The Climate Emergency: can Particle Physics ever be sustainable?

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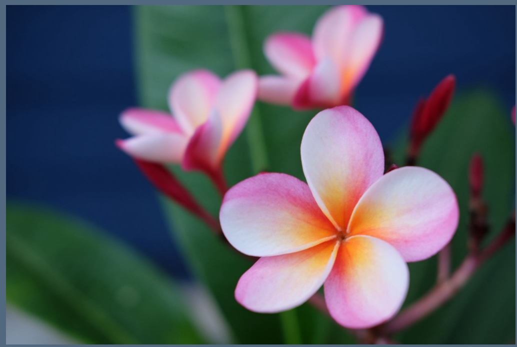
28th February 2024 (425.2 CO_2 ppm – 4.9 ppm 1 year change!!)

Outline

- The climate emergency
- CO_2e emissions & solutions from:
  - Accelerators (construction/operation)
  - Detectors
  - Computing
  - Rest (travel, conferences, buildings, etc.)



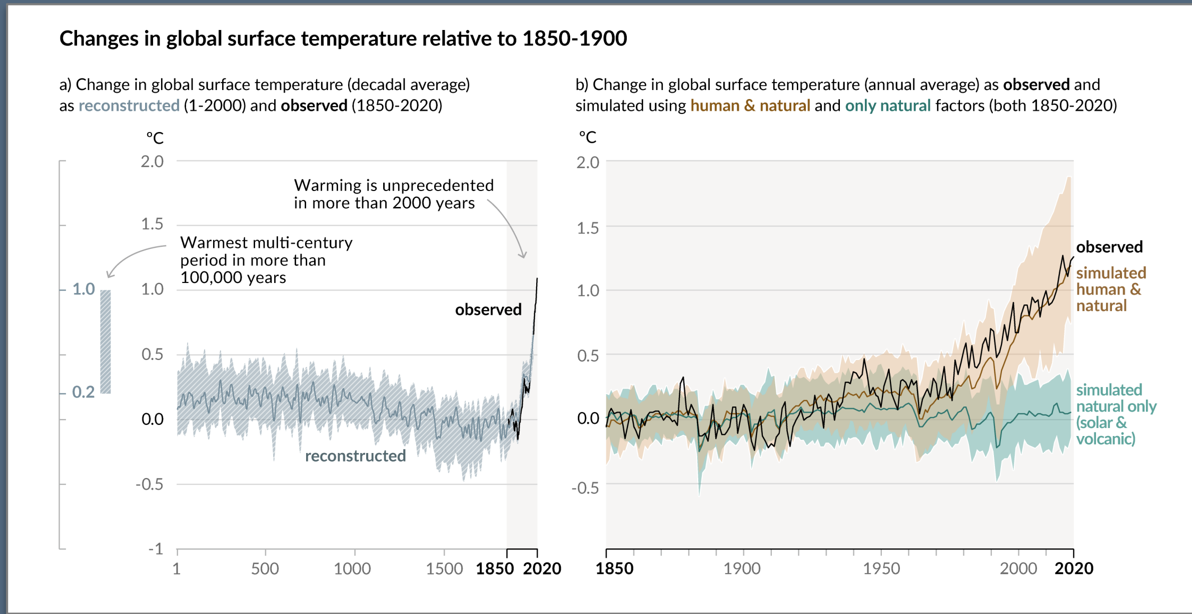
- Possible recommendations
- Disclaimer:
  - I'm not a climate/energy scientist!
  - My research is on ATLAS, so energy frontier bias!

Climate Change: an emergency

IPCC AR6

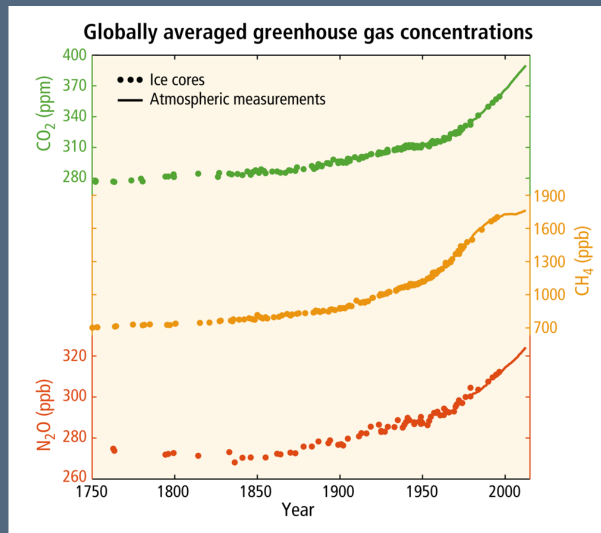
> "Recent changes in the climate are widespread, rapid, and intensifying, and unprecedented in thousands of years.

ipcc INTERGOVERNMENTAL PANEL ON climate change WMO UNEP



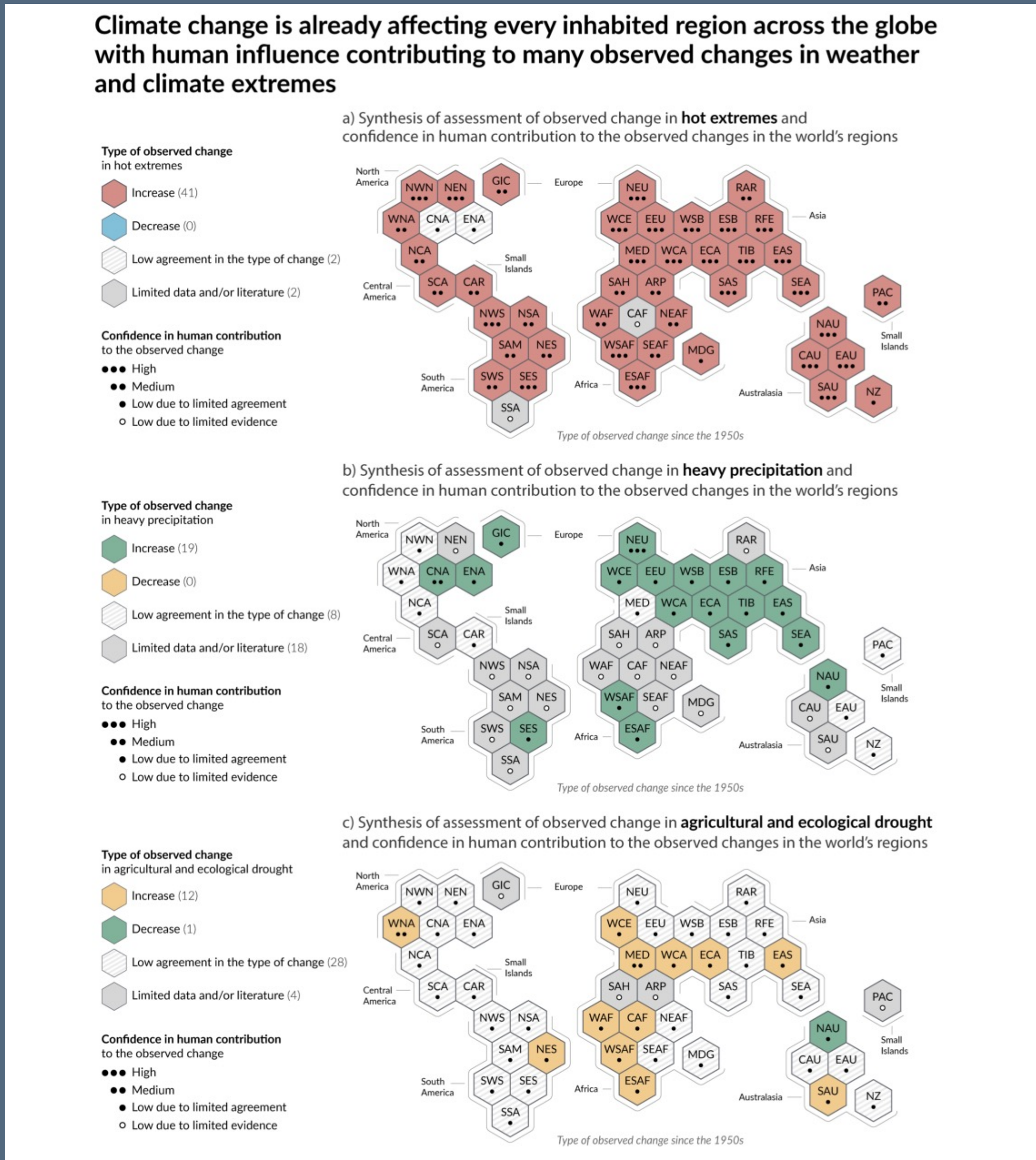
> "Unless there are immediate, rapid, and large-scale reductions in greenhouse gas emissions, limiting warming to 1.5°C will be beyond reach.

ipcc INTERGOVERNMENTAL PANEL ON climate change WMO UNEP



IPCC AR5

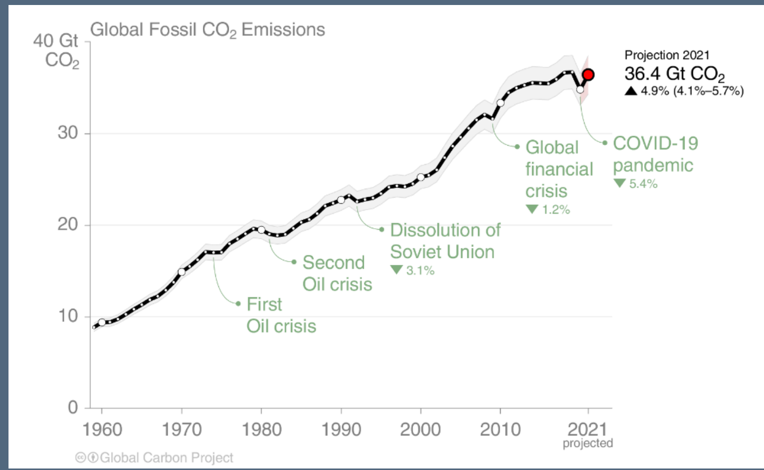
Climate Change: an emergency

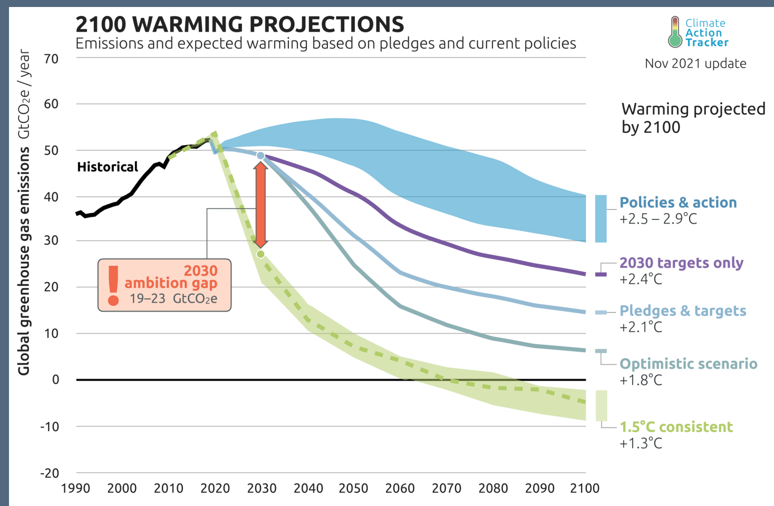


IPCC AR6

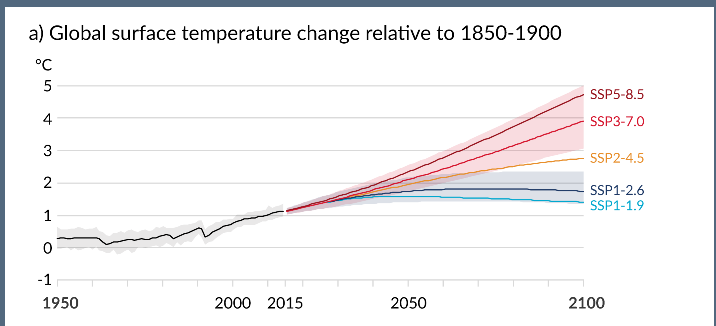
Climate Change: an emergency

- UK parliament first to approve a motion to declare an "environment and climate emergency" on 1st May 2019
- Of the top 10 GHG emitters, only Japan, Canada and the EU have legally binding target of "net zero emissions by 2050 (2045)"
  - The pandemic was a blip (lessons)
- IPCC 2015 Paris agreement: aim to stay "below 2°C" so focus on 1.5 °C
  - NDC: Countries make pledges for how to achieve this (and then increase those pledges over time)
  - Climate Action Tracker: "With all target pledges, including those made in Glasgow, global greenhouse gas emissions in 2030 will still be around twice as high as necessary for the 1.5 °C limit.





IPCC AR6



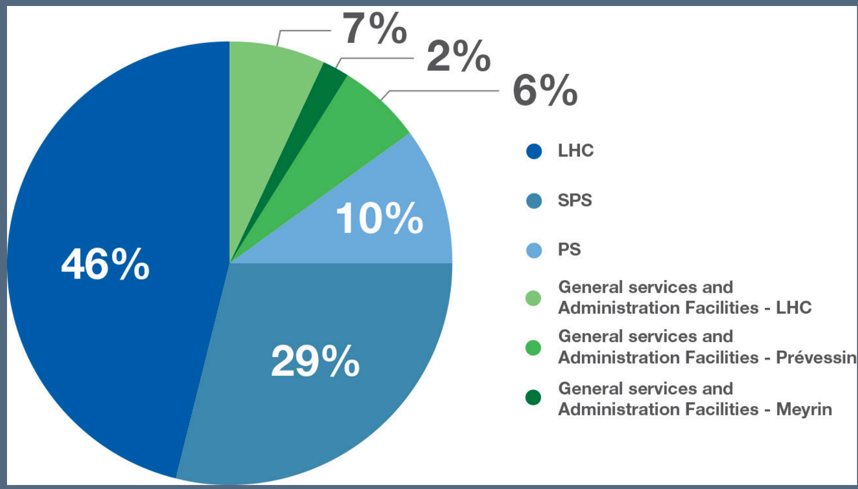
Ice ages: ~ -5°C

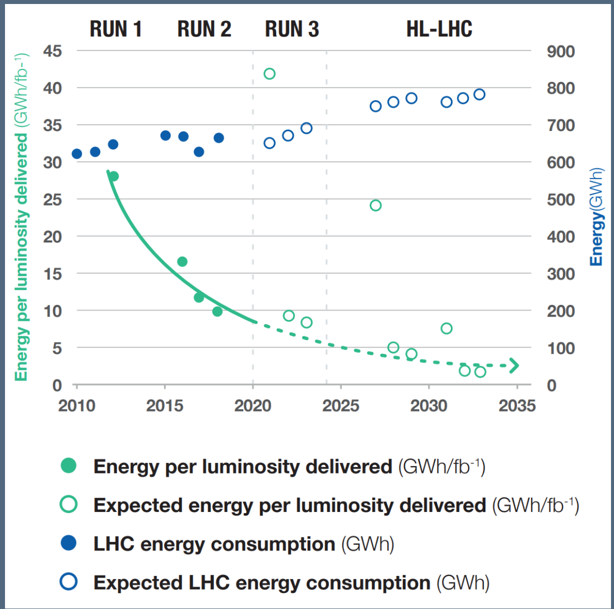
+4°C: civilization breakdown…

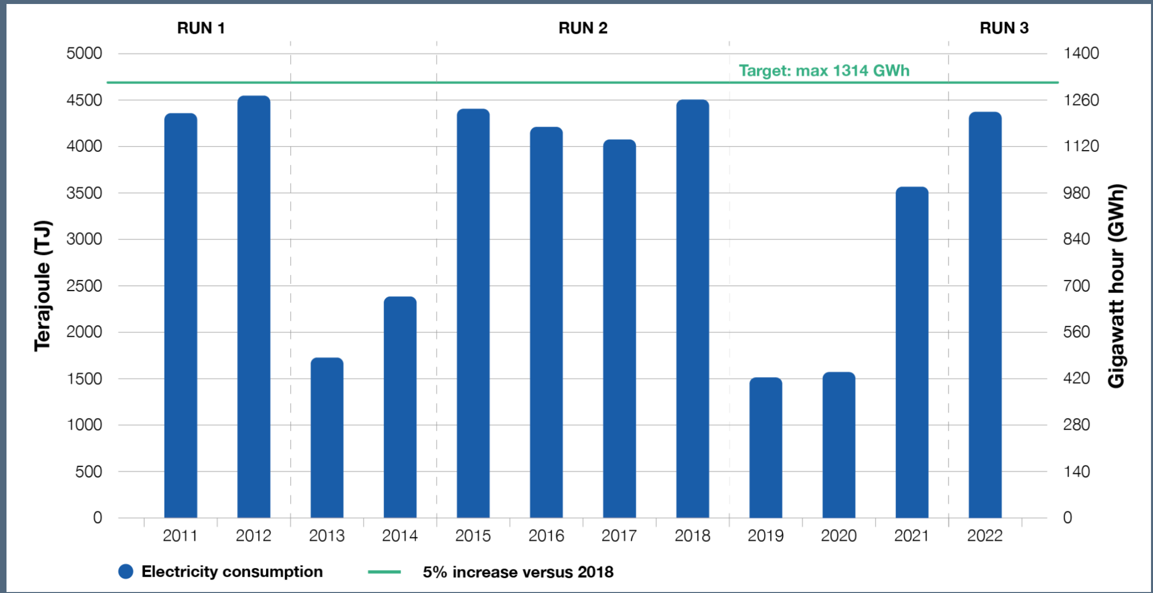
Emissions from accelerators: operations

- CERN now releases Environment reports (1st: 2017-18, 2nd: 2019-20, 3rd: 2021-22)
- CERN peak power: ~180 MW (~ 1/3 of Geneva)
- Per year: ~ 1.2 TWh (~ 2% of Switzerland, 0.03% of Europe)
- LHC: ~55% of CERN's E consumption
- Electricity mainly comes from France: 90% carbon free (2022)

Electrical power distribution 2018

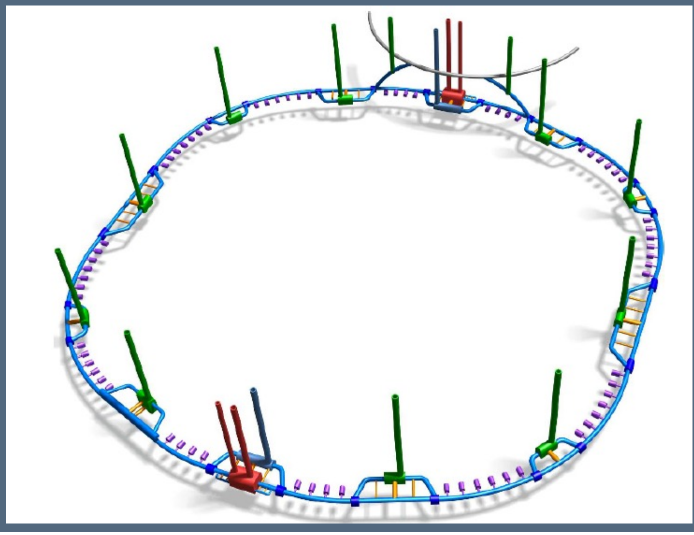


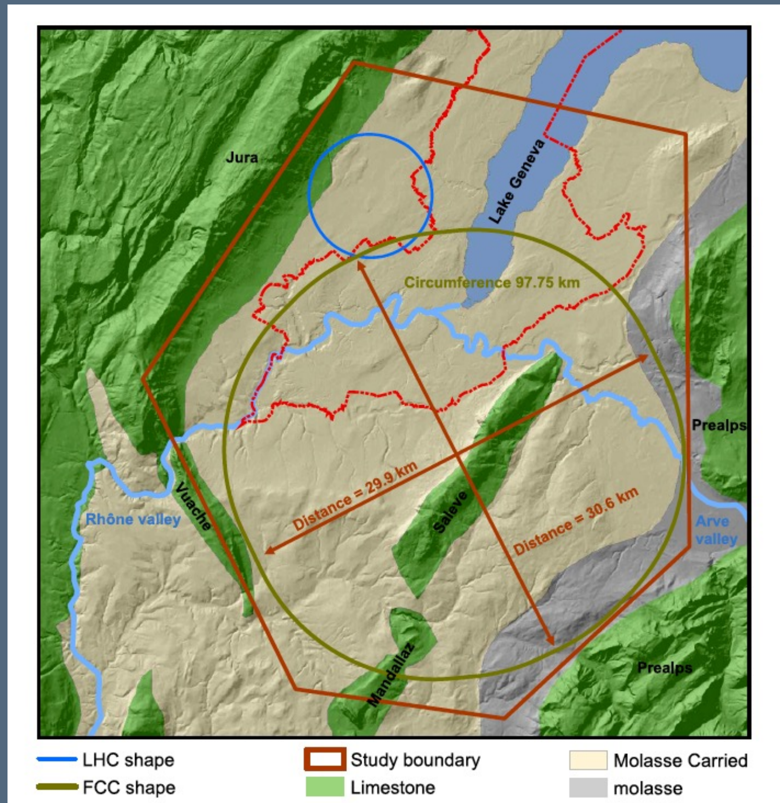




Emissions from accelerators: construction

- Potential future of energy frontier: FCC (ee then hh)
- Civil engineering:
  - Machine tunnel: one of the longest tunnels in the world: 97.75 km in circumference
  - 8 km of bypass tunnels
  - 18 shafts
  - 12 large caverns
  - 12 new surface sites
  - Excavation: 9 million cubic metres of spoil (mixture of marls and sandstone)
  - New roads





Emissions from accelerators: construction

- Concrete needed for the tunnel, which means (Portland) cement!
- Half of emissions from Portland clinker (ref)
- Ken Bloom and my rough calculation:
  - ~260k tonnes of CO_2 emissions
- Paper on emissions from road tunnels:
  - Lowest estimate: ~500k tonnes CO_2 emissions
- Comparison: Using report for CO_2e for construction of buildings: = building 8 London Shards!
- 1.4% of CH CO_2e emissions (2016)
- Plant 6 million trees!

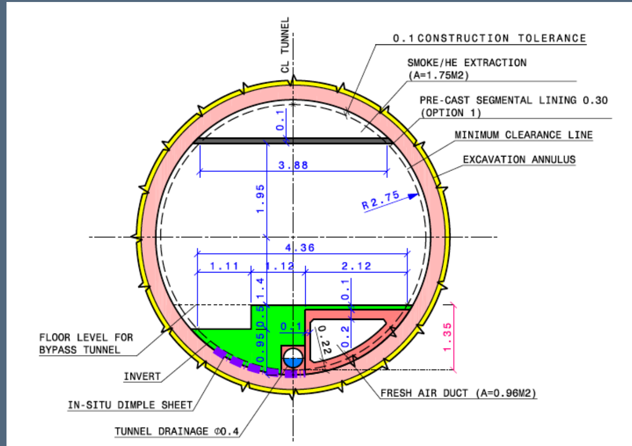


Fig. 4.4. Machine tunnel cross-section in "good" molasse.

$$CaCO_3 + \text{heat} \longrightarrow CaO + CO_2$$

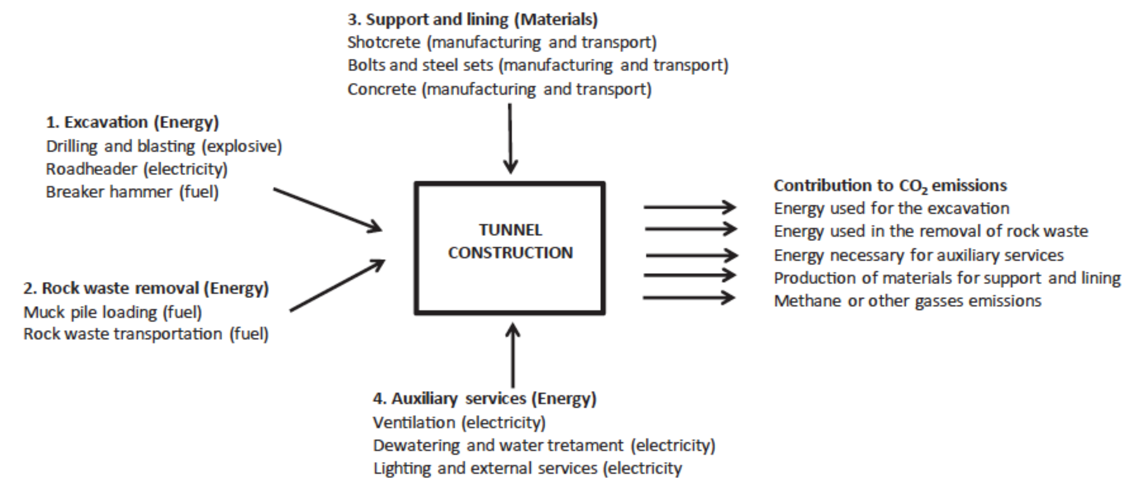
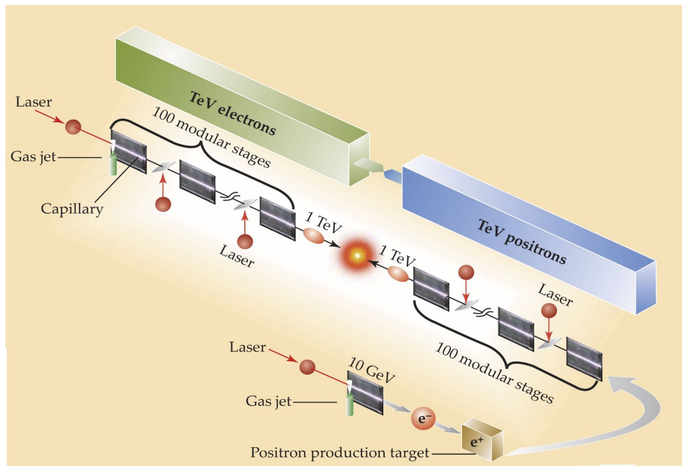


Fig. 1. Schematic overview of the system boundary.

Emissions from accelerators: solutions

- District heating:
  - Hot water from LHC cooling at Point 8 ready to heat 8000 homes in Ferney-Voltaire, CERN also looking at Point 2 and 5, and Point 1 could heat CERN building on Meyrin site
- Since 2011 series of workshops: Energy for Sustainable Science at Research Infrastructures, 7th one: September 2024 in Madrid
  - Seems very Europe-centric
- Long-standing R&D in lowering accelerator power requirements
  - Eg Energy-Recovery in a Laser-Driven Plasma Wakefield Acceleration

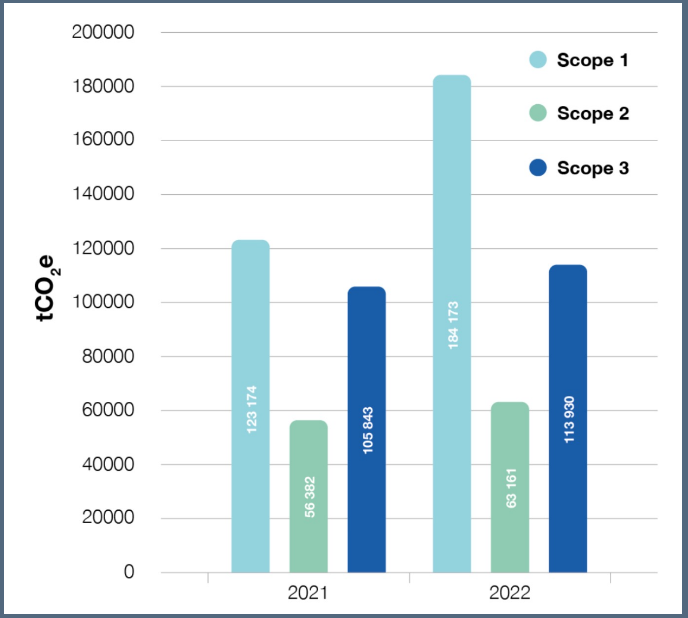


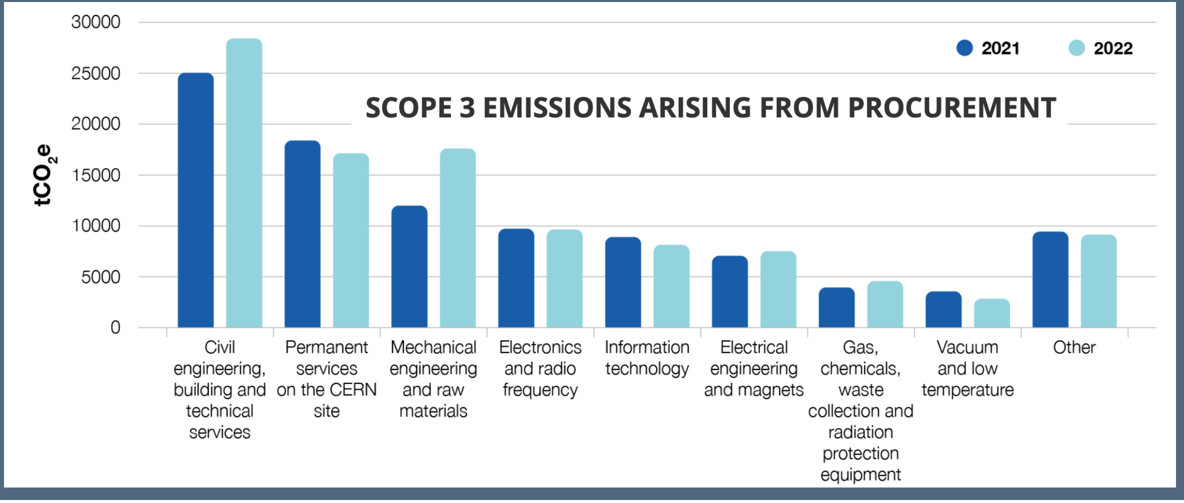
Physics Today **62**, 3, 44 (2009); https://doi.org/10.1063/1.3099645

Emissions from detectors

- Dominant CO2e emissions from CERN: gases used in experiments!
- Scope 1: direct emissions from organization/vehicles etc.
- Scope 2: indirect emissions from electricity generation, heating, etc.
- Scope 3: all other indirect emissions, upstream and downstream (business travel, personnel commutes, catering, etc.)

GROUP	GASES	tCO_2e 2021	tCO_2e 2022
Perfluorocarbons (PFCs)	CF_4, C_2F_6, C_3F_8, C_4F_{10}, C_6F_{14}	55 921	68 989
Hydrochlorofluorocarbons (HFCs)	HFC-23 (CHF_3) HFC-32 (CH_2F_2) HFC-134a ($C_2H_2F_4$) HFC-404a HFC-407c HFC-410a HFC-507	36 557	86 211
Other F-gases	SF_6, NF_3	16 838	18 355
Hydrofluoroolefins (HFO)/HFCs	R-449 R1234ze NOVEC 649	86	199
	CO_2	13 771	10 419
Total Scope 1		123 174	184 173

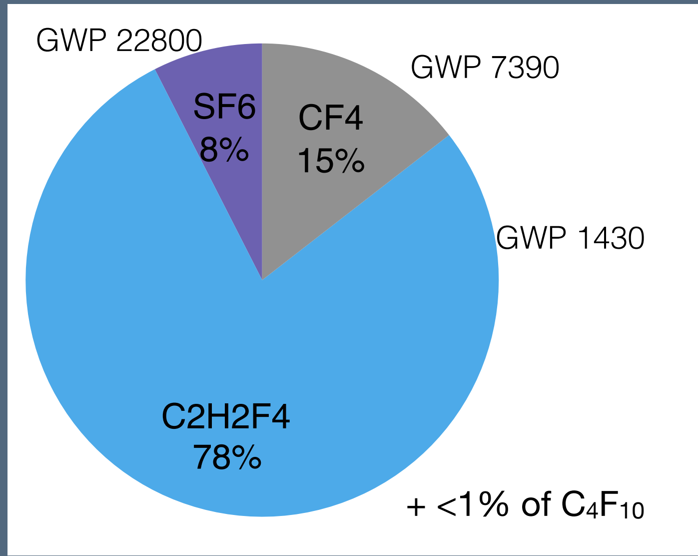


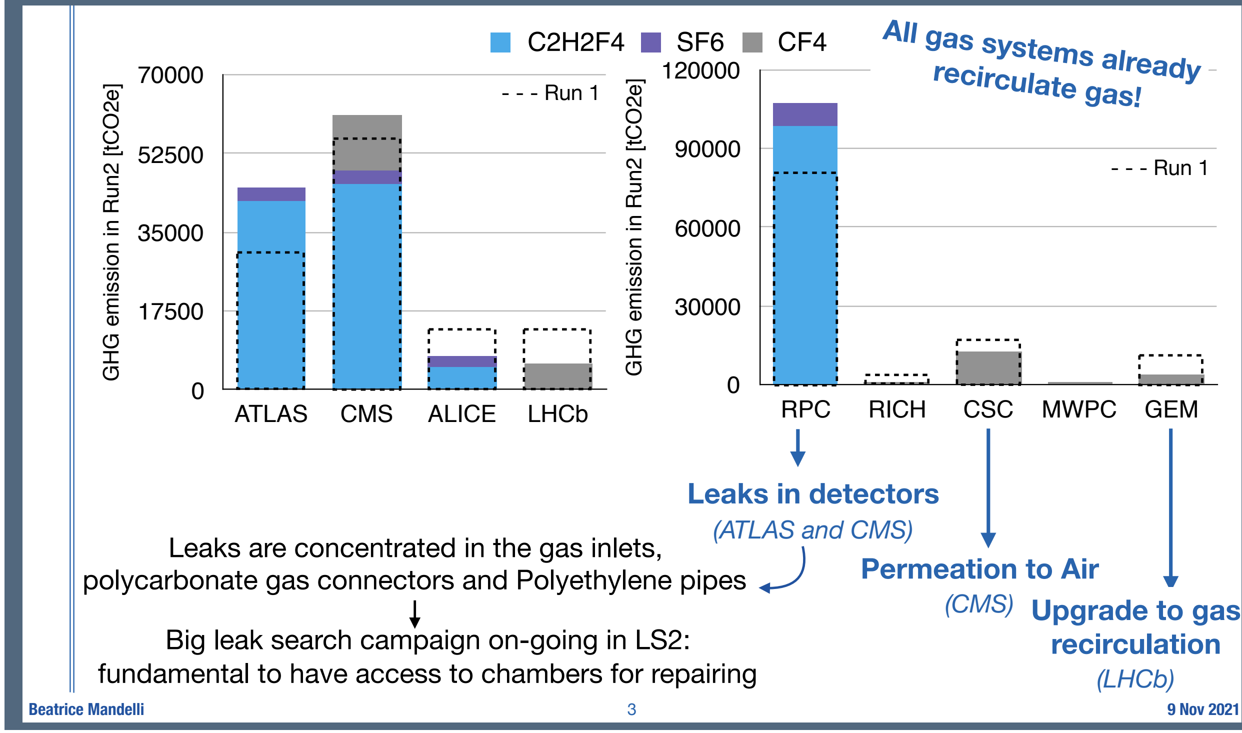


Emissions from detectors

- SF6, HFCs and PFCs: particle detection
- HFCs and PFCs: detector cooling
- HFCs: air conditioning systems
- SF6: also used for electrical insulation in power supply systems

Particle detection

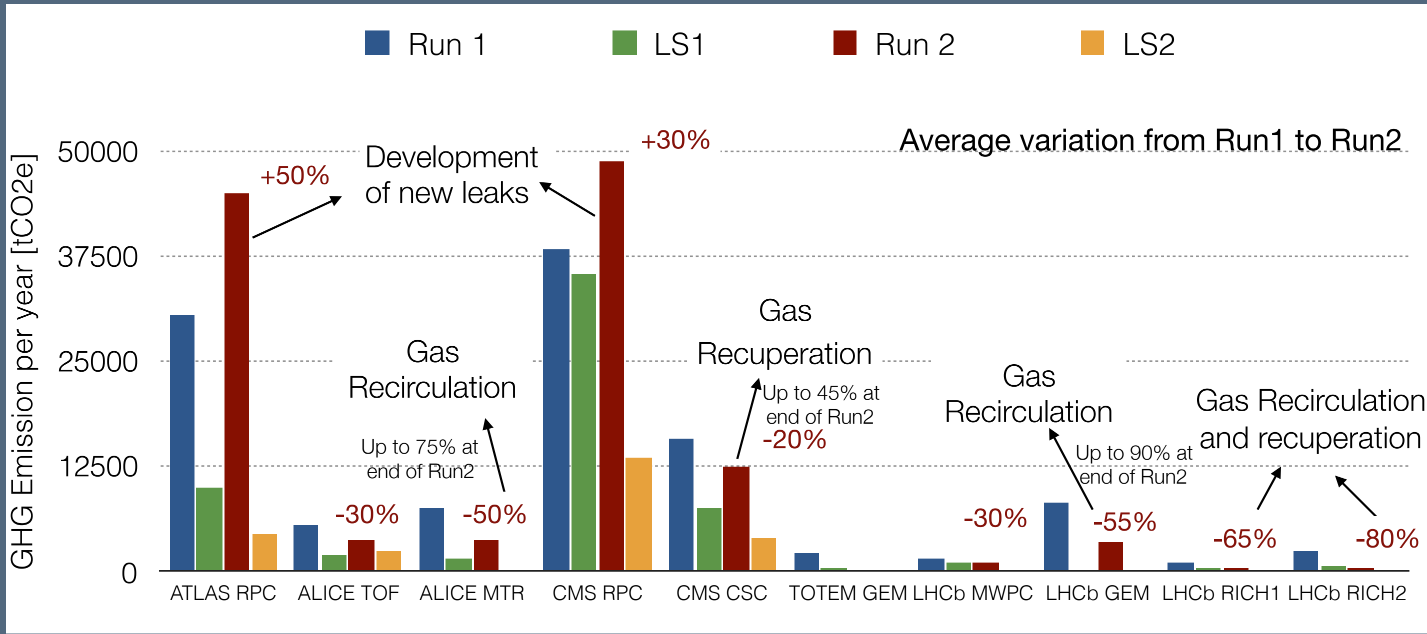




- Gas recirculation is 90%

Emissions from detectors

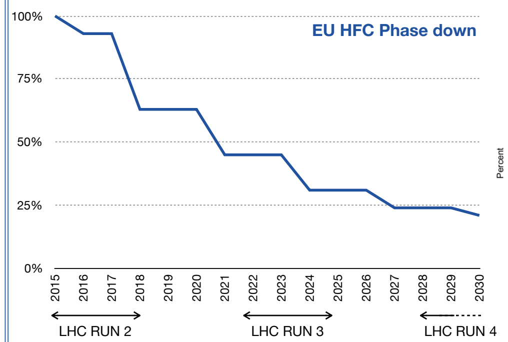
Beatrice Mandelli, CERN Gas Systems

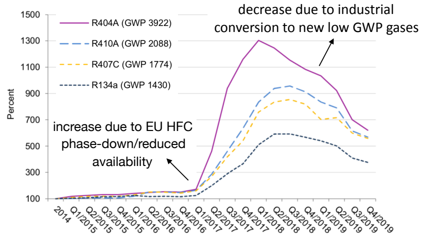


EU HFC phase-down policy

European Union "F-gas regulation":

- **Limiting the total amount** of the most important F-gases that can be sold in the EU from 2015 onwards and phasing them down in steps to one-fifth of 2014 sales in 2030.
- **Banning the use** of F-gases in many new types of equipment where less harmful alternatives are widely available.
- **Preventing emissions** of F-gases from existing equipment by requiring checks, proper servicing and recovery of the gases at the end of the equipment's life.



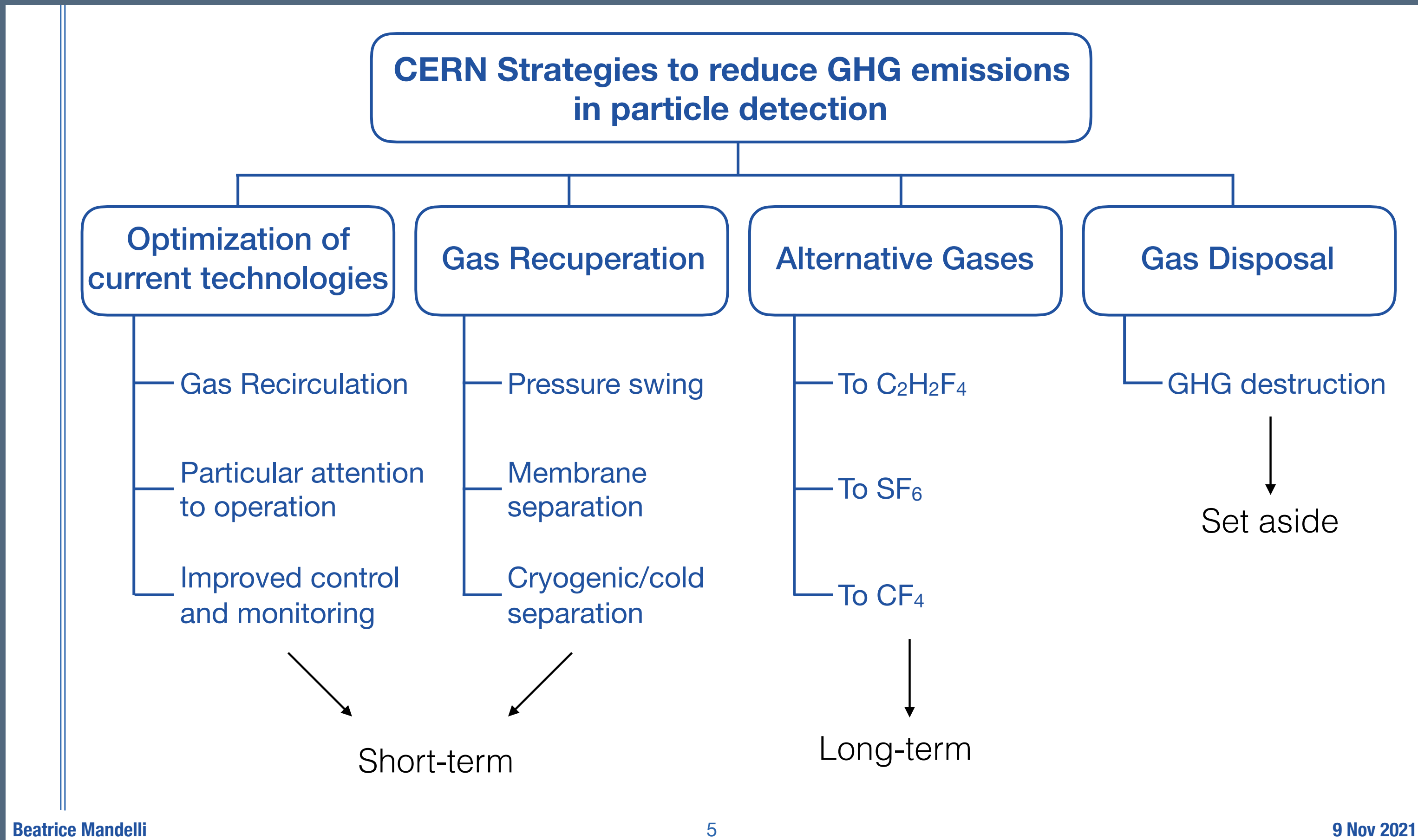


European Environment Agency, Fluorinated greenhouse gases 2019 report
Öko Recherche report, March 2020 J. Kleinschmidt et al.

Prices could increase in EU and availability in the future is not known.
Reduction of the use of F-gases is fundamental for future particle detector applications

Emissions from detectors: solutions

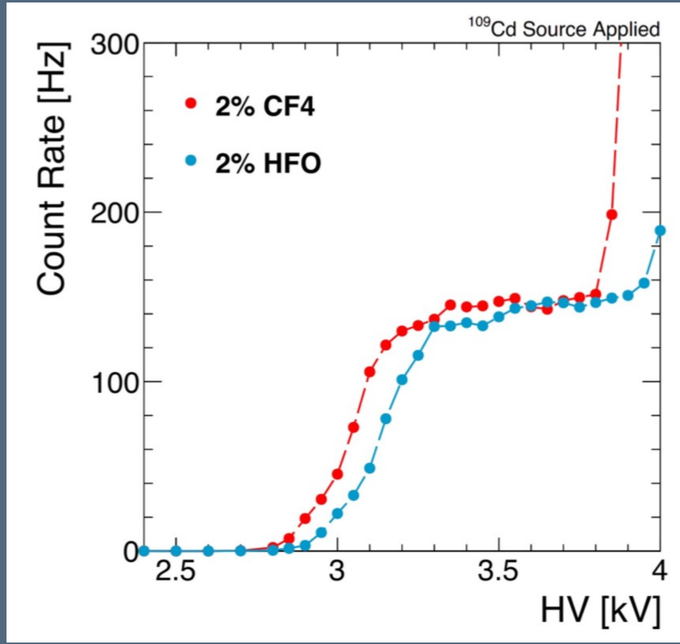
- 2020: CERN launched a working group on managing F-gases, with representatives from the departments concerned and the large LHC experiments. The group looked at issues such as the implementation of a centralised F-gas procurement policy, leak detection, replacement alternatives, training courses for personnel handling F-gases, and improving traceability and reporting.



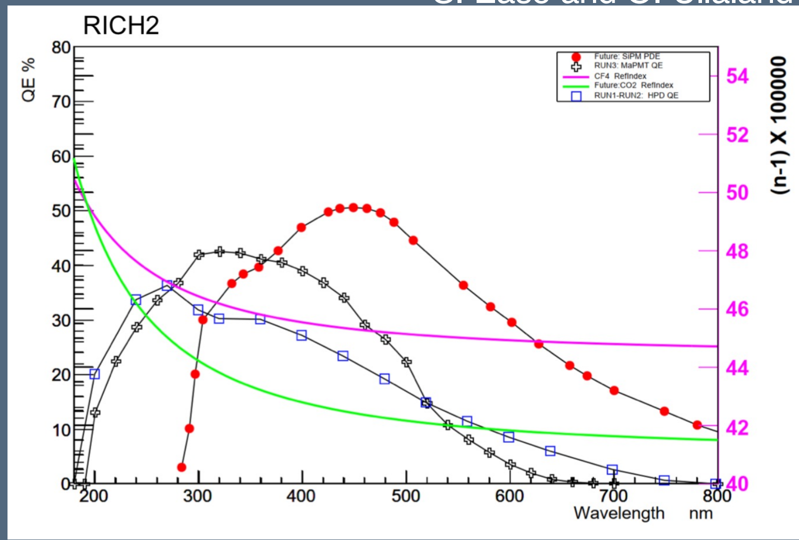
Emissions from detectors: solutions

- Alternative gas example: replace CF_4
- CF_4 prevents ageing, improves timing resolution and is a scintillator
- CMS CSC: currently 10% CF_4
  - Reduce concentration to 5%
  - Replace with CF_3I or HFO1234ze
- LHCb RICH studies:
  - CF_4 or C_4F_{10} used for good refractive index
  - Could replace C_4F_{10} with C_4H_{10} but flammable
  - Replace CF_4 with CO_2: under study
  - Use of SiPM to reduce the chromatic error and increase the yield

Presented at DPF 2019



S. Easo and O. Ullaland



Emissions from detectors: solutions

Why it is so difficult to find good GHG alternatives

When looking for alternatives eco-friendly gases, several factors have to be taken into account

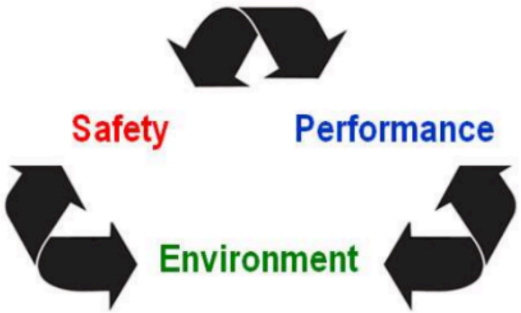
Safety

Safety first for detector operations

- Gas mixture not flammable
- Gas components cannot have high toxicity levels

Tradeoff between flammability and GWP

- Replacing F with Cl or H: it shortens atmospheric lifetime BUT increase flammability limit
- Adding C=C bound: it increases reaction with O_2



Performance

GWP is related to IR absorption over time. Low GWP gases have short atmospheric lifetimes

- Water solubility —> rain out
- OH reactivity —> oxidation
- UV absorbance —> photolysis

RPC short and long term performance are affected

- Good quenching gases required
- Radiation-hard gas required
- Gases cannot heavily react with H_2O or UV radiation

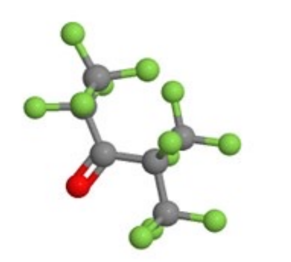
Environment

GWP represents the main environment concern

Emissions from detectors: solutions

G. D. Hallewell

- Crucial to do R&D in finding replacements or ensure 100% leak-free and 100% recirculation
  - **CERN has tested NOVEC 649: Equivalent radiation stability to C_6F_{14} used as a liquid coolant in all LHC experiments**
- FCC-ee detectors:
- CLD (similar to CLIC): RPCs for the muon detector
- IDEA: large drift chamber (similar to KLOE and MEG2) containing He:iC4H10 90:10, iC4H10 GWP: ~3, for muon: large area µ-Rwell chambers, also use 10% iC4H10



NOVEC 649 $C_6F_{12}O$
(GWP_{20} = ≤ 1)
[12]
$CF_3CF_2C(O)CF(CF_3)_2$

C_6F_{14}
(GWP_{20} = 5890)
[16]

FCC-ee CDR

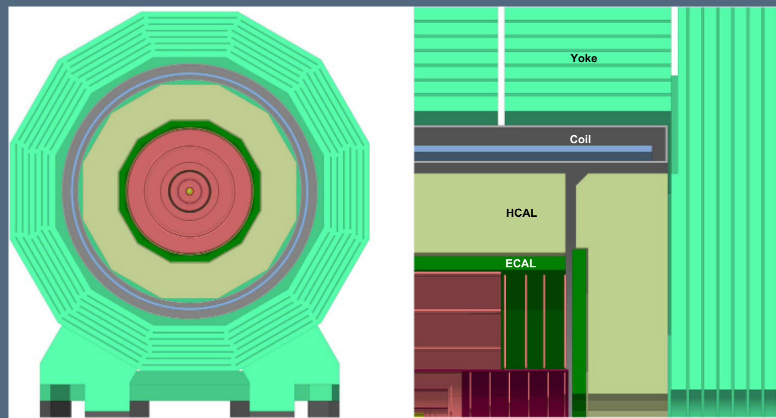


Fig. 7.4. The CLD concept detector: end view cut through (left), longitudinal cross section of the top right quadrant (right).

Embedded emissions from accelerators & detectors

HECAP+ 2023

- Future projects need to compute the full life cycle analysis of emissions of all accelerator and detector components

Best Practice 6.1: Life cycle data for a silicon wafer
The ecological impacts of a 1 cm^2 silicon wafer (thickness 775 μm, diameter 300 mm, weight 0.128 kg) as identified in 2000, are summarised in Table 6.1 [194].

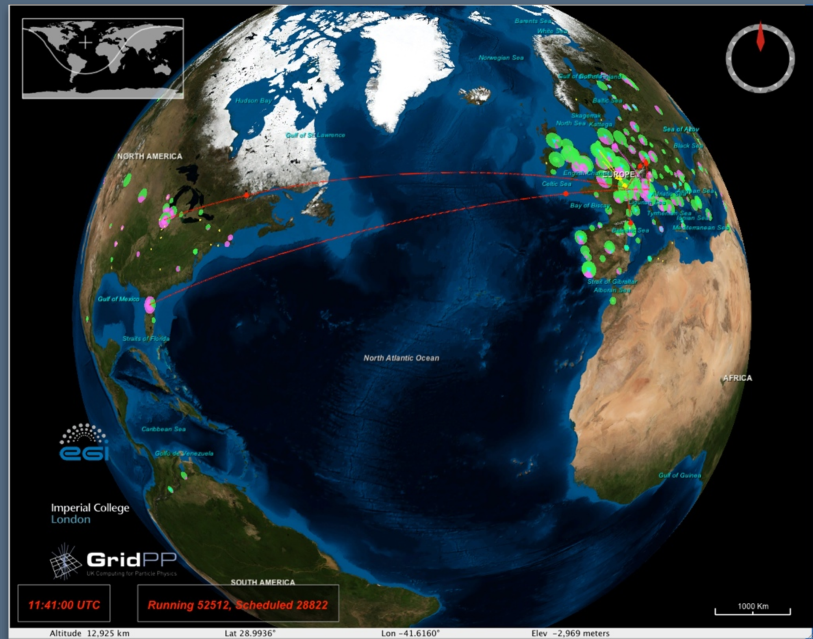
Inputs	Quantity	Outputs	Quantity
Hydrogen chloride HCl (hydrochloric acid)	0.00675 kg	Co-products: Si in other co-products	0.000286 kg
Graphite (as electrode material)	0.000163 kg	Co-products: Silicon tetrachloride	0.00415 kg
Wood chips	0.00183 kg	Co-products: Si residues for solar cells	65.2×10^{-6}
Petroleum coke	0.000597 kg	Polished silicon wafer	1 cm^2
Quartz	0.00486 kg		
Electricity	0.385 kWh		
Dry wood	0.00398 kg		

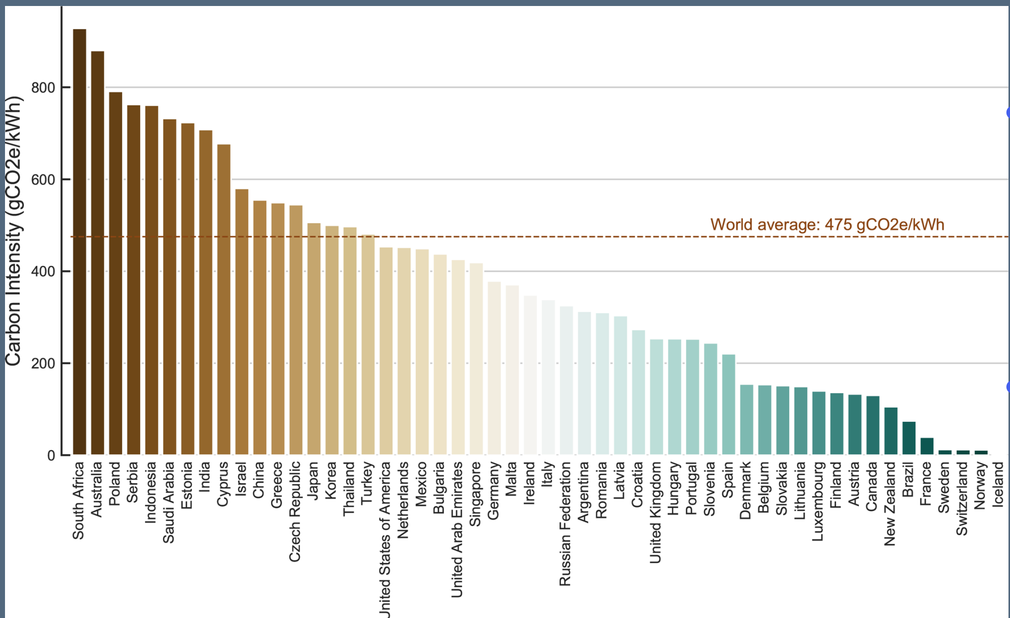
Air emissions	Quantity	Discharge to Water	Quantity
CH_4	68.8×10^{-6} kg	Metal chlorides	0.000787 kg
CO	0.000167 kg		
CO_2	0.00833 kg	Waste	Quantity
Ethane	29×10^{-6} kg	SiO_2	16.3×10^{-6} kg
H_2O	0.00188 kg		
Methanol	85.1×10^{-6} kg		
NOx	13.8×10^{-6} kg		
Particulate matter	0.000201 kg		
SO_2	34.4×10^{-6} kg		
Hydrogen	0.000125 kg		

Table 6.1: Inputs, outputs and emissions of silicon wafer production [194].

Emissions from Computing

- Global IT sector could be 2-6% of global CO2e emissions, growing to 20% by 2030
- 70% from data centres and communication networks
- HEP uses Grid centres all over the world, yet emissions from electricity vary wildly



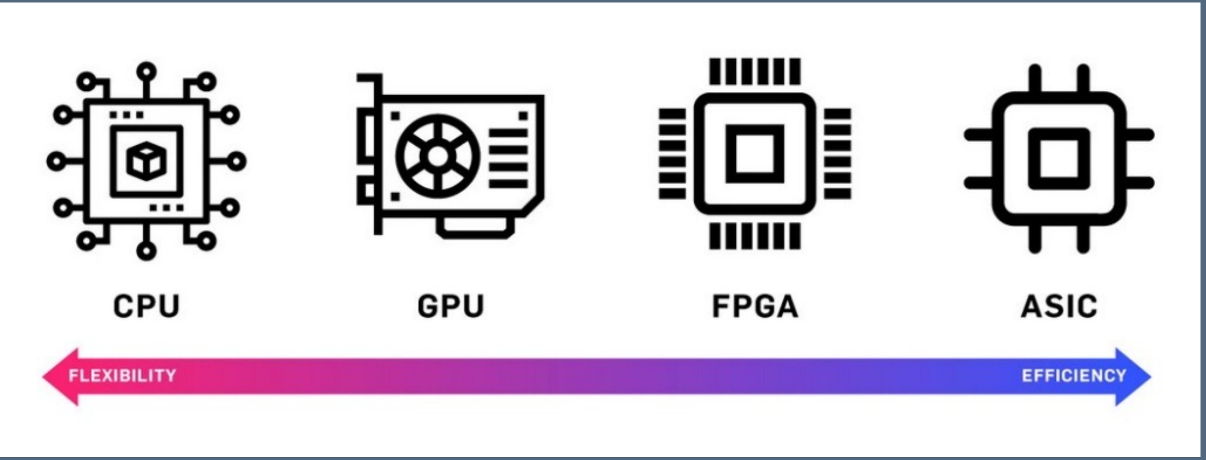


- Solutions:
  - Choose sites with green electricity…
  - Green500 list
  - Optimize your code ;-)
- Far future (2040):
  - All OECD electricity grids will be emissions free…
  - …. But huge demand for electricity

Emissions from Computing

- Embedded emissions…
  - 326 (620) kg CO_2e 13' (16') MacBook Pro, 128 GB (1 TB) storage
- … far outnumber running emissions (80-85% of lifetime emissions)
  - 2g (3g) CO_2e/h MacBook Pro
  - 10g CO_2e/h average-efficient laptop
  - 50g CO_2e/h desktop with screen
  - + 22g CO_2e/h for servers, networks
- Replacing farms less often can help a lot
- In general ASIC/FPGA/GPU/TPU use less power than CPUs, but exact numbers depend on software/architecture

Numbers from Mike Berners-Lee



Emissions from FNAL

- In the US, DOE requirements to report yearly on environmental impacts including emissions
- REC: Renewable Energy Certificates

2019 FNAL Environment Report

Scope 1 & 2 Greenhouse Gas Emissions

Goal: Reduce direct GHG emissions by 50 percent by FY 2025 relative to FY 2008 baseline
Interim Target (FY 2019): -31.0%

Current Performance: -62.5%

	FY 2008	FY 2019	% Change
Facility Energy	343,366.8	161,122.7	-53.1%
Non-Fleet V&E Fuel	142.6	186.6	30.9%
Fleet Fuel	691.6	0.0	-100.0%
Fugitive Emissions	40,165.1	139.1	-99.7%
On-Site Landfills	0.0	0.0	N/A%
On-Site WWT	0.0	0.0	N/A%
Renewables	0.0	0.0	N/A%
RECs	0.0	-17,435.4	N/A
Total (MtCO2e)	**384,366.1**	**144,013.0**	**-62.5%**

Scope 3 Greenhouse Gas Emissions

Goal: Reduce indirect GHG emissions by 25 percent by FY 2025 relative to FY 2008 baseline
Interim Target (FY 2019): -13.0%

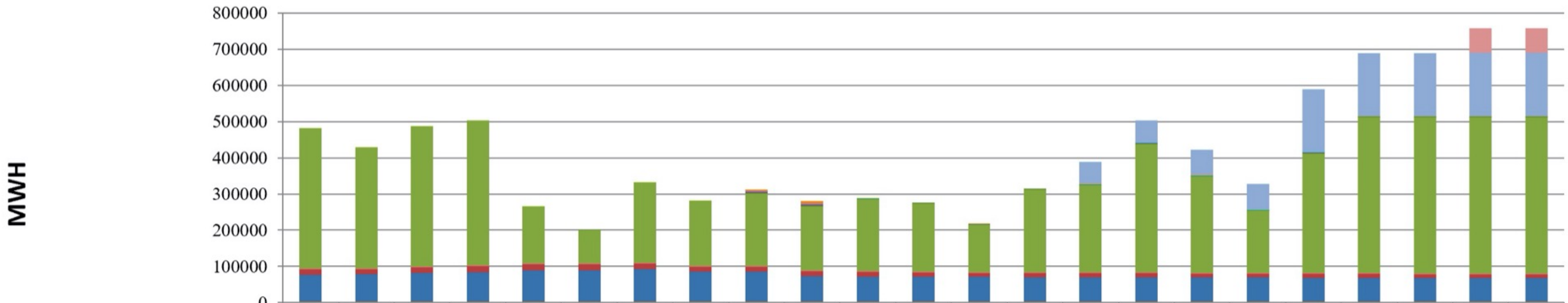
Current Performance: -51.0%

	FY 2008	FY 2019	% Change
T&D Losses*	22,287.8	7,306.8	-67.2%
T&D RECs Credit	0.0	-1,148.5	N/A
Air Travel	2,215.8	2,530.1	14.2%
Ground Travel	168.9	128.5	-23.9%
Commute	4,633.3	5,392.5	16.4%
Off-Site MSW	191.8	247.7	29.1%
Off-Site WWT	4.8	11.0	129.2%
Total (MtCO2e)	**29,502.4**	**14,468.1**	**-51.0%**

* Includes T&D losses for purchased renewable electricity

Emissions from FNAL

Electricity Projections for Fermilab

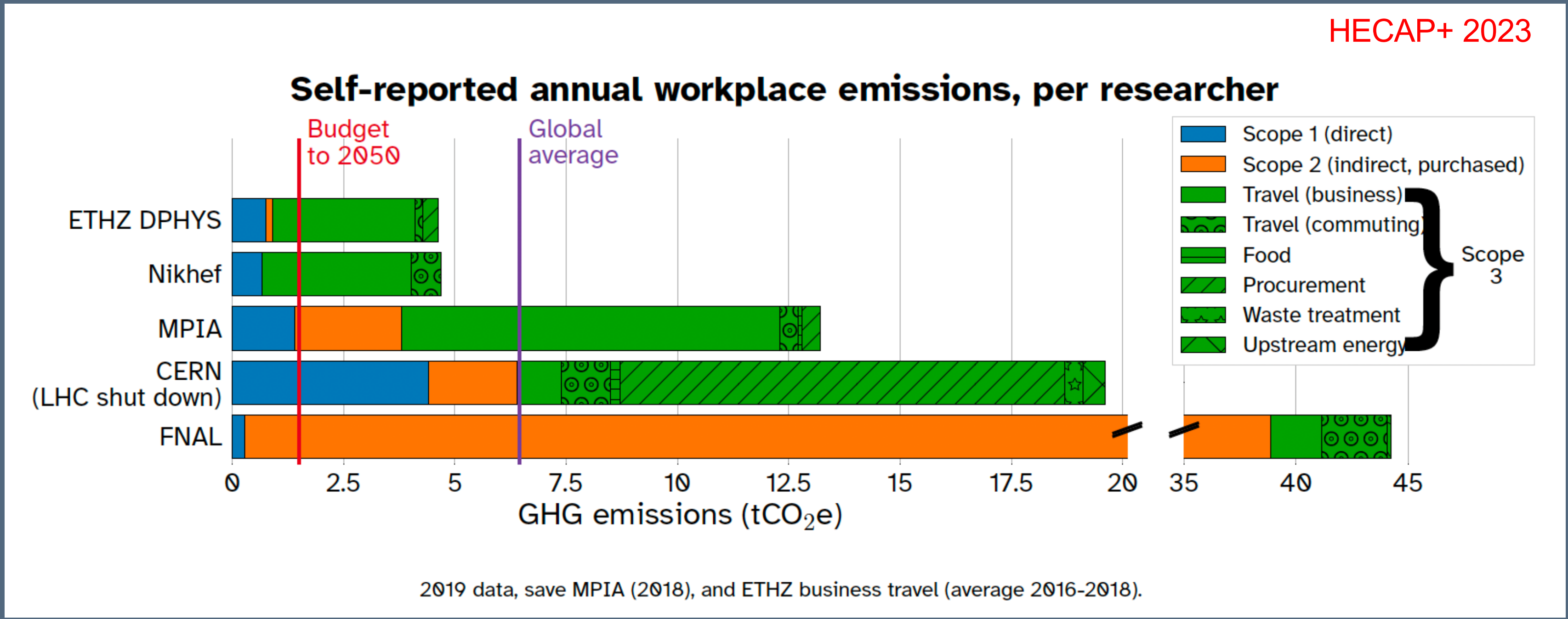


	FY08	FY09	FY10	FY11	FY12	FY13	FY14	FY15	FY16	FY17	FY18	FY19
LBNF												
PIP-II												
SBN Near & Far Detectors									3942	8869.5	548.9508	521.6047
Mu2e (MC-2)											324.825	348.5065
Muon G-2 (MC-1)									5080.8	5080.8	932.8659	947.4887
Existing Particle Accelerators HEMSF	391208.4	337149.6	390287.5	402903.2	160678.4	94728.31	224836.8	182507.3	203178.3	179476.8	200217.4	189303.5
Existing High Performance Computing HEMSF	16548.45	17215.17	17230.22	19718.99	19542.3	18389.43	16574.14	14742.82	14742.82	15904	15321	14334
Site Base	74689.13	75595.25	80021.26	80555.81	85979.34	86723.26	90333.26	83857.44	83617.98	70310.89	69309.99	68919.64

	FY20	FY21	FY22	FY23	FY24	FY25	FY26	FY27	FY28	FY29	FY30
LBNF										68328	68328
PIP-II			61320	61320	70956	70956	173448	173448	173448	173448	173448
SBN Near & Far Detectors	669.758	700.8	700.8	700.8	700.8	700.8	700.8	700.8	700.8	700.8	700.8
Mu2e (MC-2)	471.1054	1752	1752	1752	1752	1752	1752	1752	1752	1752	1752
Muon G-2 (MC-1)	1057.261	1057.261	876	876	876	876	876	876	876	876	876
Existing Particle Accelerators HEMSF	133630	229464.3	242312.3	357463.3	267470.5	172838	332149.8	432510	432866.6	433220.6	433570.1
Existing High Performance Computing HEMSF	13131.06	13131.06	13131.06	13131.06	13131.06	13131.06	13131.06	13131.06	13131.06	13131.06	13131.06
Site Base	68533.19	68150.6	67771.85	67396.88	67025.65	66658.15	66294.31	65934.12	65577.52	65224.5	64875

Emissions from Universities

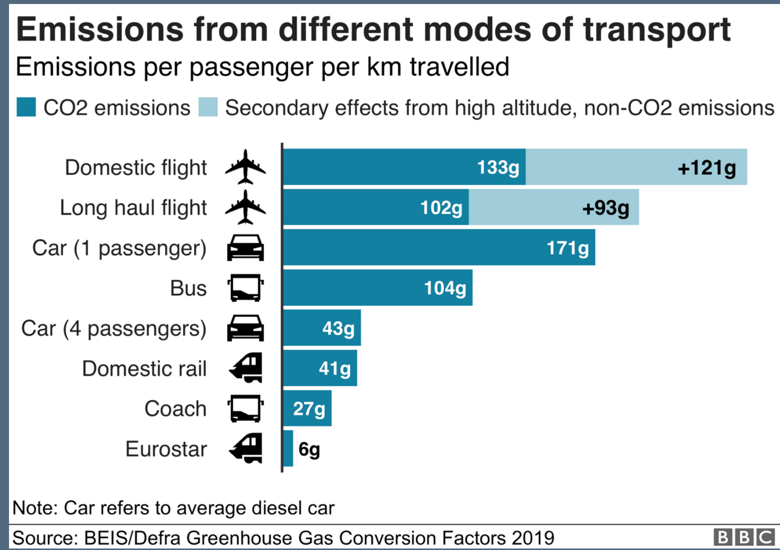
- Heating/cooling + hot water + light/appliances = 40% of energy consumption of a UK citizen
- Not only helps Climate, but is cheaper to run
- B Corporations certification
- Green Labs: "research labs consume 10 times more energy and 4 times more water than office spaces", green lab certification, LEAF



Remaining carbon budget:
(50% chance of staying < 1.5℃) 460 GtCO2
Per year per person: 2.2t

Emissions from Travel

- Commuting, conferences, etc.
- A nearly carbon-neutral conference model
- Although aviation is 2.4% (2018) of global emissions (more than Australia or Italy or France!), rate of growth is large and carbon neutral flights long way off (CO_2 emissions increased by 32% from 2013-2018)
- Environmental groups calling for frequent flyers levy since eg in 2015 only 12% of people in England took 3 flights or more!
- Carbon offsetting as short term mitigation? controversial



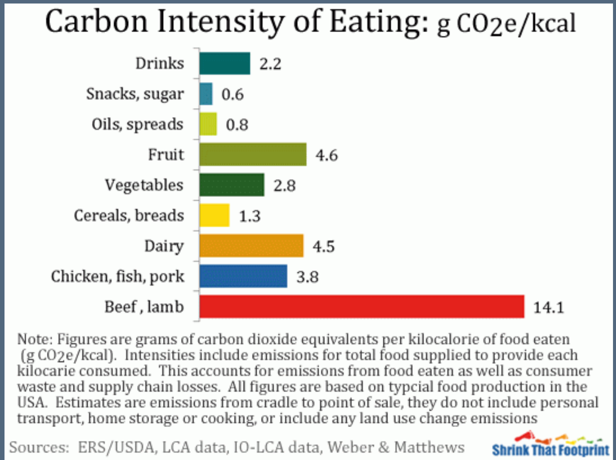
	AGU Fall Meeting 2019	ICHEP Melbourne 2012	ICHEP Valencia 2014	ICHEP Chicago 2016	ICHEP Seoul 2018	ICHEP Prague 2020 (virtual)
Number of participants	24,009	764	966	1,120	1,178	2,877
GHG emissions per participant [kg CO_2e]	2,883	8,432	1,902	2,699	2,648	0

Table 5.3: Total number of participants of recent ICHEP conferences and the GHG emissions per participant. The corresponding numbers for the American Geophysical Union (AGU) Fall Meeting [147] are shown for reference.

HECAP+ 2023

Emissions from food

- IPCC report in August 2019 on Land Usage
- How about migrating our PP catering (meetings, conf, workshops) in that direction?



Carbonfootprint.com				
My Carbon footprint:	tonnes of CO2e		pesc.	vegan
House	0.92	9%	0.90	0.90
Flights	2.74	27%	1.37	1.37
Car	2.64	26%	0.96	0.96
Bus+Rail	0.07	1%	0.14	0.14
Food	1.58	15%	1.32	0.98
Secondary (clothes, etc.)	2.37	23%	2.38	1.19
Total	**10.32**		**7.07**	**5.54**
Target:	**6.192**			

Pre-pandemic

Average UK	6.5	
Average EU	6.4	
Average world	5	
Target:	2	60%

Mike Berners-Lee: average UK: 13 tonnes of CO2e

My ATLAS footprint?
Scope1+2 ~240 ktCo2e/4 = 60 ktCO2e/3k
= 20 tCO2e

POSSIBLE RECOMMENDATIONS

Input to the ESU

VB (RHUL)
Cham Ghag (UCL)
Francesco Spano (RHUL)
David Waters (UCL)

CERN Courier article

ECFA group of early career researchers asked to give input to European Strategy, document released which includes statements supporting the environmental sustainability of the field

Outcome

7 Environmental and societal impact

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.***

B. Particle physics, with its fundamental questions and technological innovations, attracts bright young minds. Their education and training are crucial for the needs of the field and of society at large. ***For early-career researchers to thrive, the particle physics community should place strong emphasis on their supervision and training. Additional measures should be taken in large collaborations to increase the recognition of individuals developing and maintaining experiments, computing and software. The particle physics community commits to placing the principles of equality, diversity and inclusion at the heart of all its activities.***

C. Particle physics has contributed to advances in many fields that have brought great benefits to society. Awareness of knowledge and technology transfer and the associated societal impact is important at all phases of particle physics projects. ***Particle physics research centres should promote knowledge and technology transfer and support their researchers in enabling it. The particle physics community should engage with industry to facilitate knowledge transfer and technological development.***

D. Exploring the fundamental properties of nature inspires and excites. It is part of the duty of researchers to share the excitement of scientific achievements with all stakeholders and the public. The concepts of the Standard Model, a well-established theory for elementary particles, are an integral part of culture. ***Public engagement, education and communication in particle physics should continue to be recognised as important components of the scientific activity and receive adequate support. Particle physicists should work with the broad community of scientists to intensify engagement between scientific disciplines. The particle physics community should work with educators and relevant authorities to explore the adoption of basic knowledge of elementary particles and their interactions in the regular school curriculum.***

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.*

SnowMass2021

- Community Engagement Frontier: TG07 Environmental & Societal Impacts
- Coordinators: VB, Ken Bloom (U of Nebraska), Mike Headley (SDSTA-SURF)
- White papers released 15th March, Community meeting in Seattle in July

Climate impacts of particle physics

Kenneth Bloom[1,*], Veronique Boisvert[2,**], Daniel Britzger[3], Micah Buuck[4], Astrid Eichhorn[5], Michael Headley[6], Kristin Lohwasser[7], and Petra Merkel[8]

[1]University of Nebraska-Lincoln, Lincoln, NE, USA
[2]Royal Holloway University London, United Kingdom
[3]Max-Planck-Institute for Physics, Munich, Germany
[4]SLAC National Accelerator Laboratory, Menlo Park, CA, USA
[5]CP3-Origins, University of Southern Denmark, Denmark
[6]Sanford Underground Research Facility (SURF), Lead, SD, USA
[7]University of Sheffield, United Kingdom
[8]Fermi National Accelerator Laboratory (Fermilab), Batavia, IL, USA

Abstract. The pursuit of particle physics requires a stable and prosperous society. Today, our society is increasingly threatened by global climate change. Human-influenced climate change has already impacted weather patterns, and global warming will only increase unless deep reductions in emissions of CO_2 and other greenhouse gases are achieved. Current and future activities in particle physics need to be considered in this context, either on the moral ground that we have a responsibility to leave a habitable planet to future generations, or on the more practical ground that, because of their scale, particle physics projects and activities will be under scrutiny for their impact on the climate. In this white paper for the U.S. Particle Physics Community Planning Exercise ("Snowmass"), we examine several contexts in which the practice of particle physics has impacts on the climate. These include the construction of facilities, the design and operation of particle detectors, the use of large-scale computing, and the research activities of scientists. We offer recommendations on establishing climate-aware practices in particle physics, with the goal of reducing our impact on the climate. We invite members of the community to show their support for a sustainable particle physics field [1].

Submitted to the Proceedings of the US Community Study
on the Future of Particle Physics (Snowmass 2021)

*Contact author, e-mail: kenbloom@unl.edu
**Contact author, e-mail: Veronique.Boisvert@rhul.ac.uk

SnowMass2021

- Summary report:

Finally, **HEP must take greater responsibility for its impacts on climate change** by addressing and mitigating these impacts through DOE project policies and individual community member actions.

- P5 Town meetings:
  - SLAC on 3-4th May: talk from Ken Bloom
- P5 presented their report on 7th December 2023

P5 presentation

Exploring the Quantum Universe

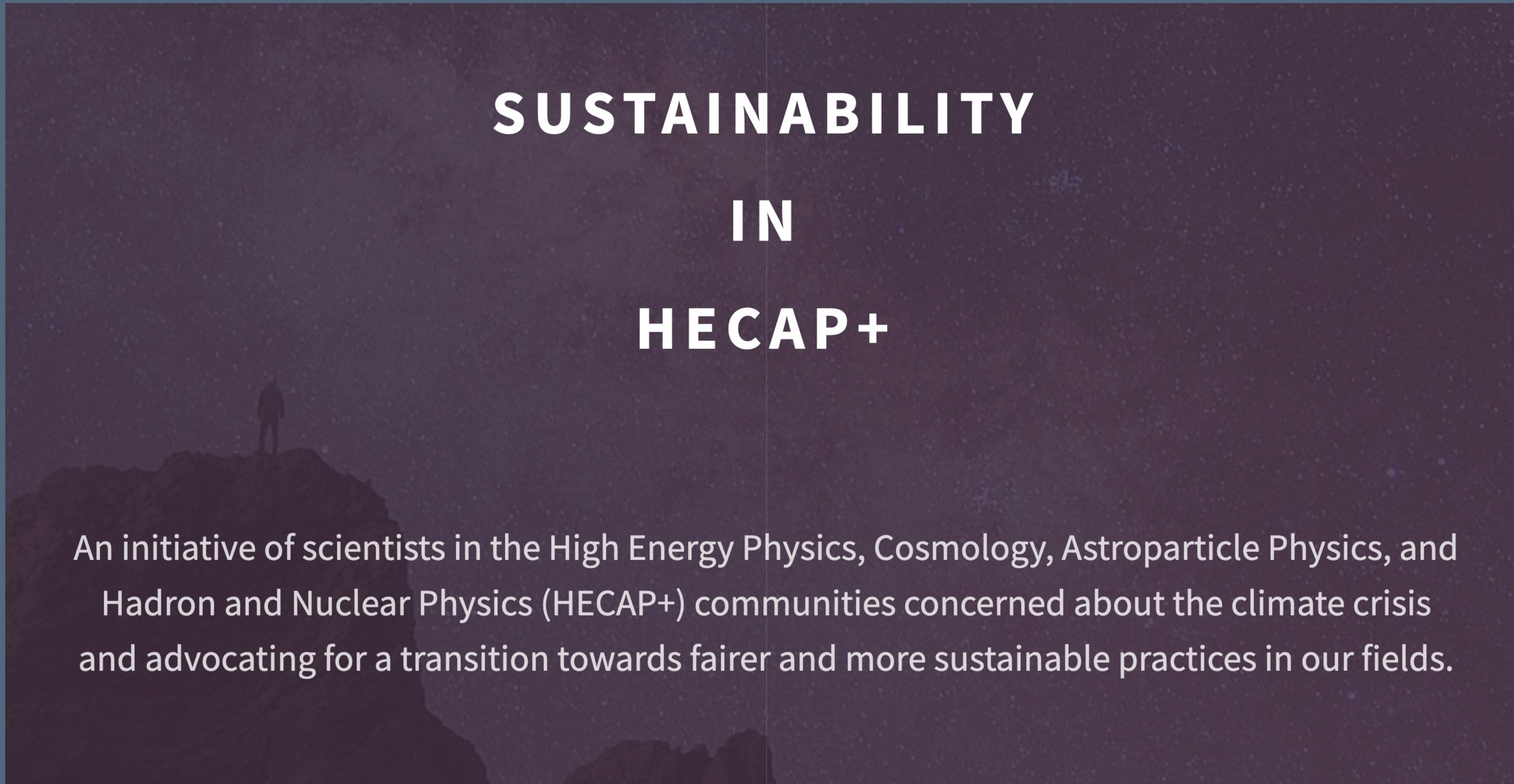
Area Recommendations

Software, Computing, and Cyberinfrastructure

16. Resources for national initiatives in **AI/ML, quantum, computing, and microprocessors** should be leveraged and incorporated into research and R&D efforts to maximize the physics reach of the program.
17. Add support for a sustained R&D effort at the level of **$9M per year in 2023 dollars to adapt software and computing systems to emerging hardware,** incorporate other advances in computing technologies, and fund directed efforts to transition those developments into systems used for operations of experiments and facilities.
18. Through targeted investments at the level of **$8M per year in 2023 dollars**, ensure sustained support for key **cyberinfrastructure** components. This includes widely-used software packages, simulation tools, information resources such as the Particle Data Group and INSPIRE, as well as the shared infrastructure for preservation, dissemination, and analysis of the unique data collected by various experiments and surveys in order to realize their full scientific impact.
19. **Research software engineers and other professionals at universities and labs** are key to realizing the vision of the field and are critical for maintaining a technologically advanced workforce. We recommend that the funding agencies embrace these roles as a critical component of the workforce when investing in software, computing, and cyberinfrastructure.

Sustainability

20. HEPAP, potentially in collaboration with international partners, should conduct a dedicated study aiming at **developing a sustainability strategy for particle physics.**



Released on 5th June 2023: Full report available

Show support here

Recommendations

- New experiments and facility construction projects should report on their planned emissions and energy usage as part of their environmental assessment
  - Eg LHCb TDR for Phase II, CLIC LCA, ISIS-II LCA (H. Wakeling)
- Review across all international laboratories to ascertain whether emissions are reported clearly and in a standardized way
- Take steps to mitigate impact on climate change by setting concrete reduction goals and defining pathways to reaching them
  - spend a portion of research time on directly tackling challenges related to climate change

Sustainable Concrete Construction

CERN Innovation Programme on Environmental Applications

Recommendations

- Minimize the travel emissions of users
- Long-term projects should consider the evolving social and economic context
- Actively engage in learning about the climate emergency and about the climate impact of particle-physics research
  - See next slide!
- Promote and publicize their actions surrounding the climate emergency to the general public and other scientific communities
- Engage with the broader international community to collectively reduce emissions

Learn More – Sustainability at STFC

STFC's sustainability learning programme created with The University of Oxford is open for registration.

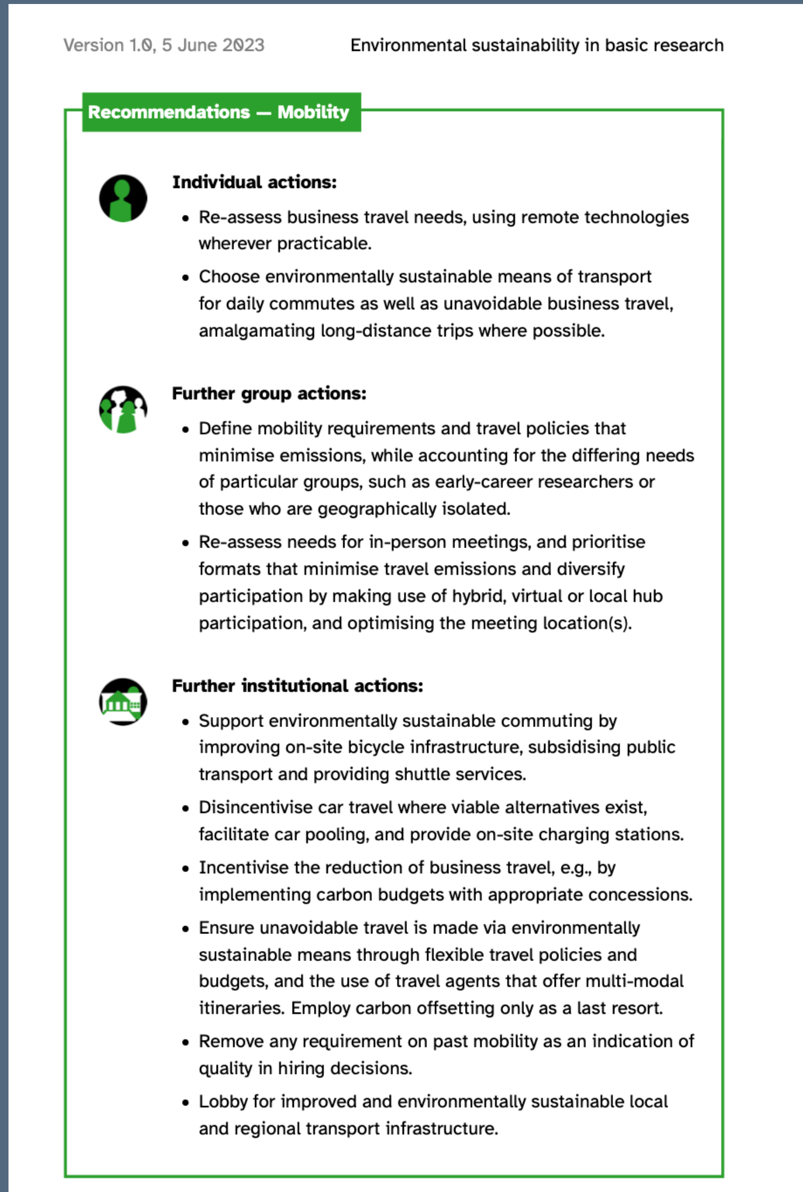
- The 'Creating a sustainable STFC' on-line course is specifically for STFC staff.
- Participants come away with a personalised action plan that will help them embed sustainability into their work.
- Find out about the course and how to register for one of the upcoming intakes visit the sustainability pages on The Source.

More information about sustainability including STFC's environmental data and targets can be found on the sustainability pages on The Source.

Science and Technology Facilities Council

Recommendations

- Eg ATLAS Sustainability Forum!
  - atlas-sustainability-forum@cern.ch
- Detailed Recommendations in each area listed in HECAP+ report



Version 1.0, 5 June 2023 Environmental sustainability in basic research

Recommendations — Mobility

Individual actions:

- Re-assess business travel needs, using remote technologies wherever practicable.
- Choose environmentally sustainable means of transport for daily commutes as well as unavoidable business travel, amalgamating long-distance trips where possible.

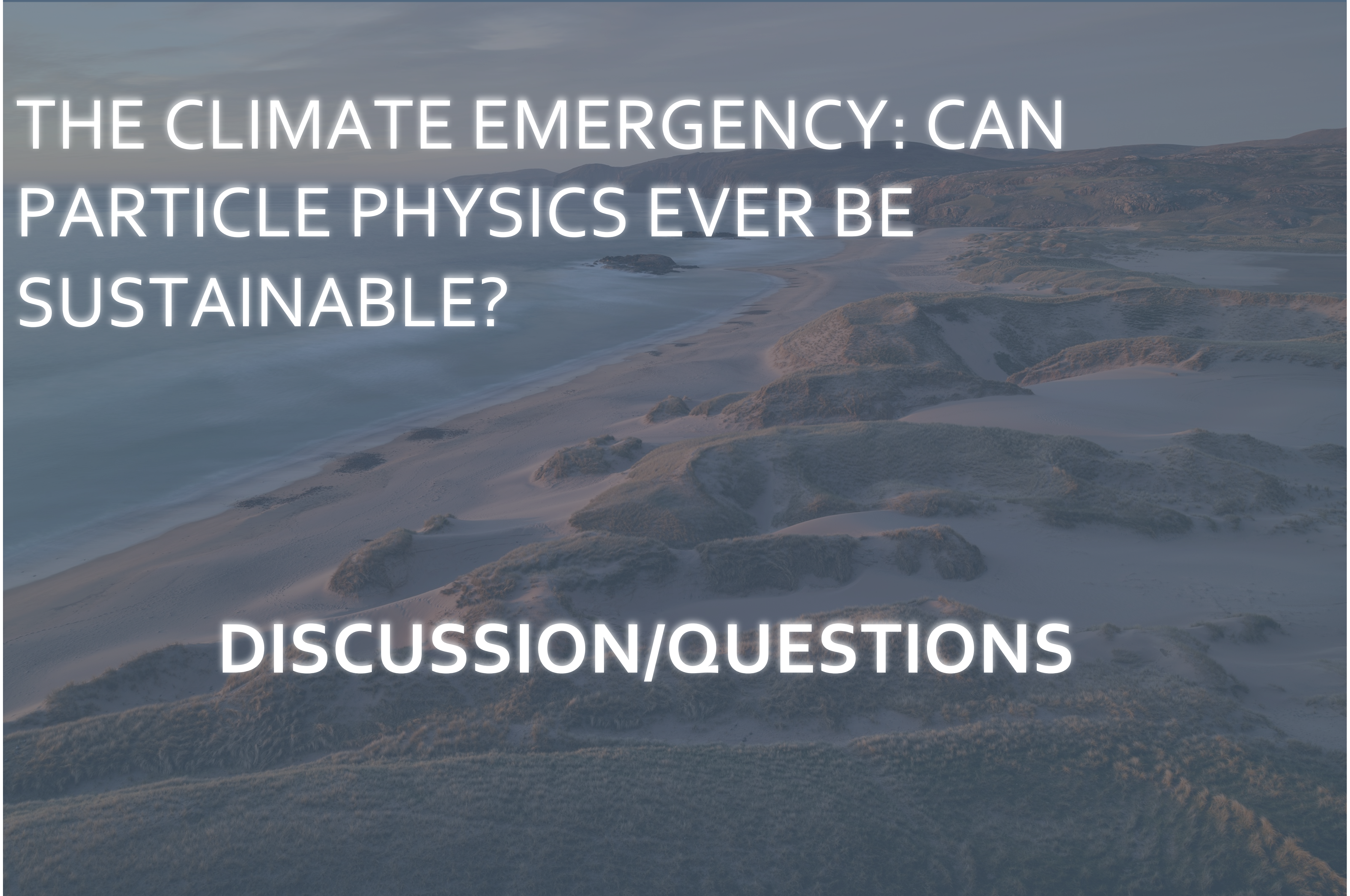
Further group actions:

- Define mobility requirements and travel policies that minimise emissions, while accounting for the differing needs of particular groups, such as early-career researchers or those who are geographically isolated.
- Re-assess needs for in-person meetings, and prioritise formats that minimise travel emissions and diversify participation by making use of hybrid, virtual or local hub participation, and optimising the meeting location(s).

Further institutional actions:

- Support environmentally sustainable commuting by improving on-site bicycle infrastructure, subsidising public transport and providing shuttle services.
- Disincentivise car travel where viable alternatives exist, facilitate car pooling, and provide on-site charging stations.
- Incentivise the reduction of business travel, e.g., by implementing carbon budgets with appropriate concessions.
- Ensure unavoidable travel is made via environmentally sustainable means through flexible travel policies and budgets, and the use of travel agents that offer multi-modal itineraries. Employ carbon offsetting only as a last resort.
- Remove any requirement on past mobility as an indication of quality in hiring decisions.
- Lobby for improved and environmentally sustainable local and regional transport infrastructure.

Sustainable HEP 2024 - 3rd edition: 10th-12th June 2024: free, online-only, time zone friendly (Daniel on org committee)



THE CLIMATE EMERGENCY: CAN PARTICLE PHYSICS EVER BE SUSTAINABLE?

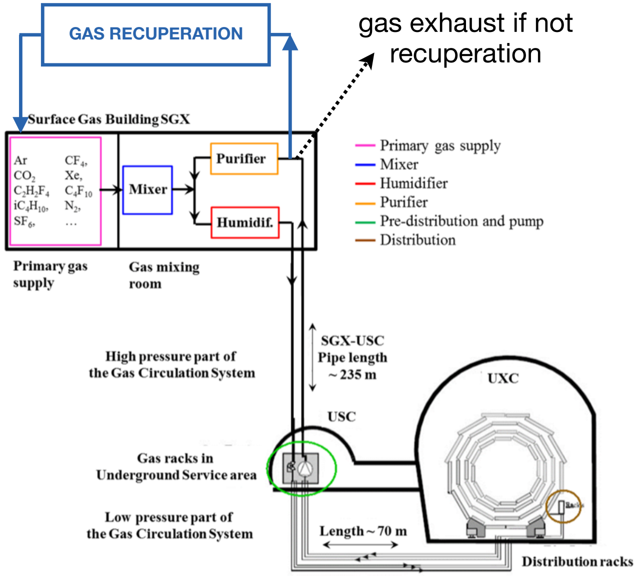
DISCUSSION/QUESTIONS

BACK UP

Gas Recuperation systems at LHC experiments

Sometimes it is not possible to recirculate 100% of the gas mixture due to detector constrains

- Air **permeability**, max recirculation **fraction**, impurities, etc.
- A fraction of gas has to be **renewed**
  - Some gas is sent to the atmosphere
- This fraction of gas mixture can be sent to a recuperation plant where the GHG is extracted, stored and re-used
  - **Challenges**: R&D, custom development, operation and recuperated gas quality
- Gas recuperation also to **empty/fill** the detectors during LS



LHCb RICH1 and RICH2

During LS2 need to empty the detectors for maintenance/upgrade:

RICH1: 4 m³ of C_4F_{10} → Gas recuperation system for empty/filling and cleaning from Air contamination

RICH2: 100 m³ of CF_4 → New gas recuperation system developed for the empty and filling of the detector

CMS CSC

Small Permeability to Air: accumulation of N_2

↓

Need to inject fresh gas continuously to keep N_2 stable and guarantee detector performance

↓

~80 l/h of CF_4 would be lost in exhaust without gas recuperation system

The R134a recuperation system for RPCs

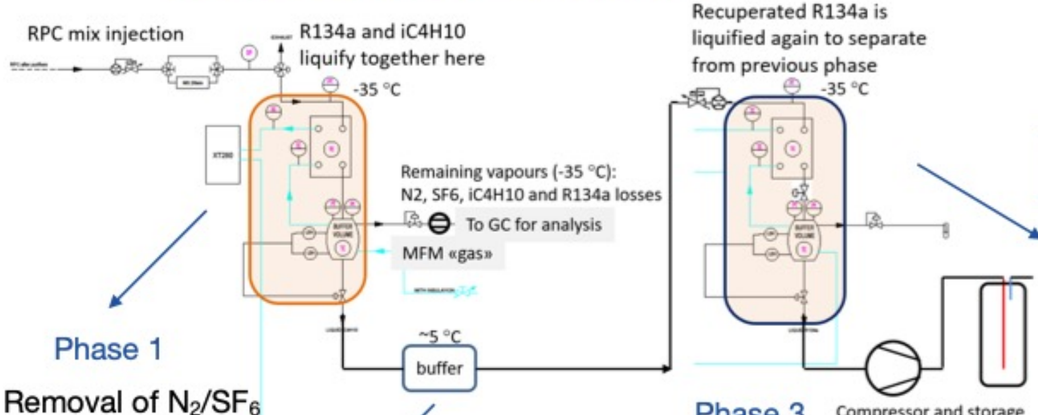
ATLAS and CMS RPC Gas Systems

- Detector volume ~15 m^3
- Gas mixture: ~95% **$C_2H_2F_4$**, ~5% iC_4H_{10}, 0.3% **SF_6**
- Gas recirculation: ~90%
  - Maximum recirculation validated for RPC detectors
- **Fundamental to repair detector leaks**
  - To have the gas at the exhaust of the gas system

R134a and iC_4H_{10} form an azeotrope

↓

A mixture of liquids whose proportions cannot be altered or changed by simple distillation



Phase 1

Removal of N_2/SF_6 by simple distillation

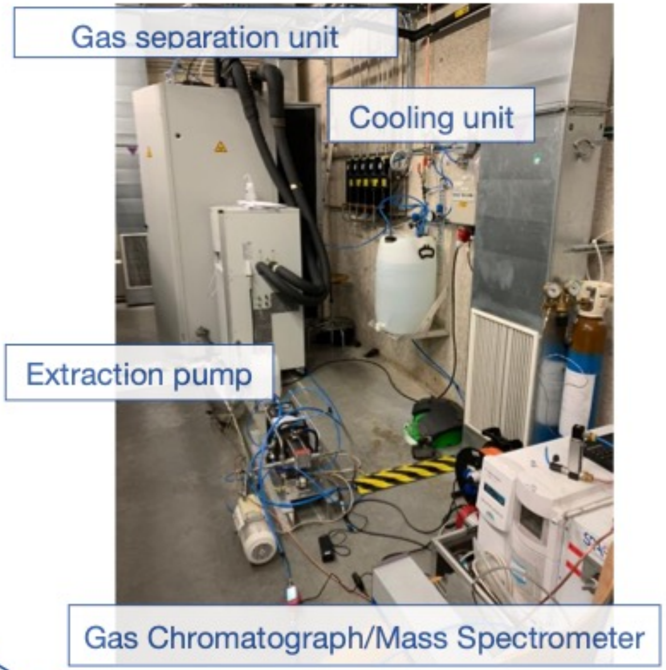
Phase 2

Detachment of R134a from iC_4H_{10}

Phase 3

Compression of R134a

$C_2H_2F_4$ recuperation prototype system under study in CMS Experiment



Recuperation efficiency ~80%

First $C_2H_2F_4$ recuperation system under construction: installation foreseen beginning of 2023 in CMS experiment

Gas disposal

Abatement plants are employed when GHGs are polluted and therefore are not reusable

In case all studies on recuperation will not bring to efficient recuperation plants, industrial system able to destroy GHGs avoiding their emission into the atmosphere have been considered

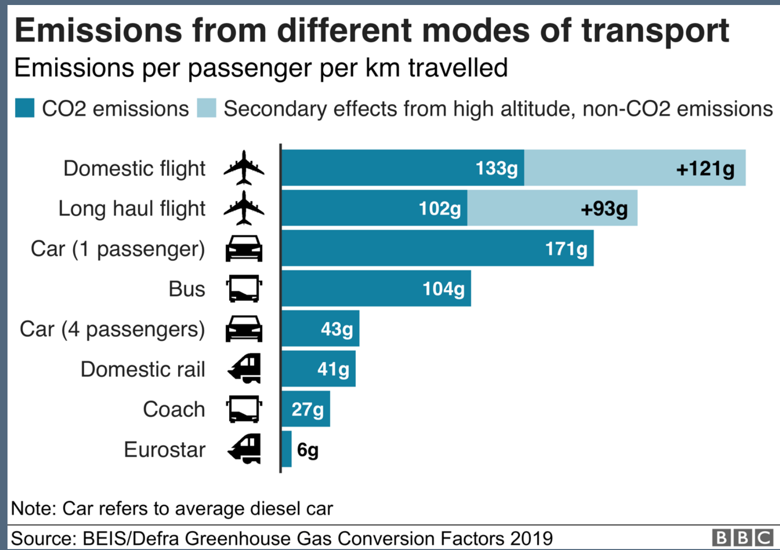
Quite heavy infrastructure required:

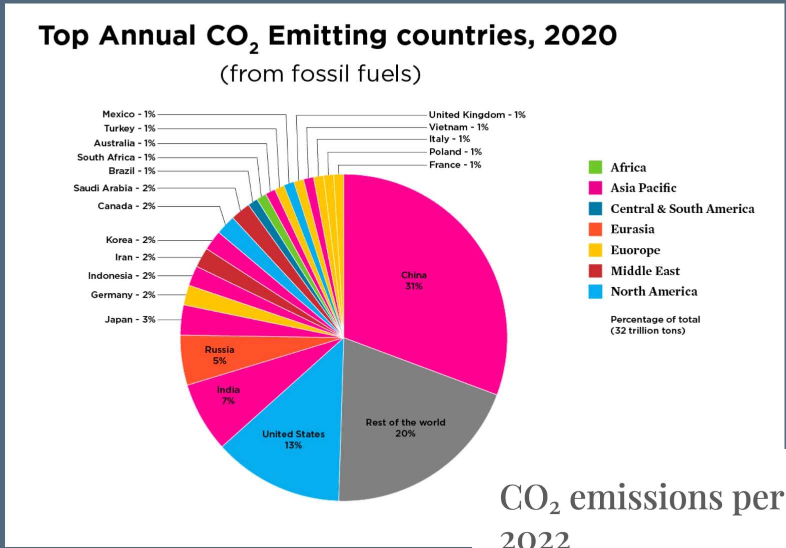
- CH_4/city gas + O_2 supply + N_2 supply
- Waste water treatment
- PFC/HFC are converted in CO_2 + HF acid dissolved in water
- disposal of remaining waste/mud
  - To have the gas at the exhaust (600-1000 l/h)

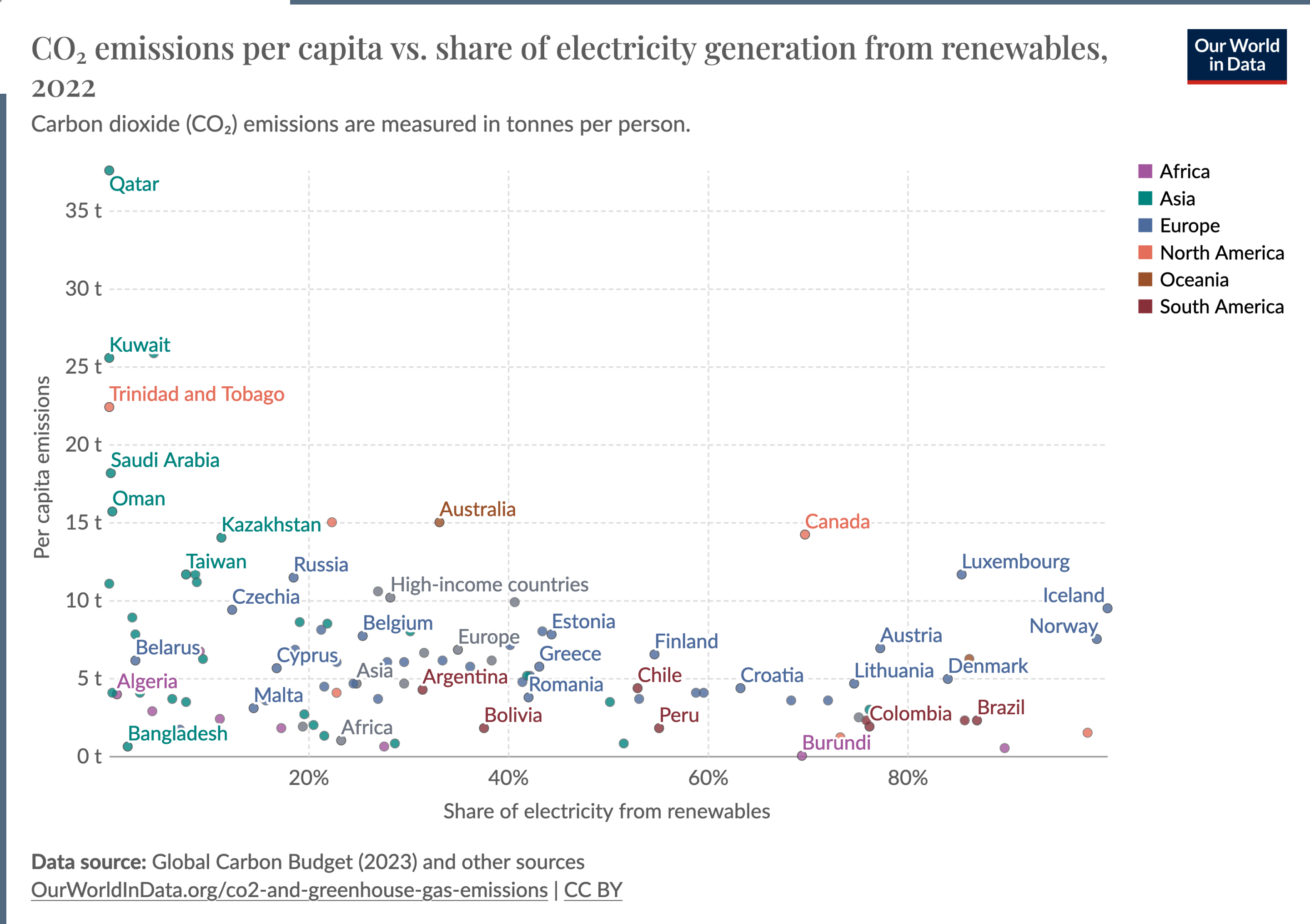
Found also companies available to take PFC/HFC based mixture for disposal: but extremely expensive

Carbon footprint of PP researchers

- Flying!
  - 15% of E consumption for an average UK citizen
  - Particle Physicists fly a lot (esp. seniors)! Let's say, per year:
    - 8 European trips (eg use from London to Zurich): 8 x 148 Kg CO_2: 1184 Kg CO_2
    - 1 overseas trip (eg use from London to NYC): 986 Kg CO_2
    - Total: 2170 Kg CO_2: ~87 countries where the average citizen emits less CO_2 in a year (incl. India, Morocco, Peru, Colombia)!
    - Using: Guardian calculator
  - A nearly carbon-neutral conference model
  - Best calculator: https://www.atmosfair.de/en/offset/fix/




Top Annual CO_2 Emitting countries, 2020
(from fossil fuels)
Mexico - 1%
Turkey - 1%
Australia - 1%
South Africa - 1%
Brazil - 1%
Saudi Arabia - 2%
Canada - 2%
Korea - 2%
Iran - 2%
Indonesia - 2%
Germany - 2%
Japan - 3%
United Kingdom - 1%
Vietnam - 1%
Italy - 1%
Poland - 1%
France - 1%
China 31%
Russia 5%
India 7%
United States 13%
Rest of the world 20%
Africa
Asia Pacific
Central & South America
Eurasia
Euorope
Middle East
North America
Percentage of total (32 trillion tons)

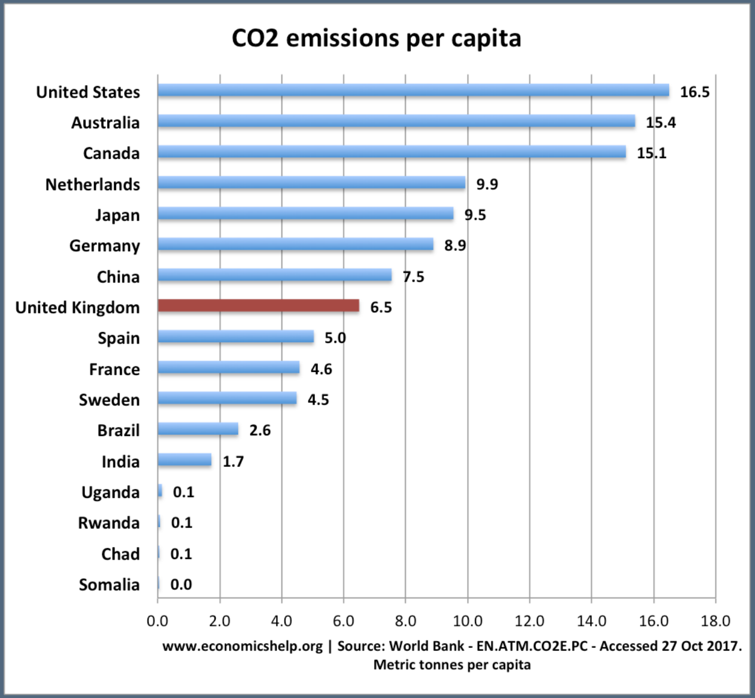

CO_2 emissions per capita vs. share of electricity generation from renewables, 2022
Carbon dioxide (CO_2) emissions are measured in tonnes per person.
Our World in Data
Qatar
Kuwait
Trinidad and Tobago
Saudi Arabia
Oman
Kazakhstan
Australia
Canada
Taiwan
Russia
High-income countries
Luxembourg
Czechia
Iceland
Belgium
Estonia
Norway
Europe
Finland
Austria
Belarus
Cyprus
Greece
Asia
Chile
Croatia
Lithuania
Denmark
Algeria
Argentina
Romania
Malta
Bolivia
Peru
Colombia
Brazil
Africa
Bangladesh
Burundi
35 t
30 t
25 t
20 t
15 t
10 t
5 t
0 t
Per capita emissions
20%
40%
60%
80%
Share of electricity from renewables
Africa
Asia
Europe
North America
Oceania
South America
Data source: Global Carbon Budget (2023) and other sources
OurWorldInData.org/co2-and-greenhouse-gas-emissions | CC BY

List of top CO_2 emitters

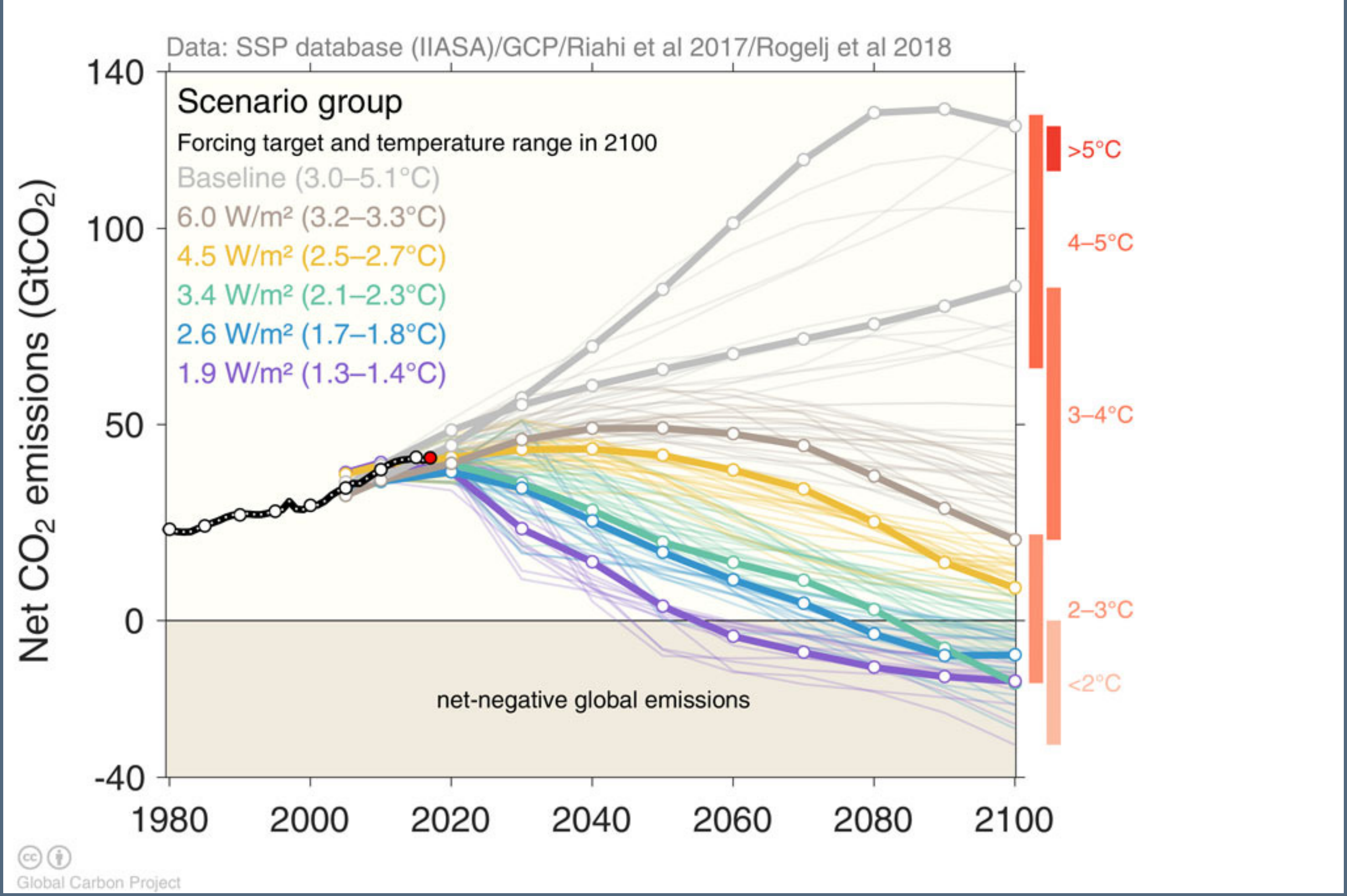
Forbes

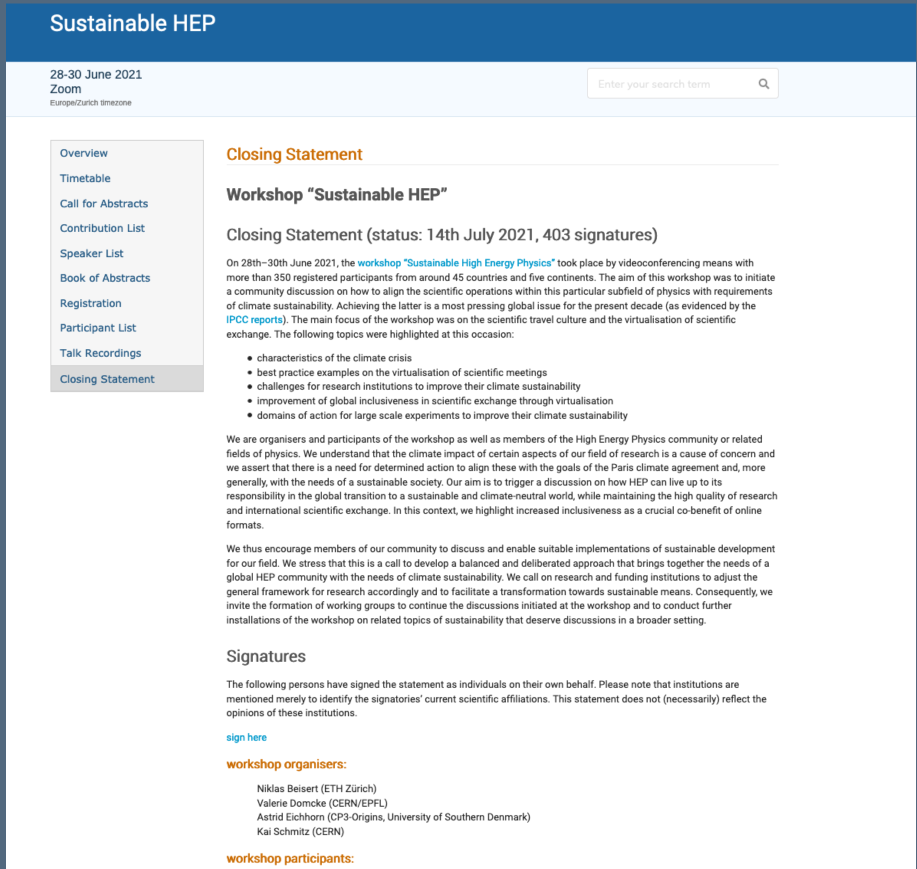
Country	2018 CO2 Emissions in Billion Metric Tons	Global Share	Change Since Kyoto Protocol
China	9.43	27.8%	54.6%
U.S.	5.15	15.2%	-12.1%
India	2.48	7.3%	105.8%
Russia	1.55	4.6%	5.7%
Japan	1.15	3.4%	-10.1%
Germany	0.73	2.1%	-11.7%
South Korea	0.70	2.1%	34.1%
Iran	0.66	1.9%	57.7%
Saudi Arabia	0.57	1.7%	59.9%
Canada	0.55	1.6%	1.6%

Economicshelp.org



Emissions pathway





Sustainable HEP

28-30 June 2021
Zoom
Europe/Zurich timezone

Enter your search term

- Overview
- Timetable
- Call for Abstracts
- Contribution List
- Speaker List
- Book of Abstracts
- Registration
- Participant List
- Talk Recordings
- Closing Statement

Closing Statement

Workshop “Sustainable HEP”

Closing Statement (status: 14th July 2021, 403 signatures)

On 28th–30th June 2021, the workshop “Sustainable High Energy Physics” took place by videoconferencing means with more than 350 registered participants from around 45 countries and five continents. The aim of this workshop was to initiate a community discussion on how to align the scientific operations within this particular subfield of physics with requirements of climate sustainability. Achieving the latter is a most pressing global issue for the present decade (as evidenced by the IPCC reports). The main focus of the workshop was on the scientific travel culture and the virtualisation of scientific exchange. The following topics were highlighted at this occasion:

- characteristics of the climate crisis
- best practice examples on the virtualisation of scientific meetings
- challenges for research institutions to improve their climate sustainability
- improvement of global inclusiveness in scientific exchange through virtualisation
- domains of action for large scale experiments to improve their climate sustainability

We are organisers and participants of the workshop as well as members of the High Energy Physics community or related fields of physics. We understand that the climate impact of certain aspects of our field of research is a cause of concern and we assert that there is a need for determined action to align these with the goals of the Paris climate agreement and, more generally, with the needs of a sustainable society. Our aim is to trigger a discussion on how HEP can live up to its responsibility in the global transition to a sustainable and climate-neutral world, while maintaining the high quality of research and international scientific exchange. In this context, we highlight increased inclusiveness as a crucial co-benefit of online formats.

We thus encourage members of our community to discuss and enable suitable implementations of sustainable development for our field. We stress that this is a call to develop a balanced and deliberated approach that brings together the needs of a global HEP community with the needs of climate sustainability. We call on research and funding institutions to adjust the general framework for research accordingly and to facilitate a transformation towards sustainable means. Consequently, we invite the formation of working groups to continue the discussions initiated at the workshop and to conduct further installations of the workshop on related topics of sustainability that deserve discussions in a broader setting.

Signatures

The following persons have signed the statement as individuals on their own behalf. Please note that institutions are mentioned merely to identify the signatories' current scientific affiliations. This statement does not (necessarily) reflect the opinions of these institutions.

sign here

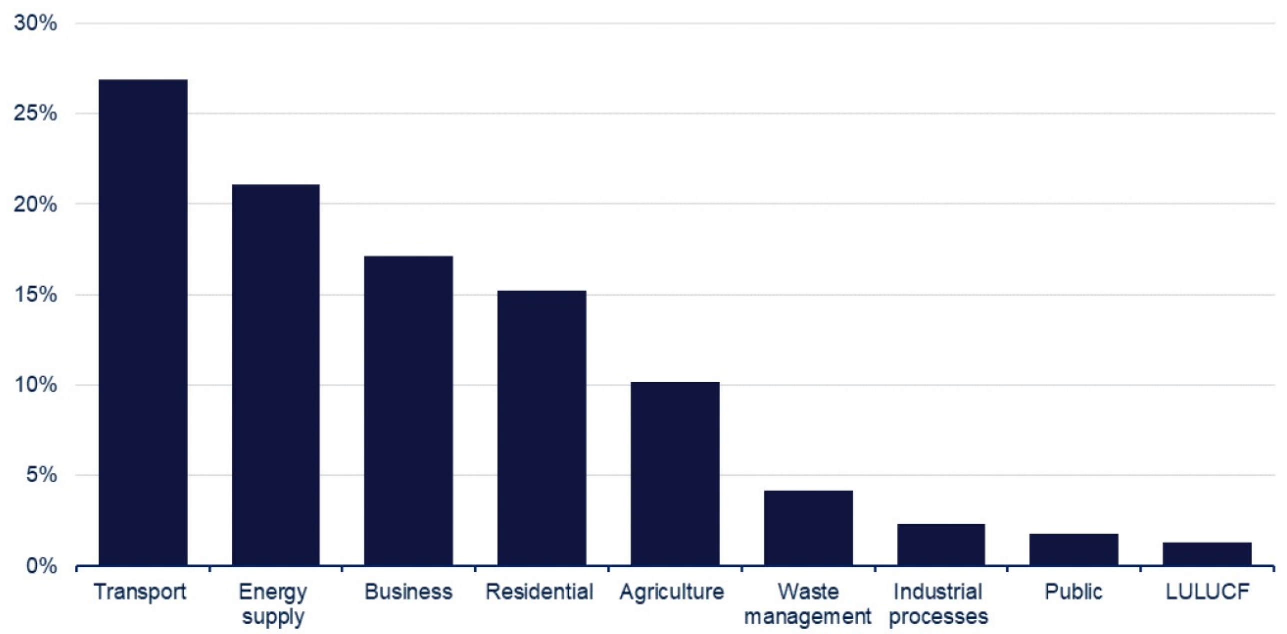
workshop organisers:

Niklas Beisert (ETH Zürich)
Valerie Domcke (CERN/EPFL)
Astrid Eichhorn (CP3-Origins, University of Southern Denmark)
Kai Schmitz (CERN)

workshop participants:

Also: white paper for Australian Astronomy: [“The imperative to reduce carbon emissions in astronomy”]

Figure 4: Territorial UK greenhouse gas emissions by NC sector, 2019 (%)



Source: Table 1.2, Final UK greenhouse gas emissions national statistics 1990-2019 Excel data tables

Note: LULUCF is land use, land use change and forestry.

World Emissions Clock

Green electricity grids by 2035

- Germany's target updated in 2022
  - The US, Canada and UK have already committed to a similar goal [100% renewable electricity grid by 2035]. Denmark is already aiming for more than 100% renewable power by 2027, Austria 100% by 2030 and Portugal and the Netherlands are well on track with recent plans to expand renewable capacities till 2030."

- US pledge
- UK CCC plan: