, the question is how to store it?

Energy outlook March 16 2023



By 2040, 8 hours of energy use for C^3 at 150 MW **is < 1% of grid capacity**



NREL Storage Futures Study

With access to renewables (e.g. dedicated solar/wind farms), we can leverage the grid to smooth energy load curve

→ ***any facility can have access to 20 gCO_2e/kWh energy with their own solution (e.g. Green ILC)***

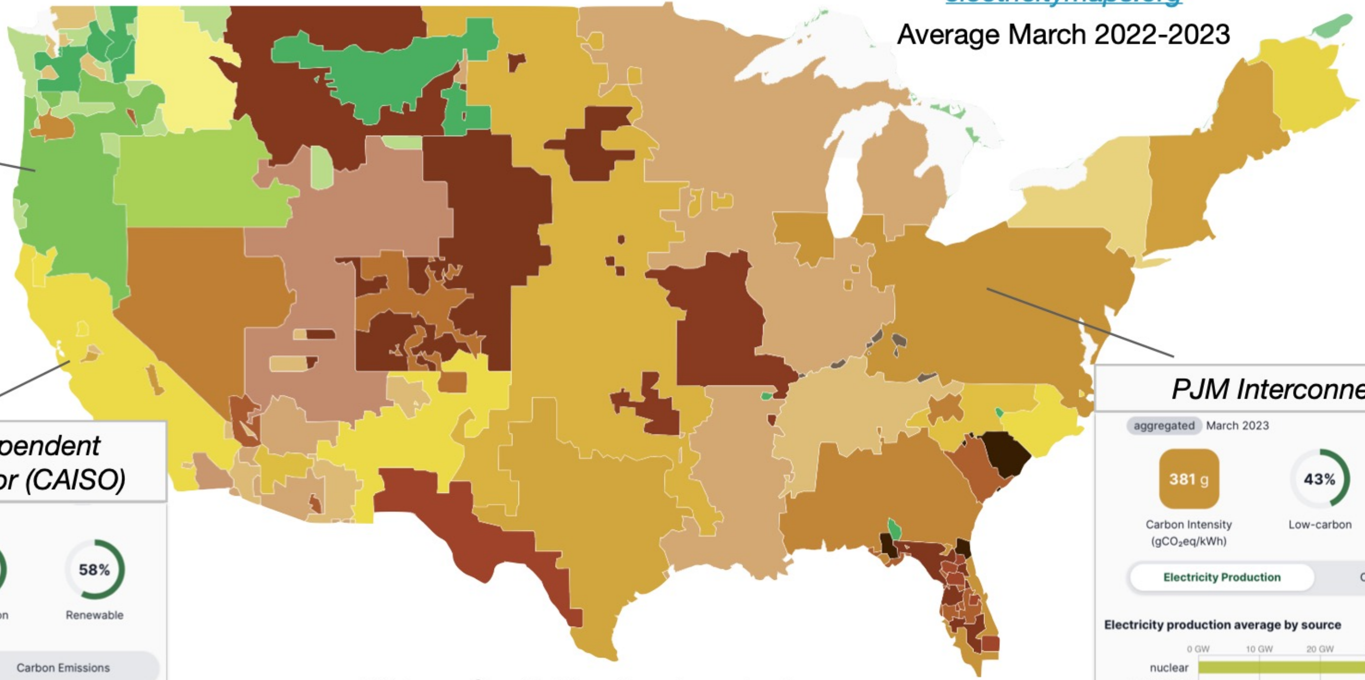
B. Bullard, SLAC

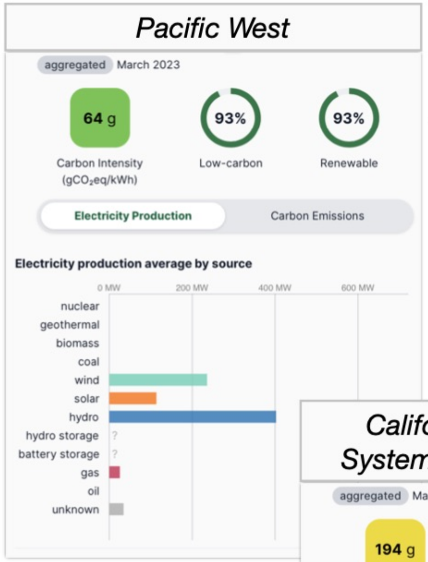
Machine Siting?

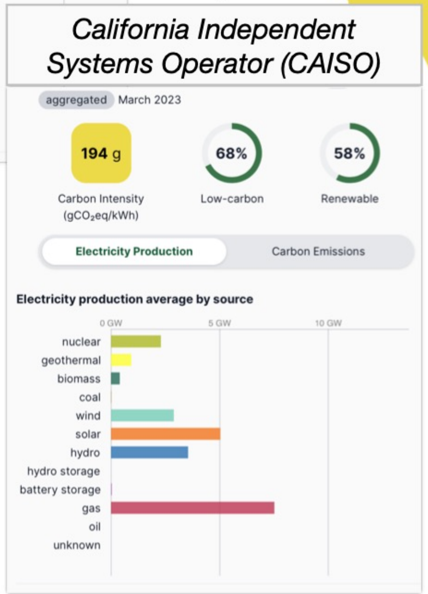
Siting options for C^3

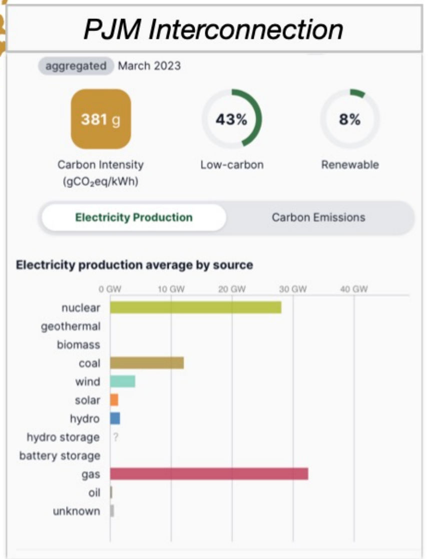
electricitymaps.org

Average March 2022-2023









PJM 2022 estimate used in Janot, Blondel 2022

C^3 has flexibility in site choice

Carbon intensity for electricity generation varies across US, driven by hydro in Northwest, solar in Southwest, and nuclear in Northeast

Not representative of operations beginning in ~2040! Need projections

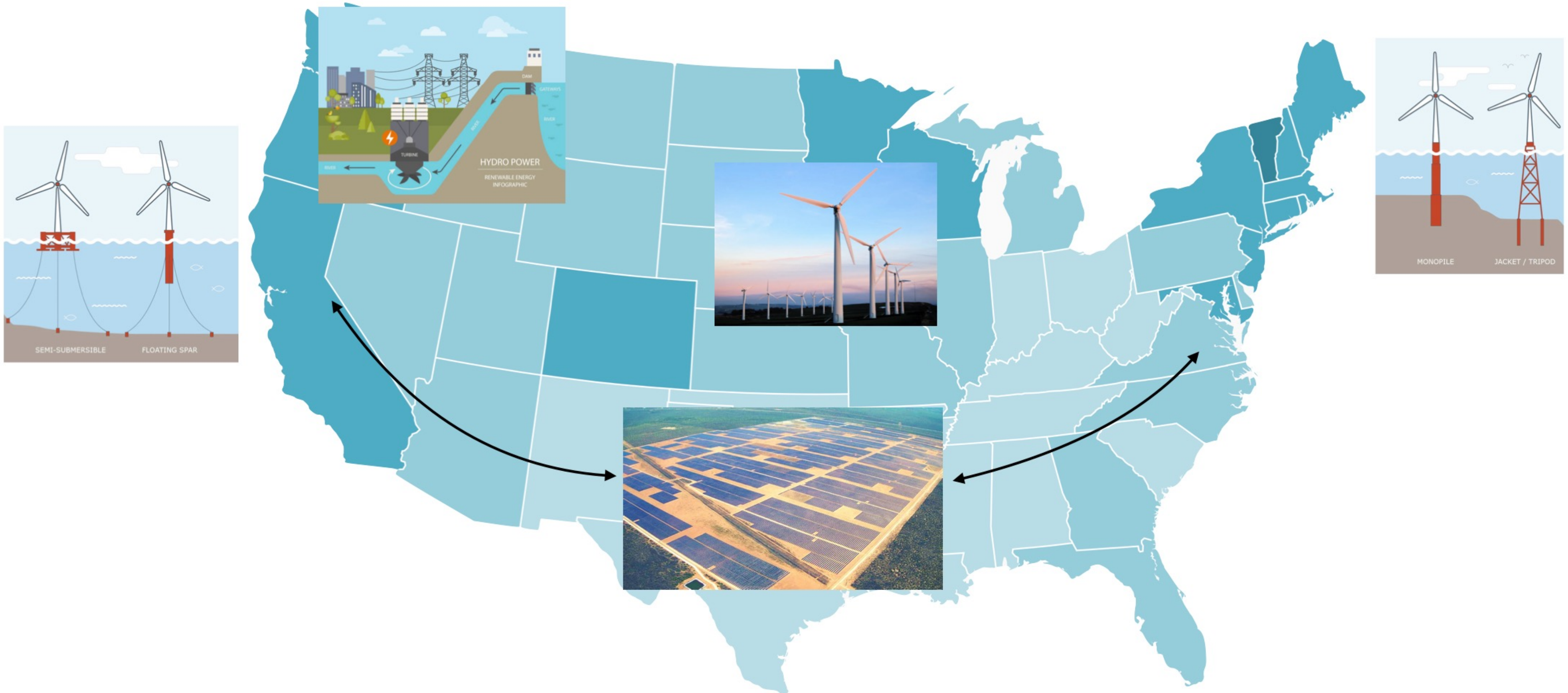
A sustainable strategy for the Cool Copper Collider 15

B. Bullard, SLAC

Machine Siting?

Dedicated energy production

SLAC

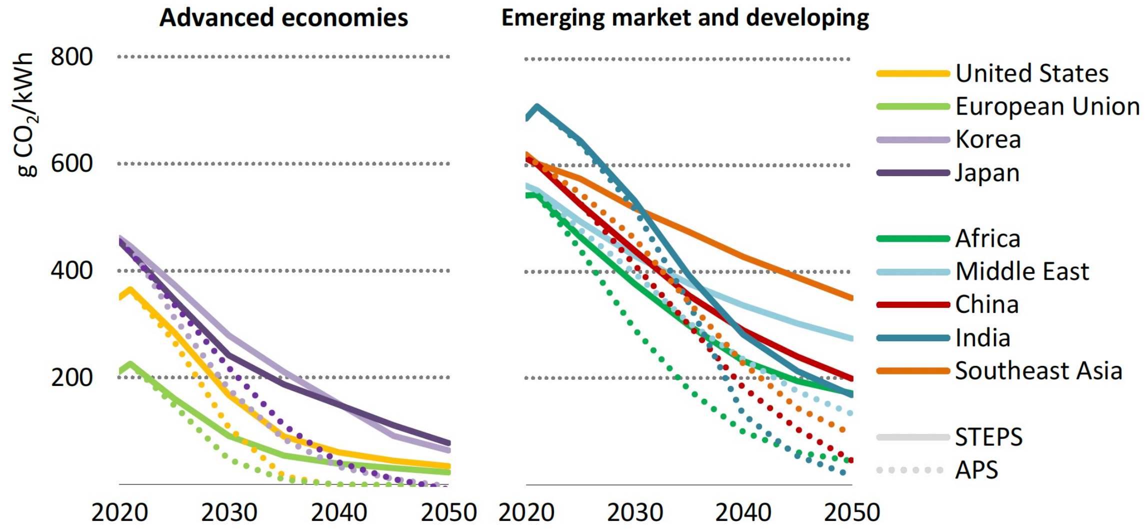


→ *Evaluated a mix of energy solutions, **C³ could produce its own power with renewables for ~$150m***

A sustainable strategy for the Cool Copper Collider 18

CO2 Intensity of Electricity in the Future

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

IEA (2022), World Energy Outlook 2022, IEA, Paris
https://www.iea.org/reports/world-energy-outlook-2022,

But: "Not enough to look at operation power and guess the CO2 from this power in ~2050 in your favourite country"

What will the CO2 impact of electricity be for the next generation of colliders?

Electricity CO2 intensity will go down as regenerative energies rise (e.g. France summer 40 gCO2e/kWh to ~10-15 in 2050)

But: Not enough – big gap (see beginning of talk) between stated policies to announced pledges, even bigger to net zero we are not on a path to net zero!

- The energy transition will be a huge effort: storage, transport (grid) → carbon intensity heavily site dependent

Therefore

- Power consumption remains important
- Consensus needed which values to use
- How to treat site dependencies?
  (All projects would look best in Norway…)

Comparison: Assume France in 2040 12.5 g CO2e/kWh and 1 TWh consumption / a → 12.5 ktons CO2e / kWh

- 1 year of operations corresponds roughly to 1 km of tunnel (CLIC tunnel 6.5 ktons/km, machine 2.5 ktons/km, +services)

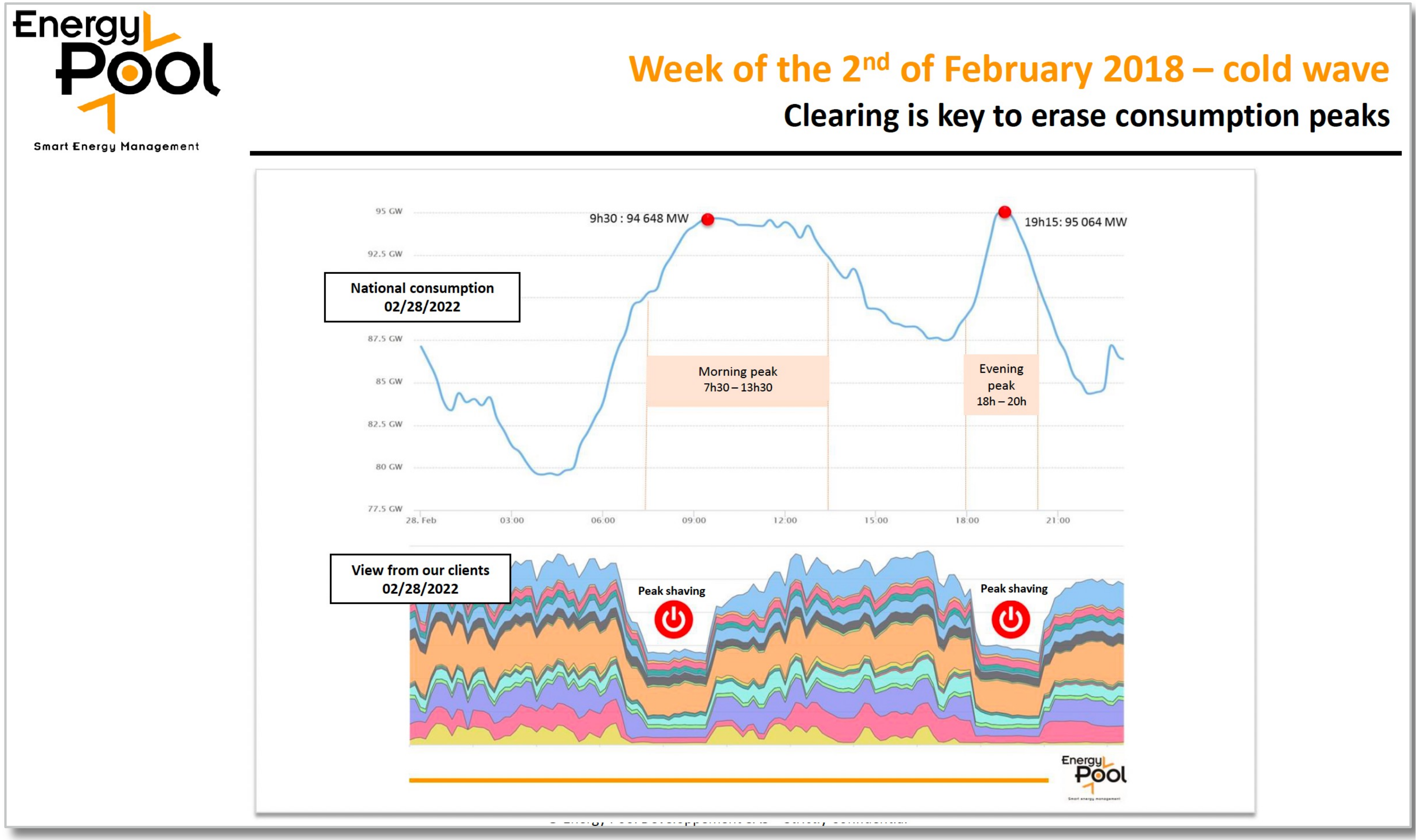
Demand Side Flexibility

There is enough regenerative energy available, but not 24/7

(Regenerative) Power availability varies
NB: Linear accelerators have no stored beam
→ ideal for flexible operation

Study by Fraunhofer institute considered running on renewables and participating in **demand side flexibility**

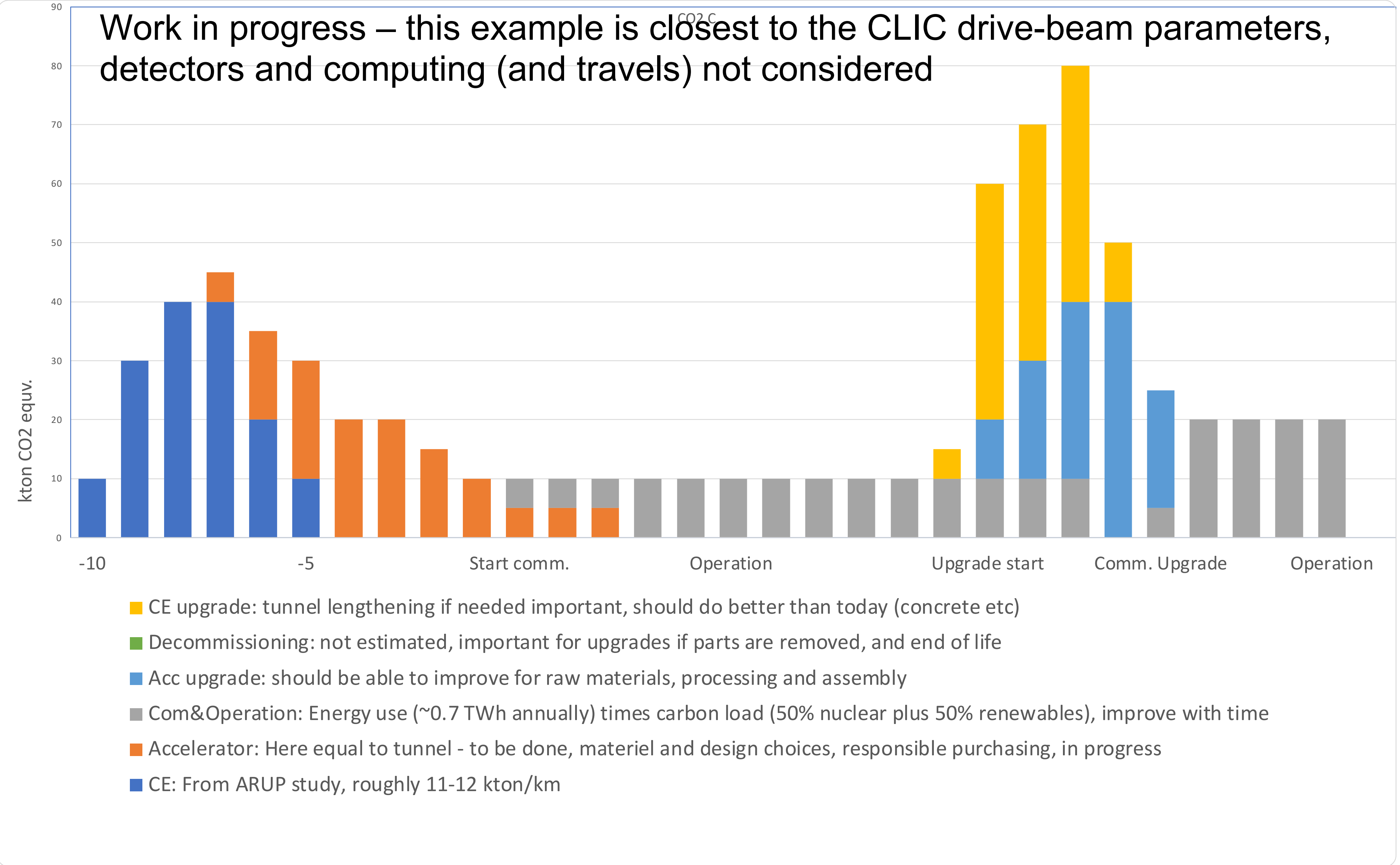
- **CLIC's total energy consumption could be generated from renewables, but still needs public grid for continuity**
- Running when energy is cheap and available.
- Design electricity contracts accordingly.
- Operating modes with power modulation were investigated.



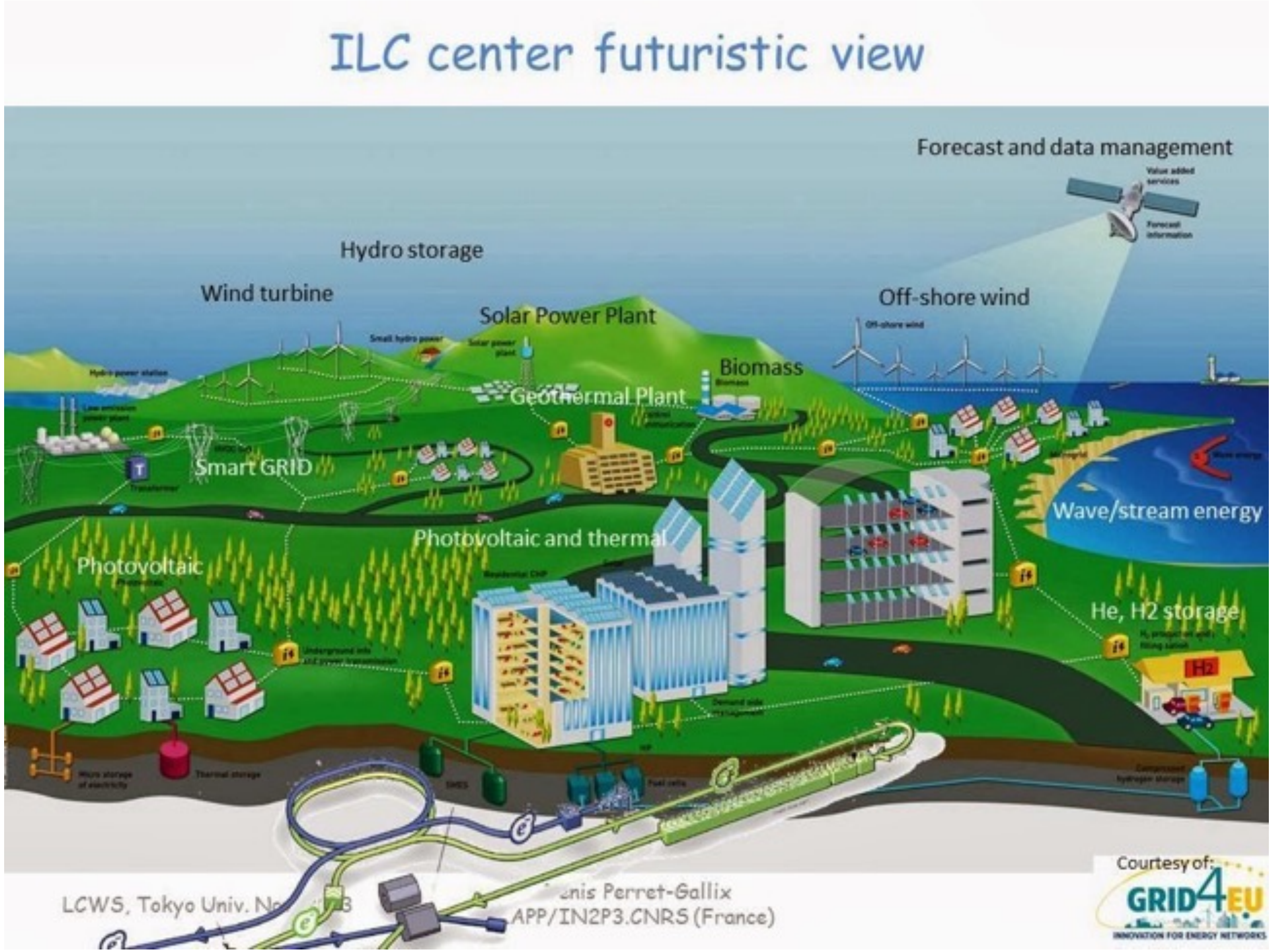
C. Gaunand, B. Remenyi: *Introduction to Demand Side Flexibility*
ESSRI Workshop 2022 https://indico.esrf.fr/event/2/contributions/94/

Towards Carbon Accounting with LCA

Work in progress – this example is closest to the CLIC drive-beam parameters, detectors and computing (and travels) not considered

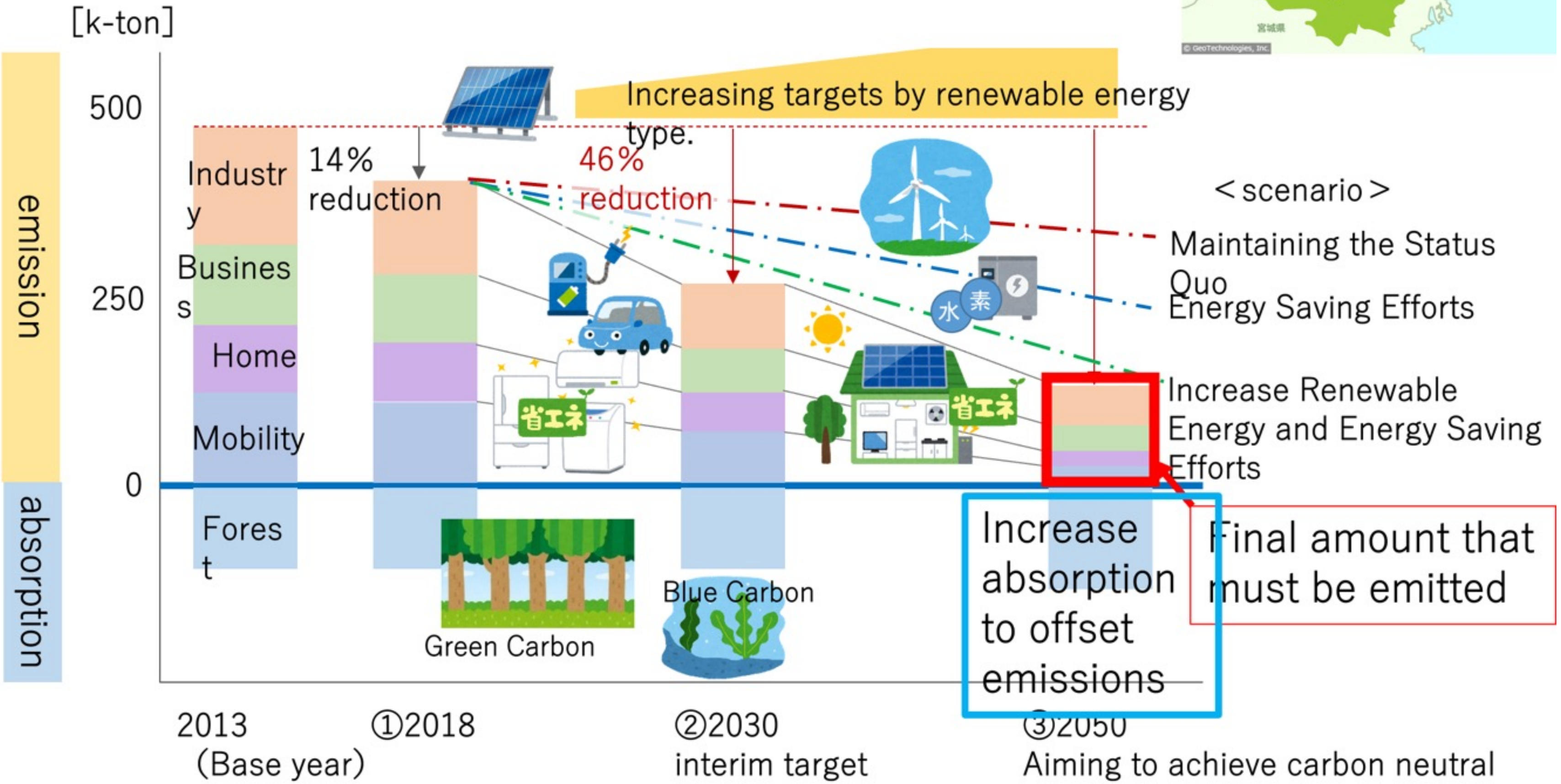


Green ILC in Tohoku Region



A typical example of policy development in line with government policy is the goal of Miyako City (51,000 people, 1,259 km², Largest in area in Iwate), located on the coast of Iwate Prefecture.

- Goal: Achieve carbon neutrality by 2050 !
- To achieve this, emissions will be gradually reduced and increase green carbon (Forest) and blue carbon (Coastal Seaweed).



Back to Morioka Workshop …

Experiences from ESS on Green Facilities

Anders Sunesson
ESS
Workshop on Sustainability in Future Accelerators
Mats Lindroos, Mamad Eshraqi, Kent Hedin, Marko Kalafatic

www.europeanspallationsource.se
September 26, 2023

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/

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)

The ISIS-II Neutron & Muon Source Life Cycle Assessment:
An Introduction

Hannah Wakeling
John Adams Institute for Accelerator Science, University of Oxford

EAJADE Workshop on Sustainability in Future Accelerators (WSFA2023)
26th September 2023

UNIVERSITY OF OXFORD
ISIS Neutron and Muon Source

A sustainable strategy for the Cool Coppe

Martin Breidenbach[1], Brendon Bullard[1], Emilio Nanni[1], Dimitris Ntounis[1,2],
1) SLAC National Accelerator Laboratory, 2) Stanford University

EAJADE Workshop on Sustainability in Future Accelerators (WSFA2023)
September 27, 2023

SLAC NATIONAL ACCELERATOR LABORATORY
Stanford University

CERN Accelerates SUSTAINABILITY!

R. Losito, CERN
26 September 2023
EAJADE Workshop on Sustainability in Future Accelerators (WSFA2023)
https://indico.desy.de/event/39980/

FUTURE CIRCULAR COLLIDER

CERN

Linear colliders
Sustainability studies for LCs
Life Cycle Assessments

Steinar Stapnes

EAJADE WP4: Morioka 27.9.2023

ARUP

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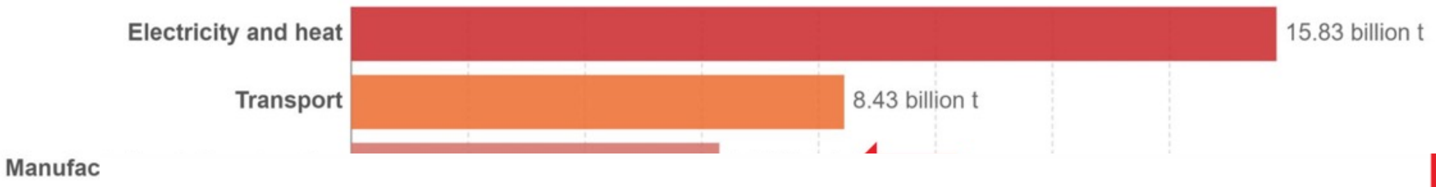
ARUP



Global GHG Emissions (tCO_2e)

Land-us

ARUP

UN Breakthrough Outcomes for 2030

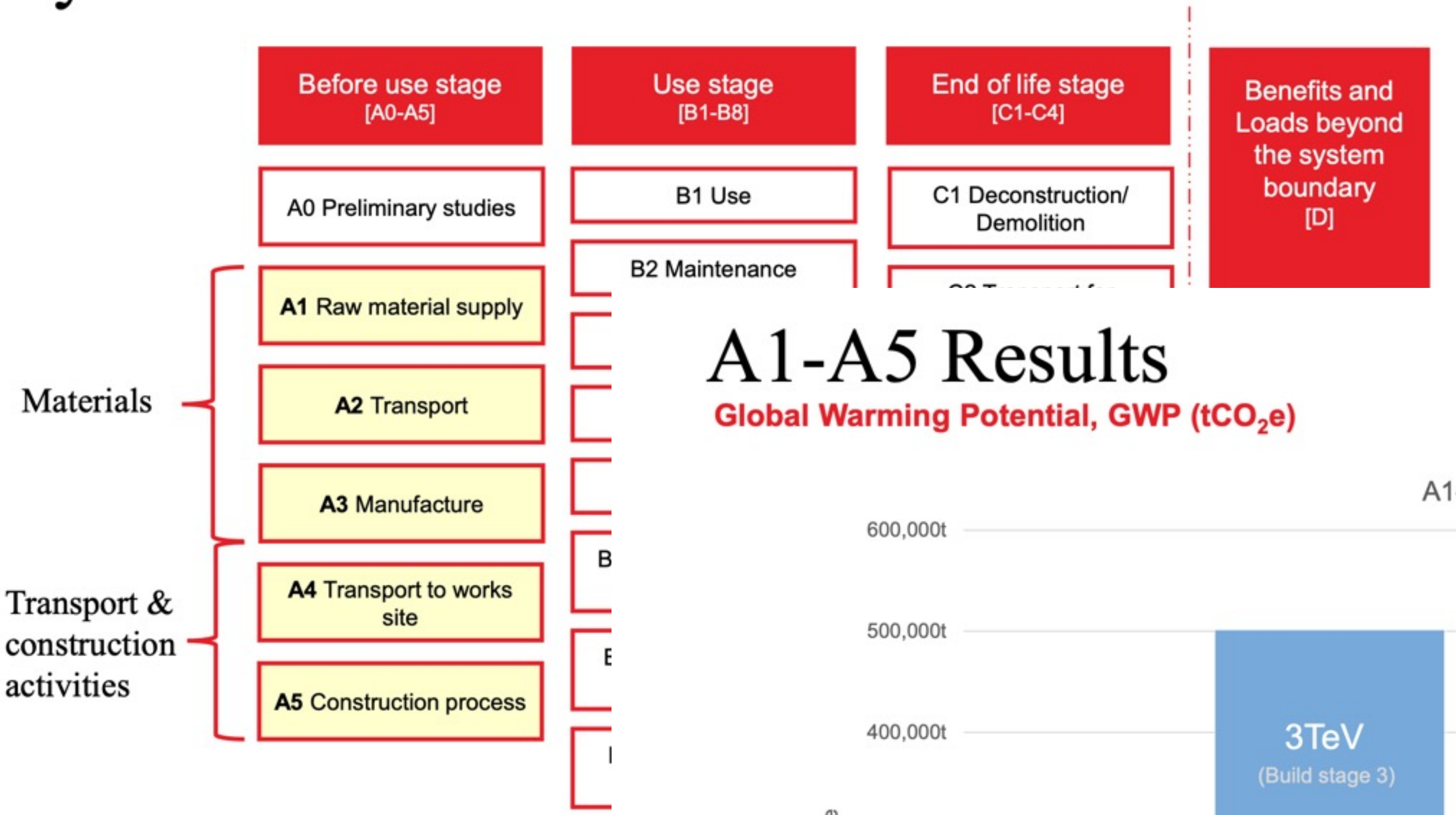
100% of projects due to be completed in **2030** or after are **net zero carbon in operation**

with at least **40% less** embodied carbon compared to current practice

2030 Breakthroughs UNFCCC

ARUP

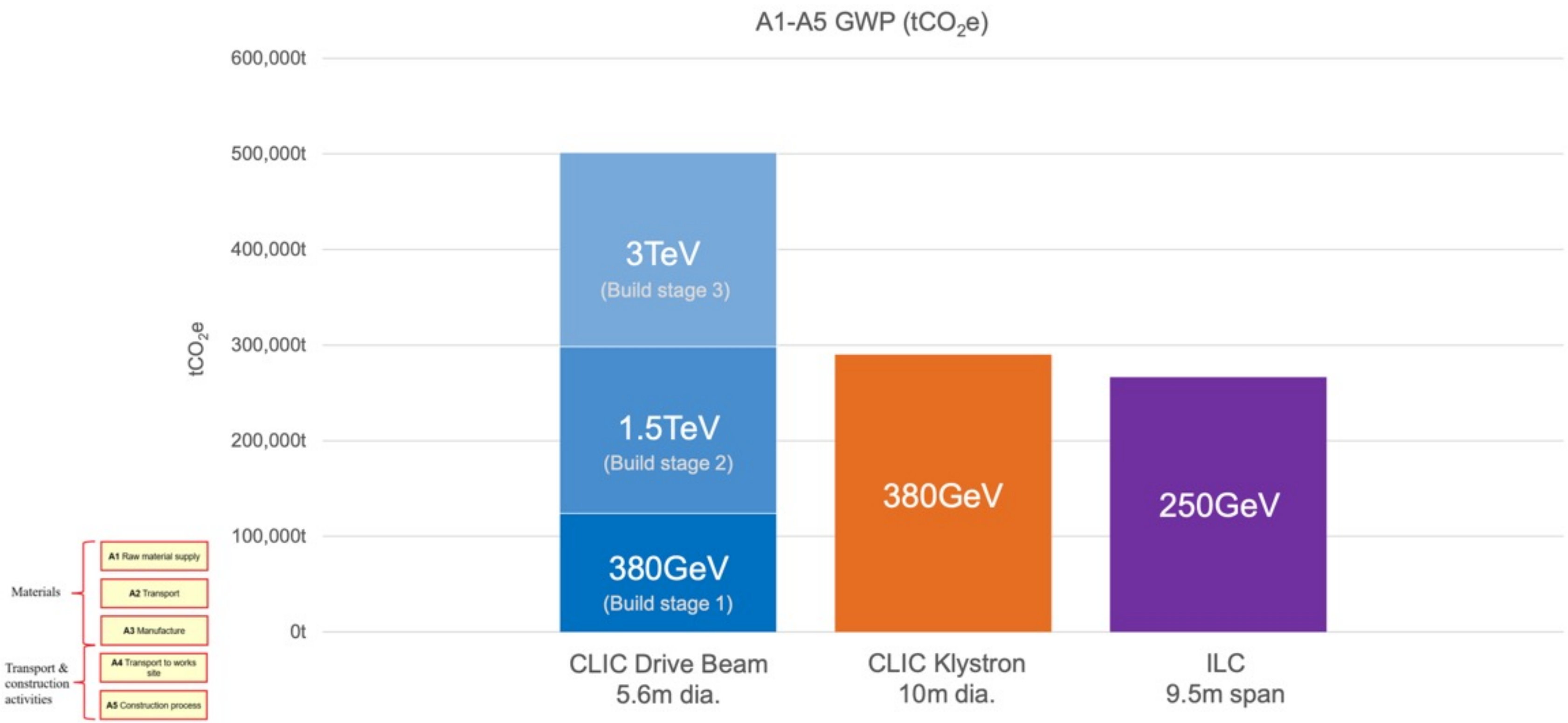
System boundaries



ARUP

A1-A5 Results

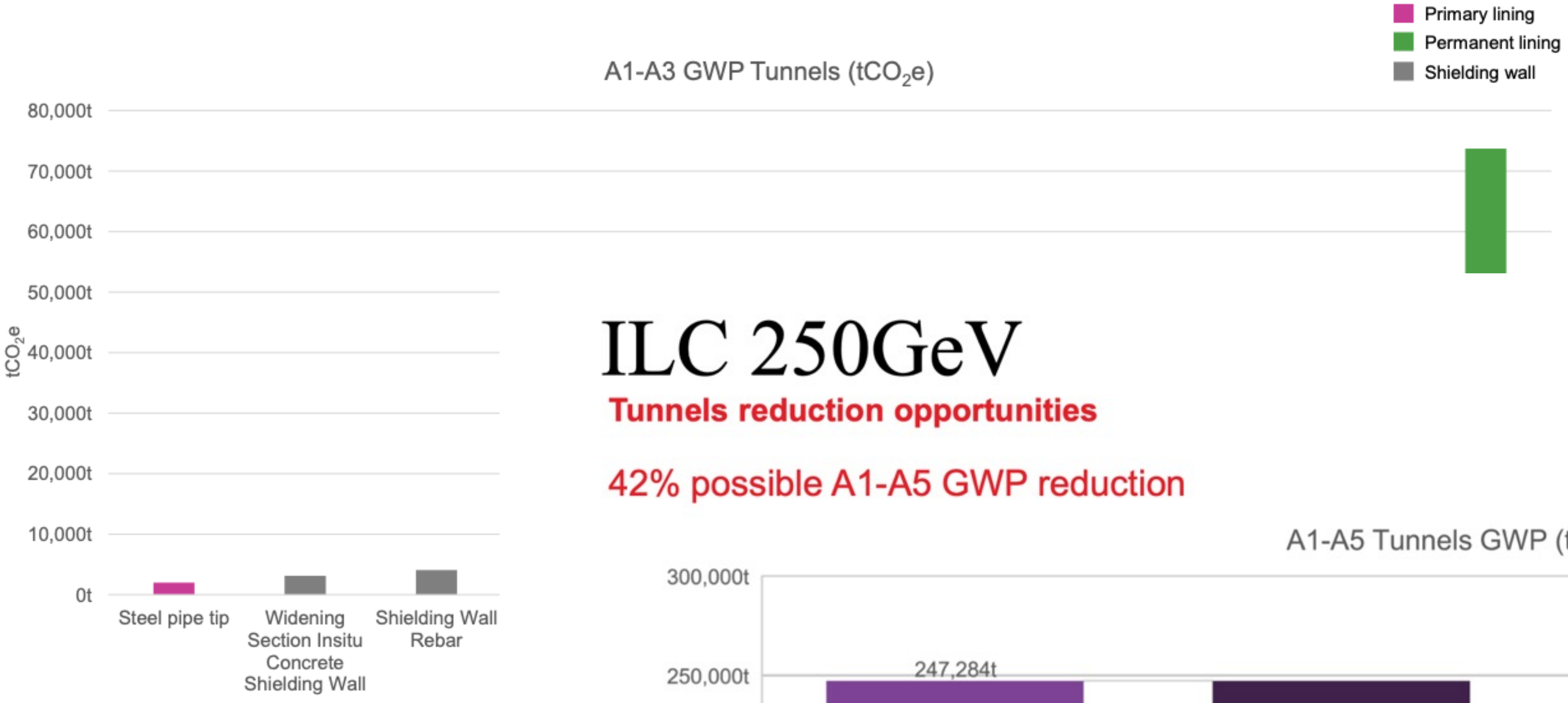
Global Warming Potential, GWP (tCO_2e)



ILC 250GeV

ARUP

A1-A3 Global Warming Potential (tCO_2e)

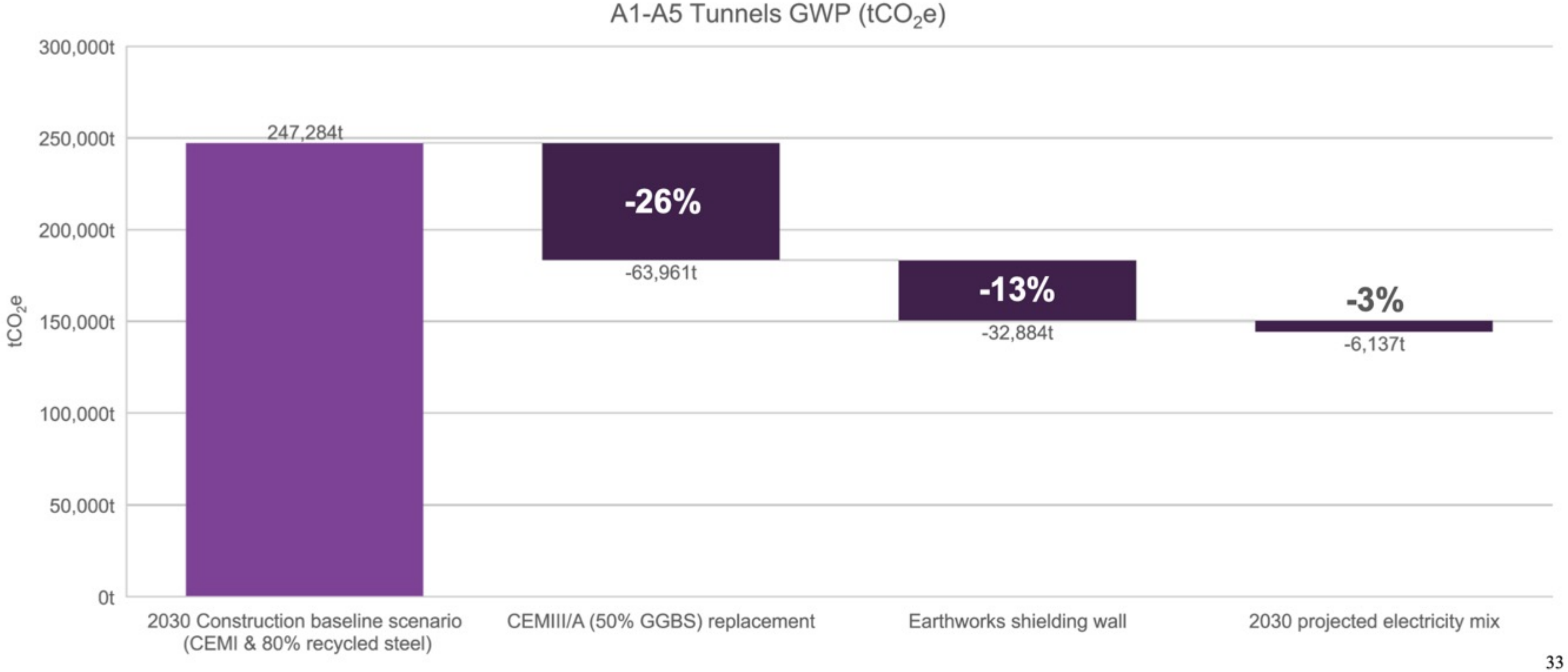


ILC 250GeV

ARUP

Tunnels reduction opportunities

42% possible A1-A5 GWP reduction

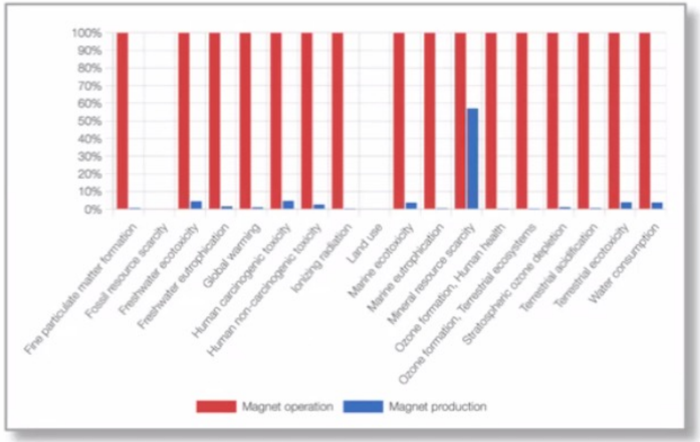


Assessing the Machine …

Stolen from Benno

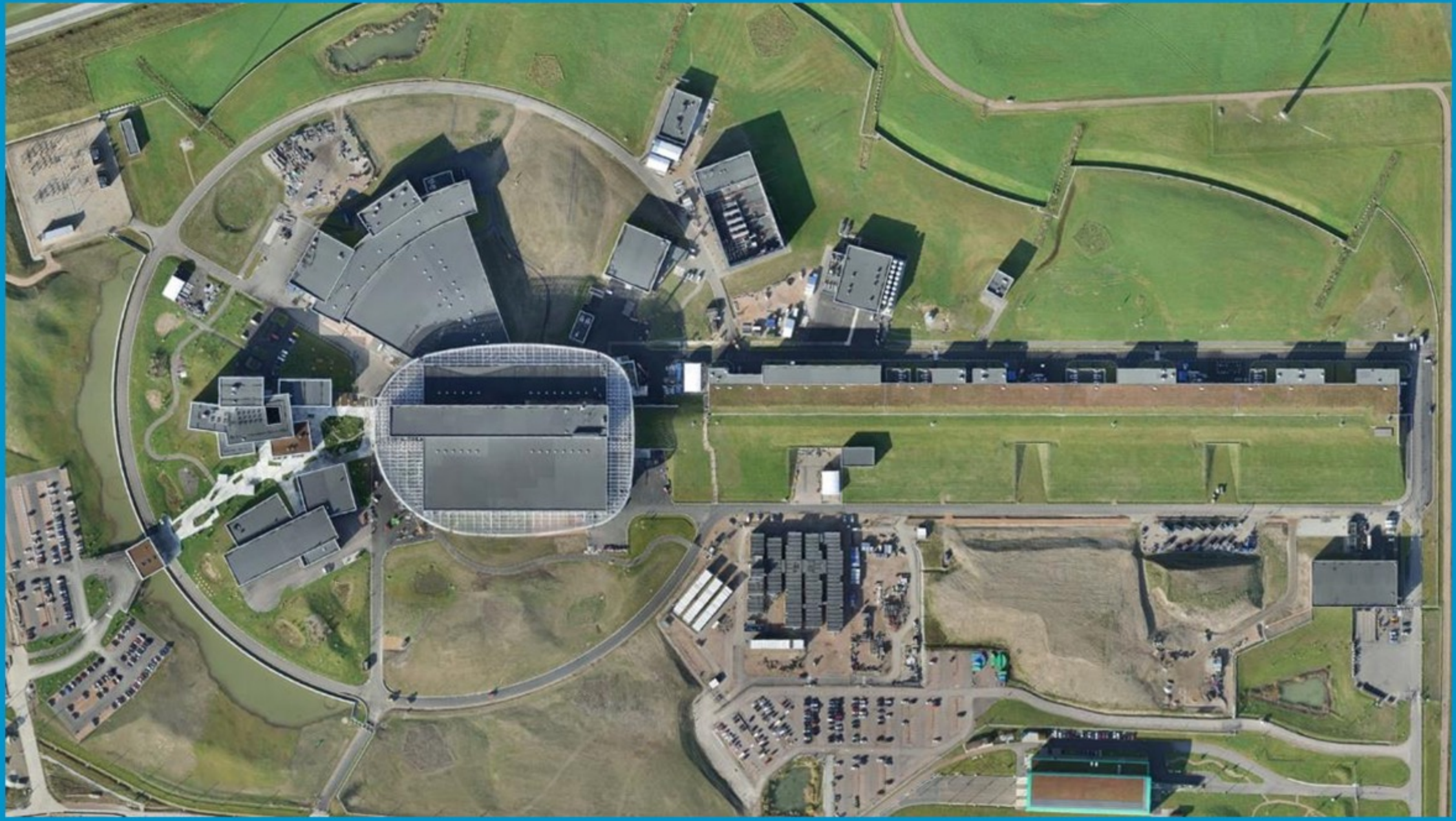
Accelerator LCA

- I have re-started work on magnets:
- Following discussions with Hannah Wakeling, I work with OpenLCA (https://www.openlca.org)
- Allows to make a professional LCA of a magnet -> good, but a LOT of work
- Could be used to get impact factors (kg steel / kg copper -> GWP or other estimators) and apply that to all magnets in a list
- Restarted looking at CLIC list of magnets



10 2/15/24 Benno List

Experiences from ESS on Green Facilities



Anders Sunesson

ESS

Workshop on Sustainability in Future Accelerators

Mats Lindroos, Mamad Eshraqi, Kent Hedin, Marko Kalafatic

www.europeanspallationsource.se

September 26, 2023

Overview

- ESS is planned as green facility:
  - Re-use of cooling water for district heating
  - High temperature water to i
  - Active strategy for power su
- Pioneering developments
  - Flicker-free HV modulator to
  - Compact and cost-effective
  - Multi-beam IOT high efficie
  - Optimisation of klystron effi
- ESS active in two EU Horiz
  - iFAST (Horizon 2020) and Fl

Green ESS implementations

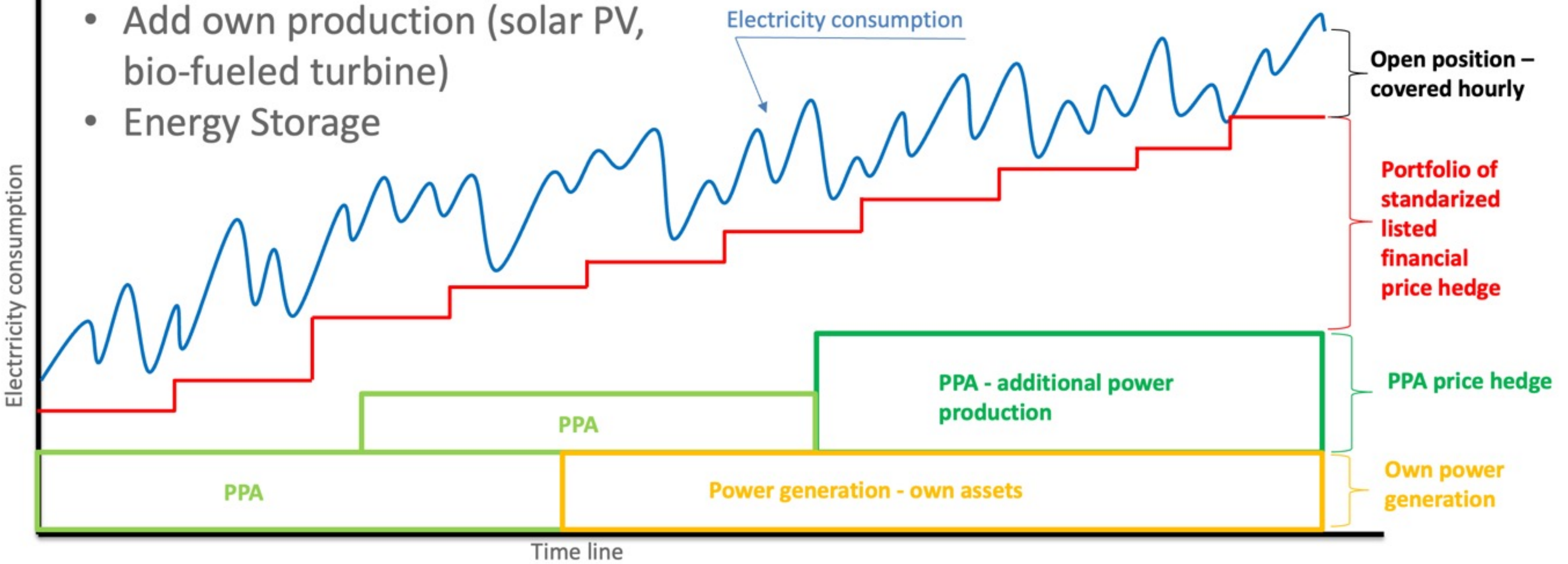
- Implementations:
  - Cooling water is provided in three temperature ranges: Low (ca 8 deg C), Medium, (ca 25 deg C), and High (45+ deg C), all supplies control temperature of input
  - The heated medium and high temperature water is fed to heat exchangers and heat pumps (optional) to lift the temperature to 80 deg C, and the energy is used in district heating (ESS sells the energy)
  - Heated water is also used for heating of ESS premises and for hot water, either via heat exchanger or heat pump
  - The use of heat pumps depends on the temperatures and electric power prices and the heat price
  - ESS operates procurement of electrical power according to a strategy with both variable and fixed hedges. The selling of heat is part of the strategy

Overall Energy Strategy
Relationship between electricity/heat

Electricity provided by ESS to EON to run CPS

Possible Future Energy Strategy

- Buy directly from producer (PPA)
- Add own production (solar PV, bio-fueled turbine)
- Energy Storage



The ISIS-II Neutron & Muon Source Life Cycle Assessment:
An Introduction

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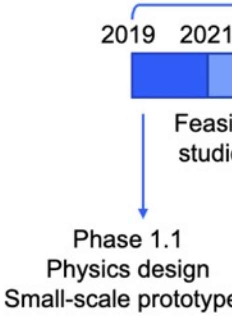
UNIVERSITY OF OXFORD

UKRI Science and Technology Facilities Council

ISIS Neutron and Muon Source

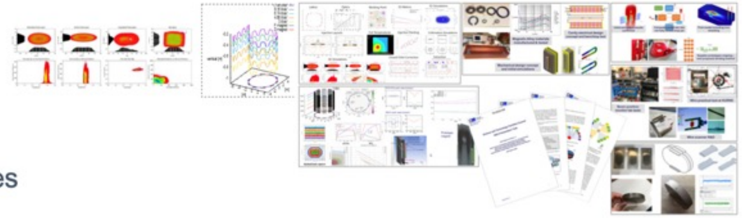
The ISIS-II Project

- Currently, Europe (including the UK) is a world leader in neutron- and muon-based science.
- Over the next decades, reactor-based sources will be shut down and other sources will reach the end of their lifetimes.
- ISIS-II would be the next g



Science and Technology Facilities Council
ISIS Neutron and Muon Source
www.isis.st
@isisn
uk.linkedin.c

Designs and prototypes



- Environmental sustainability estimates
- High-level requirements
- Resource planning
- Targets design
- Neutronics design
- RCS and AR accelerator design
- FFA accelerator design
- Linac design
- Muon and proton irradiation solutions
- ISIS upgrade (180 MeV) feasibility
- Engineering prototypes
- Siting options and planning

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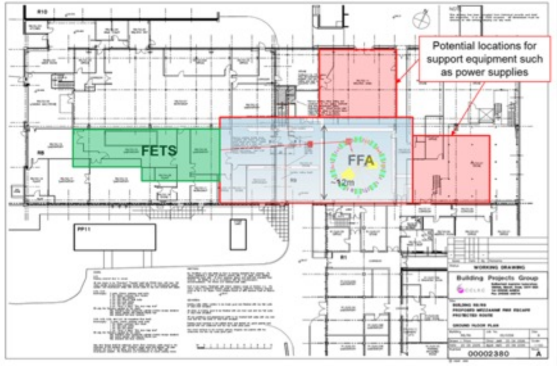
www.isis.stfc.ac.uk
@isisneutronmuon
uk.linkedin.com/showcase/isis-neut

ISIS-II project phase 1.2b plan

- Construction of a small FFA test ring on the end of the Front End Test Stand (FETS) at RAL in order to explore the beam dynamics fully.
- Completion of compression ring designs.
- Linear accelerator design integrated with choice of pulse compression ring.
- Completion of target, moderator and shielding design for high and low repetition rate neutron targets and a muon target.
- Production of an optimal concept design with credible initial cost estimates.



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Construction CO_2e impact

Transportation of chalk mound:
89 tCO_2e (V_{130m}) or 208 (V_{12}

Access and service tunnels an
5459 tCO_2e (concrete structur

Supporting buildings:
3500 (steel frame) + 785 (conc
= **4287 tCO_2e**

Tunnel & shielding:
6310 tCO_2e (concrete structur

TOTAL = 16 $ktCO_2e$

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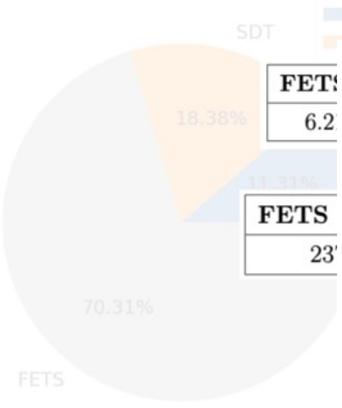
Operation

Cumulative CO2 emissions for the FETS(Front End Test Stand), Drift Tube (DT) and Separated Drift Tube (SDT) including SDT electromagnet power and including cooling.



FETS
6.2

FETS
23

Power consumption breakdown of co

Components: 5.39x10⁸ kW

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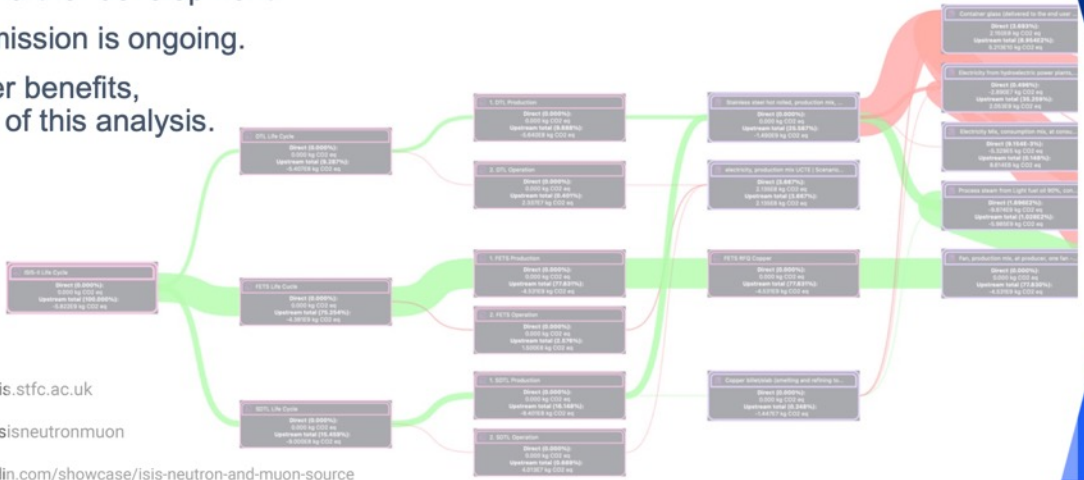
ISIS Neutron and Muon Source

Life Cycle Assessment Conclusion (so far!)

- **Taking note that these are initial results, with further development needed**: even with highly optimistic UK 2050 power mix forecasts, concrete and steel construction impacts (16 $ktCO_2e$) do not outweigh the full lifetime electrical operation impacts (34 $ktCO_2e$).
  - This is solely through examining the GWP. Other impacts are being examined but the investigation needs further development.
- Investigation of decommission is ongoing.
- LCA software has further benefits, and is the current focus of this analysis.



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CERN Accelerates SUSTAINABILITY!

R. Losito, CERN

26 September 2023

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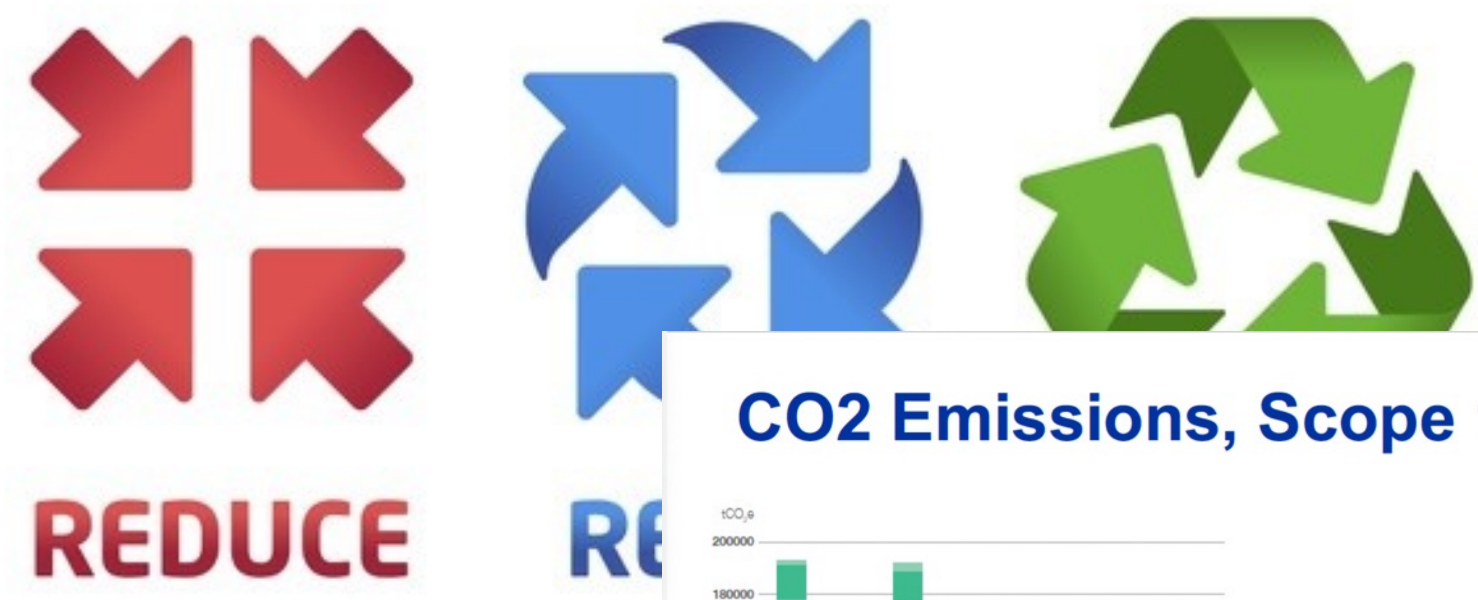
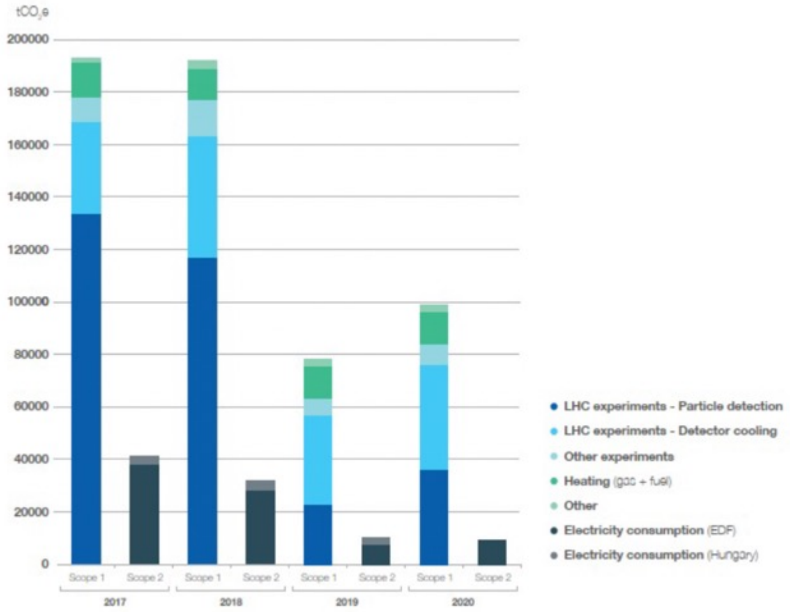
https://indico.desy.de/event/39980/



CO2 Emissions, Scope 1 (Direct) and 2 (Indirect)

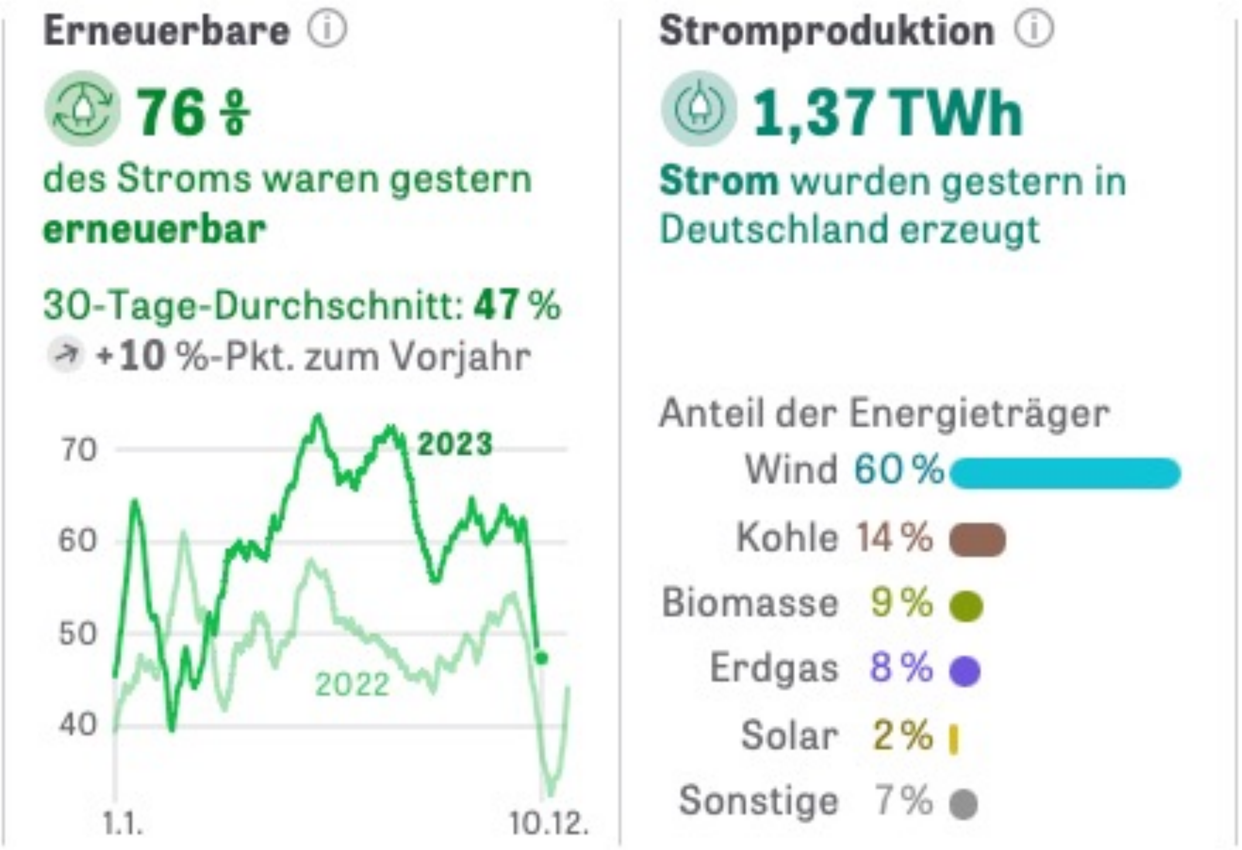


CERN SCOPE 1 AND SCOPE 2 EMISSIONS FOR 2017-2020 BY CATEGORY.
Other includes air conditioning, electrical insulation, emergency generators and CERN vehicle fleet fuel consumption. Emission factors for electricity: EDF Bilan des émissions de GES 2002-2020 for EDF and Bilan Carbone® V8 for Hungary.

- **The future is bright!!!**
  - Scope 1 emissions dominate CERN's emissions
  - Most of them due to (now) obsolete design of detectors
  - Difficult to eliminate in near future in LHC, but experiments have promised to reduce by at least ~30% with LS3.
    - Repair leaks
    - Change fluids
      - Massive use of CO_2 as coolant
- **For the next generation of colliders, this line will *(almost)* not be there anymore!!!**
- *Scope 3 emissions are less than 5%...*

Area needed to generate 1.3 TWh/y
(no contingency, no distribution, no storage…)

CERN Total Energy Consumption: 1.3 TWh



Die ZEIT, 11 Dec 2023

20.000 CERN users use as much energy as 224.000 German citizens.

How can we procure CO_2 free energy?

- **We already do!!!**
- 80% of our energy comes from French Nuclear, the rest is purchased on the market through EDF and reflects the standard mix of French energy.
- The EU is establishing a new policy that aims at encouraging the investment in renewables, targeting at the same time stability for the producer and for the customer through 2 mechanisms:
  - ***Power Purchase Agreements*** : between producers and large consumers, long (>15 years) contracts at fixed or indexed price with limiting mechanisms
  - ***Two-way Contracts for Difference***: Between providers and public entities, used to stabilise the price for both the consumers and the providers limiting losses for the providers but also unjustified gains.

FUTURE CIRCULAR COLLIDER

All powered by electricity

Power demand estimation by operation mode

Reduced by 9% compared to 2022

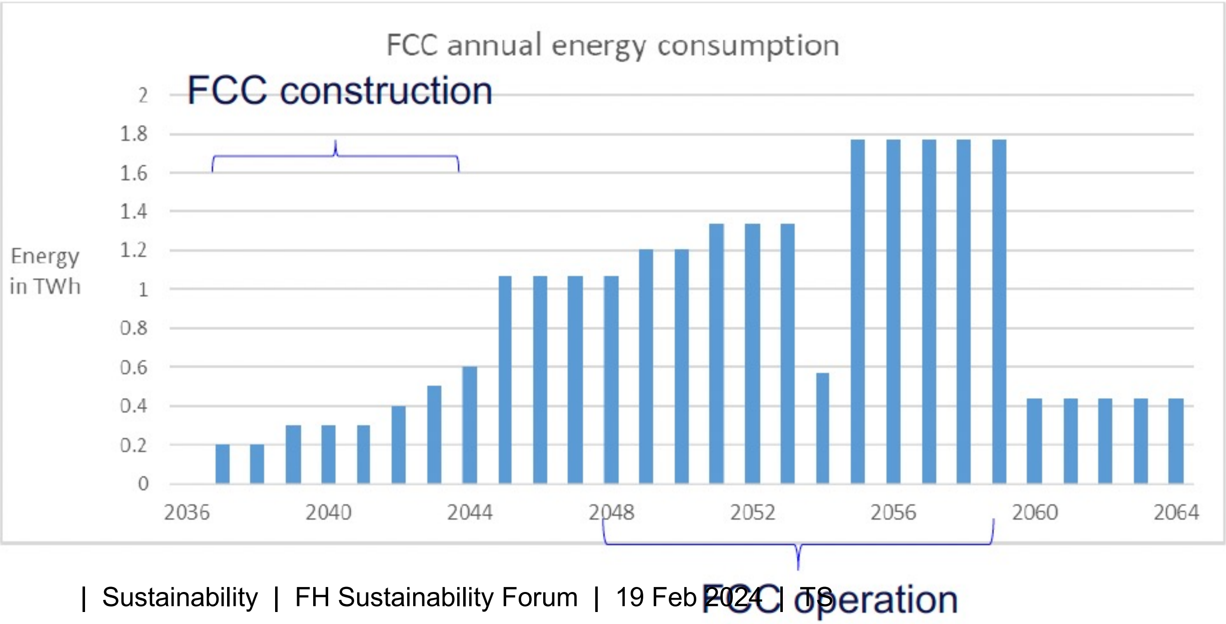
2023		Z	W	H	TT
Beam energy (GeV)		45.6	80	120	182.5
Magnet current		25%	44%	66%	100%
Power ratio		6%	19%	43%	100%
PRF EL (MW)	Storage	146	146	146	146
PRFb EL (MW)	Booster	2	2	2	2
Pcryo (MW)	Storage	1.2	11.5	11.5	27.6
Pcryo (MW)	Booster	0.35	0.80	1.50	7.40
Pcv (MW)	all	25	26	28	33
PEL magnets (MW)	Stroage	6	17	39	89
PEL magnets (MW)	Booster	1	3	5	11
Experiments (MW)	Pt A & G	10	10	10	10
Data centers (MW)	Pt A & G	4	4	4	4
General services (MW)		26	26	26	26
Power during beam operation (MW)		222	247	273	357

FCC electricity consumption 2036 - 2065

Electricity for FCC

First consumption started with construction, then commissioning and operation.
Based on runs (beam operation) and long shutdowns (maintenance and upgrade).

FCC operation is foreseen to be in the range of 20TWh over 15 years (<400 ktonCO_2e) ≈ 2 years of LHC detectors operation



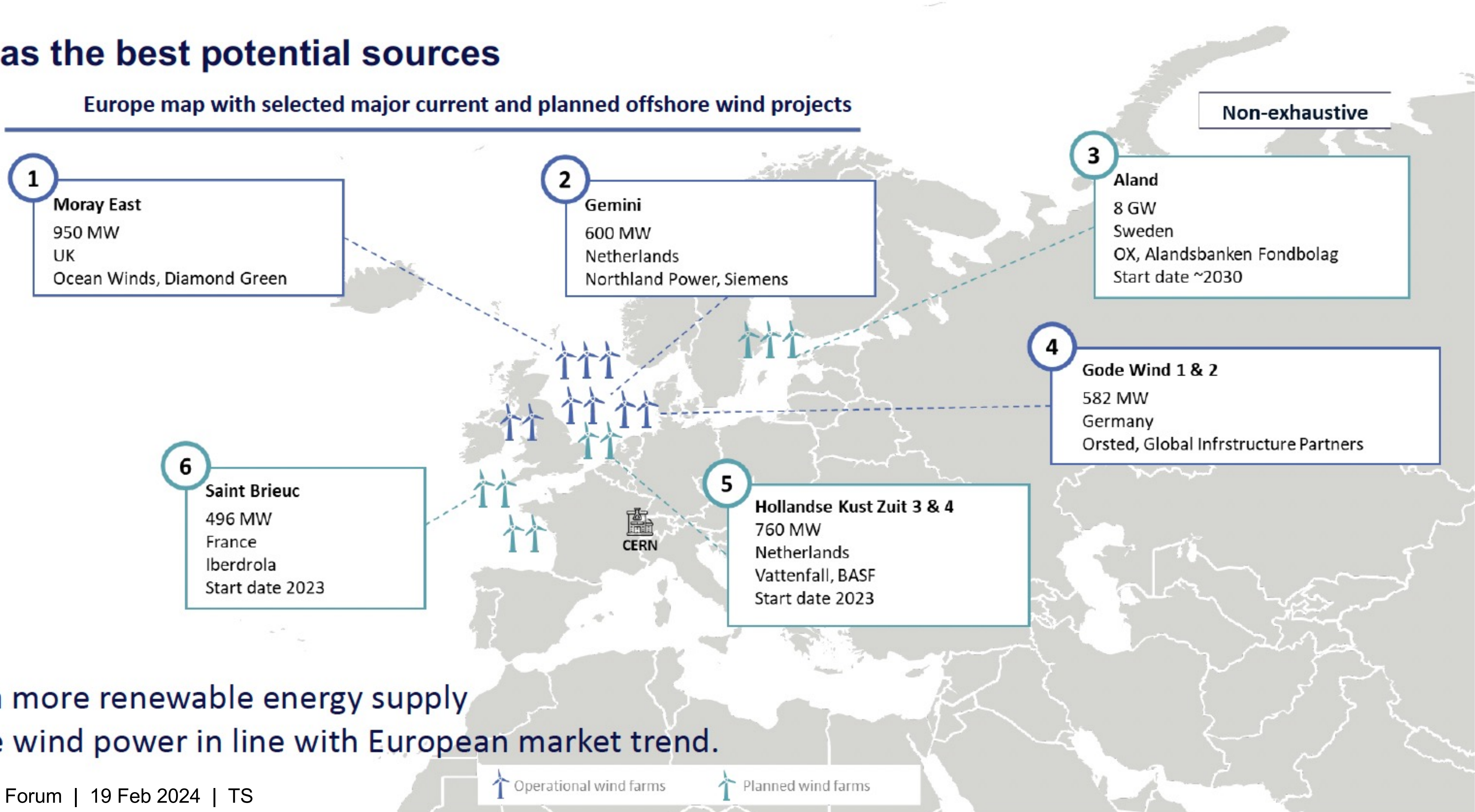
From CERN annual report (2018 LHC in operation)
CERN's total amount of greenhouse gas emissions, those produced directly by the Organization, was 192 100 tonnes of CO_2 equivalent, tCO_2e, in 2018, 92% of which is related to the activities of the large LHC experiments.

CERN's total amount of indirect greenhouse gas emissions, those due to CERN's electricity consumption, was 31 700 tCO_2e in 2018.

CERN environment report (2017-2018)

FCC renewable energy supply

Offshore wind farms as the best potential sources



CERN is moving forward to a more renewable energy supply

FCC target = 80% of offshore wind power in line with European market trend.

A sustainable strategy for the Cool Copper Collider

Martin Breidenbach[1], Brendon Bullard[1], Emilio Nanni[1], Dimitris Ntounis[1,2], Caterina Vernieri[1,2]
1) SLAC National Accelerator Laboratory, 2) Stanford University

EAJADE Workshop on Sustainability in Future Accelerators (WSFA2023)
September 27, 2023

C^3 Excavation models

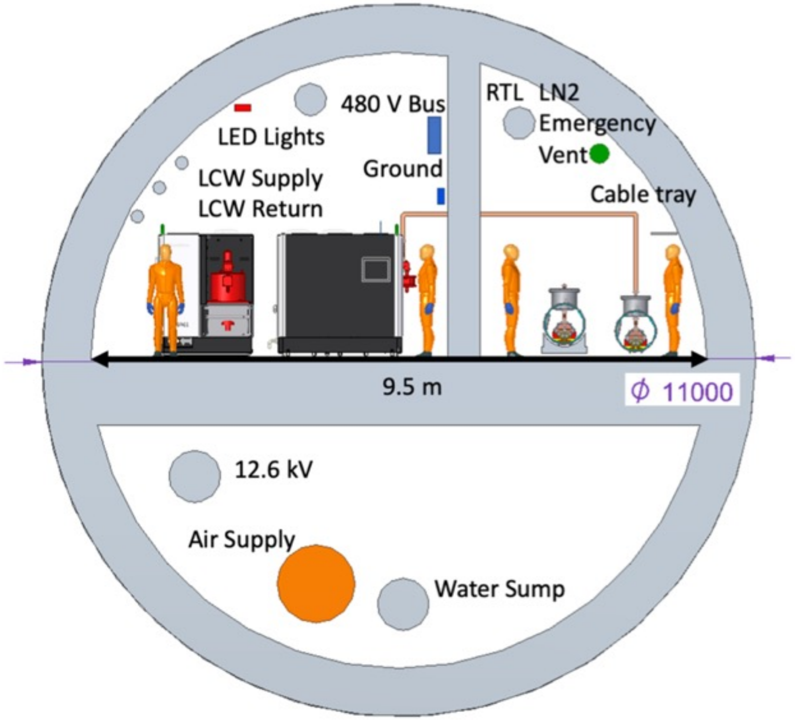
Bored tunnel

Total of 600k m^3 total excavation, 225k m^3 concrete

- 200k m^3 of excavation comes from tunnel volume, concretes include all site requirements
- Emissions estimated using Snowmass report parameters

Releases ~60 kton CO_2 from concrete

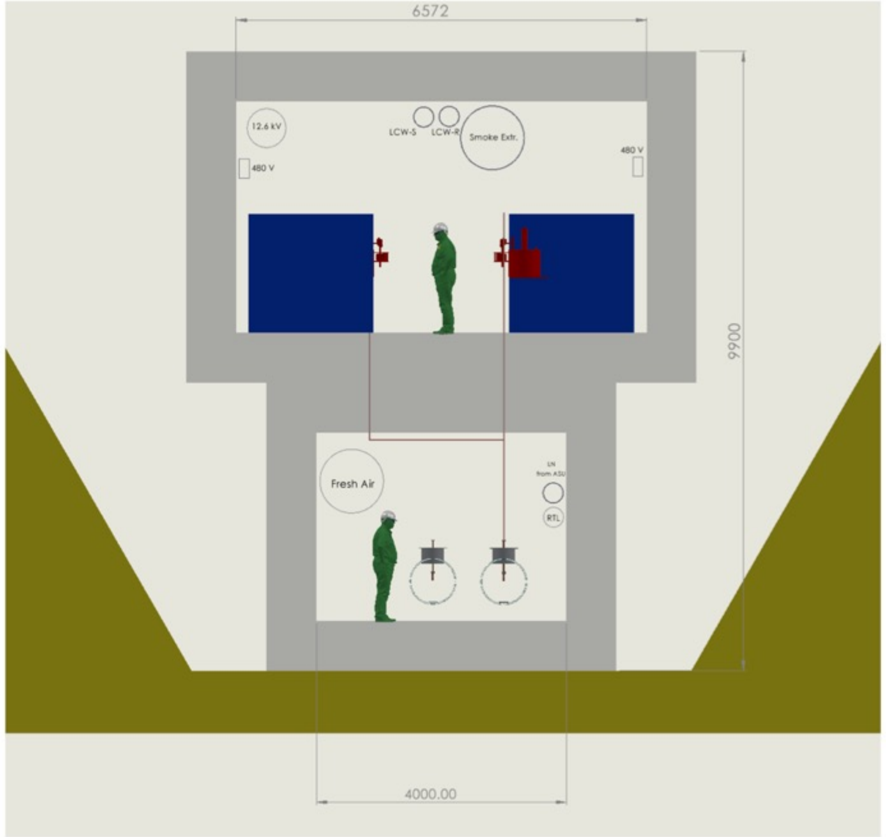
Double it to account for top-down vs. bottom-up **(120 kton CO_2)**



Cut and cover

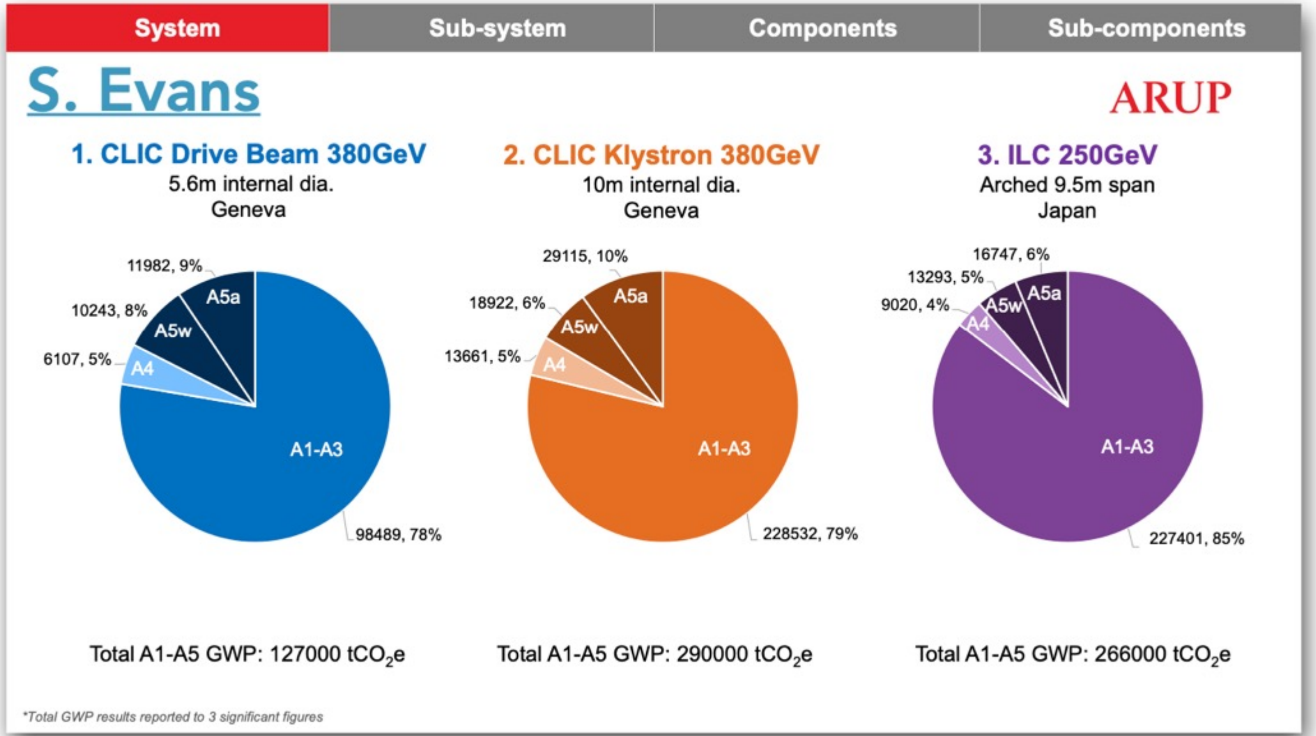
Preferred option for reduced construction costs and emissions (but not required)

- Much of the displaced earth is pushed on top (shielding), only ~40k m^3 must be transported away



Collider project inputs

- ARUP analysis indicates 80% of construction emissions arise from materials (A1-A3), remaining from material transport and construction process
  - More thorough than Snowmass report - rely on it for inputs for other Higgs factory parameters!
  - Approximate global warming potential (GWP) for tunnels ~6 tn/m for CLIC/ILC, apply for circular collider concepts



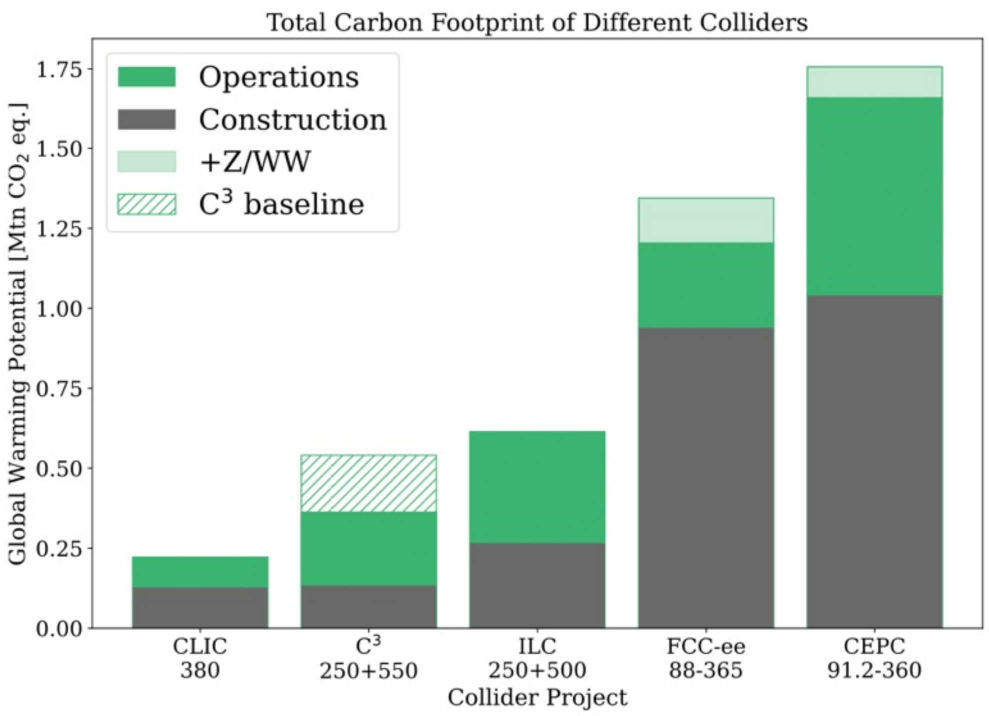
Project	Main tunnel length (km)	GWP (kton CO_2e)		
		Main tunnel	+ Other	+ A4-A5
FCC	90.6	578	751	939
CEPC	100	638	829	1040
ILC	13.3	97.6	227	270
CLIC	11.5	73.4	98	125
C^3	**8.0**	**133**		**146**

Estimating +30% concrete volume for shafts, klystron gallery, caverns +25% for A4-A5 construction processes for circular colliders

For C^3, estimate A4-A5 for surface site is half that for tunnel (ILC/CLIC)

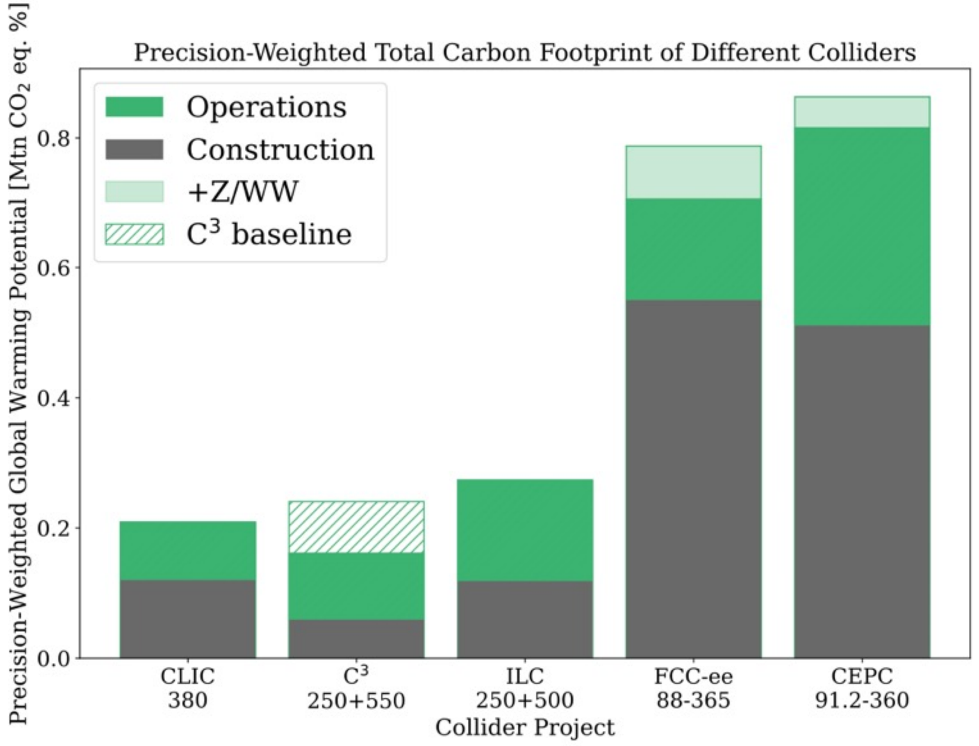
Total carbon footprint

Absolute total emissions



Impact of embodied carbon in construction materials is the driving factor of GWP

Total emissions x average coupling precision



Considering also the physics reach, linear colliders are clearly superior with optimized C^3 on top!

Science and Technology Facilities Council

ASTeC

Sustainable Accelerator R&D in the UK

Ben Shepherd

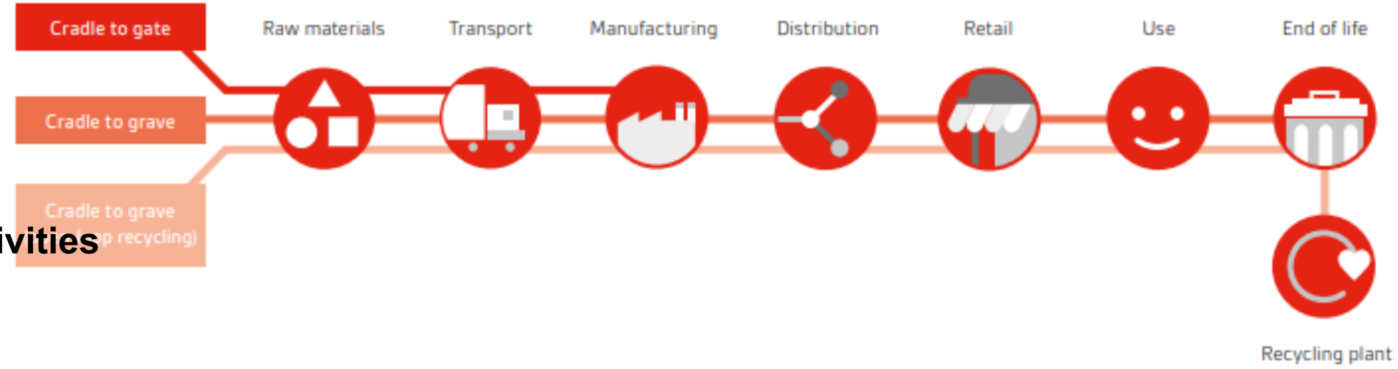
Accelerator Science and Technology Centre, STFC Daresbury Laboratory

The International Workshop on Sustainability in Future Accelerators

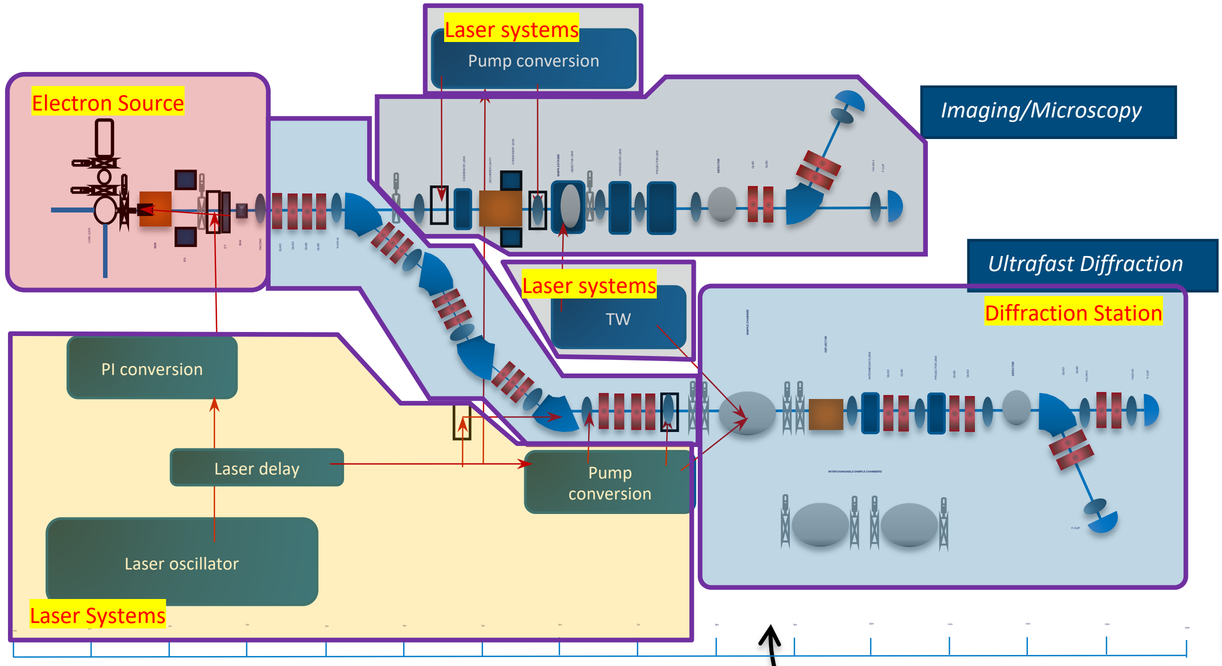
Morioka, Japan

25-27 September 2023

Lifecycle analysis



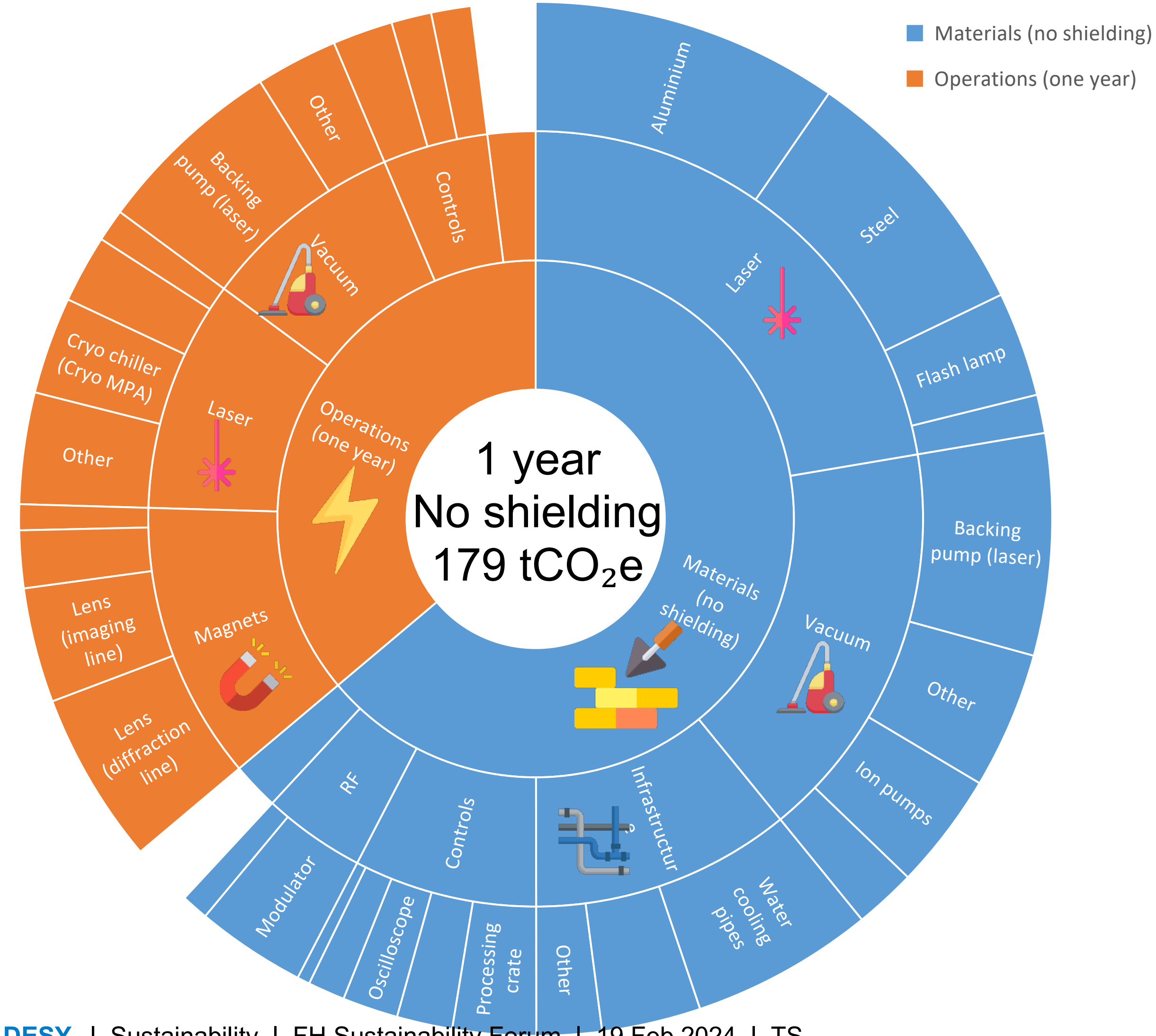
- Detailed review of the **climate impact of accelerator activities**
- Where are the **Big Sources** of emissions?
  - **Manufacturing?** Steel / Copper / Aluminium / Concrete
  - **Operations?** Running RF and magnet systems. Cooling & AC
  - ~~**Disposal?** End of life of components –~~ not considered (yet)
- How can we **reduce these** for the biggest impact?
  - Using different materials
  - Improved efficiency
  - Smart powering schemes
- **RUEDI*** is our case study for this exercise
- Considered wider applicability for other accelerators too
- Figure of merit is **kgCO_2e** per "delivered unit"
  - Other environmental impact indicators are available (land use change, ocean acidification, eutrophication etc) so this isn't really the same as a full LCA
  - So at the end, we should have a database listing carbon emissions for components in every area
- Look at the big picture; **not** every gram of CO_2 - not a bean-counting exercise!

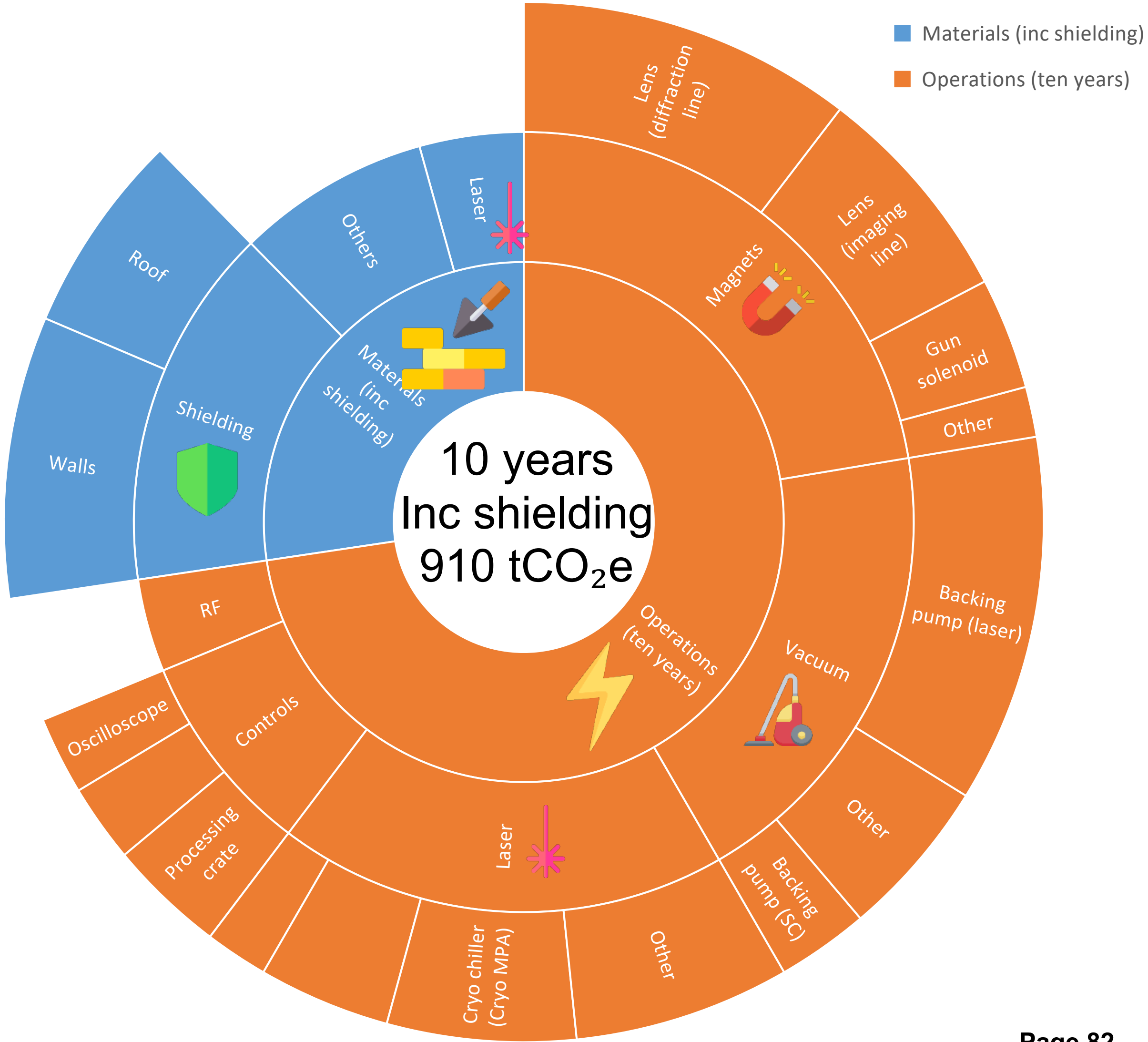


*RUEDI = Relativistic Ultrafast Electron Diffraction & Imaging
Working towards TDR now

RUEDI report: overall picture

Shielding: **137 tCO_2e**
Other materials: **113 tCO_2e**
Operation for 1 year: **66 tCO_2e**





Linear colliders

Sustainability studies for LCs
Life Cycle Assessments

Steinar Stapnes

EAJADE WP4: Morioka 27.9.2023

Initial considerations

- Resource optimization as traditionally done for accelerators:
  - Length/complexity -> construction cost
  - Power/energy consumption -> operating costs

Traditionally we optimize for energy reach and luminosity wrt to cost and power

- Sustainability in a wider sense adds new construction and operation optimization criteria:
  - Energy use not only costs but also CO_2, embedded CO_2 in construction materials and components, rare earth usage, responsible sourcing in general for all parts, landscaping, integration in local communities, life cycle assessments including decommission and many more issues

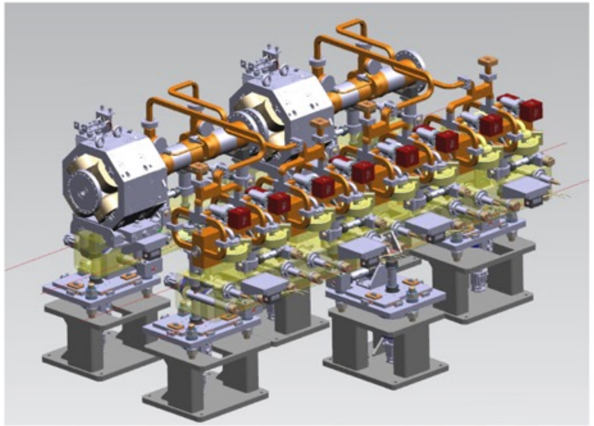
Approaches to increase sustainability

- Overall system design
  - Compact accelerator -> high gradients, high field magnets
  - Energy efficient -> low losses (wall-plug to beam)
  - Effective -> small beam sizes to maximize luminosities
  - Energy recovery concepts
  - Civil engineering including landscaping and “community” integration
- Subsystem and component design, e.g.
  - High-efficiency cavities and klystrons
  - Permanent magnets, HTS magnets
  - Heat-recovery. e.g. in tunnel linings, possibly other components
  - Responsible sourcing and material choices for all parts
- Sustainable operation concepts
  - Renewables
  - Adapt to power availability
  - Exploit energy buffering potential
  - Recover low grade energy (heat)

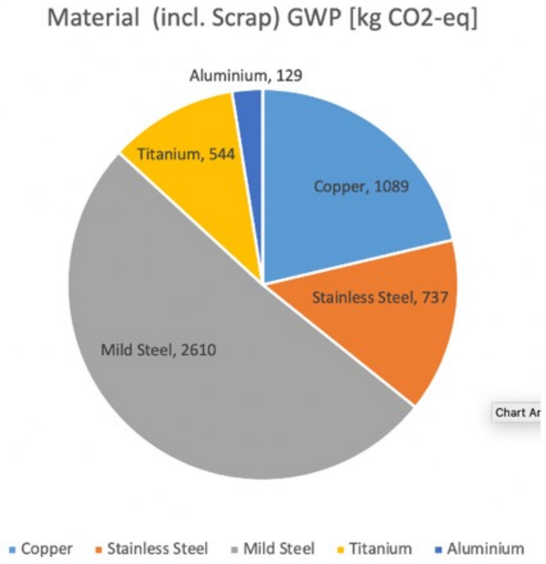
Good progress on the red points (was also part of our tradiational approach), initial progress/focus on the yellow/black ones

Looking at the impact of the accelerator components

- Study to estimate the Green House Gas emissions from raw materials in CLIC 2-beam module, including waveguides and supports
- ~2.5t CO2-eq / m:
  -> about half of CO2 for tunnel
- Half of CO2 impact is steel for supports
  -> optimization potential
- Services (power, cabling, cooling, ventilation) not included
- Situation in magnet-heavy sections (e.g. turn-arounds, bends, damping rings) may be different



CO2 impact of accelerator components is comparable to CO2 of main tunnel – to be studies but easily 5 kton/km



Note (yesterday's warning): What about material processed away, recycled or not ?

Sustainable Technologies

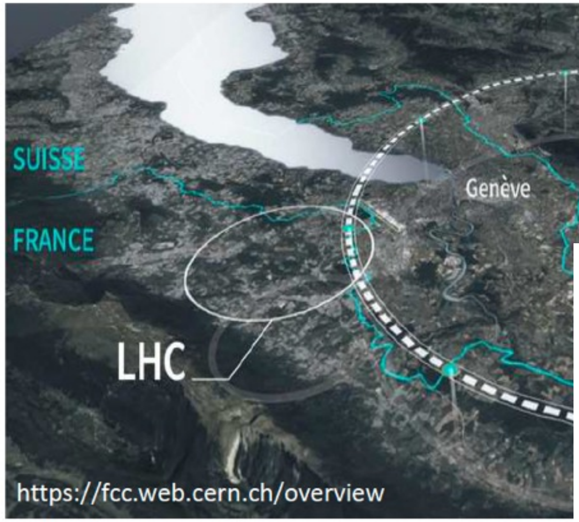
- High-Efficiency Klystrons @ CERN: I. Syratchev
- Sustainable Accelerator R&D in the UK: B. Sheperd

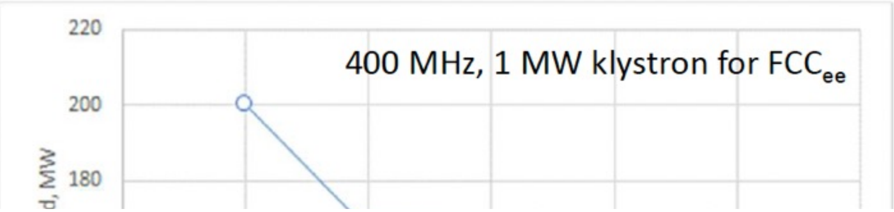
High Efficiency Klystrons

High Efficiency Klystrons Projects at CERN

I. Syratchev for CERN & ULAN HE klystron team

Grid power required for the large-scale HEP Accelerators.



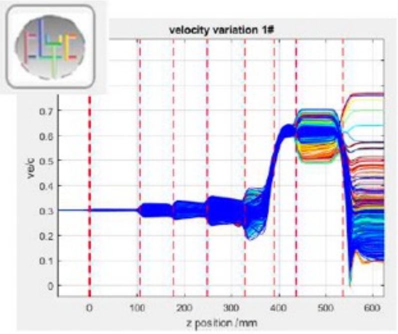


High Efficiency klystrons activity was initiated at CERN in 2014. In 2021 it was transformed into a CERN's **project**.

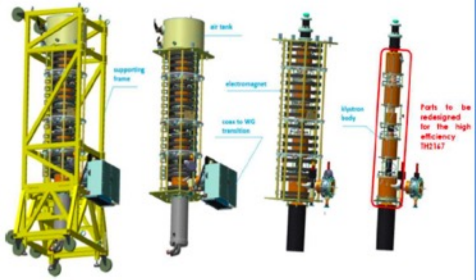
Objectives: Development, design, fabrication and testing of the new HE klystrons for application in various particle accelerators.

To operate FCC$_{ee}$, **100 MW** RF power is needed to ac and to compensate for th synchrotron radiation.

100 MW, CW ~ 100 000 Microwave ovens

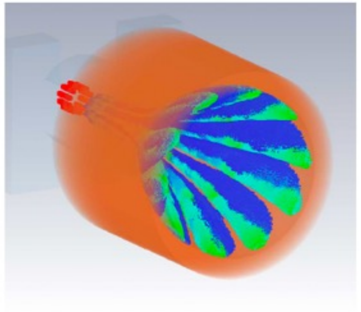


Task 1: Design & simulations
- Maintenance and distribution of the CERN made klystron code KlyC.
- High level expertise in using commercial tools like CST PIC, HFSS etc.



Task 2: HE LHC 400 MHz klystron
- Retrofit upgrade of Thales klystron (60% to 70%) in close collaboration with industry.
- **A base line option for HL-LHC.**

Selected topic

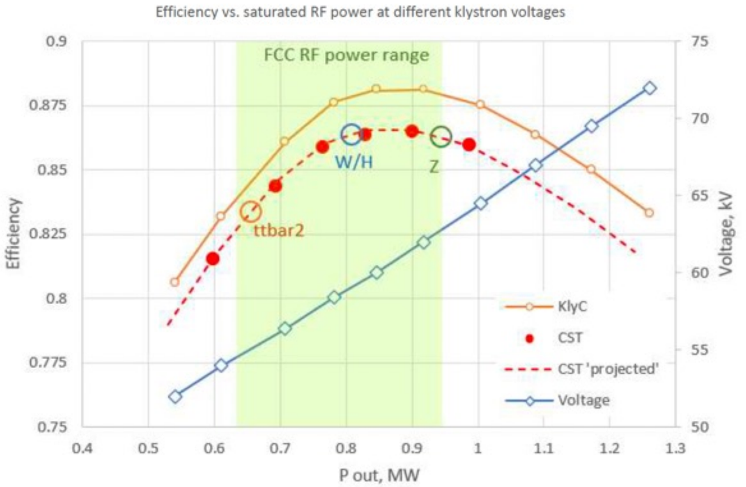


Task 3: Novel two-stage klystron technology with 80%+ RF production efficiency
- Design, fabrication and testing of the 400 MHz 1MW CW klystron for **FCC** in collaboration with industry.
- Promote this new technology towards CLIC, ILC and Muon_C.

First commercial X-band 10 MW HE (56%) klystron. CERN-Canon collaboration.

Task 4: High efficiency X-band pulsed klystrons in the power range 10-50MW
- Strong Collaboration with industry (Canon, CPI and Thales).
- Important for multiple projects (CompactLight, DEFT, EUPRAXIA etc.).
- Great show case for CERN's technology and **contribution to worldwide society.**

400 MHz HE Two-Stages MBK for FCC_{ee}. Performance summary.



Featured:

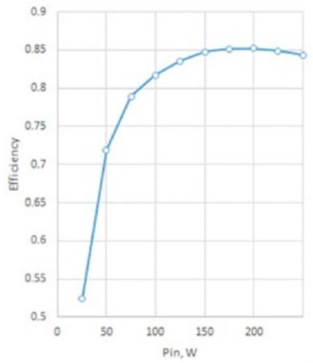
- **Very efficient**. 86% @ Z,W,H and 83% @ ttbar2.
- **Compact**. Total length <3m.
- **Low Voltage**. Up to 64kV @ 1 MW.
- **High RF power gain**. 43dB @ 1MW.
- **Broadband**. 3.5 MHz @ -1dB.
- **Robust**. Can handle mismatch up to -15dB.

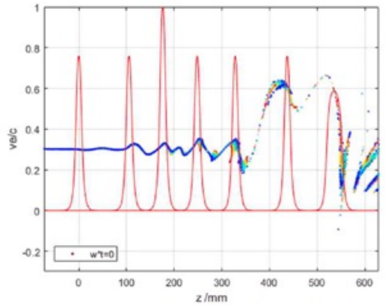
Project status @ CERN

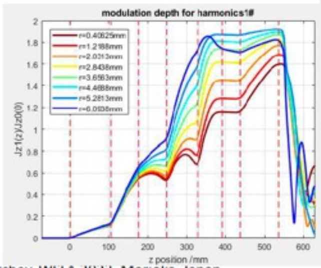
- ✓ RF circuit
- ✓ Collector
- ✓ Cathode
- ✓ Solenoid
- ✓ Special High Voltage isolated RF feedthrough (prototype).
- ❑ Integration
- ❑ Thermal/mechanical analysis

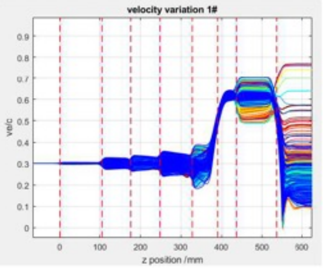
High Efficiency 10 MW, 1.3 GHz, pulsed ILC TS 15 beams MBK

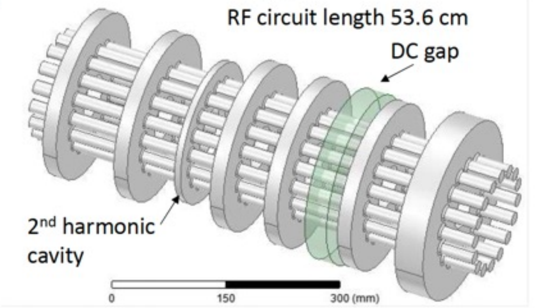
Parameter	TS MBK	E37536	Unit
Operating frequency	1300	1300	MHz
Voltage at the 1st stage	25	118.8	kV
Voltage at the 2nd stage	140		
Total beam current	88	129.5	A
Number of beamlets	16	6	
Number of cavities	7	6	
Perveance at the 1st stage	1.68	0.53	μA/V$^{3/2}$
Perveance at the 2nd stage	0.105		
Output RF power	10.5	10	MW
Saturated power gain	47.2	48.2	dB
Saturated efficiency	85	65	%
Length of RF circuit	536	---	mm



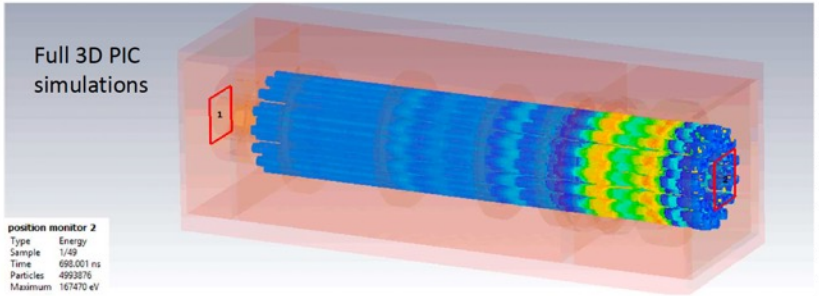








High Efficiency 24 MW, 1 GHz, pulsed CLIC TS 30 beams MBK.



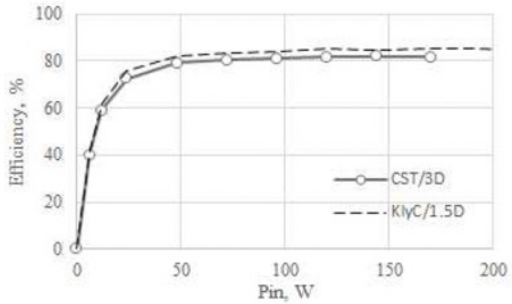
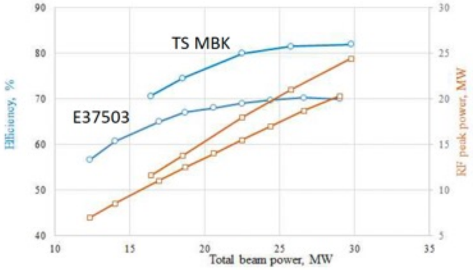


TABLE I. Design and simulated parameters (CST/3D) of the CLIC TS MBK and Canon MBK E3750 catalogue data

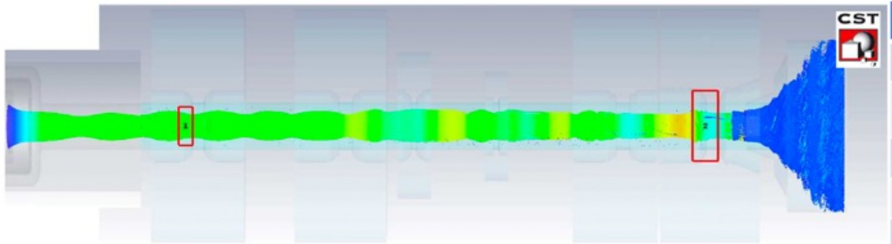
Parameter	TS MBK	E37503	Unit
Operating frequency	1000	1000	MHz
Voltage at the 1st stage	25	160	kV
Voltage at the 2nd stage	140		
Total beam current	212	180	A
Number of beamlets	30	6	
Number of cavities	6	6	
Perveance at the 1st stage	1.77	0.47	μA/V$^{3/2}$
Perveance at the 2nd stage	0.133		
Output RF power	24.1	20	MW
Saturated power gain	52	54	dB
Saturated efficiency	82	70	%
Length of RF circuit	900	1500	mm



Retro-fit High Efficiency (70%) 350kW, 0.4 GHz CSM LHC klystron upgrade for HL-LHC.

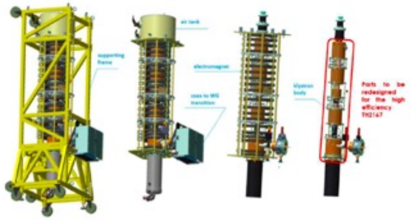
(in collaboration with Thales)

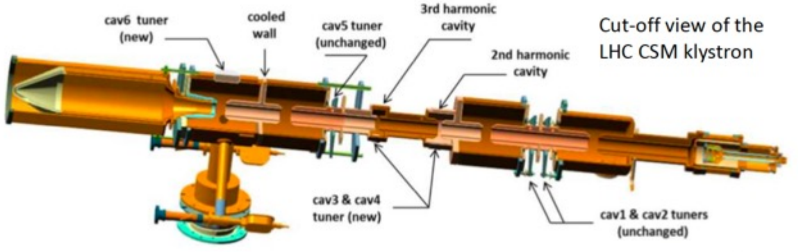
3D PIC full simulations



	LHC/CSM	LHC/Thales
Frequency, GHZ	0.4	0.4
Beam power, MW	0.5	0.5
Perveance,	0.72	0.72
RF power, MW	**0.35**	**0.30**
Efficiency, %	70	60

Re-used housing, electron gun and solenoid



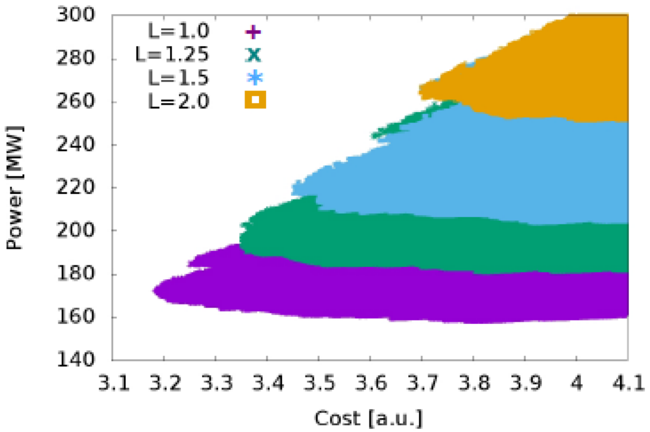


Cut-off view of the LHC CSM klystron

FAT is scheduled to May 2024.

THALES

Power optimization

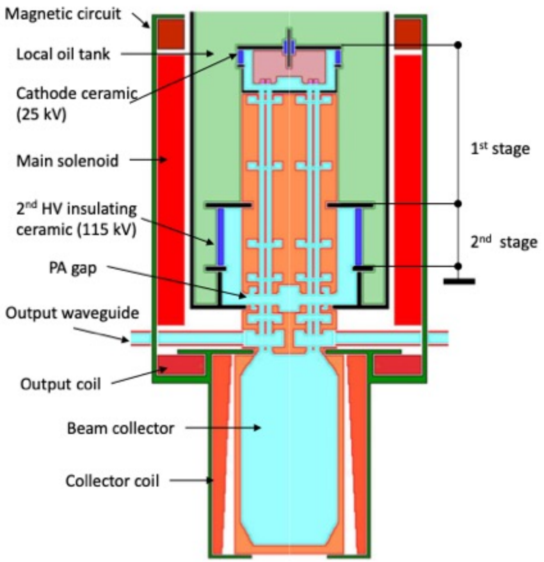


Parameter scans to find optimal parameter set, change acc. structure designs and gradients to find an optimum

The designs of CLIC, including key performance parameters as accelerating gradients, pulse lengths, bunch-charges and luminosities, have been optimised for cost and power

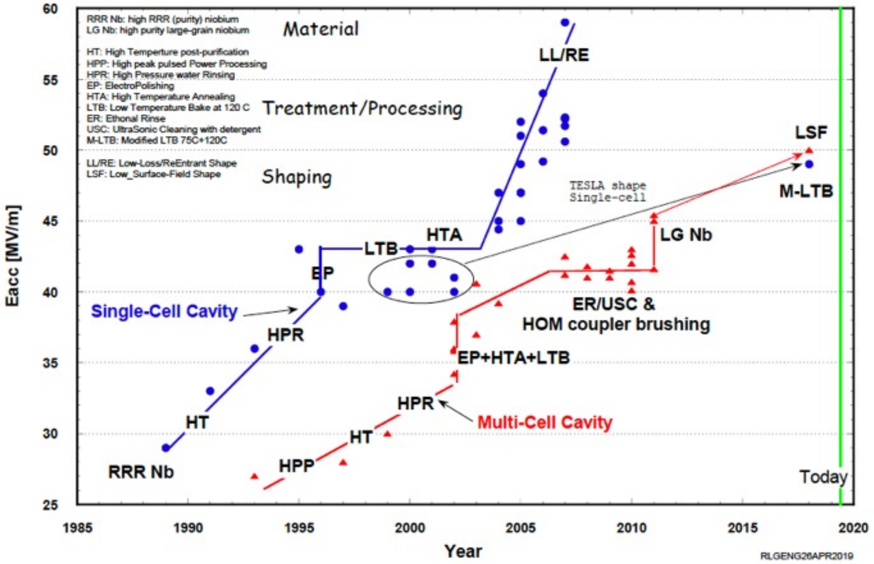
High Eff. Klystrons

L-band, X-band (for applications / collaborators and test-stands



SRF

Surface treatment, higher gradient, improve Q0, avoid electropolishing, remove bulk niobium



Permanent magnets

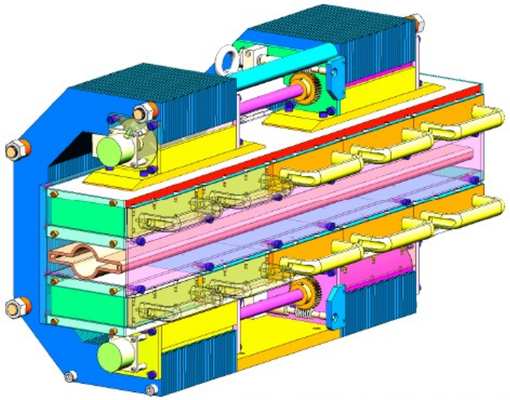
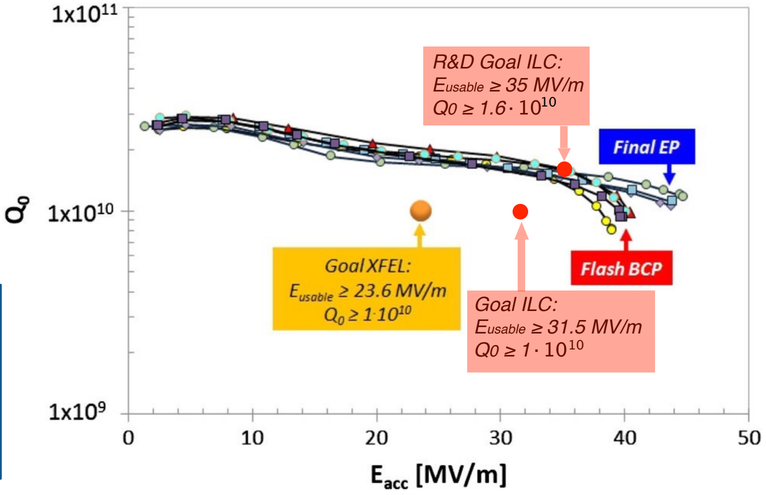


Figure 3: Overview of possible design of PM dipole for ILC damping ring.

1.5 TeV CLIC power
Magnets second largest

E.g. ZEPTO project
CERN / STFC



Heat recovery

where possible

Nanobeams

reducing beam sizes
Increasing lumi

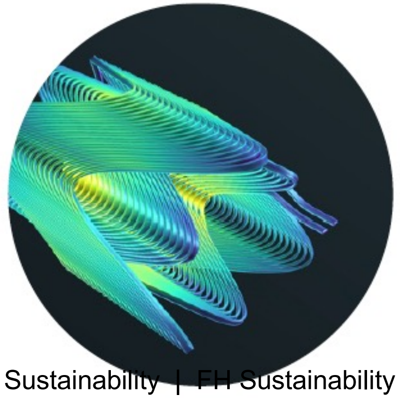
Design for sustainability

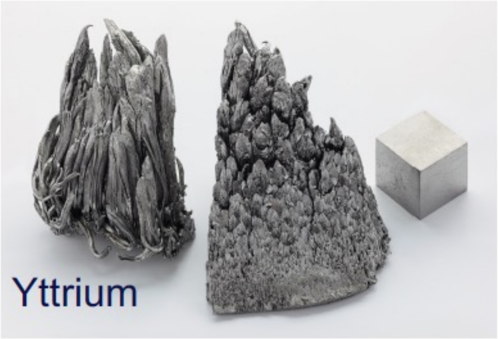
Opportunities for reduction of carbon impact

The project is still in the conceptual phase.
Looking for significant opportunities for whole-life carbon impact reduction.

- Life Cycle Assessment for civil engineering, including MATEX (excavated materials)
- Life Cycle Assessment for technical infrastructures
- Life Cycle Assessment for Accelerators

Example,
Life cycle Assessment for classical quadrupole magnets and superconducting HTS magnets (as proposed at FCC week 2023).
Rare-Earth Elements + rare-gases, is it more sustainable?





Copper, 4kgCO2/kg
Helium, 587kgCO2/l
RRE, 170kgCO2/kg

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Accelerator Science and Technology Centre, STFC Daresbury Laboratory

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Morioka, Japan

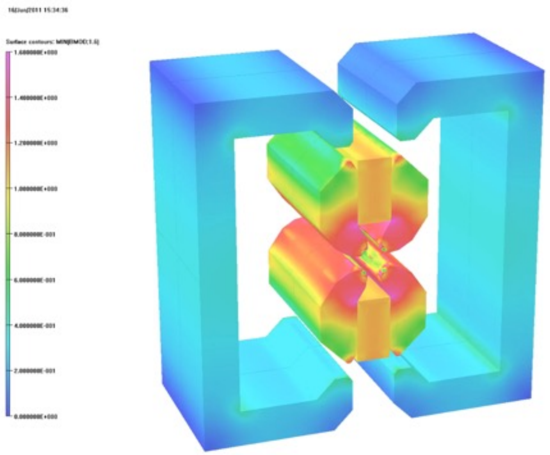
25-27 September 2023

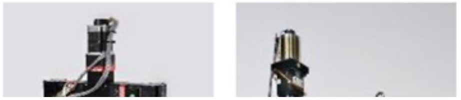
Shepherd *et al*, IPAC2014 TUPRO113

Green Projects: ZEPTO

- **Ze**ro-**P**ower **T**unable **O**ptics
- Tunable PM quadrupole and dipole magnets to replace electromagnets
  - Large **tuning range** using motors to move PMs
  - Same **physical footprint**
  - No **energy usage** (except a tiny amount when adjusting)
  - Less **infrastructure** required (no big current cables, power supplies, cooling)
- Two prototypes built at STFC Daresbury Laboratory
  - **27 mm** aperture
  - **230 mm** length
  - **15-60 T/m, 4-35 T/m** ranges
  - Fixed poles, movable PMs
  - Simple control system with one motor

Ben Shepherd • Sustainable Accelerators • EAJAD



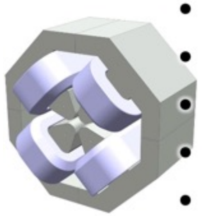


ZEPTO: comparing carbon footprints

- Electromagnetic quadrupole
- Main materials: steel, copper
- Manufacture impacts

CO_2 steel 201kg | copper 52kg

- Operation costs
  - 856W at 100% excitation
  - Another 250W for cooling
  - Assume 251 days / year operation
  - 6.7 MWh / year
  - EU avg intensity 225 gCO2e/kWh



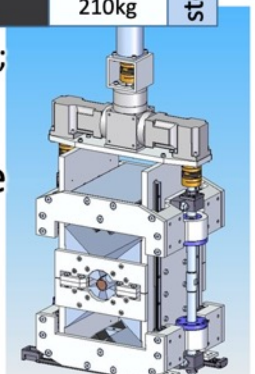
CO_2 electricity 1160 $kgCO_2e$ / year | cooling 340 $kgCO_2e$ / year

- Permanent magnet quadrupole
- Main materials: steel, NdFeB, aluminium
- Manufacture impacts ($kgCO_2e$)

CO_2 NdFeB 1097kg | aluminium 210kg | steel 91kg

(big uncertainties in NdFeB footprint; using recycled magnets could significantly reduce it)

- Operation costs: negligible
- "Carbon payback": 1 year



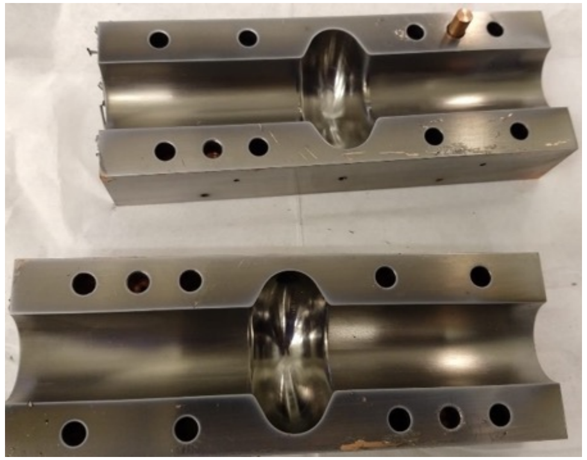
Thin Film Superconducting RF

- **Bulk niobium cavities** have been the choice for SRF for the last 50 years
- Use a considerable amount of natural material
- Performance limit of niobium has been reached
- Costly to produce
- Run at a temperature of 2 K
  - A considerable cryogenic demand and energy load

Benefits of thin films

- Use a copper supporting cavity
  - Better thermal properties, cheaper material and production
- Use different superconducting materials (e.g. Nb_3Sn, NbN and MgB_2)
  - Better performing materials than Nb that can't be formed into solid cavities
- Higher operation temperature of new alloys
- Reach higher accelerating gradients

6 GHz split cavity with Nb coating



- Easy to coat with either conventional planar magnetron or in tubular geometry used for RF cavities
- Easy to inspect
- Three 6 GHz cavities have been manufactured, mechanically polished and tested at RT and T = 4.2 K
- 1st cavity Nb coated and tested at 4.2-9.5 K

Horizon-Europe & National Progammes

- **EAJADE: M. Titov**
- **iSAS: J. d'Hondt**

Note: At ESS (presentation by A. Sunesson) also programmes iFAST (addition of solar panels to power modulators) and FlexRICAN (studying flexibility in power supply) discussed

- **Spanish Science Industry: E. Fernandez**
- **EU-Japan Regional & Cluster Cooperation Heldesk**

Workshop in autumn / winter 2024:
EAJADE + iFAST at DESY?

EU collaboration projects

- ESS participates in the Horizon programs iFAST and FlexRICAN
- The focus is on innovation and sustainability in accelerators – this mirrors ESS strategy of own power generation and energy storage
- In iFAST the addition of solar panels and direct powering of modulators via DC from solar panels has been studied, as well as introduction of solar panels
- In FlexRICAN flexibility in supply is the focus area, and subprojects cover areas like renewable power generation (solar panels, bio-fuel turbines,…), energy storage, optimisation of heat recovery, all to optimise power use for sustainability

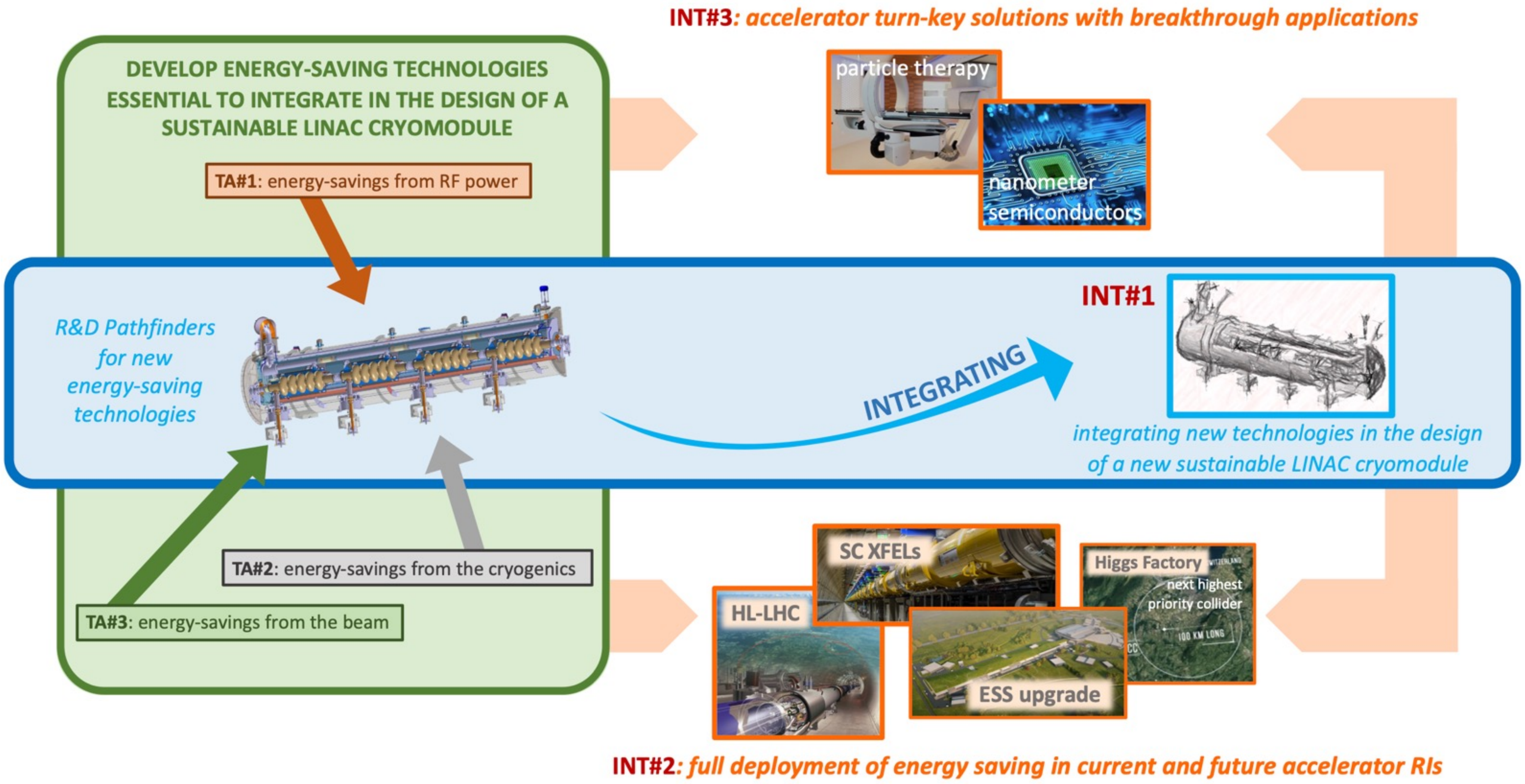
iFAST, Horizon 2020 proposal No 101004730 (2020)
FlexRICAN, Horizon 2023 proposal No 101131516 (2023)

European Horizon-Europe Programmes: iSAS

Jorgen d'Hondt

European Horizon-Europe Programmes

Jorgen d'Hondt



European Horizon-Europe Programmes

Jorgen d'Hondt

iSAS Objectives – *Technology Areas*

- **TA#1: energy-savings from RF power** – *While great strides are being made in the energy efficiency of various RF power generators, the objective of iSAS is to ensure additional impactful energy savings through coherent integration of the RF power source with smart digital control systems and with novel tuners that compensate rapidly cavity detuning from mechanical vibrations, resulting in a further reduction of power demands by up to a factor of 3.*

- **TA#2: energy-savings from cryogenics** – *While major progress is being made in reusing the heat produced in cryogenics systems, the objective of iSAS is to develop superconducting cavities that operate with high performance at 4.2 K (i.e., up to 4.5 K depending on the cryogenic overpressure) instead of 2 K, thereby reducing the grid-power to operate the cryogenic system by a factor of 3 and requiring less capital investment to build the cryogenic plant.*

- **TA#3: energy-savings from the beam** – *Significant progress has been achieved in maintaining the brightness of recirculating beams to provide high-intensity collisions to experiments, but most of the particles lose their power through radiation or in the beam dump system. The objective of iSAS is to develop dedicated power couplers for damping the so-called Higher-Order Modes (HOMs) excited by the passage of high-current beams in the superconducting cavities, enabling efficient recovery of the energy of recirculating beams back into the cavities before it is dumped, resulting in energy reduction for operating, high-energy, high-intensity accelerators by a factor ten.*

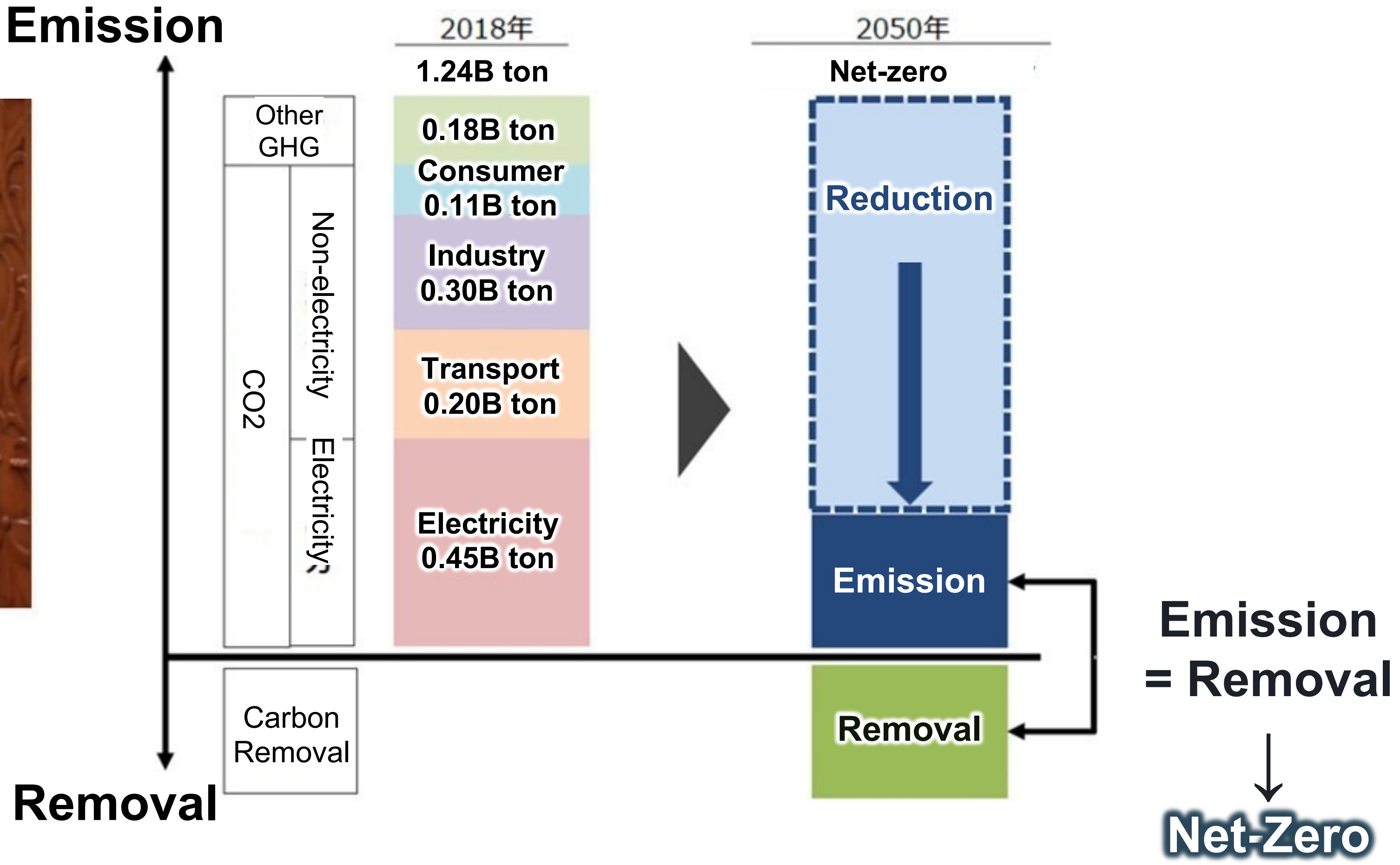
Green ILC & Japanese Industry

- Scenarios toward 2050 Carbon Neutrality in Japan and ILC: M. Yoshioka
- Efforts of Taiheiyo Cement towards Carbon Neutrality: Y. Ohgi
- The Future of Construction: Carbon-Negative Concrete for a Greener Tomorrow: K. Avadh
- Large-Scale Wooden Construction: Y. Shibuya
- Sustainable Forestry in the Tohoku region: K. Shibata
- Quantitative Evaluation of Forest CO_2 Absorption in Ichinoseki City: H. Kikuchi
- Creation of a sustainable society model utilizing IoT technology and local resources: Y. Komiya
- Commercialization of Low-Grade Waste Heat Recovery: Y. Kouno

Toward Carbon-neutral Society

- In October of 2020, the Japanese Government announced that it would realize Carbon-neutral society by 2050.

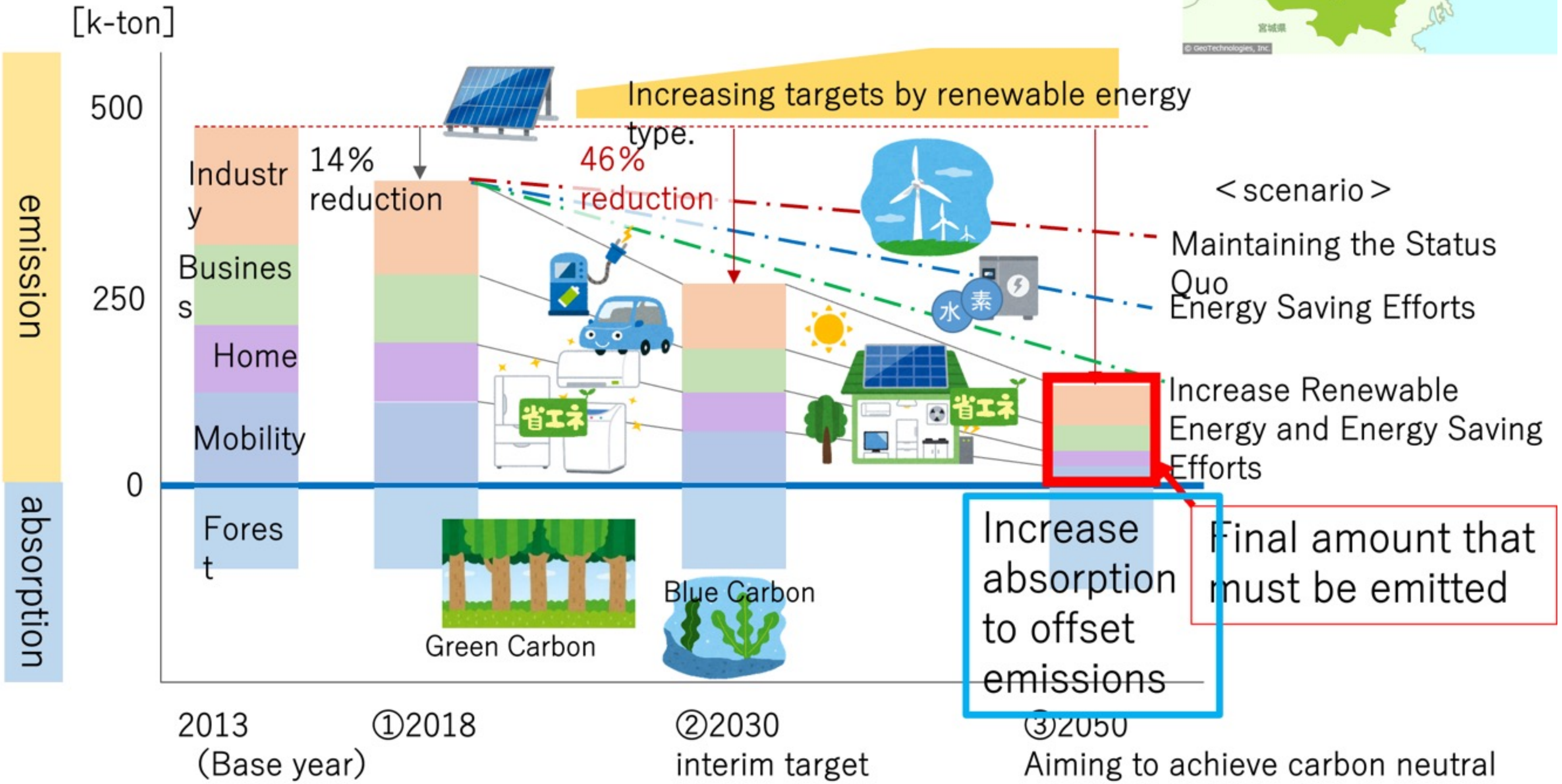
所信表明演説をする菅義偉首相（写真:つのだよしお/アフロ）

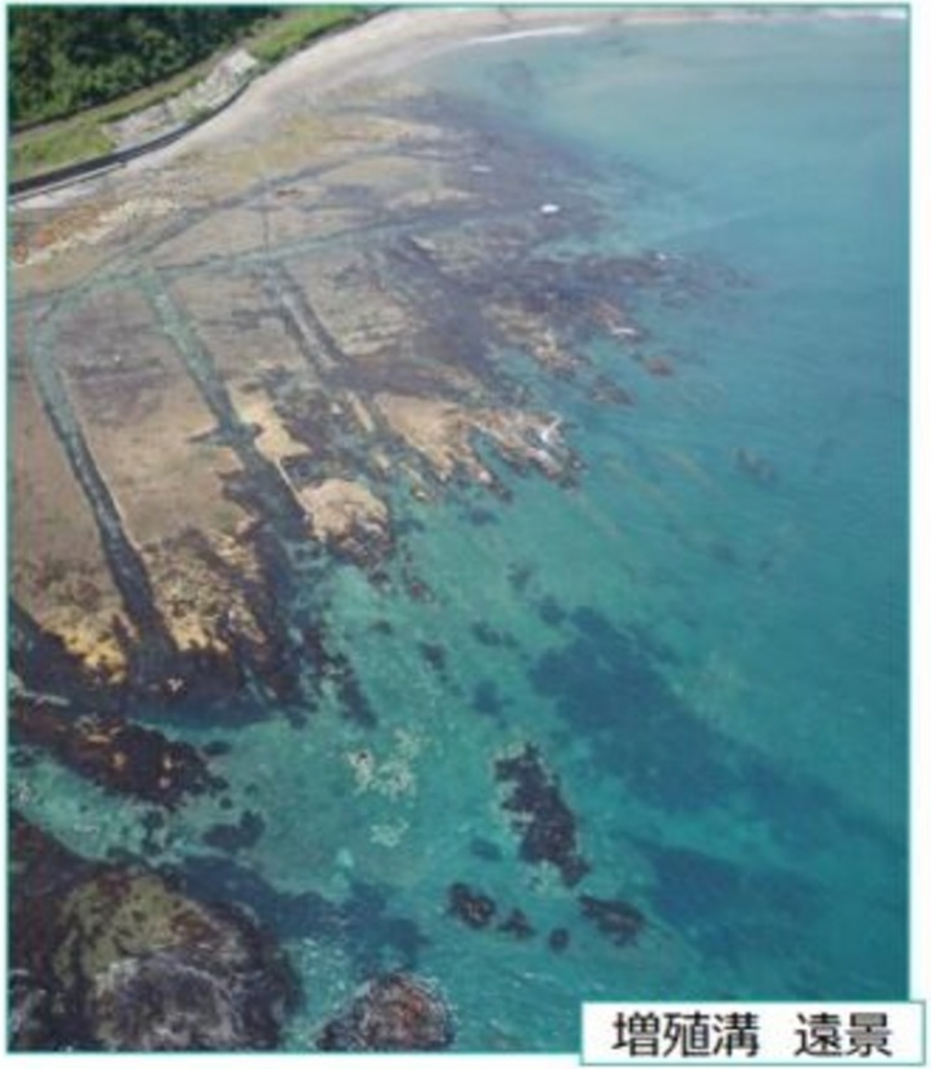


(Source: Agency for Natural Resources and Energy, Ministry of Economy, Trade and Industry (METI))

A typical example of policy development in line with government policy is the goal of Miyako City (51,000 people, 1,259 km², Largest in area in Iwate), located on the coast of Iwate Prefecture.

- Goal: Achieve carbon neutrality by 2050 !
- To achieve this, emissions will be gradually reduced and increase green carbon (Forest) and blue carbon (Coastal Seaweed).

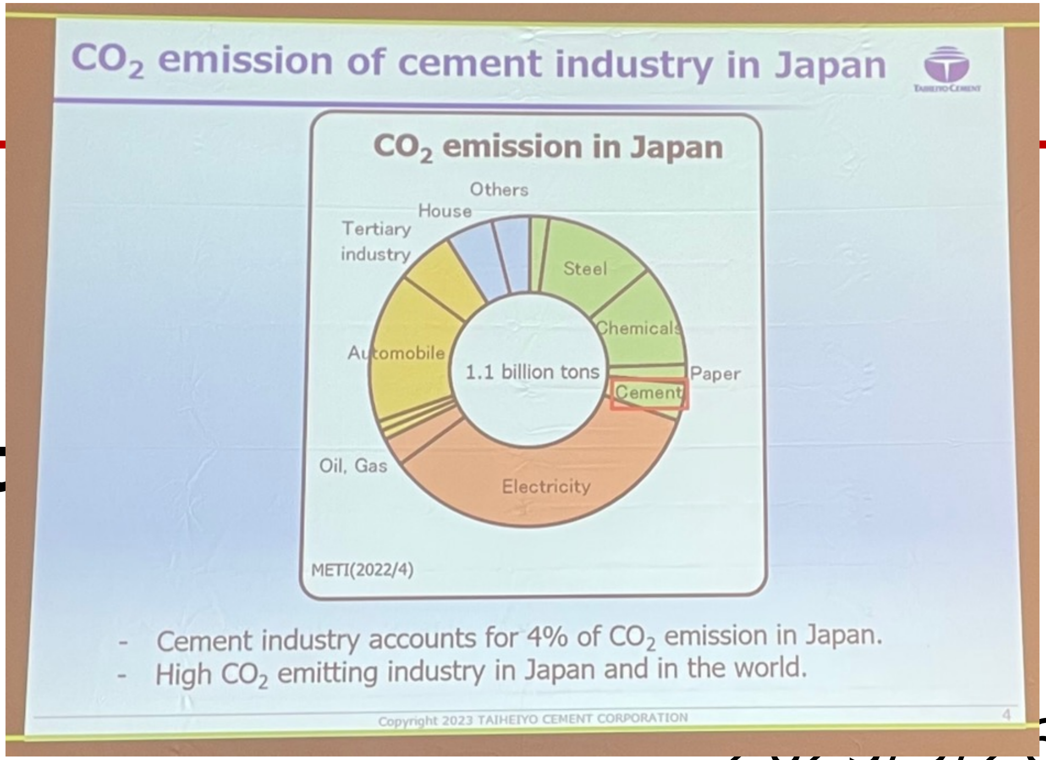




- Artificial tidal pools (4 m wide, 1 m deep trenches, 17.5 km long) are created to create a flow of fresh seawater due to the difference in tidal levels, encouraging the growth of wakame seaweed and kelp.
- Seaweed is eventually fixed to the seafloor as flow algae.3106.5 tons (CO2 equivalent) of J Blue Credits are accredited over 5 years.
- Sea urchins (very tasty) are abundant as a by-product.
- J Blue Credits are blue carbon credits issued and sold by JBE (Japanese Federation of Economic and Technical Research Associations).
- JBE is composed of the National Maritime, Port and Aviation Research Institute, the Sasakawa Peace Foundation, and university professors.

EAJADE Workshop on Sustainability in Future Accelerators (WSFA2023)

The Future of Construction: Carbon-Negative Concrete for a Greener Tomorrow



Kajima Corporation
Dr. Kumar Avadh (PhD. Universit
Research Engineer

KAJIMA CORPORATION

2023/9/26

Concrete: CO2 Emissions

Naturally Sourced

	Cement	Gravel	Sand	Water
				
CO_2 Emissions	288 kg/m^3	0 kg/m^3	0 kg/m^3	0 kg/m^3

Cement Production:

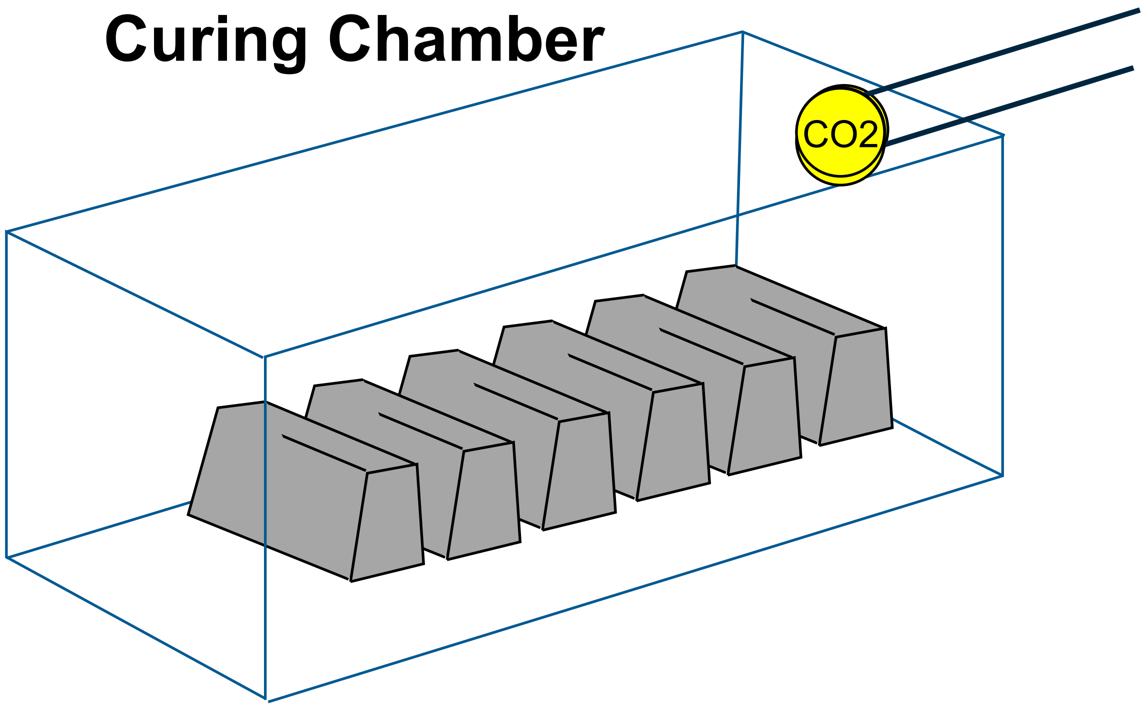
Limestone → **Burning** → **Cement**

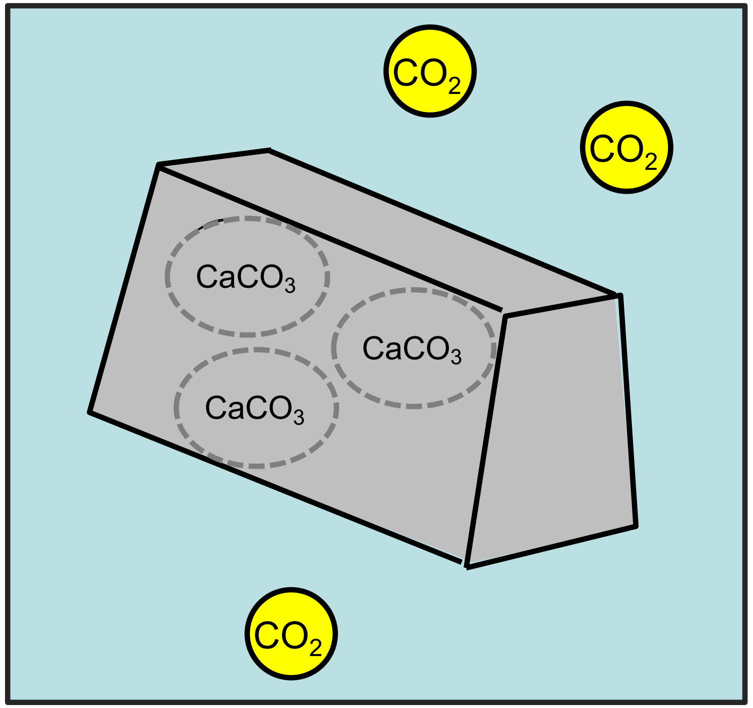
$CaCO_3$ — 1400°C — $CaO + CO_2$

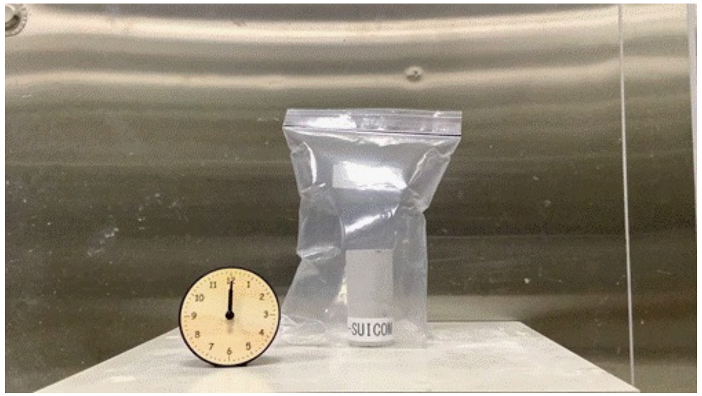
$\boxed{CO_2 = 288 \text{ kg/m}^3}$

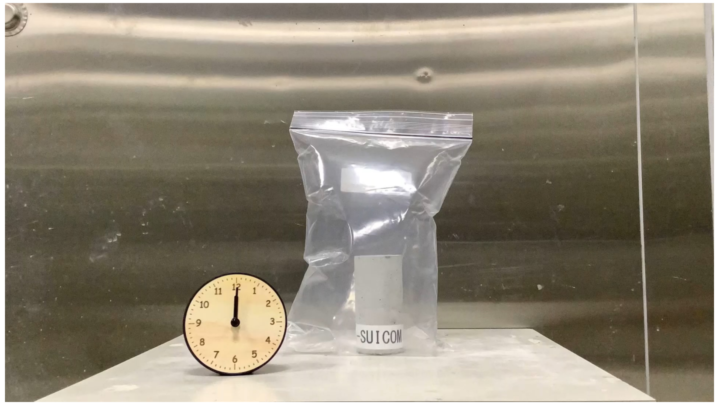
CO_2 per 1m^3 of concrete

Carbonation Curing









Absorbing CO_2 as it hardens

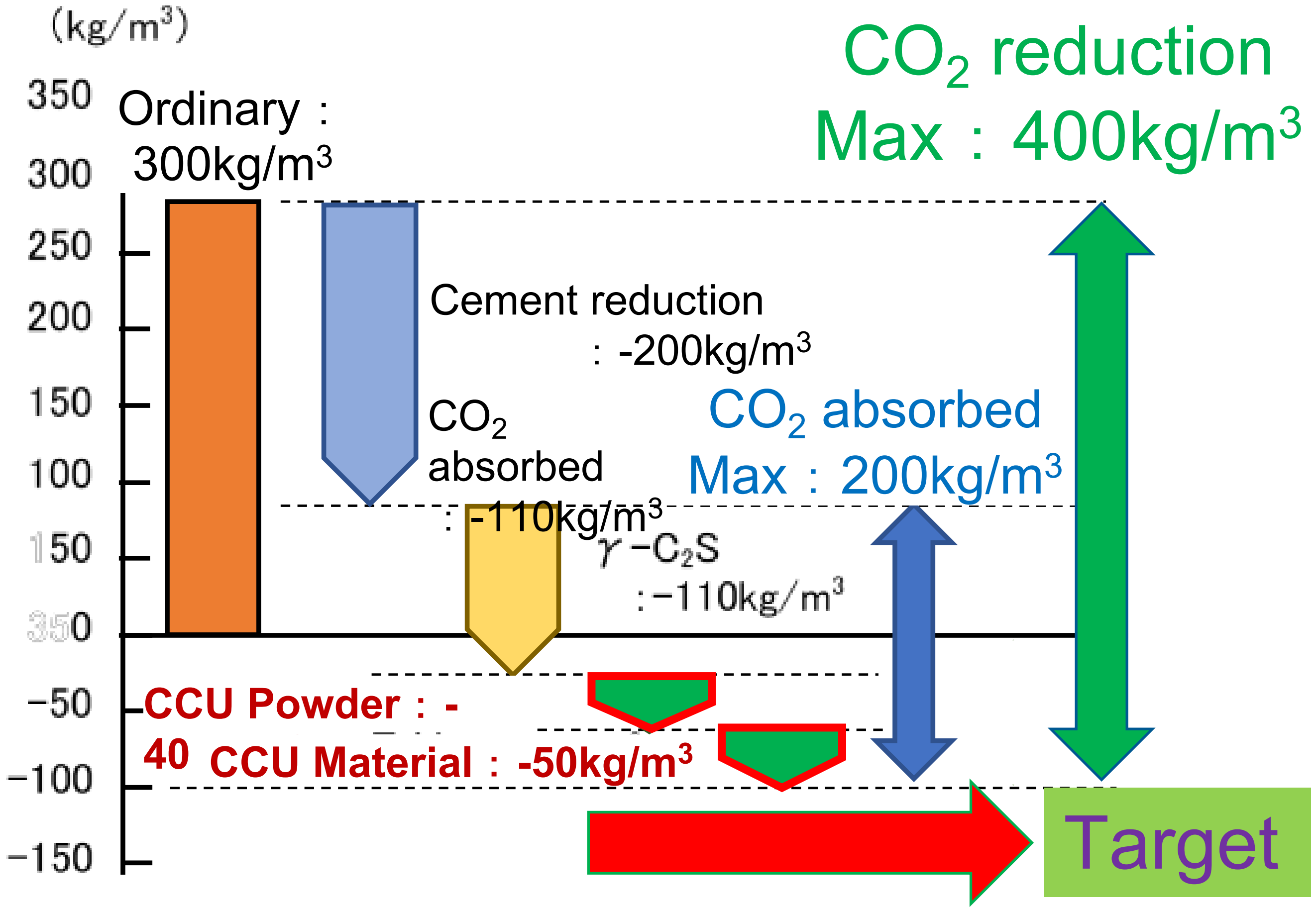
<R&D in progress> Material development

Maximizing absorption and reduction of CO_2 by using CCU materials

CO2-SUICOM® + **CCU Materials＊**

＊Materials reacted with CO_2 in advance and put into concrete

CCU: Carbon Capture and Utilization



Target of CO_2 reduction and absorption

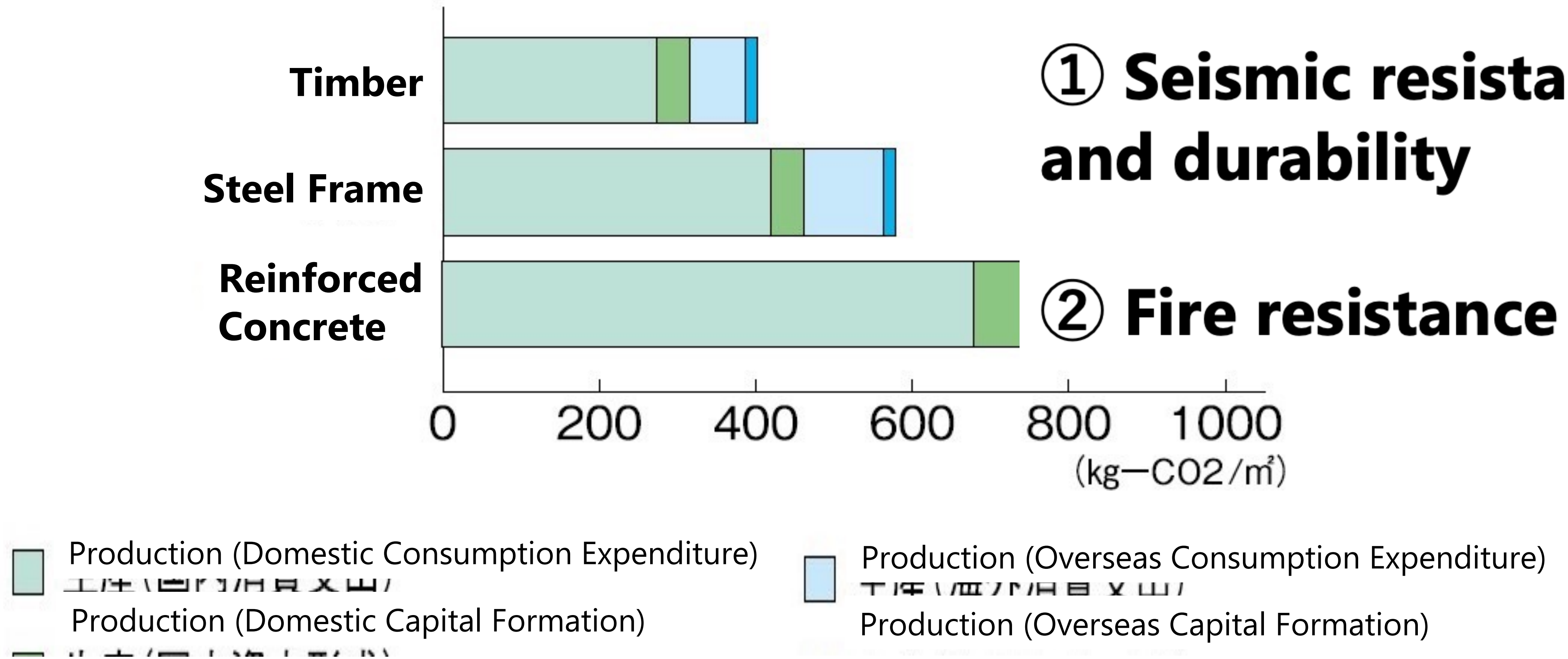
Wooden Large-scale construction for a Greener Future: Shelter Inc.'s Initiative

Shelter®

09/26/2023
Yuka Shibuya

Comparison of CO_2 Emissions during Construction between Timber and Other Structures

Comparison of Estimated CO_2 Emissions per Floor Area in Office Buildings by Structural Type:



① Seismic resistance and durability

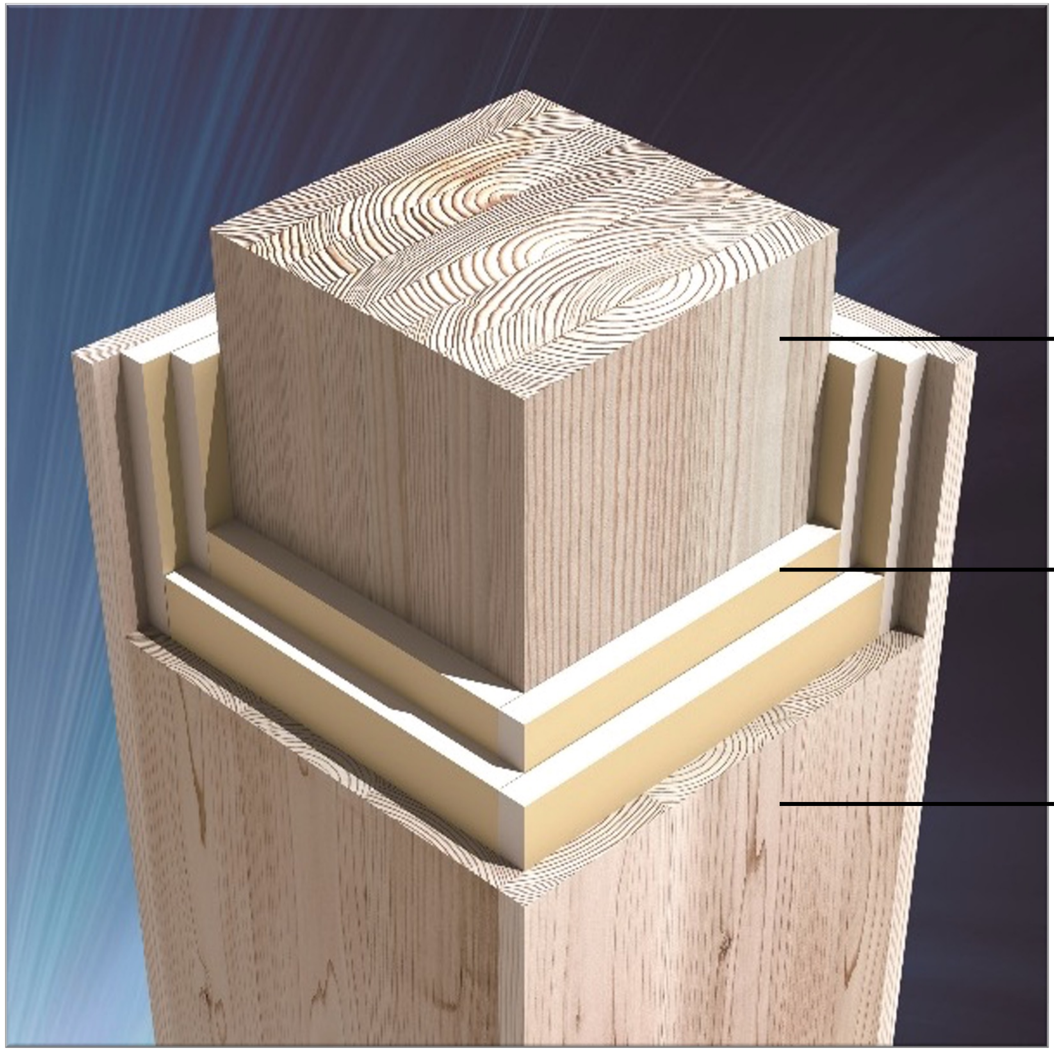
② Fire resistance

Source: Japan Housing and Wood Technology Center, a public interest foundation, "Examples of Buildings with Interior Wood Usage and Their Effects," Published in March 2022.

Seismic Resistance of the Metal Hardware Joining Method

- During the Great Hanshin Earthquake in 1995, 73 wooden houses constructed using the metal hardware joining method in the disaster-affected areas remained standing without collapsing. (The photo depicts a three-story house in the heavily affected Nada district of Kobe City.)

Wooden Fireproof Components “COOL WOOD”



- Load-bearing component (Wood)
- Fire-stop layer (Gypsum board)
- Surface material (Wood)

1-hour Fireproof COOL WOOD (Column)

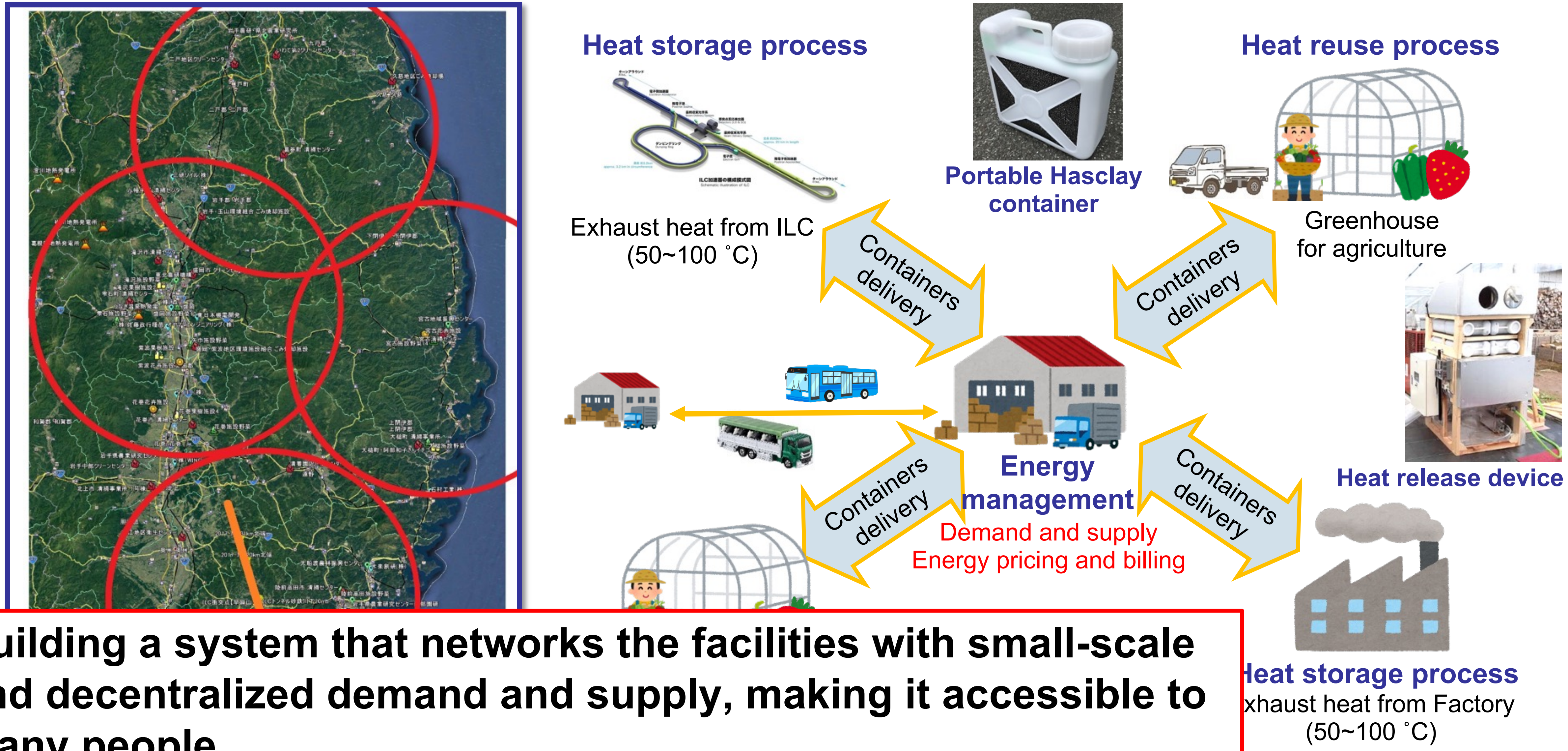
WSFA2023
Sustainability Session Ⅱ ： Green ILC & Japanese Industry

Commercialization of Low-Grade waste heat recovery

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

Yuichi Kouno

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.

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

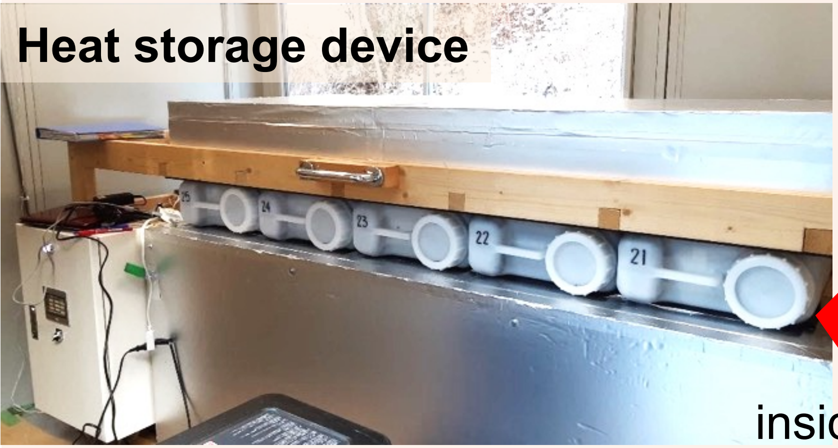
Adsorbent	Heat storage ability	Heat storage capacity(kJ/L)
HASclay	**40 ˚C or more**	**567**
Modified zeolite	80 ˚C or more	439

Demonstration tests to achieve commercialization

Thermal storage process: Hot spring

Utilizing the heat of hot spring water to store (dry) HASClay

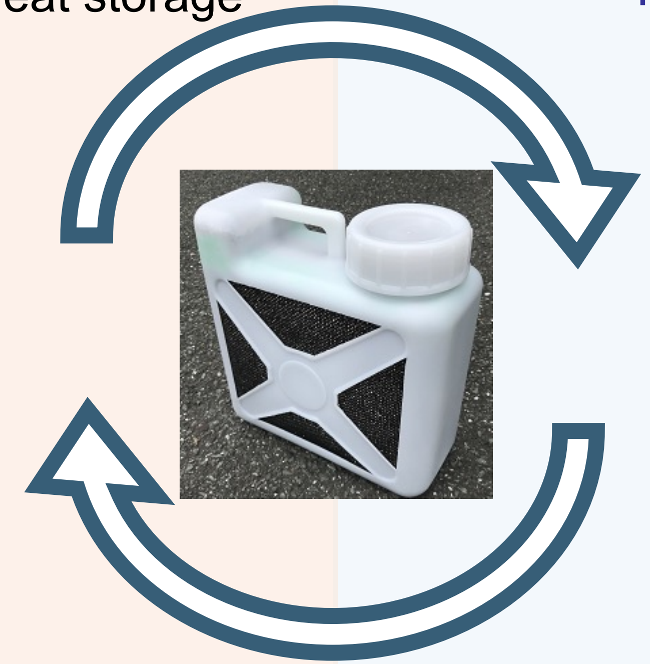
Heat storage device



inside

Panoramic view of the heat storage facility

Delivery after heat storage



Recovery and Recharging after Heat Dissipation

Heat dissipation process: Greenhouse

Utilizing HASClay for heat dissipation and using it for nighttime heating

Heat dissipation device

Strawberry cultivation greenhouse

Outlook?
Conclusions?

Thank you

Contact

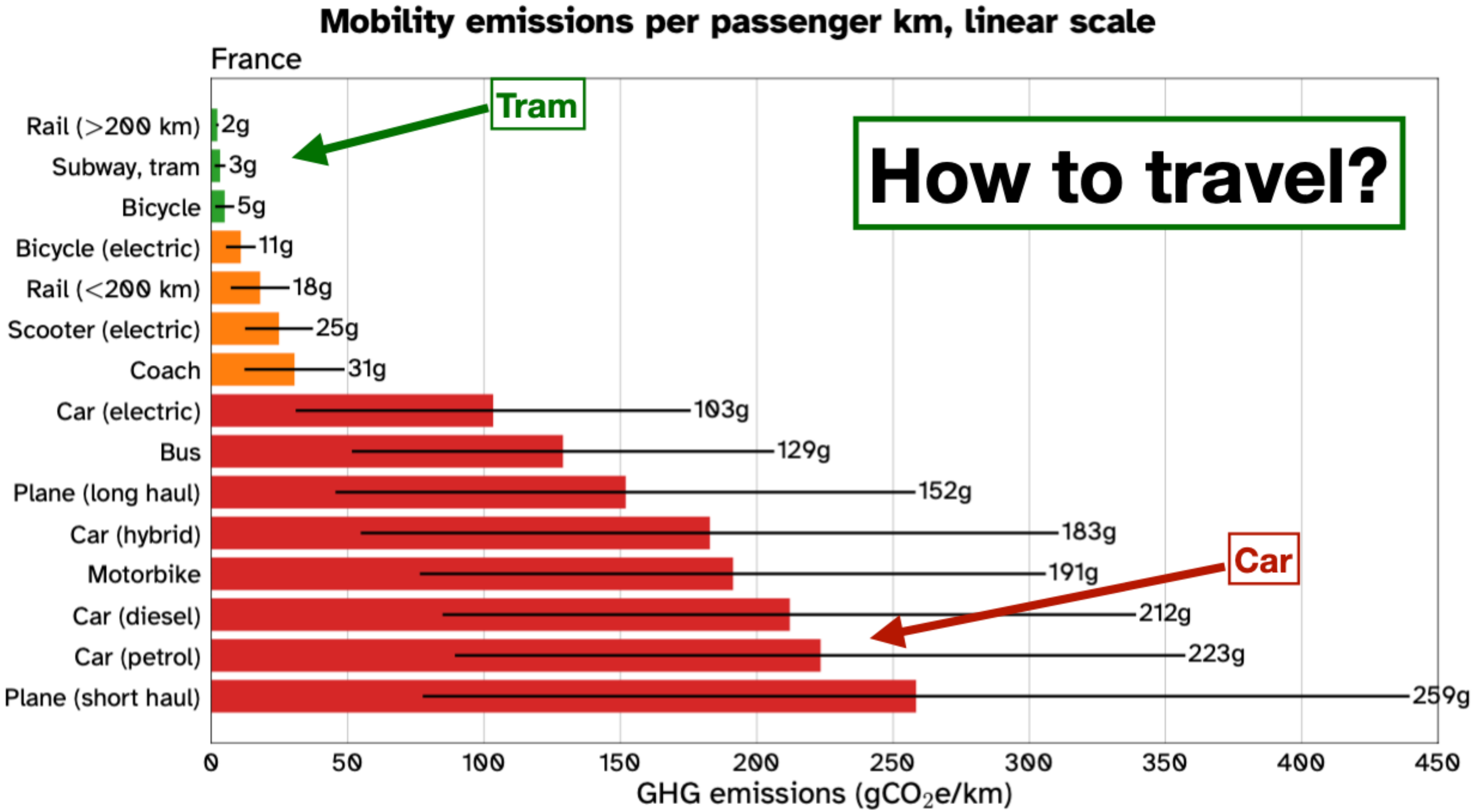
Deutsches Elektronen-
Synchrotron DESY

www.desy.de

Thomas Schörner
DESY FH
E-Mail: *thomas.schoerner@desy.de*
Phone: +49 40 8998 3429

Backup

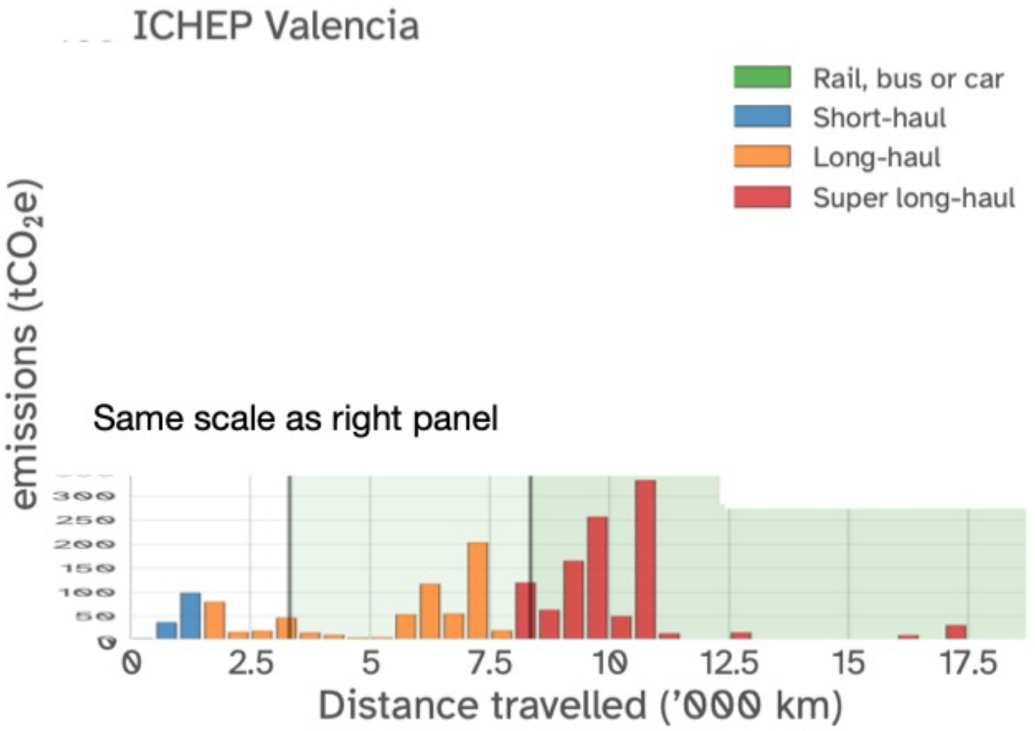
Individual Measures

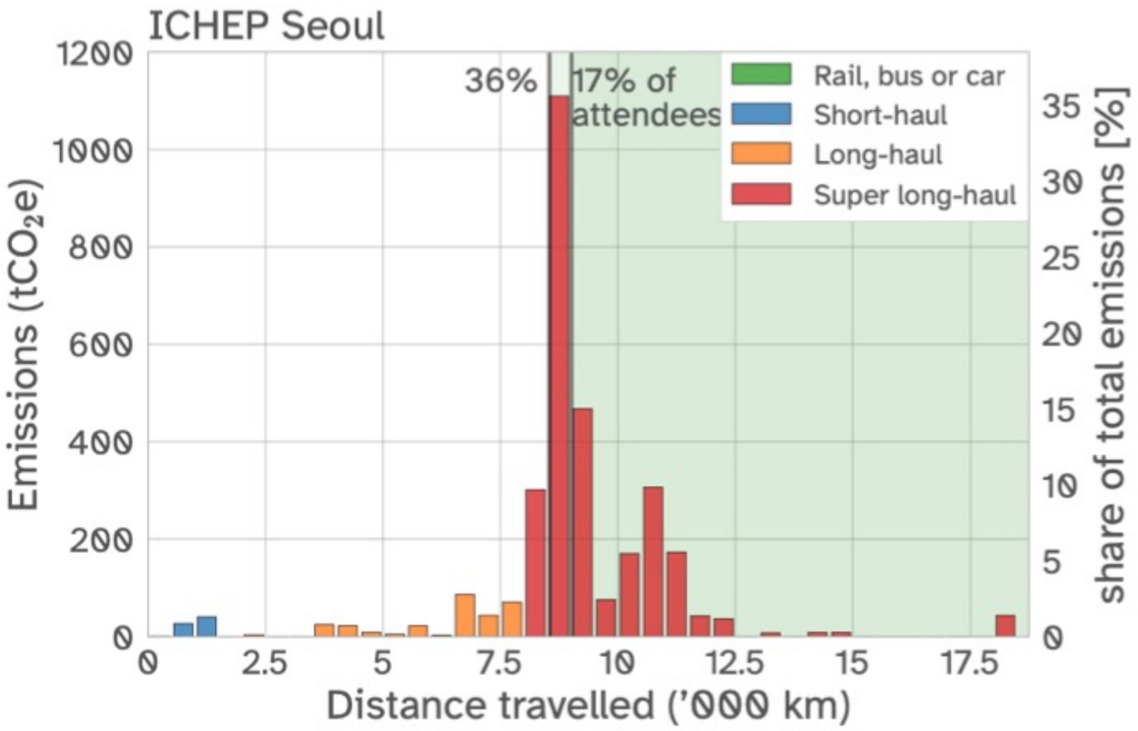


Source: Labos1.5 database. Estimates include production emissions, and may vary slightly based on occupancy of public transport, and between countries.

Individual Measures

From HECAP+ paper / M. Düren





Where to make conferences?

Individual Measures

From HECAP+ Paper / M. Düren

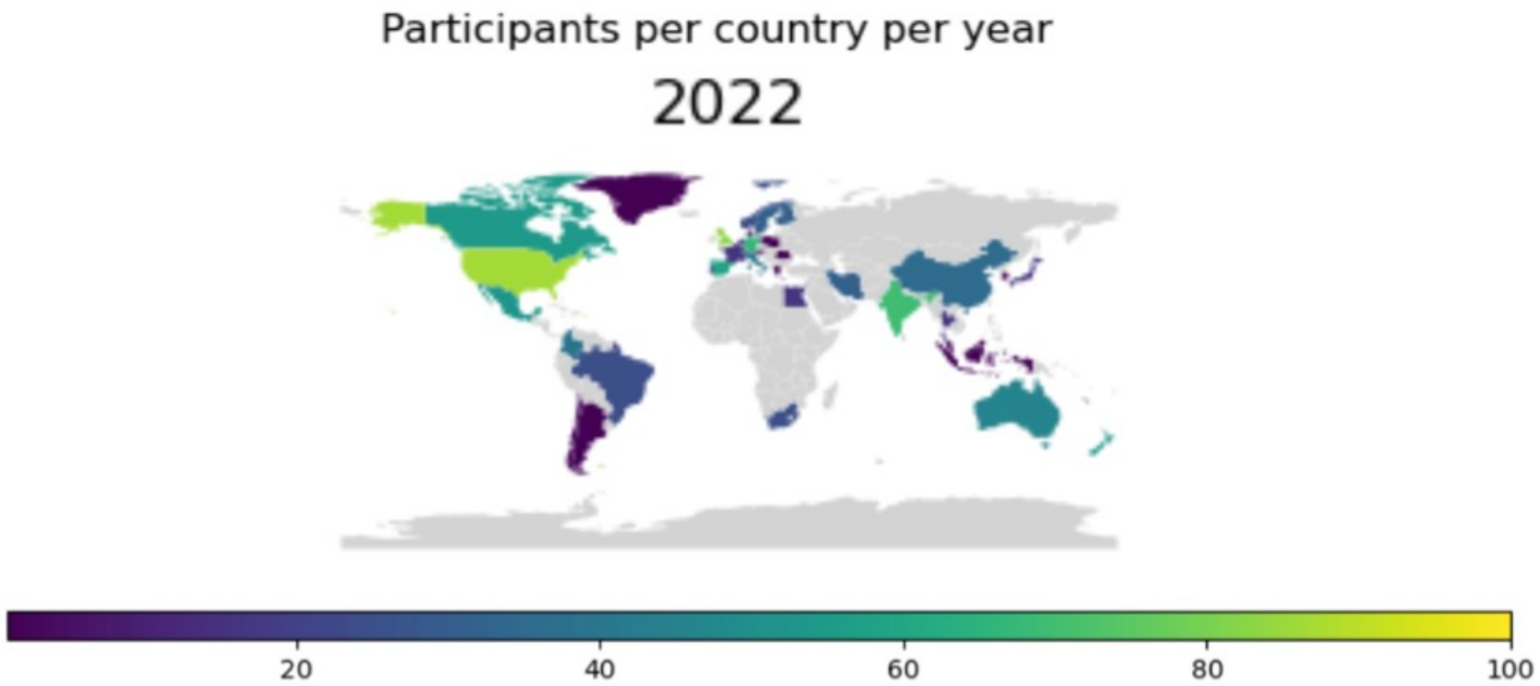


Figure 5.4: Geographical distribution of Cosmology from Home participants for each of the installments by year.

„Cosmology from Home“:
an online conference that includes all researchers