

The Climate Emergency: can Particle Physics ever be sustainable?

Véronique Boisvert (b. 329.7 CO₂ ppm)
@VBoisvertRHULPP

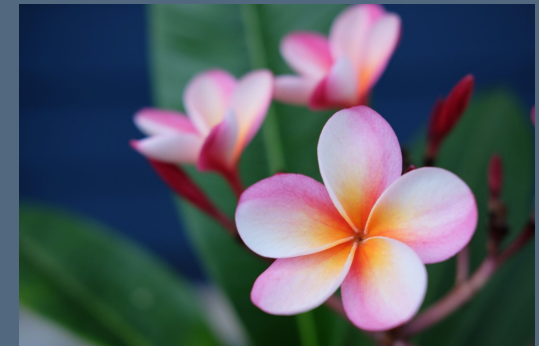


ROYAL
HOLLOWAY
UNIVERSITY
OF LONDON

19th April 2024 (427.0 CO₂ ppm – 2.2 ppm 1 year change)

Outline

- The climate emergency
- CO₂e 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!



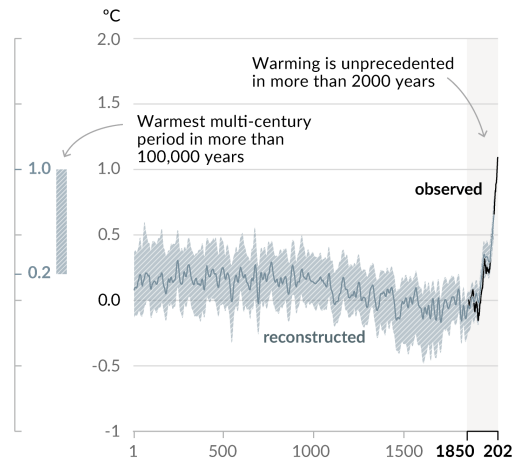
Climate Change: an emergency

IPCC AR6

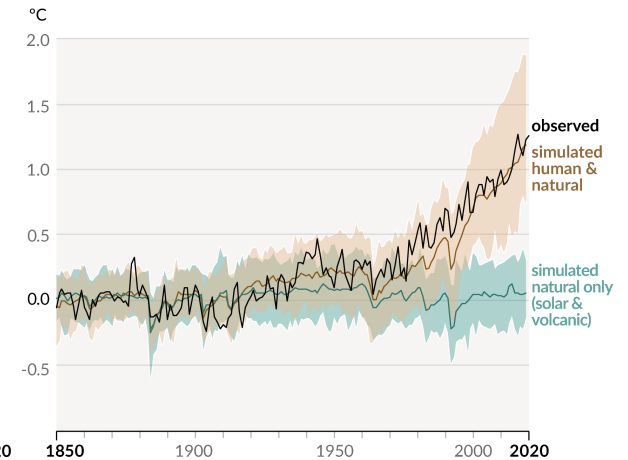
“Recent changes in the climate are widespread, rapid, and intensifying, and unprecedented in thousands of years.

Changes in global surface temperature relative to 1850-1900

a) Change in global surface temperature (decadal average) as reconstructed (1-2000) and observed (1850-2020)

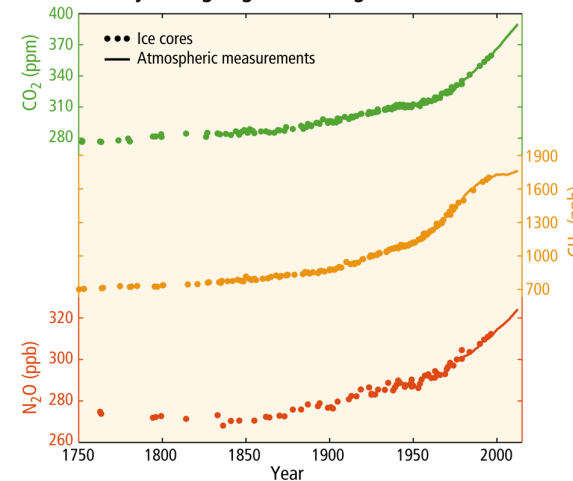


b) Change in global surface temperature (annual average) as observed and simulated using human & natural and only natural factors (both 1850-2020)



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

Globally averaged greenhouse gas concentrations

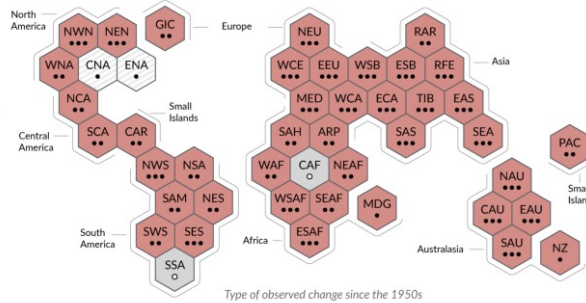
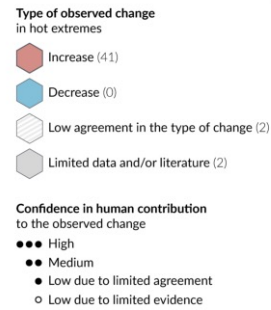


IPCC AR5

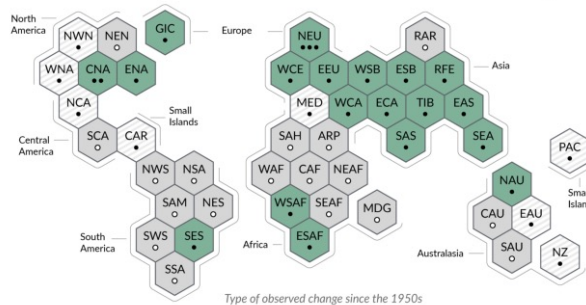
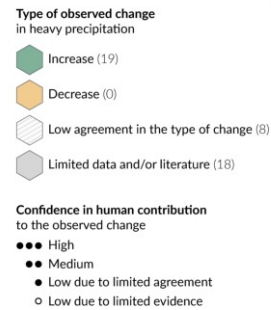
Climate Change: an emergency

Climate change is already affecting every inhabited region across the globe with human influence contributing to many observed changes in weather and climate extremes

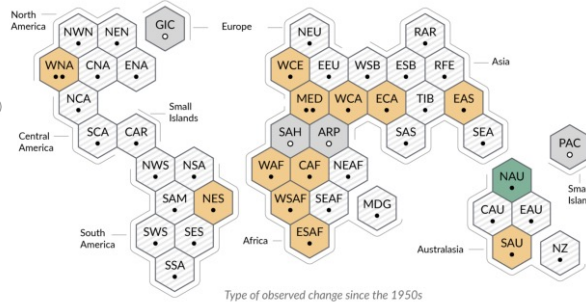
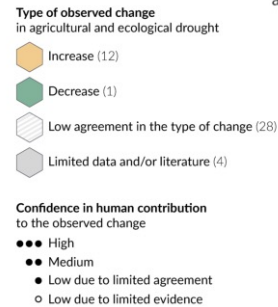
a) Synthesis of assessment of observed change in **hot extremes** and confidence in human contribution to the observed changes in the world's regions



b) Synthesis of assessment of observed change in **heavy precipitation** and confidence in human contribution to the observed changes in the world's regions



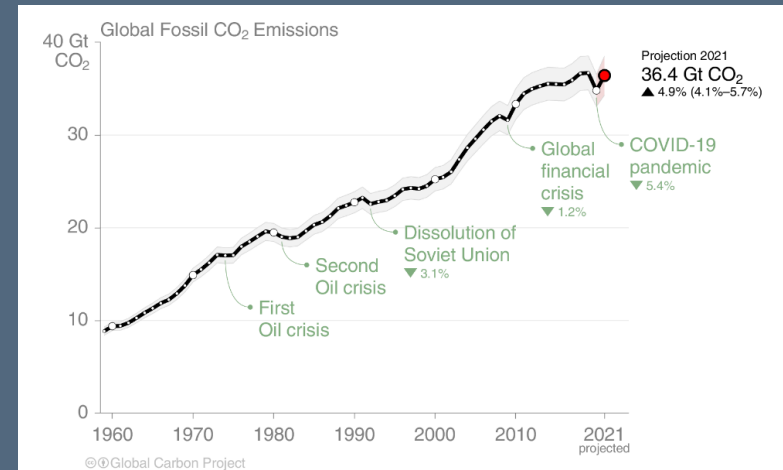
c) Synthesis of assessment of observed change in **agricultural and ecological drought** and confidence in human contribution to the observed changes in the world's regions



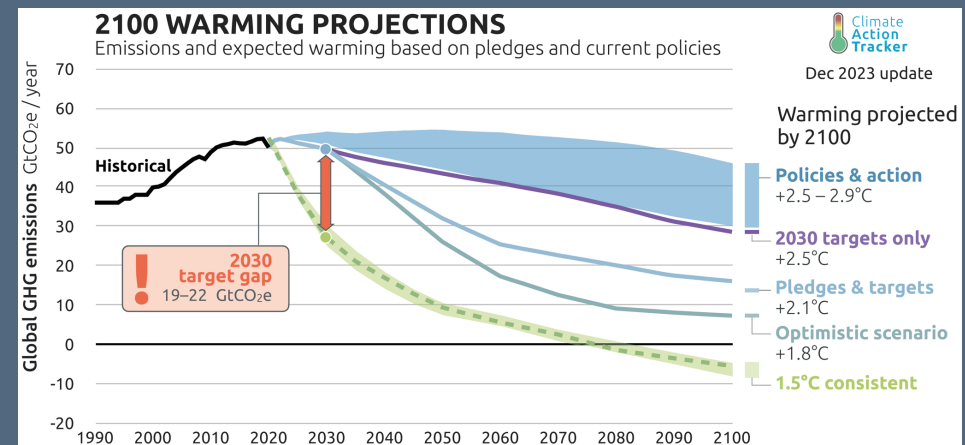
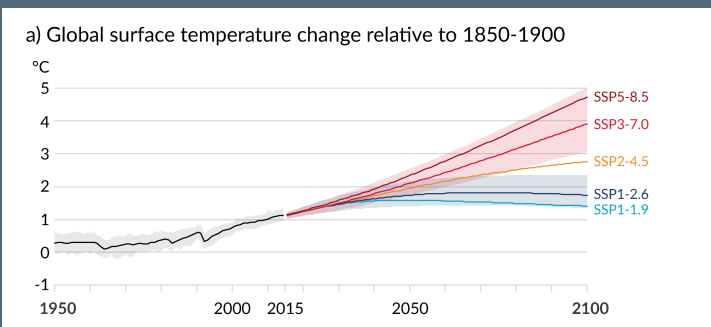
IPCC AR6

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

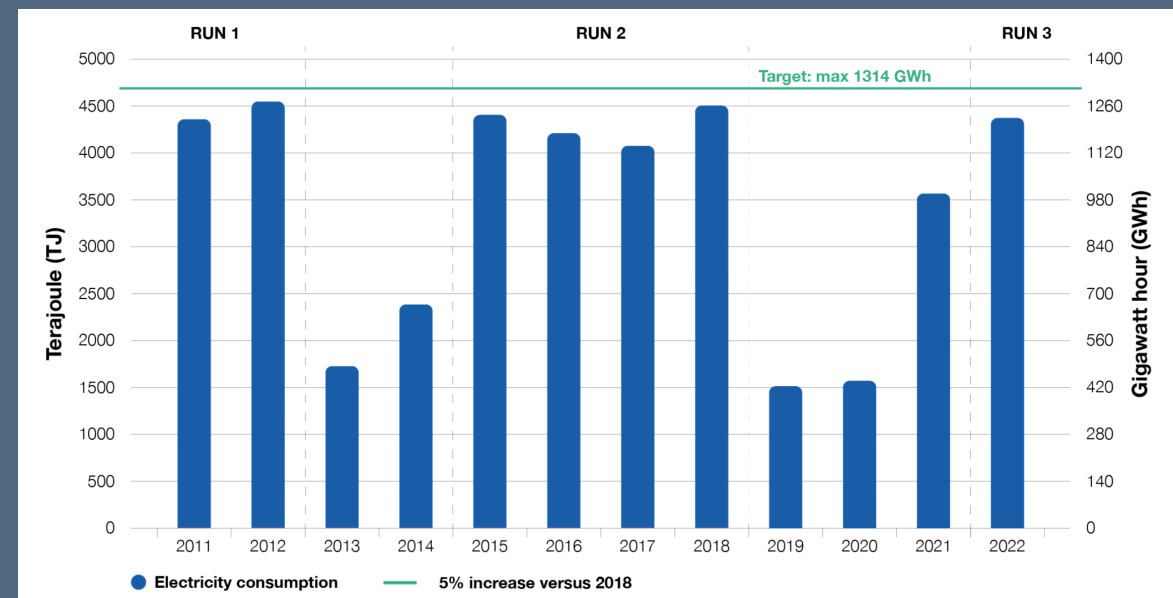
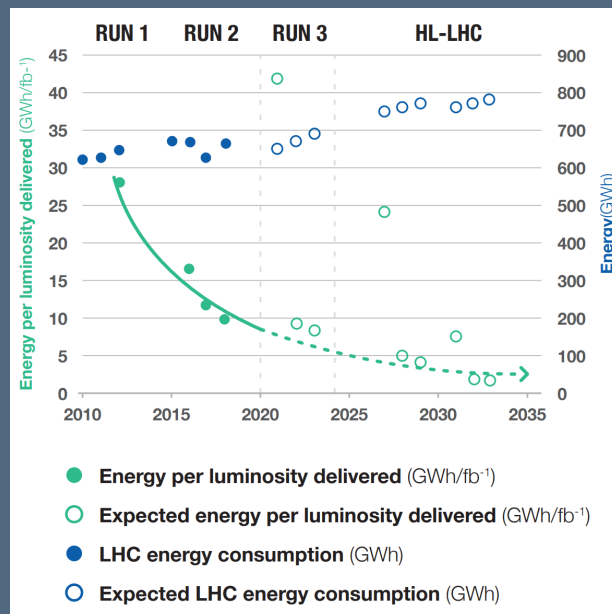
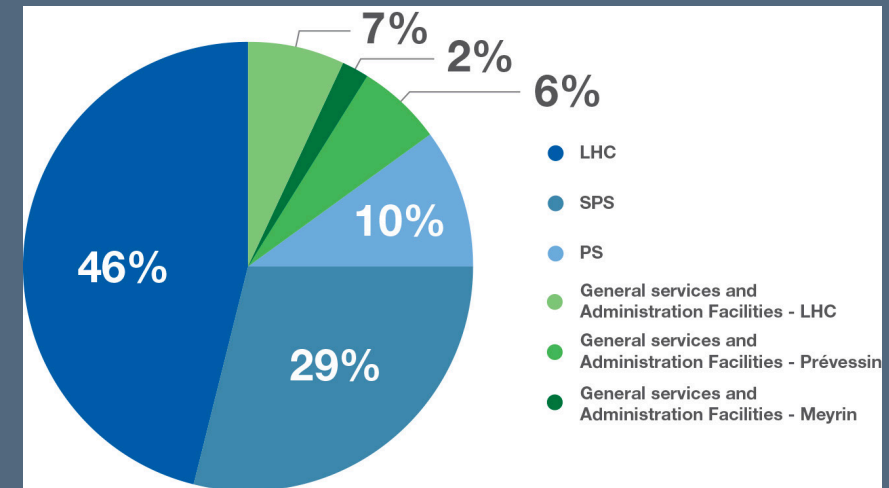


Ice ages: ~ -5°C
 +4°C: civilization breakdown...

Emissions from accelerators: operations

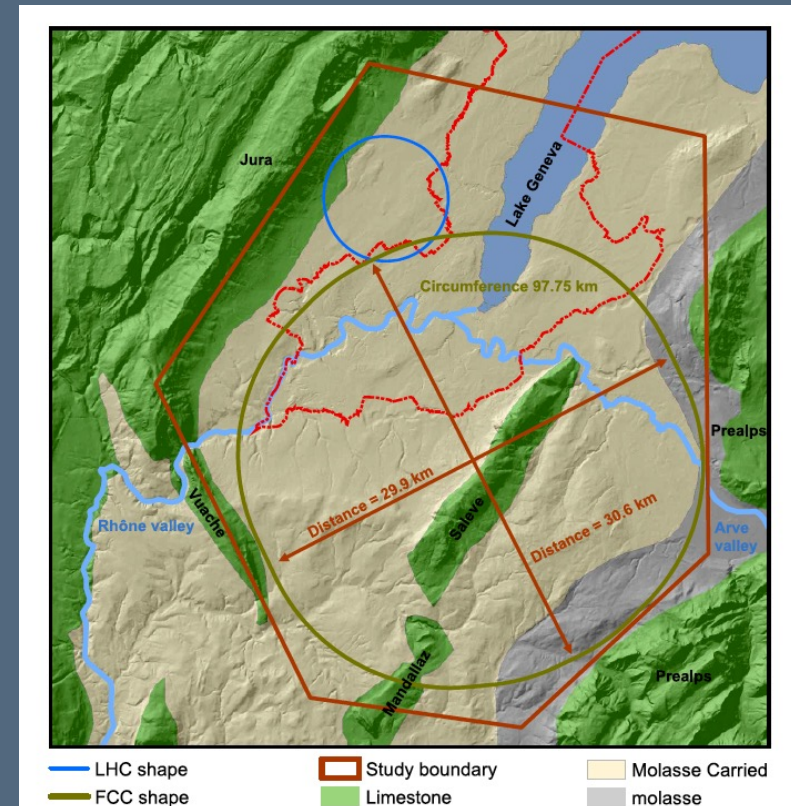
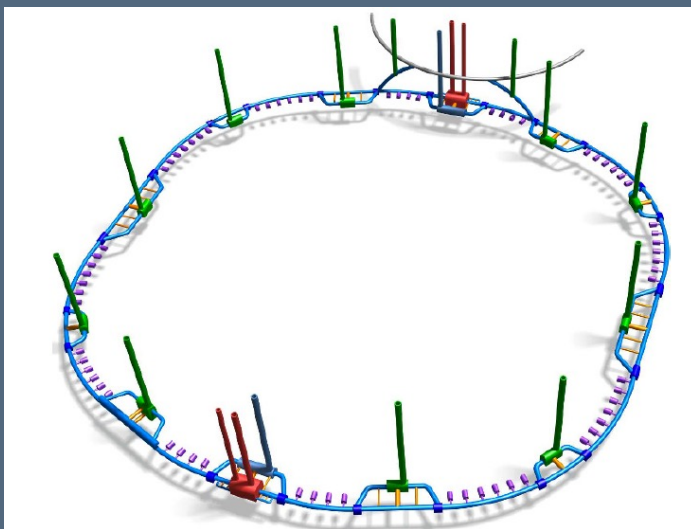
- CERN now releases [Environment reports](#) (1st: 2017-18, 2nd: 2019-20, 3rd: 2021-22)
- CERN peak power: ~180 MW (~ 1/3 of Geneva)
- Per year: ~ 1.2 TWh (~ 2% of Switzerland, 0.03% of Europe)
- LHC: ~55% of CERN's E consumption
- Electricity mainly comes from France: 90% carbon free (2022)

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 CO₂ emissions
- [Paper](#) on emissions from road tunnels:
 - Lowest estimate: ~500k tonnes CO₂ emissions
- Comparison: Using [report](#) for CO₂e for construction of buildings: = building 8 London Shards!
- 1.4% of CH CO₂e emissions (2016)
- **Plant 6 million trees!**

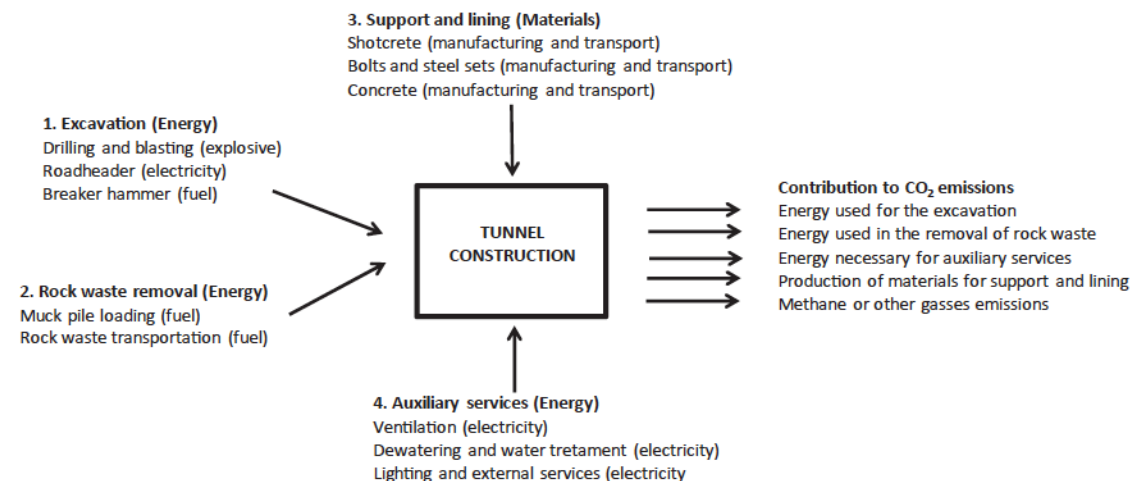
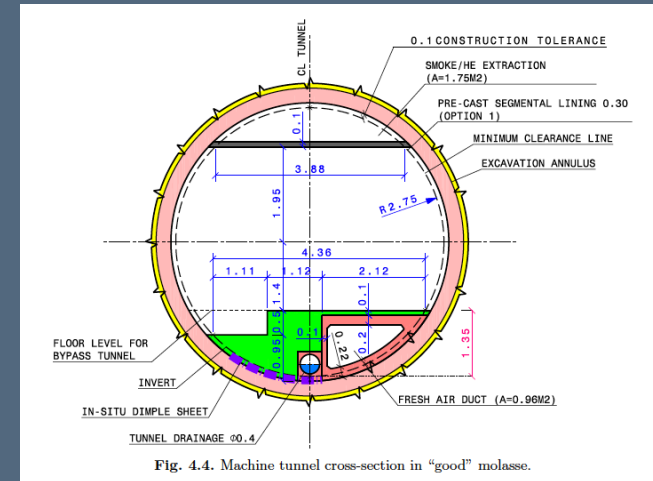
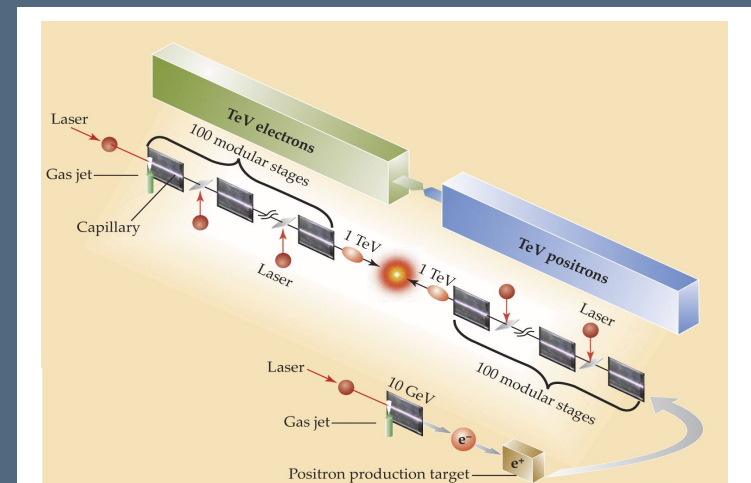


Fig. 1. Schematic overview of the system boundary.

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

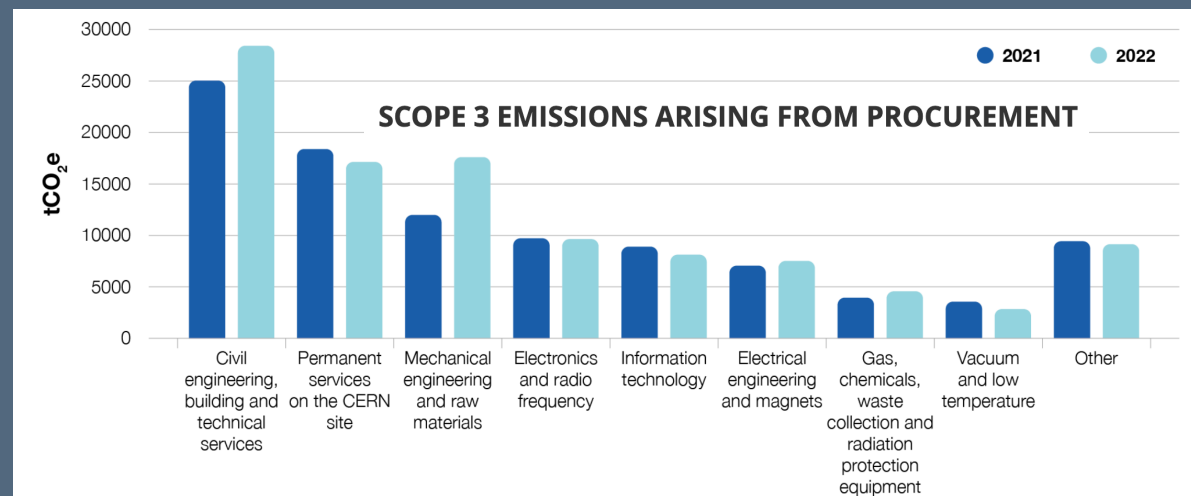
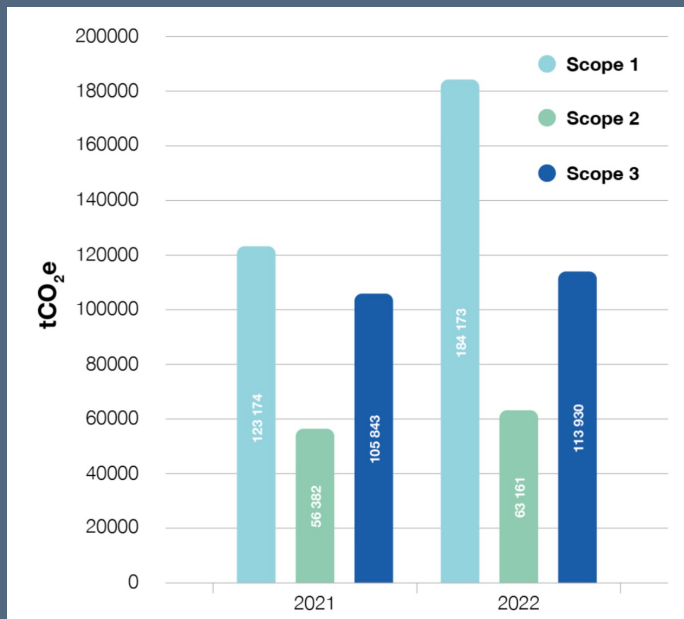


Physics Today **62**, 3, 44 (2009);
<https://doi.org/10.1063/1.3099645>

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.)

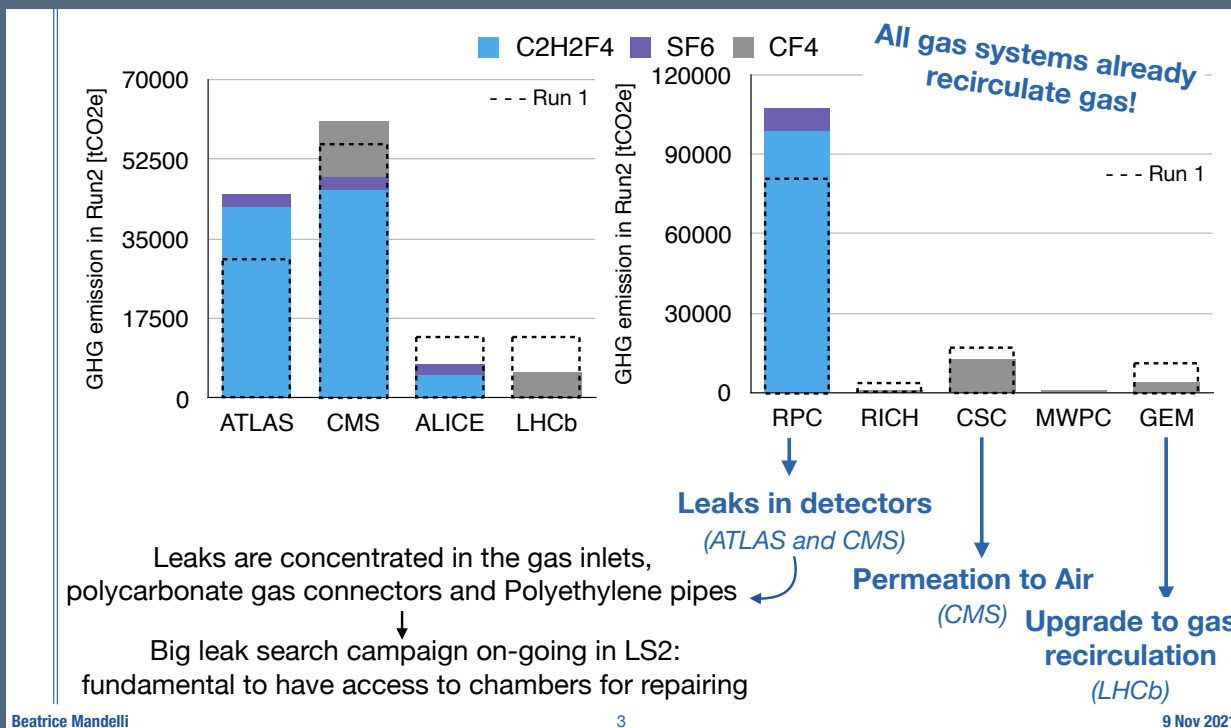
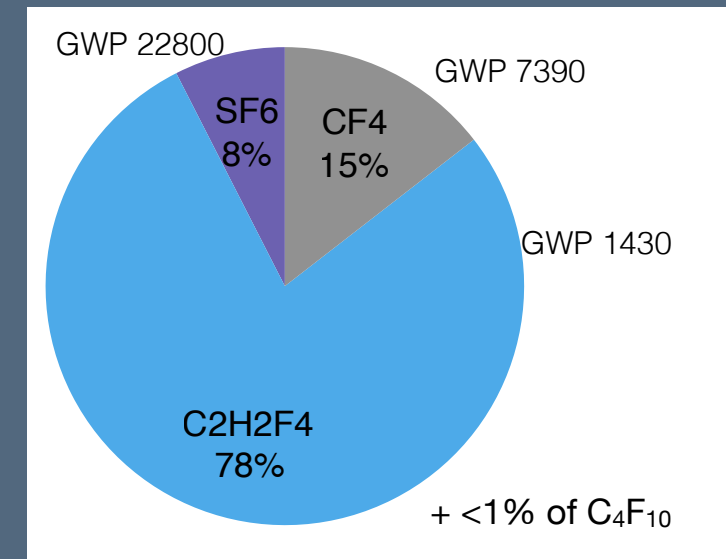
GROUP	GASES	tCO ₂ e 2021	tCO ₂ e 2022
Perfluorocarbons (PFCs)	CF ₄ , C ₂ F ₆ , C ₃ F ₈ , C ₄ F ₁₀ , C ₆ F ₁₄	55 921	68 989
Hydrochlorofluorocarbons (HFCs)	HFC-23 (CHF ₃) HFC-32 (CH ₂ F ₂) HFC-134a (C ₂ H ₂ F ₄) HFC-404a HFC-407c HFC-410a HFC-507	36 557	86 211
Other F-gases	SF ₆ , NF ₃	16 838	18 355
Hydrofluoroolefins (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

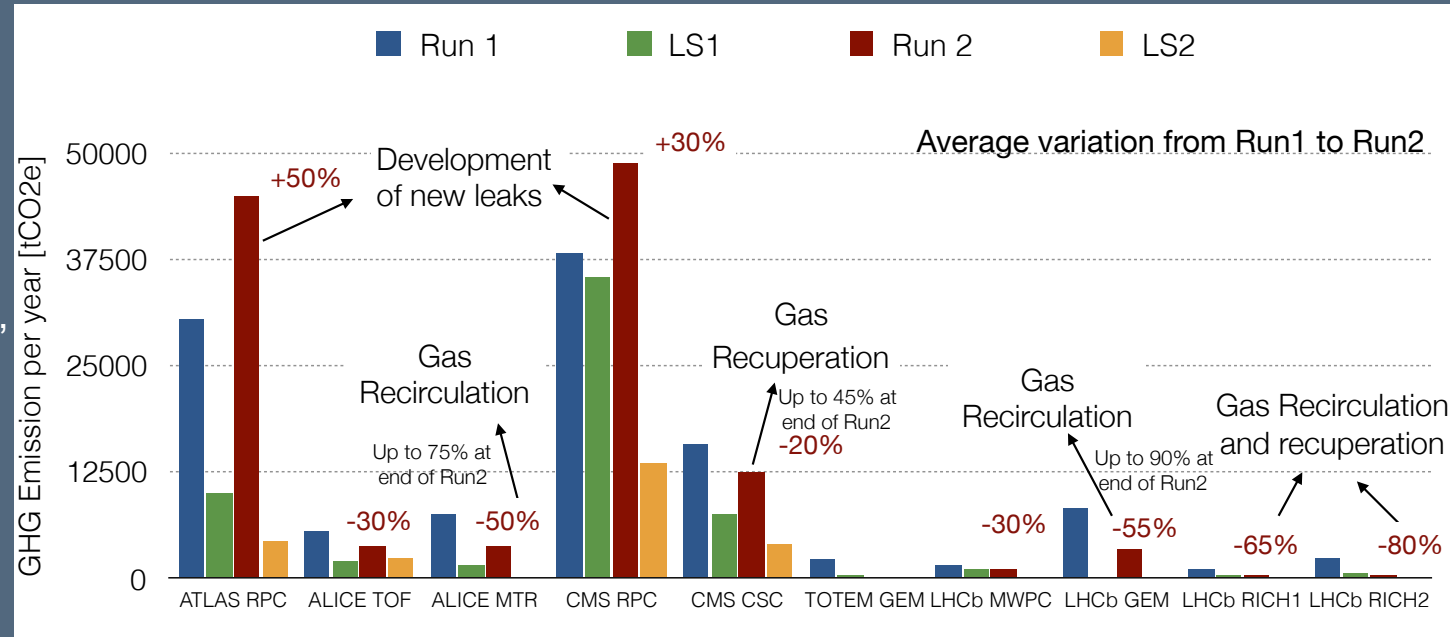
Particle detection



- Gas recirculation is 90%

Emissions from detectors

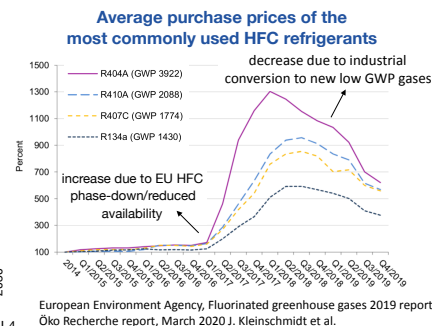
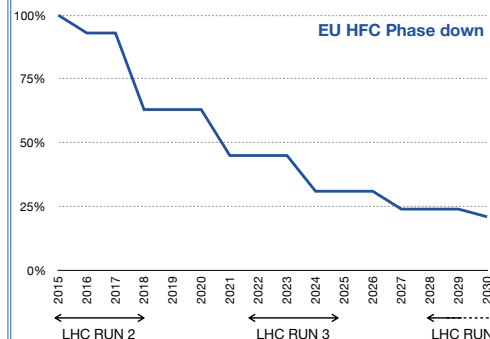
Beatrice Mandelli,
CERN Gas
Systems



EU HFC phase-down policy

European Union “F-gas regulation”:

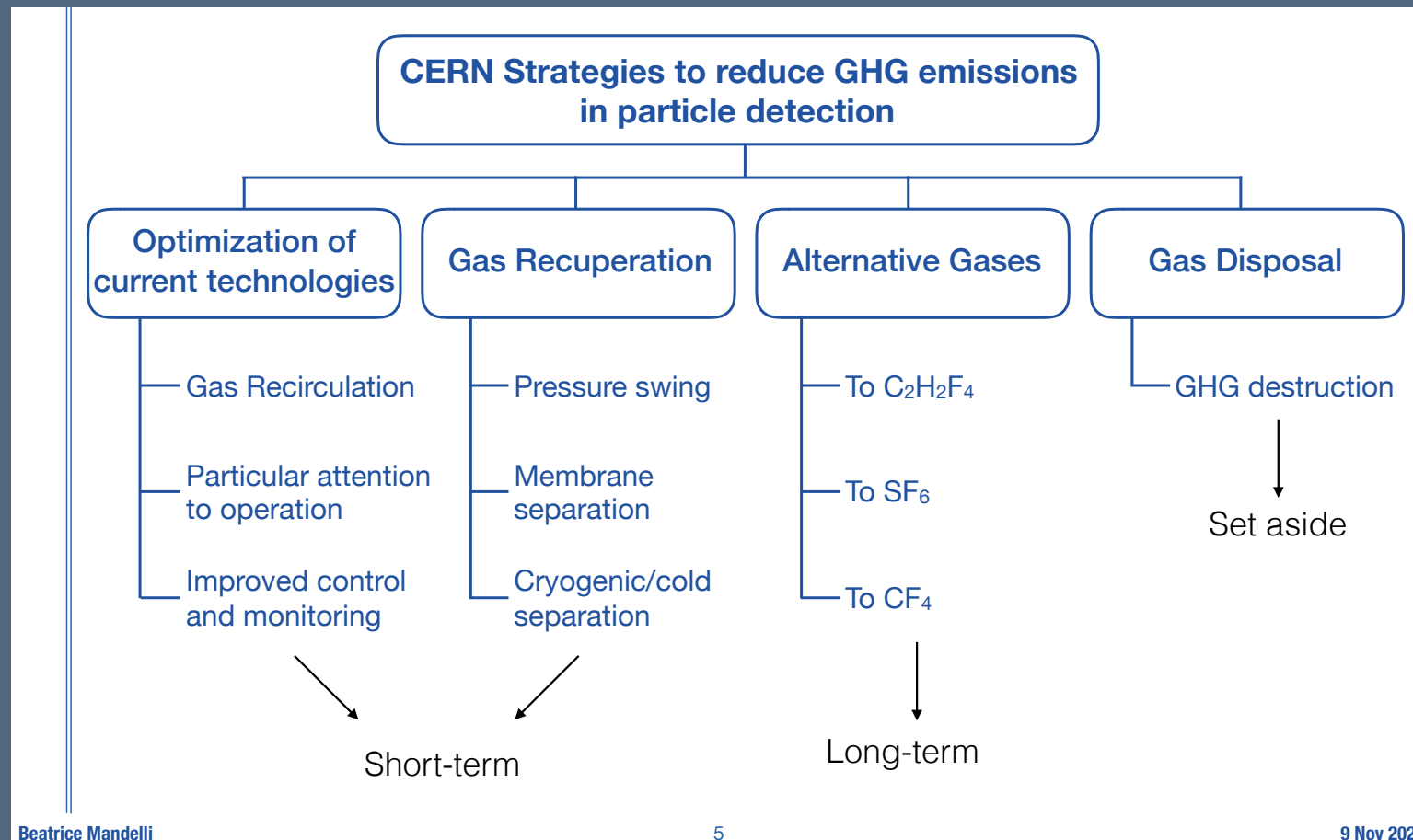
- **Limiting the total amount** of the most important F-gases that can be sold in the EU from 2015 onwards and phasing them down in steps to one-fifth of 2014 sales in 2030.
- **Banning the use** of F-gases in many new types of equipment where less harmful alternatives are widely available.
- **Preventing 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.



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

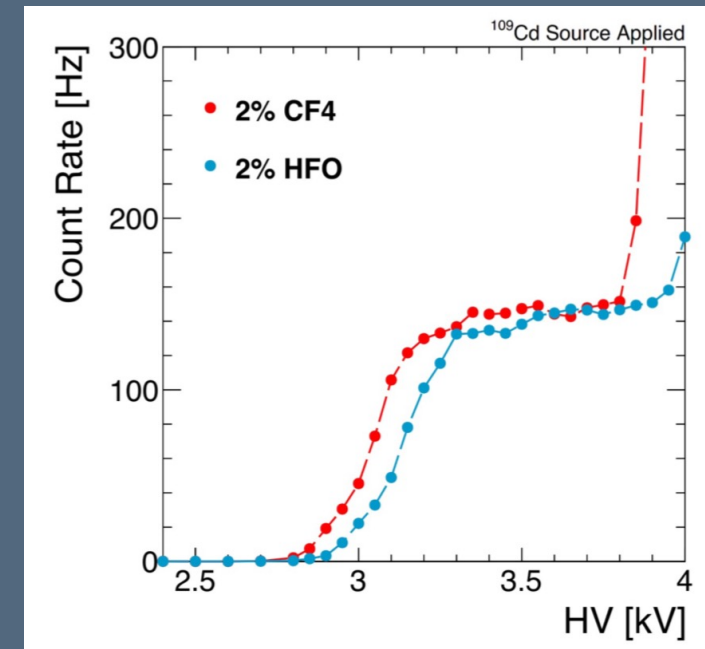
- 2020: CERN launched a working group on managing F-gases, with representatives from the departments concerned and the large LHC experiments. The group looked at issues such as the implementation of a centralised F-gas procurement policy, leak detection, replacement alternatives, training courses for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



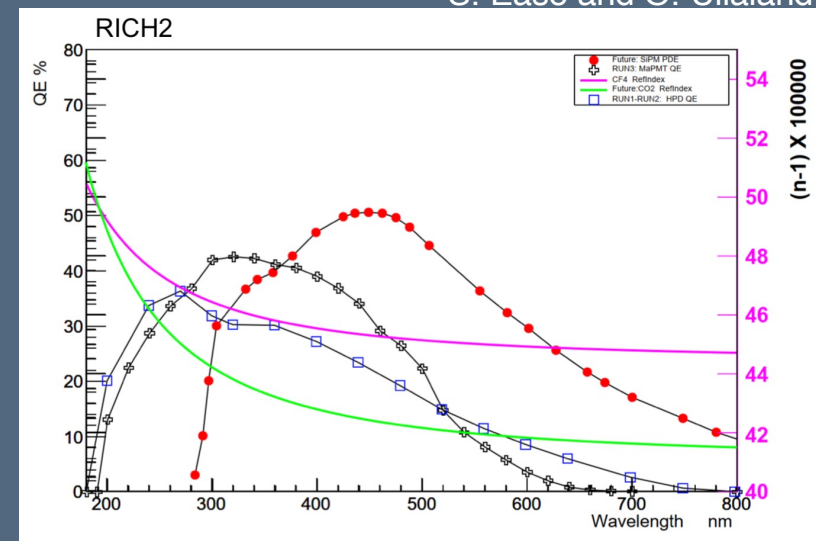
Emissions from detectors: solutions

Presented at DPF 2019

- 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 HFO_{1234ze}
- 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



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

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

Tradeoff between flammability and GWP

- Replacing F with Cl or H: it shortens atmospheric lifetime BUT increase flammability limit
- Adding C=C bond: it increases reaction with O₂



Environment

GWP represents the main environment concern

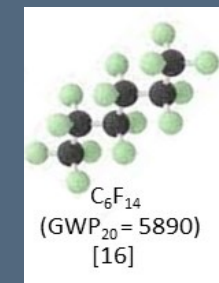
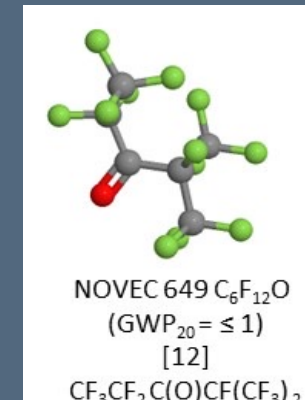
RPC short and long term performance are affected

- Good quenching gases required
- Radiation-hard gas required
- Gases cannot heavily react with H₂O or UV radiation

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



FCC-ee CDR

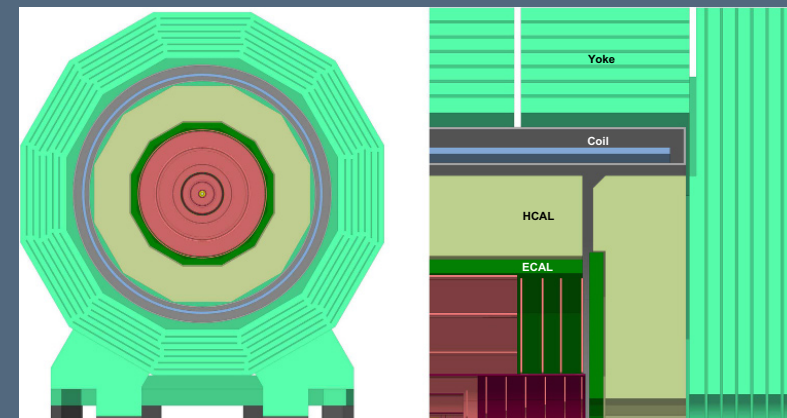


Fig. 7.4. The CLD concept detector: end view cut through (left), longitudinal cross section of the top right quadrant (right).

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 cm² silicon wafer (thickness 775 μm, diameter 300 mm, weight 0.128 kg) as identified in 2000, are summarised in

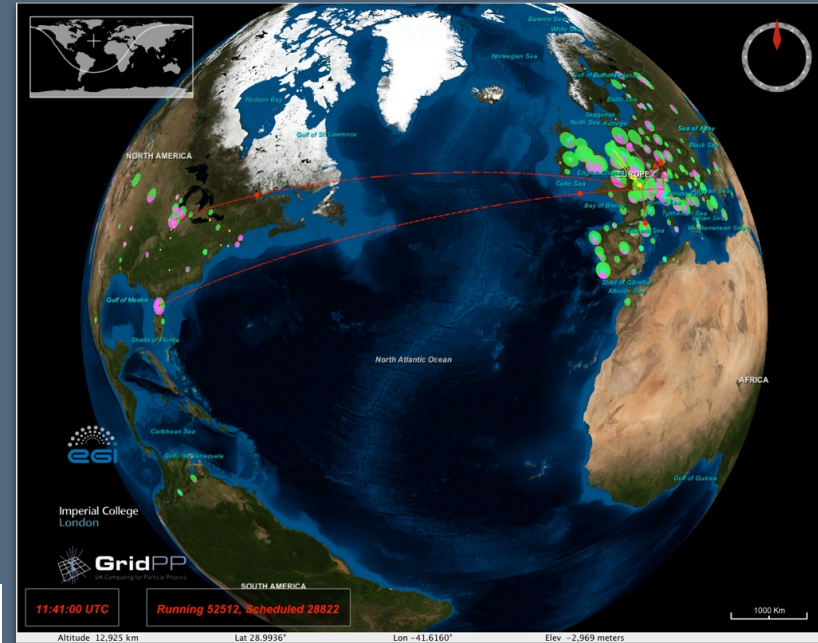
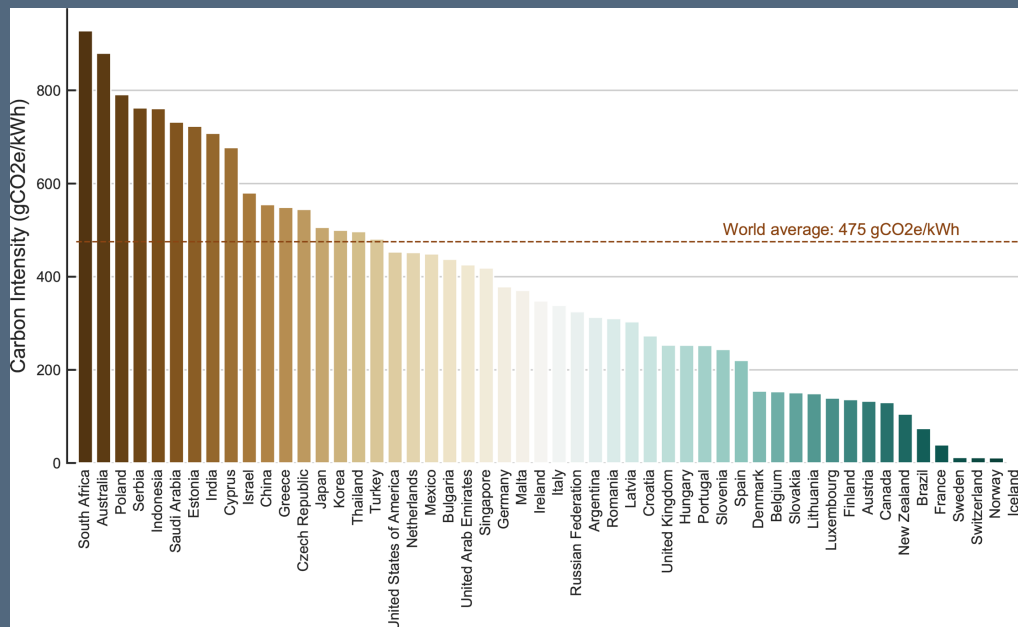
Table 6.1 [194].

Inputs	Quantity	Outputs	Quantity
Hydrogen chloride HCl (hydrochloric acid)	0.000675 kg	Co-products: Si in other co-products	0.000286 kg
Graphite (as electrode material)	0.000163 kg	Co-products: Silicon tetrachloride	0.000415 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 ₂ O	0.00188 kg		
Methanol	85.1 × 10 ⁻⁶ kg		
NO _x	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 ;-)

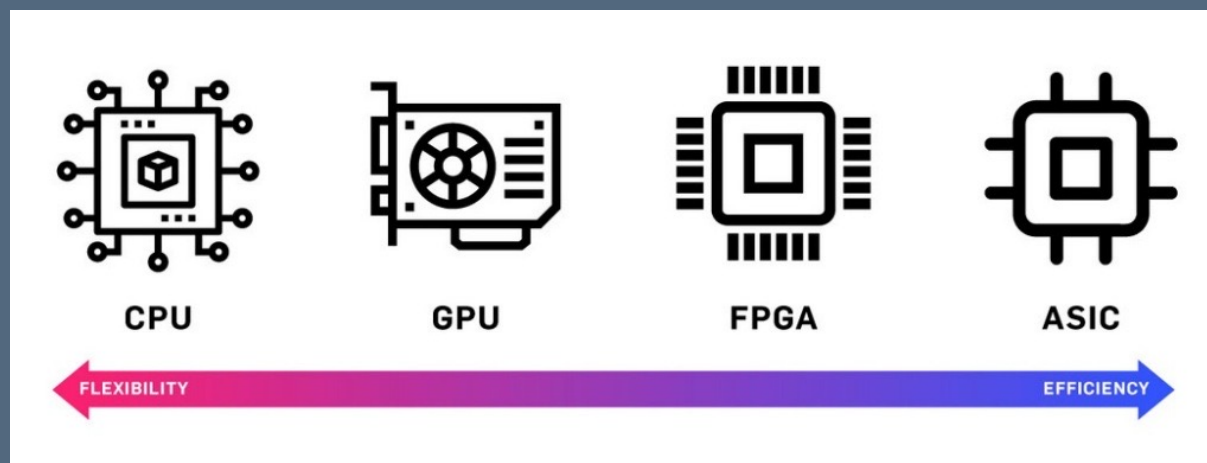
Far future (2040):

- All OECD electricity grids will be emissions free...
- But huge demand for electricity

Emissions from Computing

- **Embedded emissions...**
 - 326 (620) kg CO₂e 13' (16') MacBook Pro, 128 GB (1 TB) storage
- **... far outnumber running emissions (80-85% of lifetime emissions)**
 - 2g (3g) CO₂e/h MacBook Pro
 - 10g CO₂e/h average-efficient laptop
 - 50g CO₂e/h desktop with screen
 - + 22g CO₂e/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%

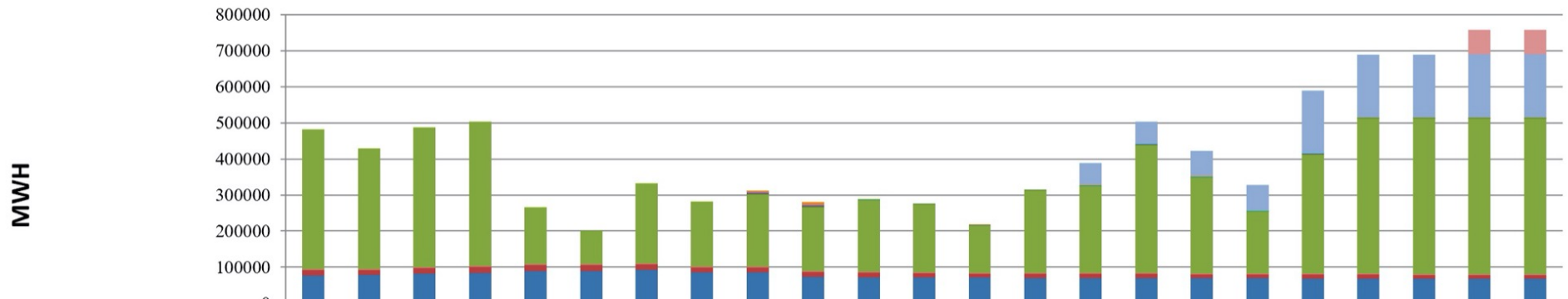
Current Performance: -51.0%

	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

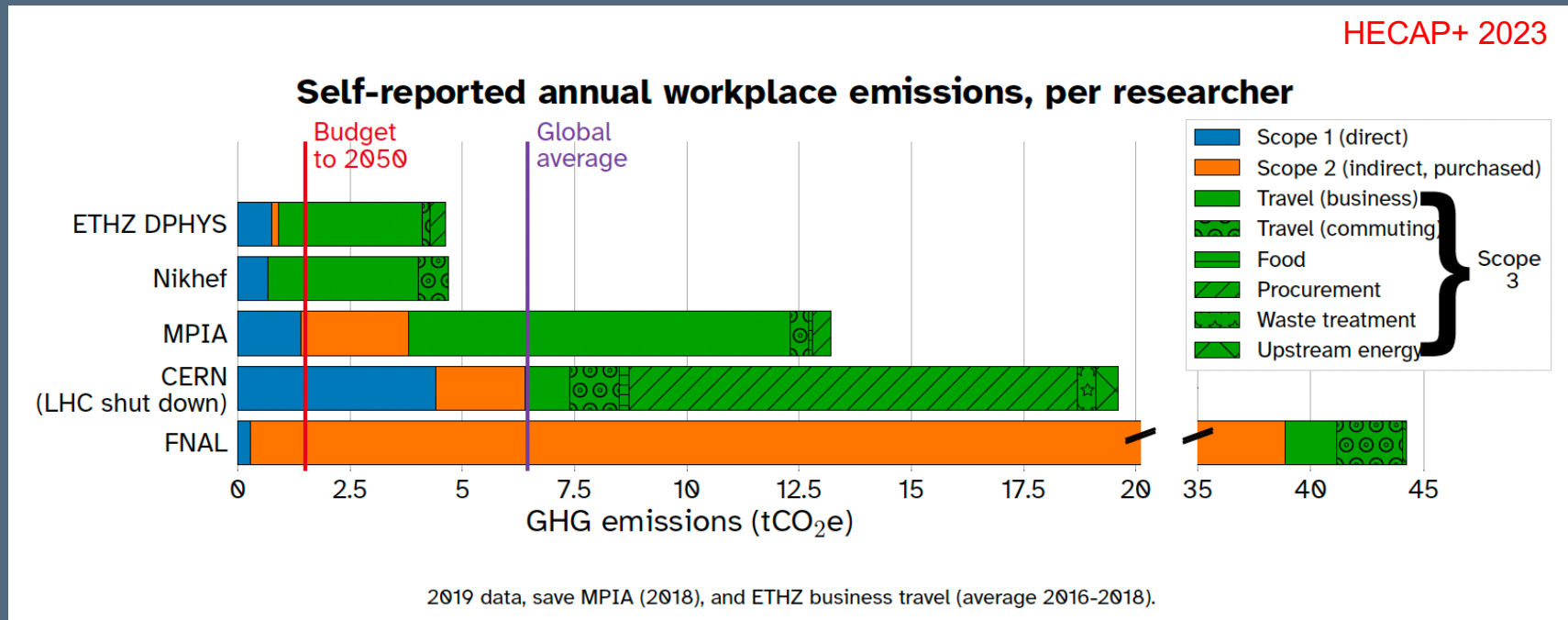
Electricity Projections for Fermilab



	FY08	FY09	FY10	FY11	FY12	FY13	FY14	FY15	FY16	FY17	FY18	FY19	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									3942	8869.5	548.9508	521.6047	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)											324.825	348.5065	471.1054	1752	1752	1752	1752	1752	1752	1752	1752	1752	1752
Muon G-2 (MC-1)									5080.8	5080.8	932.8659	947.4887	1057.261	1057.261	876	876	876	876	876	876	876	876	876
Existing Particle Accelerators HEMS	391208.4	337149.6	390287.5	402903.2	160678.4	14728.3	224836.8	182507.3	203178.3	179476.8	200217.4	189303.5	133630	229464.3	242312.3	357463.2	267470.5	172838	332149.8	432510	432866.4	433220.4	433570.1
Existing High Performance Computing HEMS	16548.45	17215.17	17230.22	19718.99	19542.3	18389.43	16574.14	14742.82	14742.82	15904	15321	14334	13131.06	13131.06	13131.06	13131.06	13131.06	13131.06	13131.06	13131.06	13131.06	13131.06	13131.06
Site Base	74689.13	75595.25	80021.26	80555.81	85979.34	86723.26	90333.26	83857.44	83617.98	70310.85	69309.95	68919.64	68533.19	68150.66	7771.85	7396.85	7025.65	6658.15	6294.31	5934.12	5577.52	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](#)



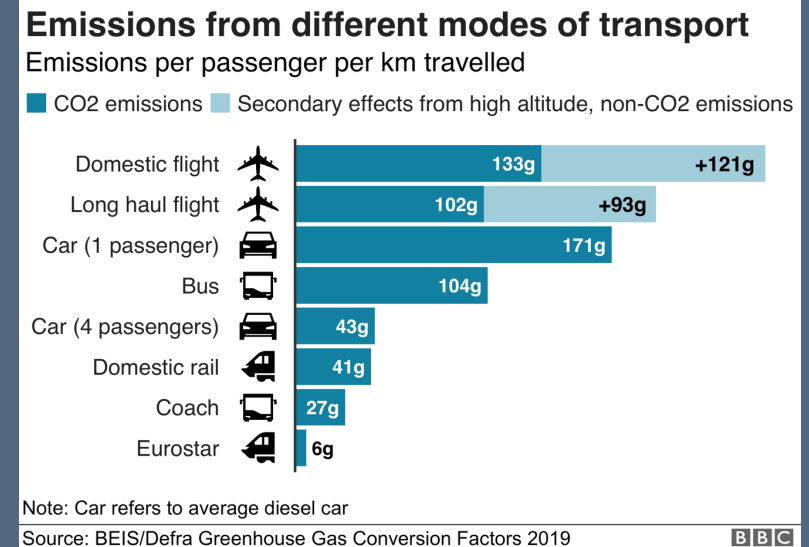
Remaining carbon budget:

(50% chance of staying < 1.5°C) 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 (CO₂ 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 ₂ e]	2,883	8,432	1,902	2,699	2,648	0

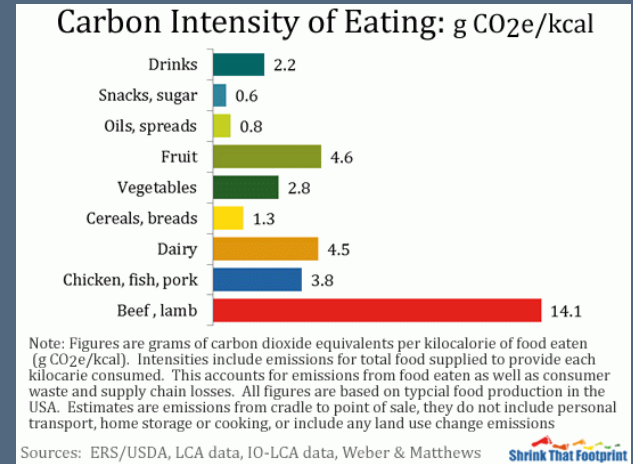
Table 5.3: Total number of participants of recent ICHEP conferences and the GHG emissions per participant. The corresponding numbers for the American Geophysical Union (AGU) Fall Meeting [147] are shown for reference.

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		perc.	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			

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



Pre-pandemic

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

My ATLAS footprint?
 Scope 1+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)

#83: Input to the European Strategy
Update: Ensuring the Future of Particle
Physics in a More Sustainable World:
3 recommendations

Submitted 319 signatures
Now opening signatures again
tinyurl.com/yaw523ng
Please sign!
Follow us on Twitter: @ESClimateChange



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: [TGo7](#)
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 Britzger³, Micah Buuck⁴, Astrid Eichhorn⁵, Michael Headley⁶, Kristin Lohwasser⁷, and Petra Merkel⁸

¹University of Nebraska-Lincoln, Lincoln, NE, USA

²Royal Holloway University London, United Kingdom

³Max-Planck-Institute for Physics, Munich, Germany

⁴SLAC National Accelerator Laboratory, Menlo Park, CA, USA

⁵CP3-Origins, University of Southern Denmark, Denmark

⁶Sanford Underground Research Facility (SURF), Lead, SD, USA

⁷University of Sheffield, United Kingdom

⁸Fermi 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 CO₂ 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



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**.

SUSTAINABILITY IN HECAP+

An initiative of scientists in the High Energy Physics, Cosmology, Astroparticle Physics, and Hadron and Nuclear Physics (HECAP+) communities concerned about the climate crisis and advocating for a transition towards fairer and more sustainable practices in our fields.

[Released on 5th June 2023: Full report available](#)

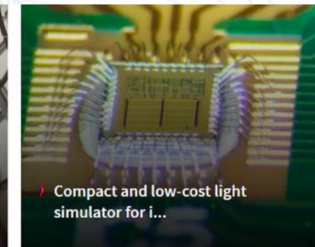
[Show support here](#)

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

Knowledge and technology for the environment - Highlights



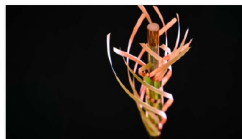
□ + Others



CERN to partner with industry on innovation to reduce environmental impact of large-scale facilities

In its commitment to minimising its environmental impact and developing technologies that can help society towards a better planet, CERN has formed an innovation partnership with ABB, with the aim of reducing the Laboratory's energy consumption

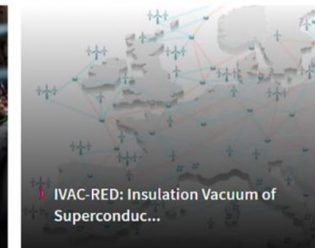
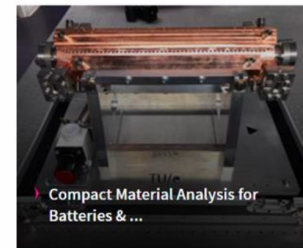
Environment | 14 June, 2022



CERN and Airbus partnership on future clean aviation

CERN and Airbus UpNext sign a collaboration agreement to assess the use of superconducting technologies for future low-emission aeroplanes.

AerospaceEnvironment | 01 December, 2022



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

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)

INDICO.CERN.CH/E/SUSTHEP24

SUSTAINABLE HEP 2024

3rd International Workshop on Sustainable High Energy Physics
10 – 12 June 2024



The 3rd edition of the Sustainable High Energy Physics (HEP) workshop, will take place Monday 10th through Wednesday 12th June from 14:00 to 17:00 CET. Within three half-days, this free, online-only workshop aims to present the intersection of HEP and the climate crisis, to highlight the sustainable initiatives ongoing in HEP, and to workshop with attendees on positive tangible outcomes. The program will consist of invited talks, panel discussions, workshops and submitted talks accompanied by a discussion forum on Mattermost.

ORGANIZING COMMITTEE

- SHREYASI ACHARYA (INFN BARI)
- JULIETTE ALIMENA (DESY)
- DANIEL BRITZGER (MPP)
- BRENDON BULLARD (SLAC)
- SHREYA SAHA (MCGILL)
- HANNAH WAKELING (OXFORD)

ADVISORY COMMITTEE


- SHANKHA BANJEREE (CHENNAI)
- NIKLAS BEISERT (ETHZ)
- VALERIE DOMCKE (CERN)
- VALERIE LANG (FREIBURG)
- PETER MILLINGTON (MANCHESTER)
- AYAN PAUL (NORTHEASTERN)

CONTACT
indico.cern.ch/e/susthep24
susthep24@physics.ox.ac.uk

10 – 12 JUNE 2024
14:00–17:00 CET
ONLINE VIA ZOOM

SCAN ME



An aerial photograph of a coastal landscape featuring sand dunes, a bay, and a coastline. The scene is captured in a soft, low-angle light, possibly during dawn or dusk, with a blue and grey color palette. The text is overlaid on this background.

THE CLIMATE EMERGENCY: CAN PARTICLE PHYSICS EVER BE SUSTAINABLE?

DISCUSSION/QUESTIONS

BACK UP

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.

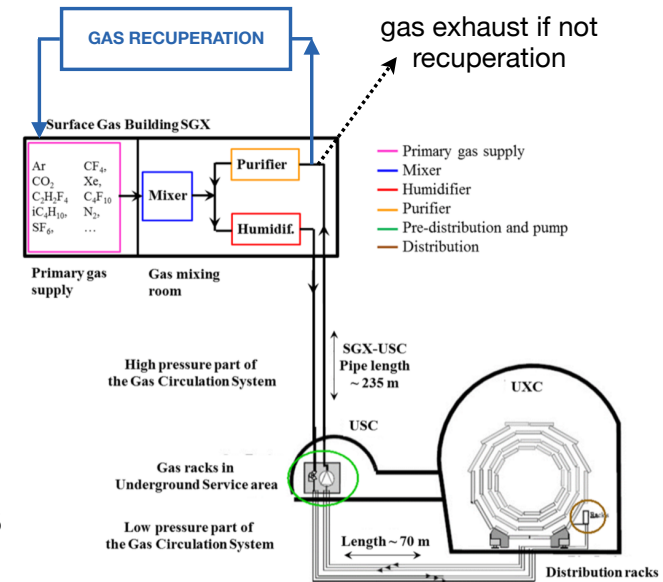
More information about sustainability including STFC's environmental data and targets can be found on the sustainability pages on The Source.



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 C₄F₁₀

RICH2: 100 m³ of CF₄

Gas recuperation system for empty/filling and cleaning from Air contamination

New gas recuperation system developed for the empty and filling of the detector

CMS CSC

Small Permeability to Air: accumulation of N₂

Need to inject fresh gas continuously to keep N₂ stable and guarantee detector performance

~80 l/h of CF₄ would be lost in exhaust without gas recuperation system

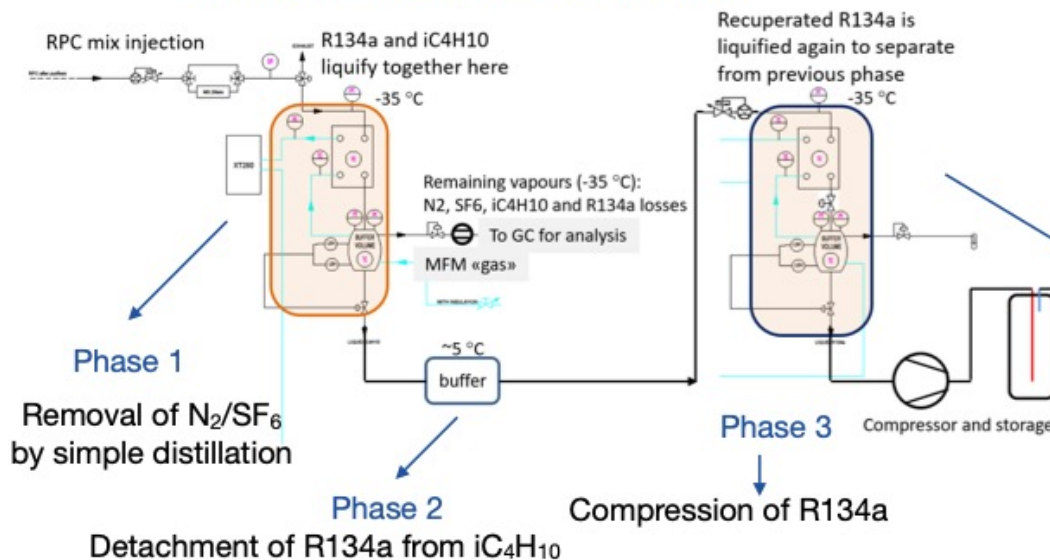
The R134a recuperation system for RPCs

ATLAS and CMS RPC Gas Systems

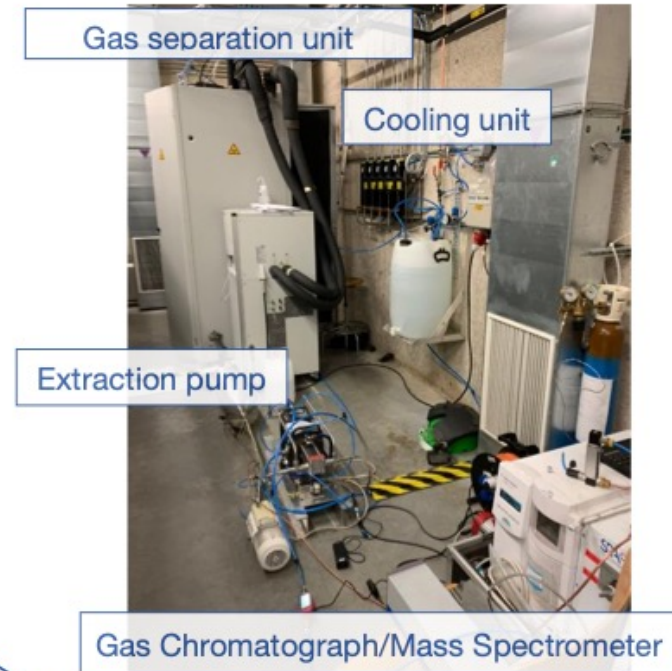
- Detector volume $\sim 15 \text{ m}^3$
- Gas mixture: $\sim 95\% \text{ C}_2\text{H}_2\text{F}_4$, $\sim 5\% \text{ iC}_4\text{H}_{10}$, $0.3\% \text{ SF}_6$
- Gas recirculation: $\sim 90\%$
- Maximum recirculation validated for RPC detectors
- **Fundamental to repair detector leaks**
- To have the gas at the exhaust of the gas system

R134a and iC₄H₁₀ form an azeotrope

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



C₂H₂F₄ recuperation prototype system under study in CMS Experiment



Recuperation efficiency $\sim 80\%$

First C₂H₂F₄ 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:

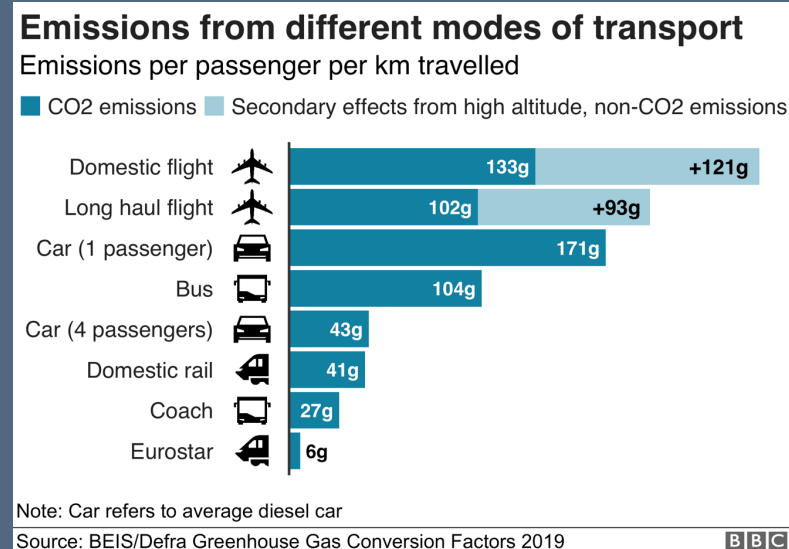
- CH₄/city gas + O₂ supply + N₂ supply
- Waste water treatment
- PFC/HFC are converted in CO₂ + HF acid dissolved in water
- disposal of remaining waste/mud
- To have the gas at the exhaust (600-1000 l/h)



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

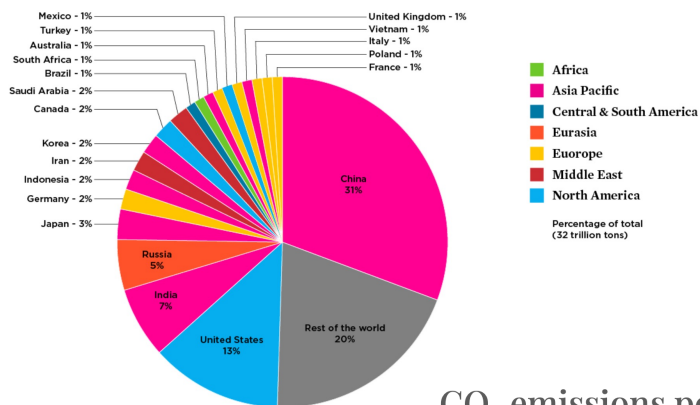
Carbon footprint of PP researchers

- 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): $8 \times 148 \text{ Kg CO}_2$: **1184 Kg CO₂**
 - 1 overseas trip (eg use from London to NYC): **986 Kg CO₂**
 - Total: **2170 Kg CO₂**: ~87 countries where the average citizen **emits less CO₂ 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 CO₂ Emitting countries, 2020

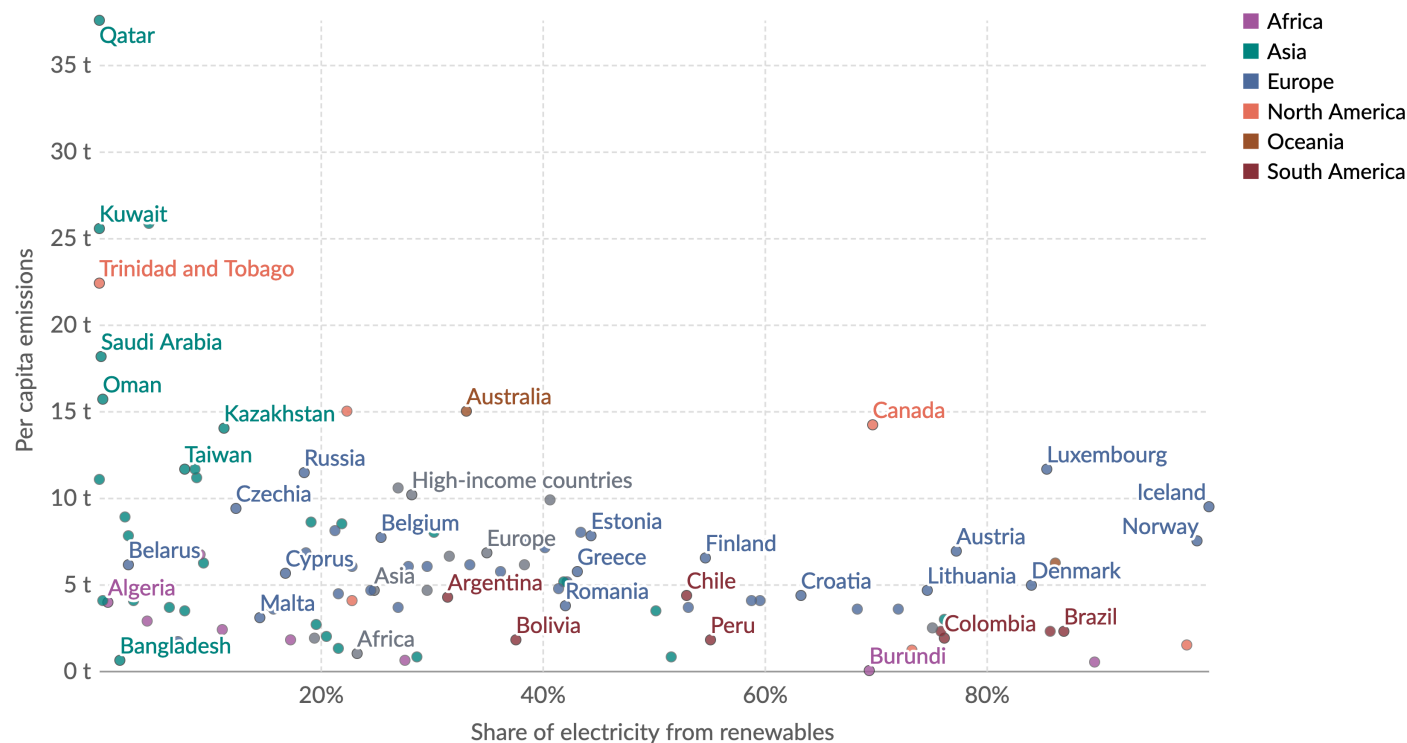
(from fossil fuels)



CO₂ emissions per capita vs. share of electricity generation from renewables, 2022

Our World in Data

Carbon dioxide (CO₂) emissions are measured in tonnes per person.



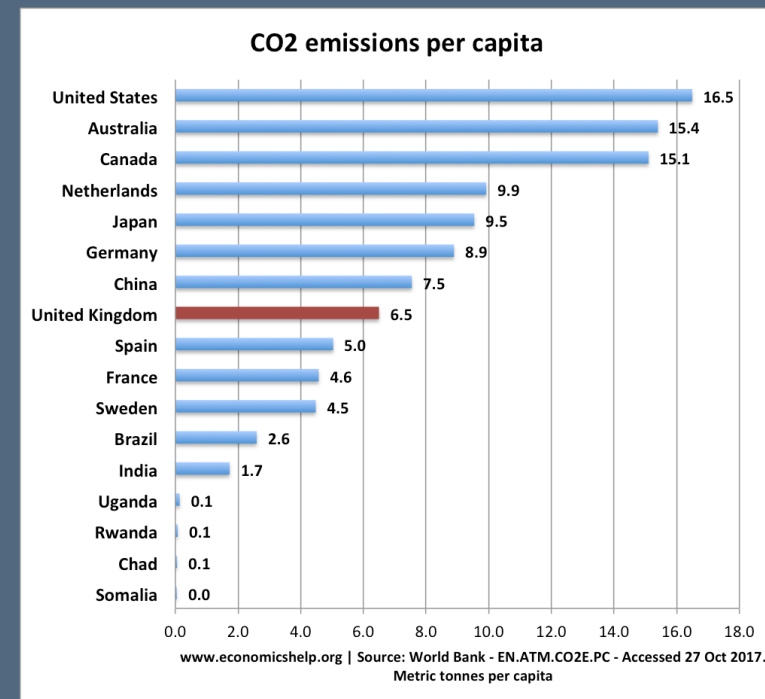
Data source: Global Carbon Budget (2023) and other sources
 OurWorldInData.org/co2-and-greenhouse-gas-emissions | CC BY

List of top CO₂ emitters

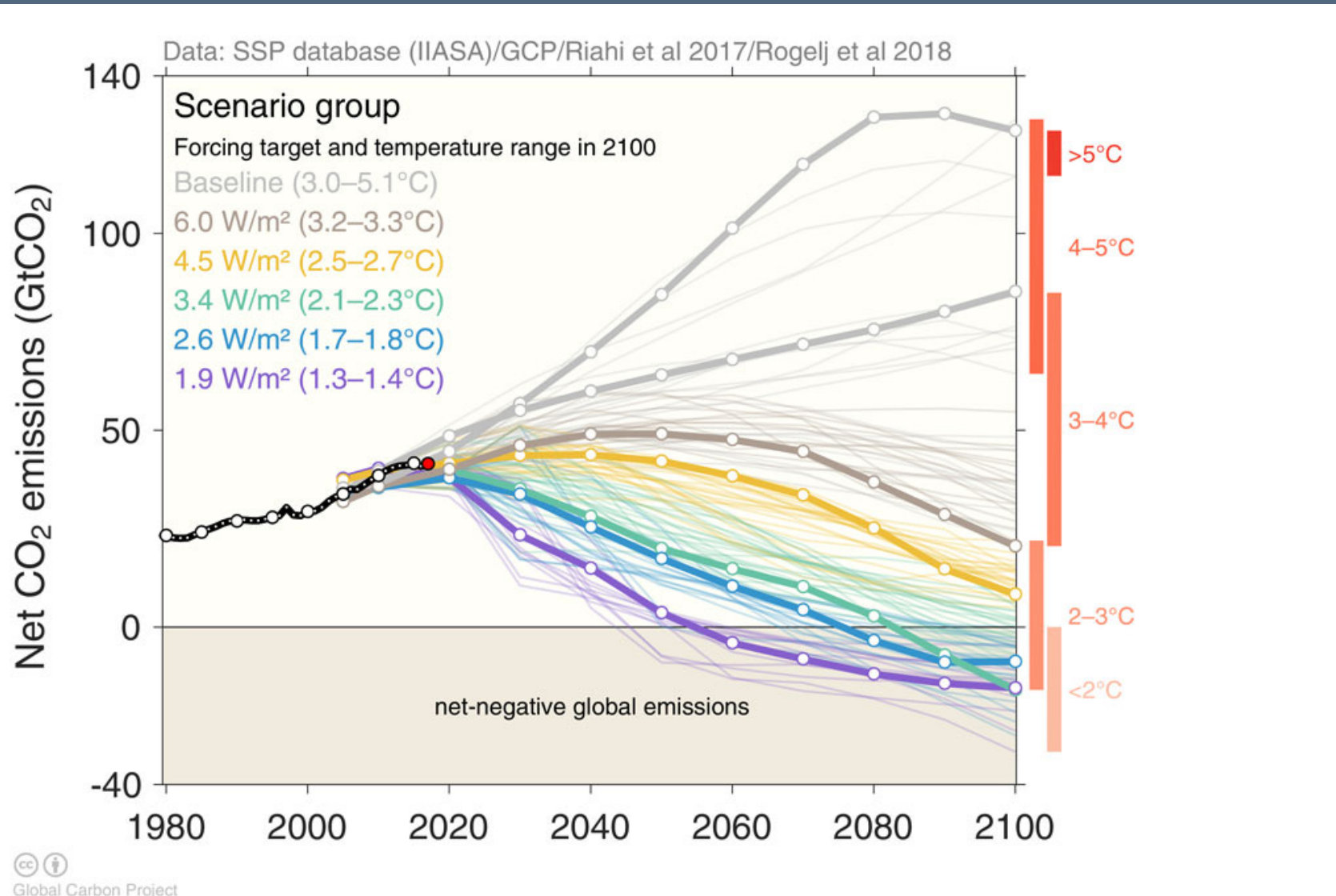
Forbes

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/Zürich timezone

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](#)

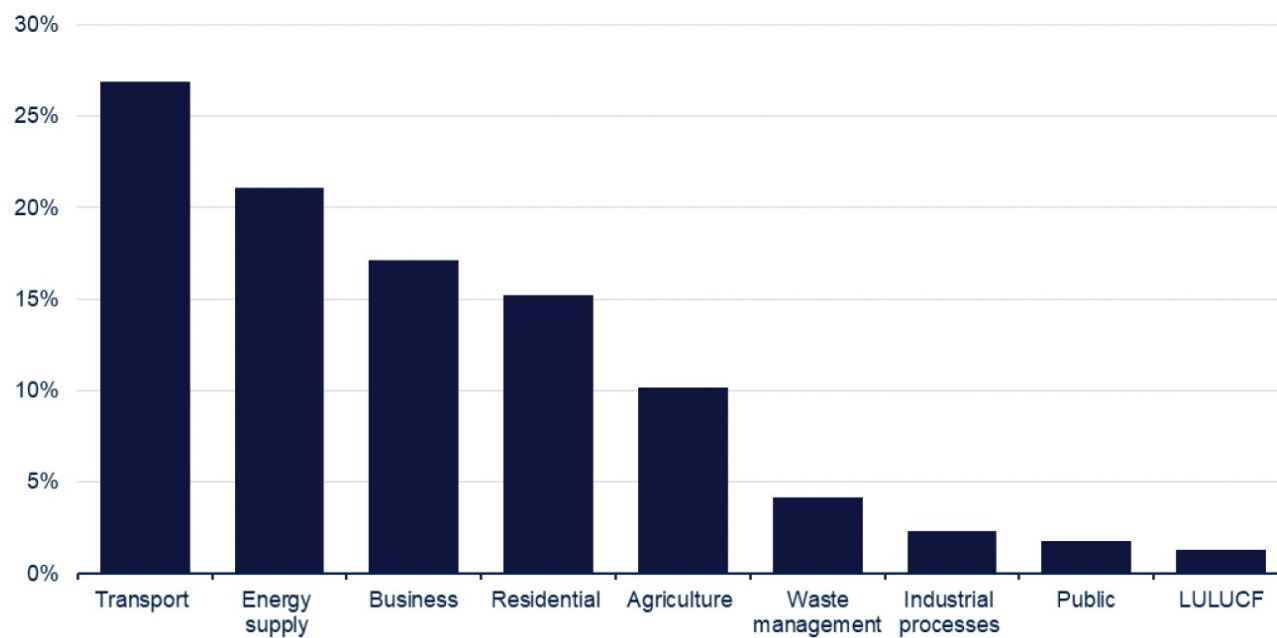
workshop organisers:

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: