The Climate Emergency: can Particle Physics ever be sustainable?

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14th June 2023 (424.1 CO_2 ppm)

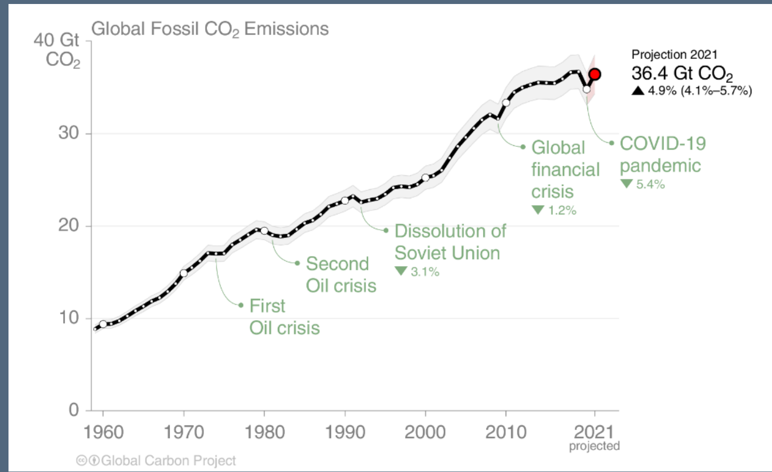
Outline

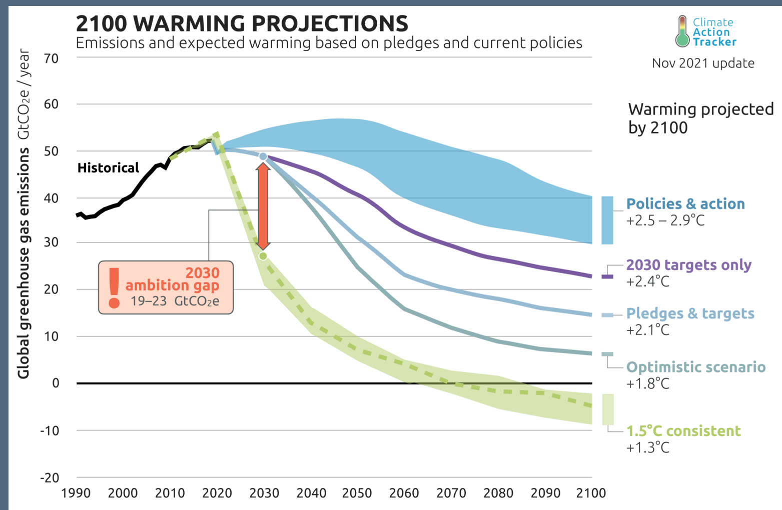
- The climate emergency
- CO_2e emissions & solutions from:
  - Accelerators (construction/operation)
  - Detectors
  - Computing
  - Rest (travel, conferences, buildings, etc.)

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

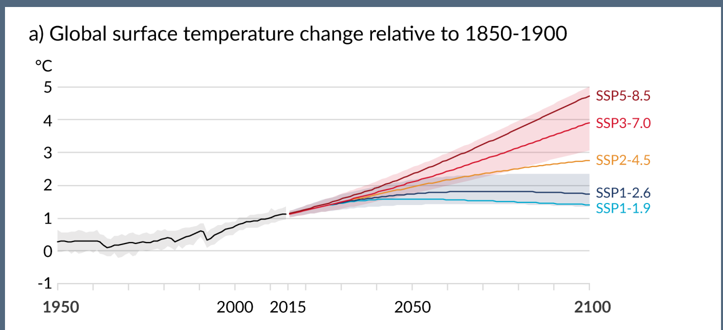
Climate Change: an emergency

- 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℃" so focus on 1.5 ℃
  - 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 ℃ limit.





IPCC AR6



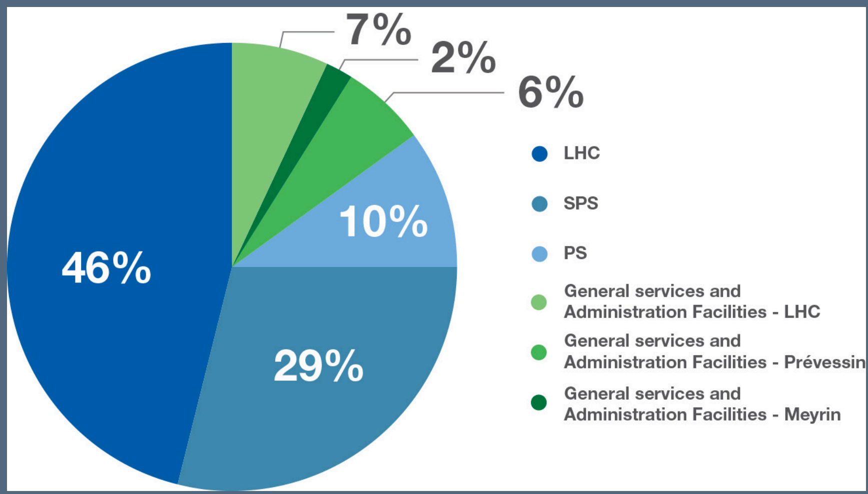
Ice ages: ~ -5℃

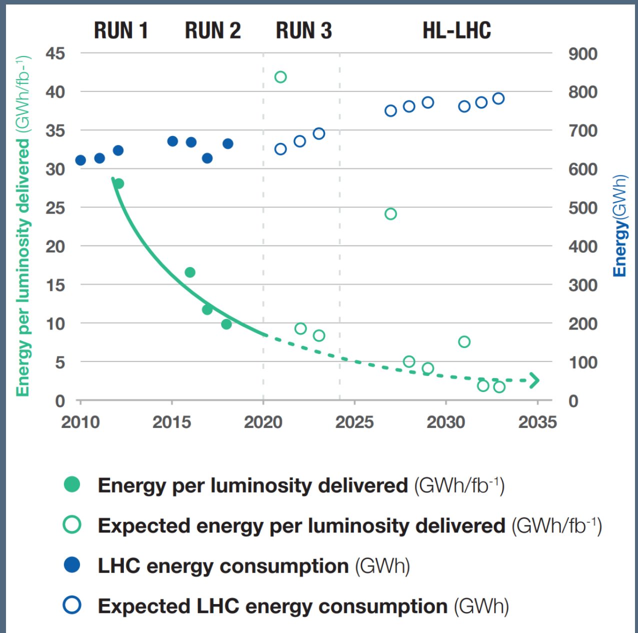
+4℃: civilization breakdown…

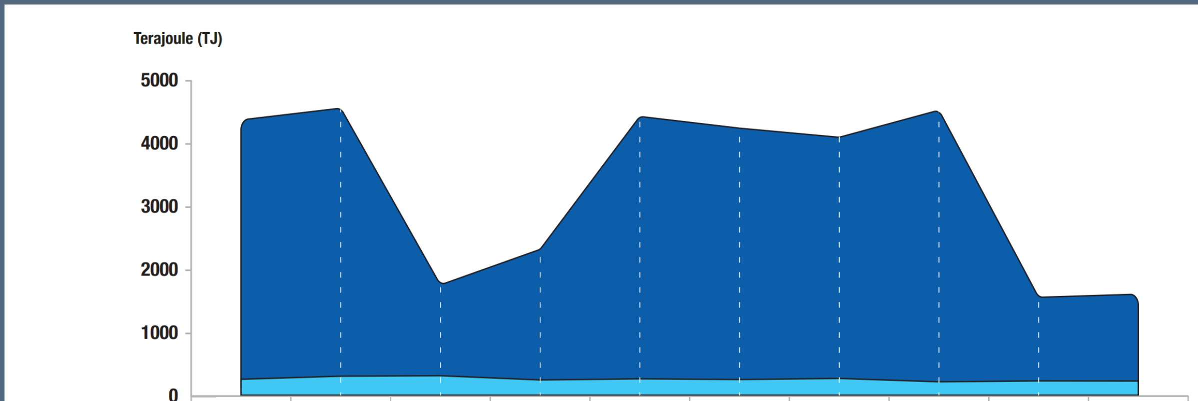
Emissions from accelerators: operations

- CERN now releases Environment reports (1st: 2017-18, 2nd: 2019-20)
- 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: 88% carbon free (2017)

Electrical power distribution 2018



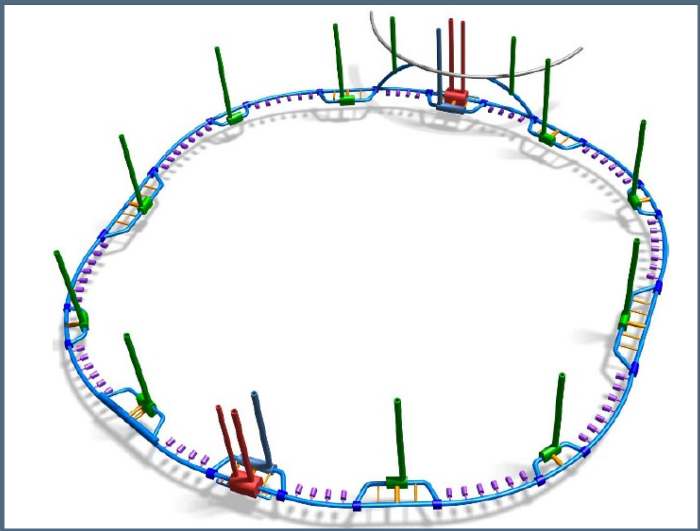


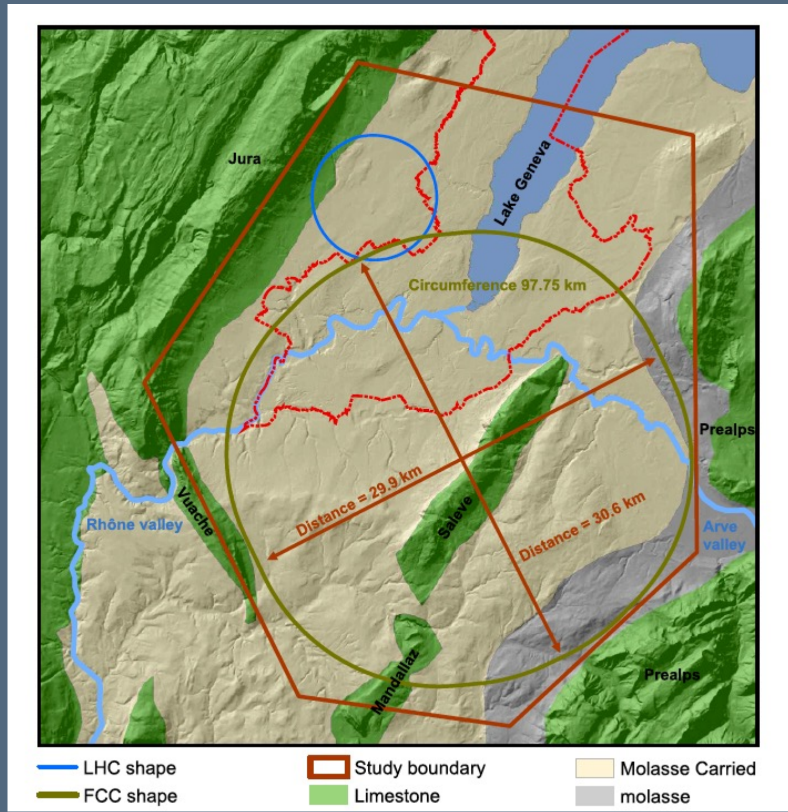


	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Electricity	4350	4536	1738	2300	4405	4219	4075	4504	1541	1591
Gas (heating)	252	301	308	241	259	248	235	212	226	224
Diesel (heating and generators)	0	10.1	2.3	0.4	1.8	1.9	16.5	5.3	1.6	1.3
Renewable energy	0	0	0	0.1	0	0.1	0.1	0.1	0.1	0.2
Petrol (transportation)	18	18	20	20	26	16	13	15	18	12

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 CO2e for construction of buildings: = building 8 London Shards!
- 1.4% of CH CO2e emissions (2016)
- Plant 6 million trees!

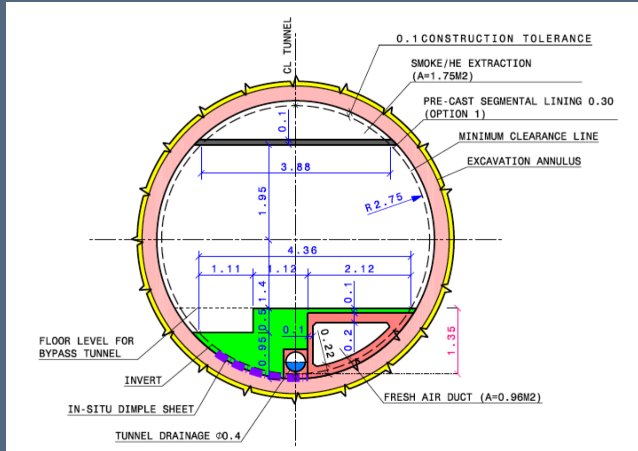


Fig. 4.4. Machine tunnel cross-section in "good" molasse.

$$CaCO_3 + heat \longrightarrow CaO + CO_2$$

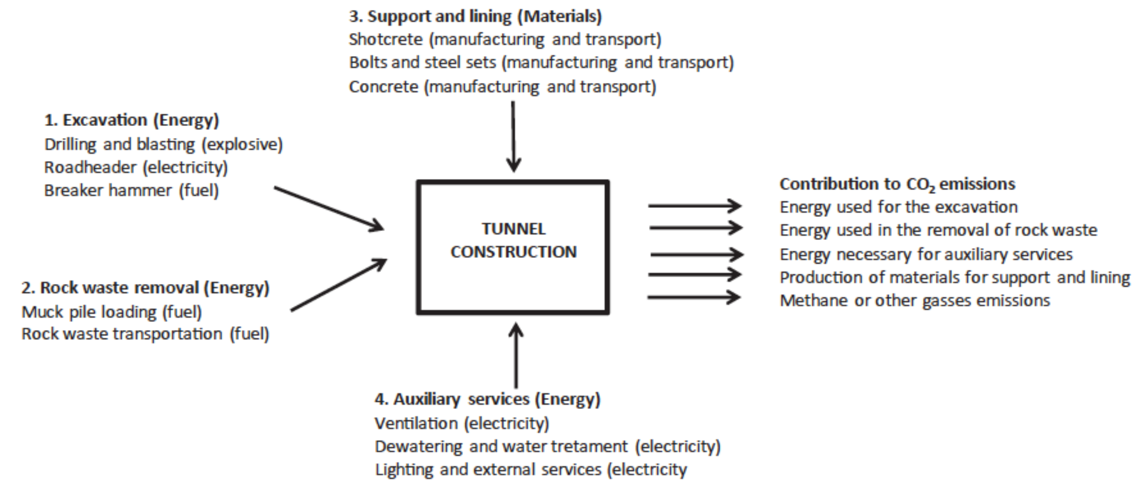
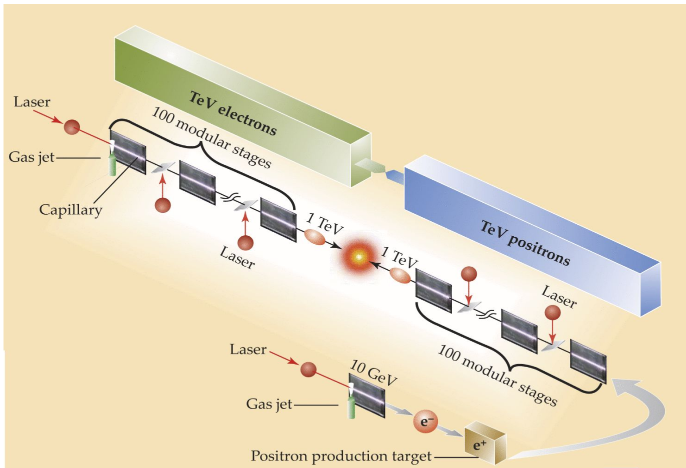


Fig. 1. Schematic overview of the system boundary.

Emissions from accelerators: solutions

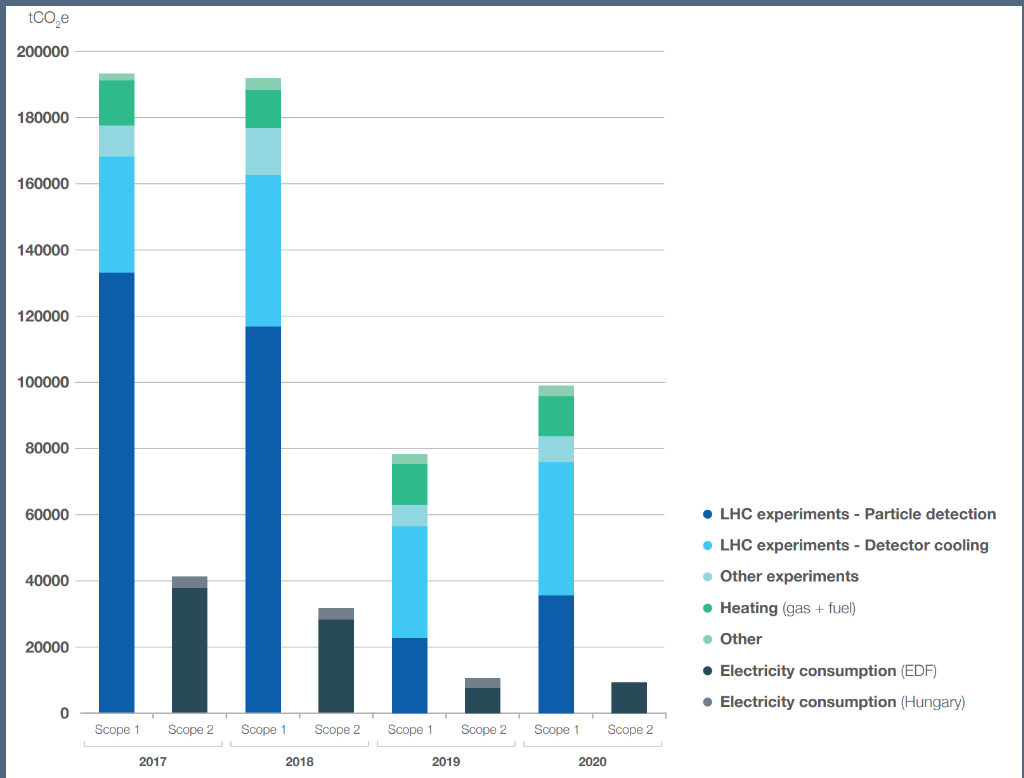
- District heating:
  - From 2022 hot water from LHC cooling at Point 8 will heat 8000 homes in Ferney-Voltaire, CERN also looking at Point 2 and 5, and Point 1 could heat CERN building on Meyrin site
- Since 2011 series of workshops: Energy for Sustainable Science at Research Infrastructures, 6th one: September 2022 at ESRF
  - Seems very Europe-centric
- Long-standing R&D in lowering accelerator power requirements
  - Eg Energy-Recovery in a Laser-Driven Plasma Wakefield Acceleration
- See following talks by M Seidel and C Jaimes



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.)



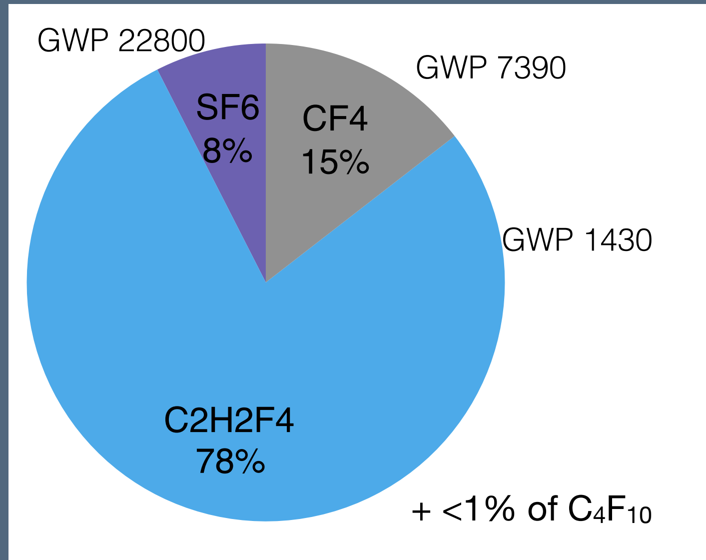
GROUP	GASES	tCO_2e 2017	tCO_2e 2018
PFC	CF_4, C_2F_6, C_3F_8, C_4F_{10}, C_6F_{14}	61 984	69 611
HFC	CHF_3 (HFC-23), $C_2H_2F_4$ (HFC-134a), HFC-404a, HFC-407c, HFC-410a, HFC R-422D, HFC-507	106 812	96 624
	SF_6	10 192	13 087
	CO_2	14 612	12 778
TOTAL SCOPE 1		193 600	192 100

CERN environmental report 2017-18

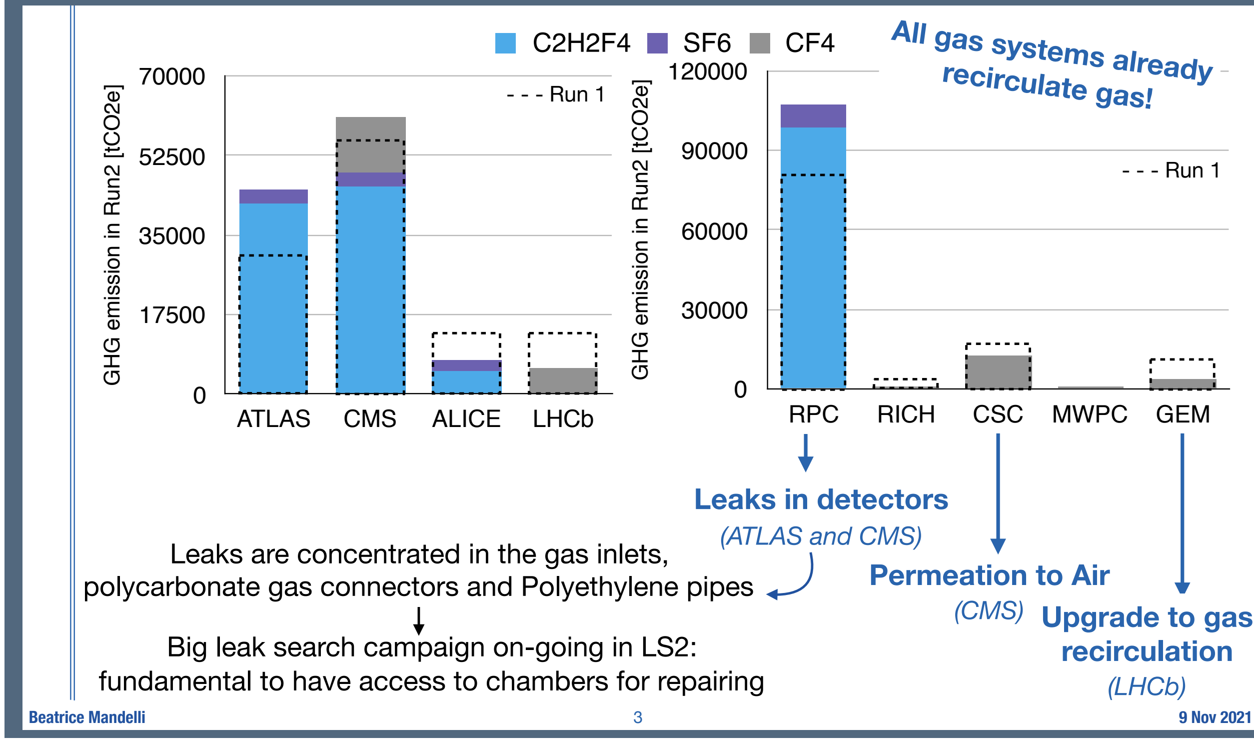
Emissions from detectors

- 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

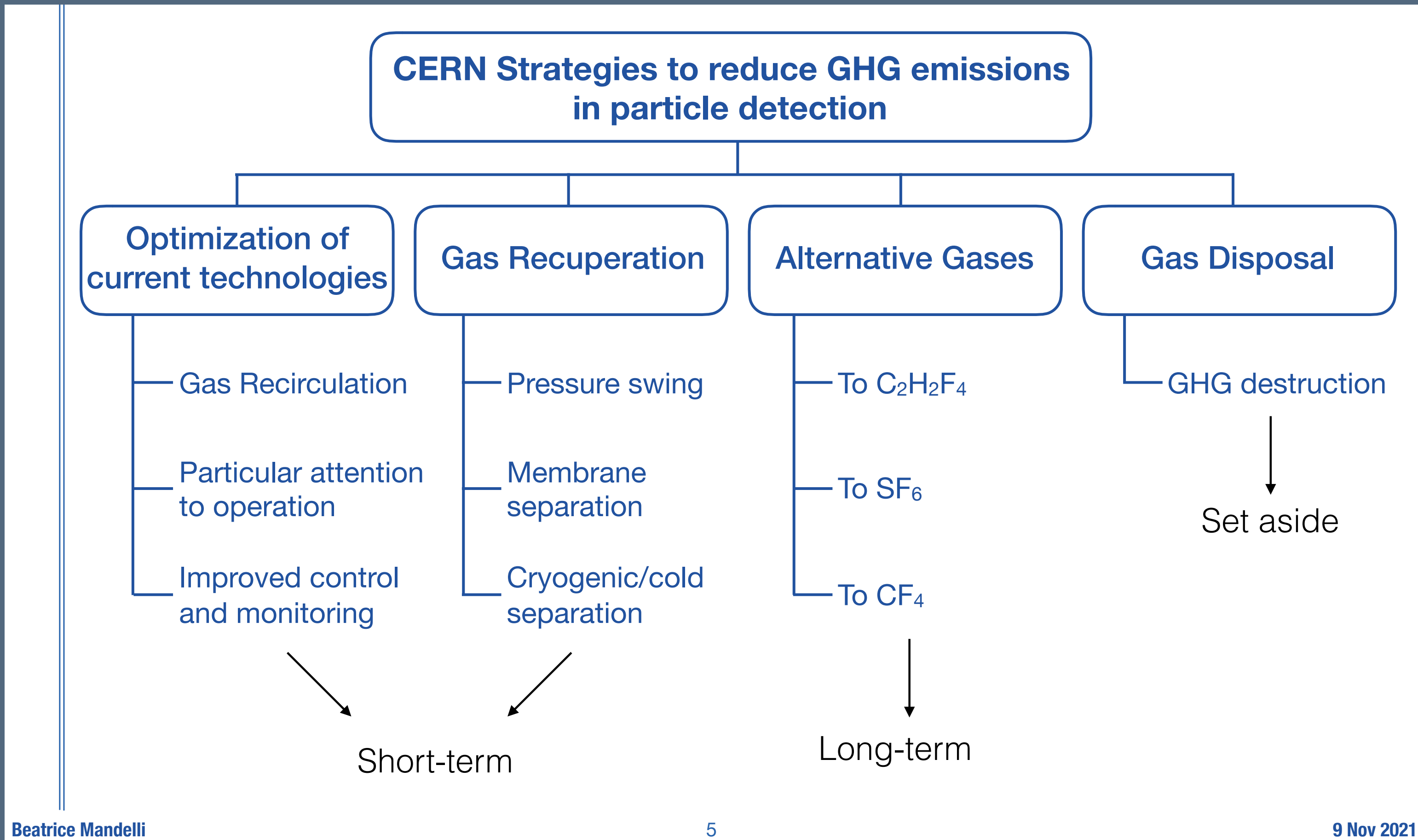


- Gas recirculation is 90%



Emissions from detectors: solutions

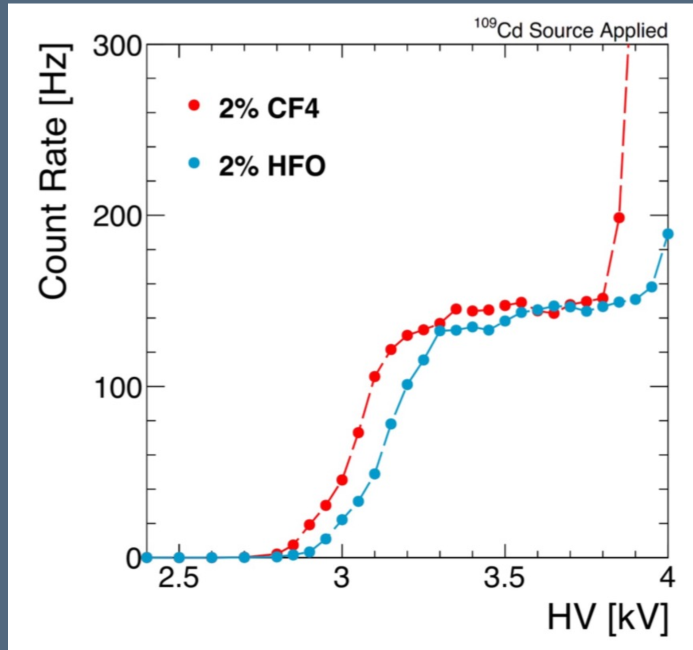
- 2020: CERN launched a working group on managing F-gases, with representatives from the departments concerned and the large LHC experiments. The group looked at issues such as the implementation of a centralised F-gas procurement policy, leak detection, replacement alternatives, training courses for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



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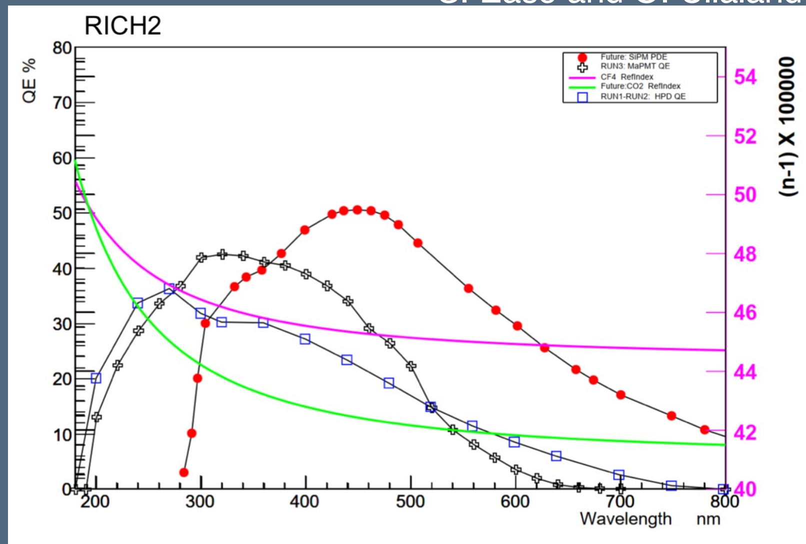


Emissions from detectors: solutions

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

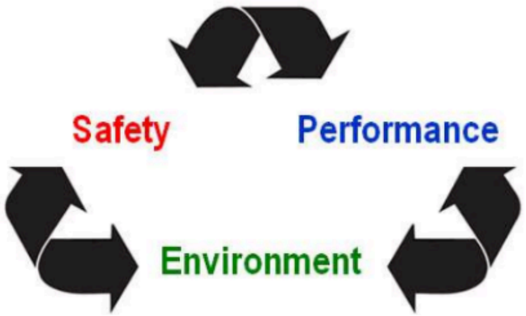
Safety

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

- FCC-ee detectors:
- CLD (similar to CLIC): RPCs for the muon detector
- IDEA: large drift chamber (similar to KLOE and MEG2) containing He:iC_4H_{10} 90:10, iC_4H_{10} GWP: ~3, for muon: large area μ-Rwell chambers, also use 10% iC_4H_{10}
- Crucial to do R&D in finding replacements or ensure 100% leak-free and 100% recirculation

FCC-ee CDR

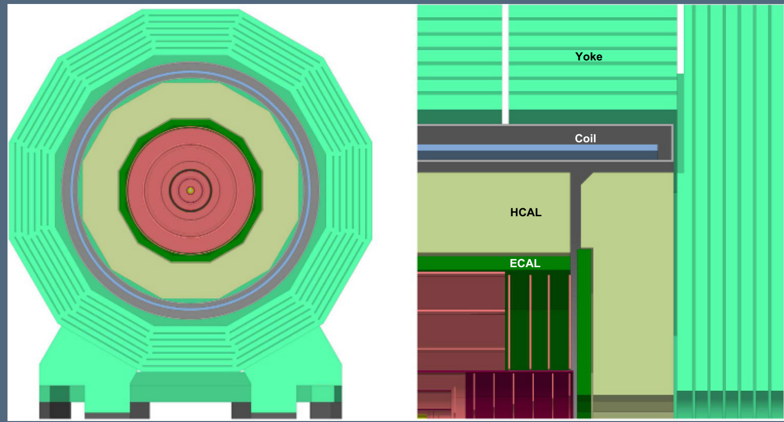
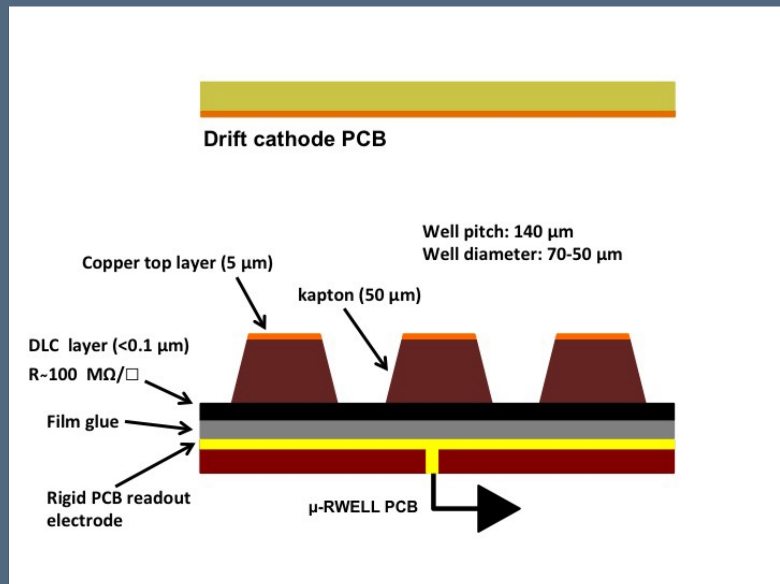


Fig. 7.4. The CLD concept detector: end view cut through (left), longitudinal cross section of the top right quadrant (right).

G. Bencivenni et al 2017 JINST 12 C06027



Embedded emissions from accelerators & detectors

- 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].

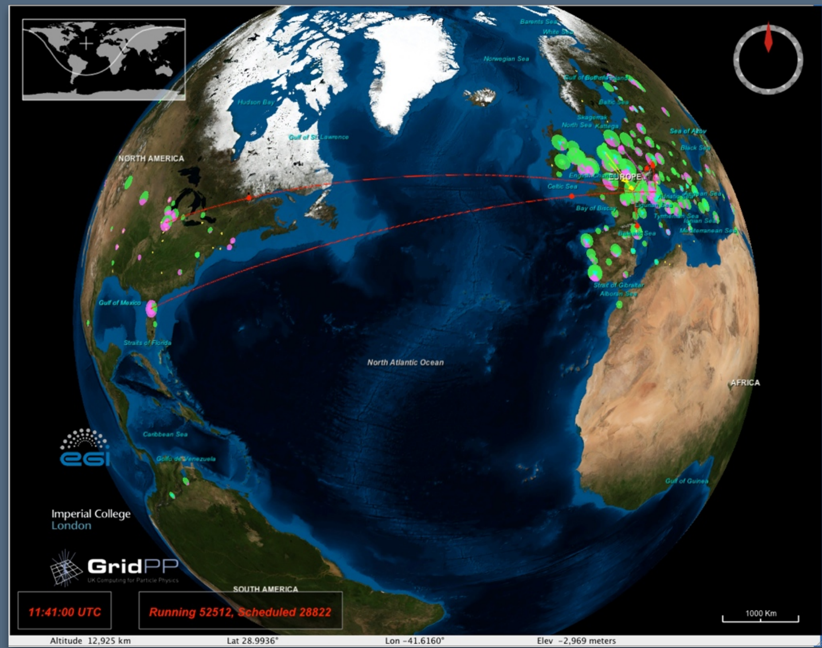
Inputs	Quantity	Outputs	Quantity
Hydrogen chloride HCl (hydrochloric acid)	0.00675 kg	Co-products: Si in other co-products	0.000286 kg
Graphite (as electrode material)	0.000163 kg	Co-products: Silicon tetrachloride	0.00415 kg
Wood chips	0.00183 kg	Co-products: Si residues for solar cells	65.2×10^{-6}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

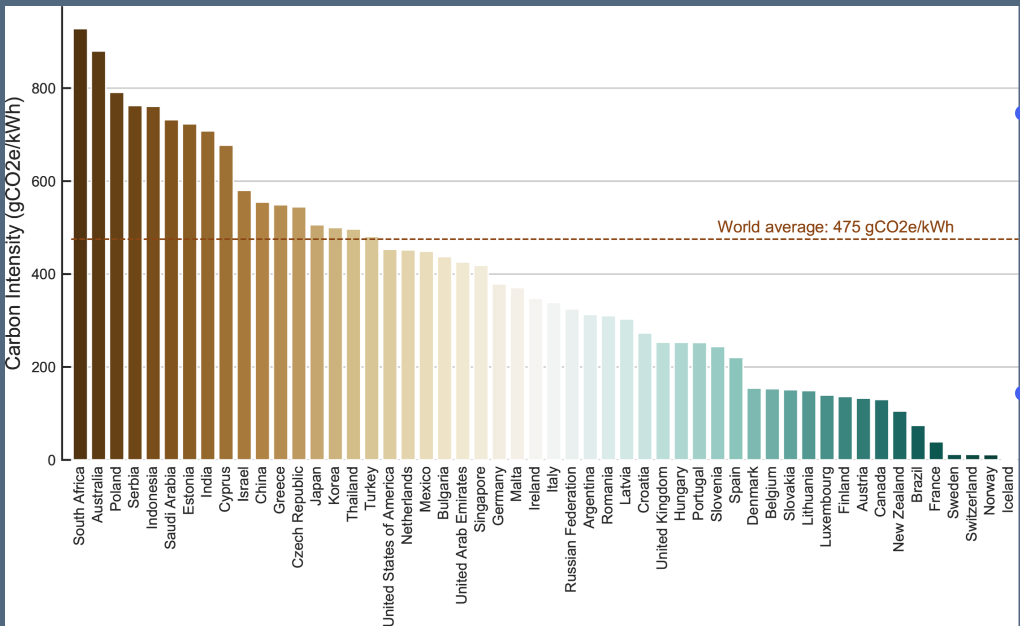
Air emissions	Quantity	Discharge to Water	Quantity
CH_4	68.8×10^{-6} kg	Metal chlorides	0.000787 kg
CO	0.000167 kg		
CO_2	0.00833 kg	Waste	Quantity
Ethane	29×10^{-6} kg	SiO_2	16.3×10^{-6} kg
H_2O	0.00188 kg		
Methanol	85.1×10^{-6} kg		
NOx	13.8×10^{-6} kg		
Particulate matter	0.000201 kg		
SO_2	34.4×10^{-6} 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 CO_2e 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



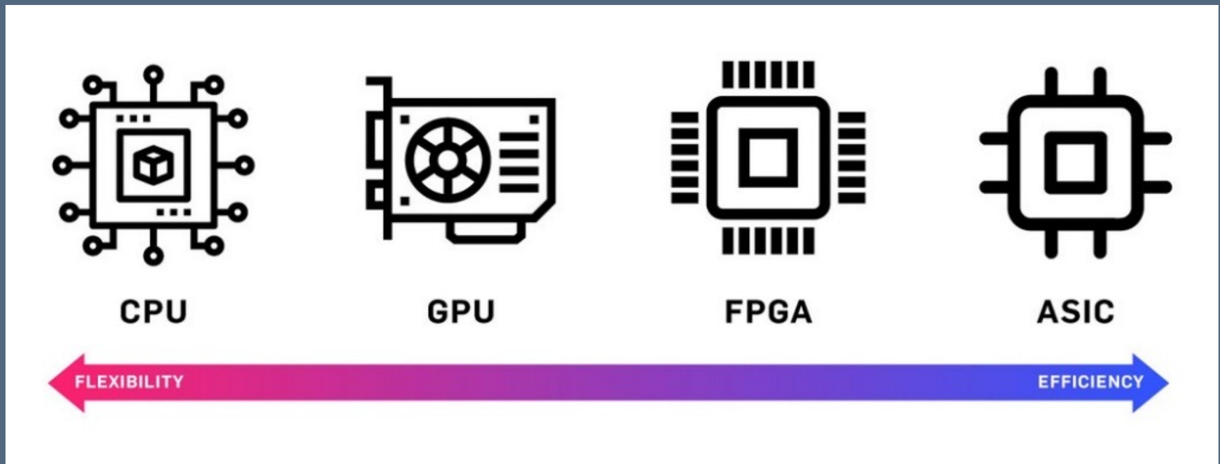


- Solutions:
  - Choose sites with green electricity…
  - Green500 list
  - Optimize your code ;-)
- Far future (2040):
  - All OECD electricity grids will be fully green…
  - …. But huge demand for electricity

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

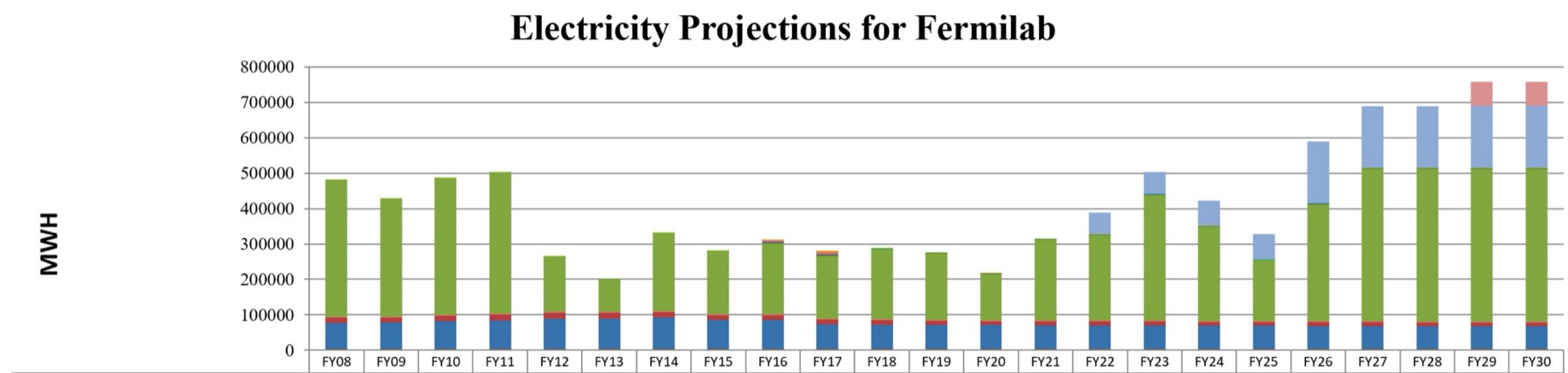
Goal: Reduce indirect GHG emissions by 25 percent by FY 2025 relative to FY 2008 baseline
Interim Target (FY 2019): -13.0%

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

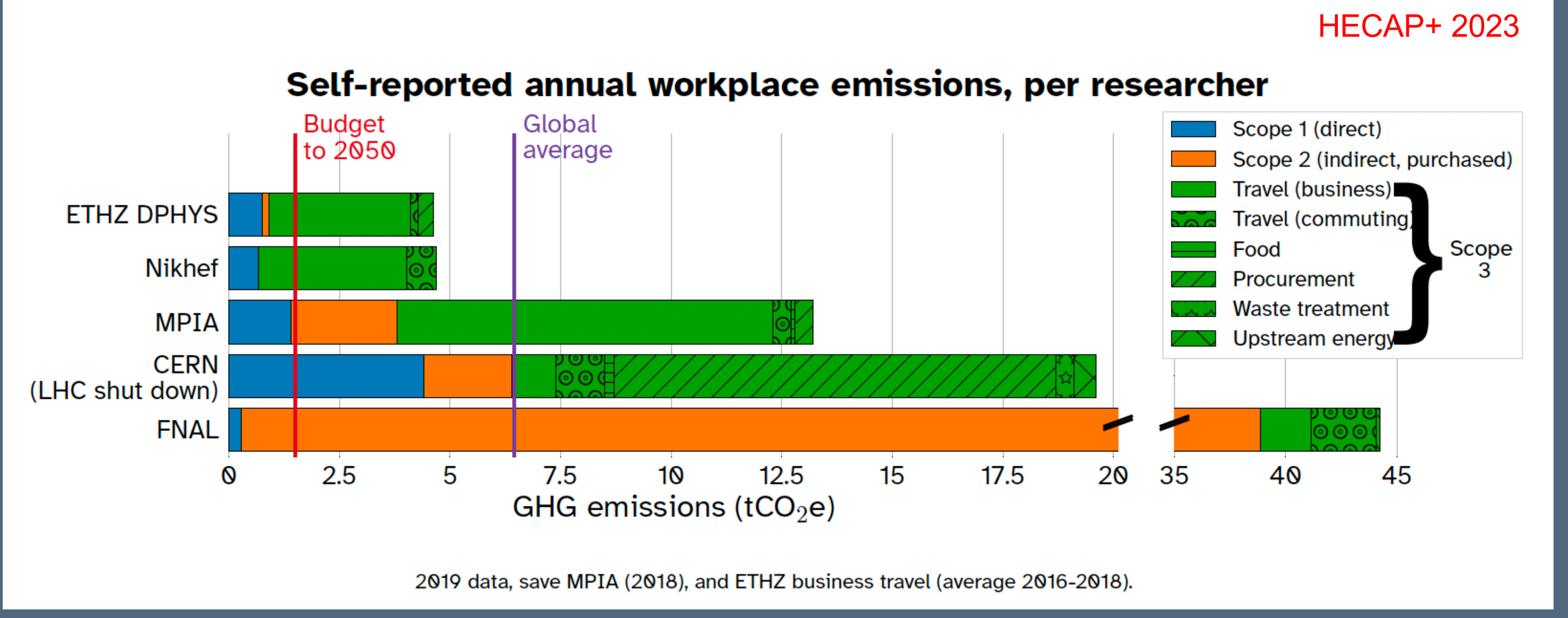


	FY08	FY09	FY10	FY11	FY12	FY13	FY14	FY15	FY16	FY17	FY18	FY19
LBNF												
PIP-II												
SBN Near & Far Detectors									3942	8869.5	548.9508	521.6047
Mu2e (MC-2)											324.825	348.5065
Muon G-2 (MC-1)									5080.8	5080.8	932.8659	947.4887
Existing Particle Accelerators HEMSF	391208.4	337149.6	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

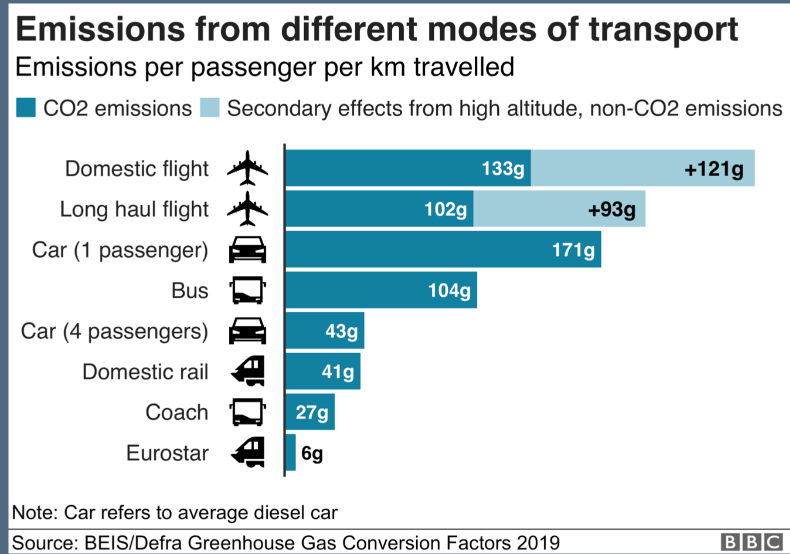
- Heating/cooling + hot water + light/appliances = 40% of energy consumption of a UK citizen
- Not only helps Climate, but is cheaper to run
- B Corporations certification
- Green Labs: “research labs consume 10 times more energy and 4 times more water than office spaces”, green lab certification, LEAF



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



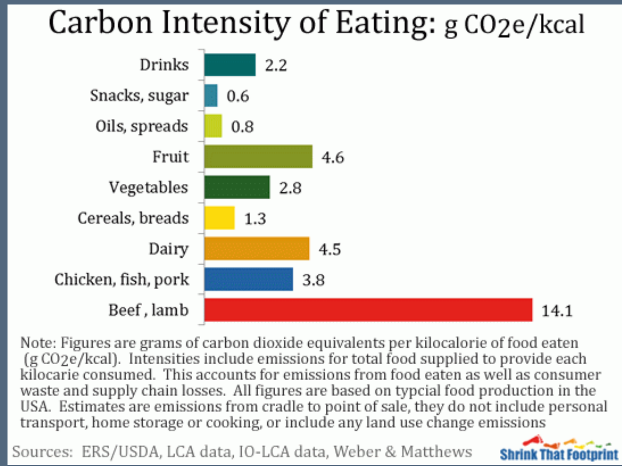
	AGU Fall Meeting 2019	ICHEP Melbourne 2012	ICHEP Valencia 2014	ICHEP Chicago 2016	ICHEP Seoul 2018	ICHEP Prague 2020 (virtual)
Number of participants	24,000	764	966	1,120	1,178	2,877
GHG emissions per participant [kg CO_2e]	2,883	8,432	1,902	2,699	2,648	0

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

European Strategy Update

- European Strategy Update web site

_Annex 3: The Working Groups

Working Group 1:	Social and career aspects for the next generation Chair: Professor Eric Laenen (Netherlands)
Working Group 2:	Issues related to Global Projects hosted by CERN or funded through CERN outside Europe Chair: Professor Mark Thomson (United Kingdom)
Working Group 3:	Relations with other groups and organisations Chair: Professor Tatsuya Nakada (Switzerland)
Working Group 4:	Knowledge and Technology Transfer Chair: Professor Leander Litov (Bulgaria)
Working Group 5:	Public engagement, Education and Communication Chair: Professor Sijbrand de Jong (Netherlands)
Working Group 6:	Sustainability and Environmental impact Chair: Professor Dirk Ryckbosch (Belgium)

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
- P5 Town meetings have now finished
- P5 needs to write their recommendations to HEPAP who then makes recommendations to DOE/NSF…

Climate impacts of particle physics

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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)

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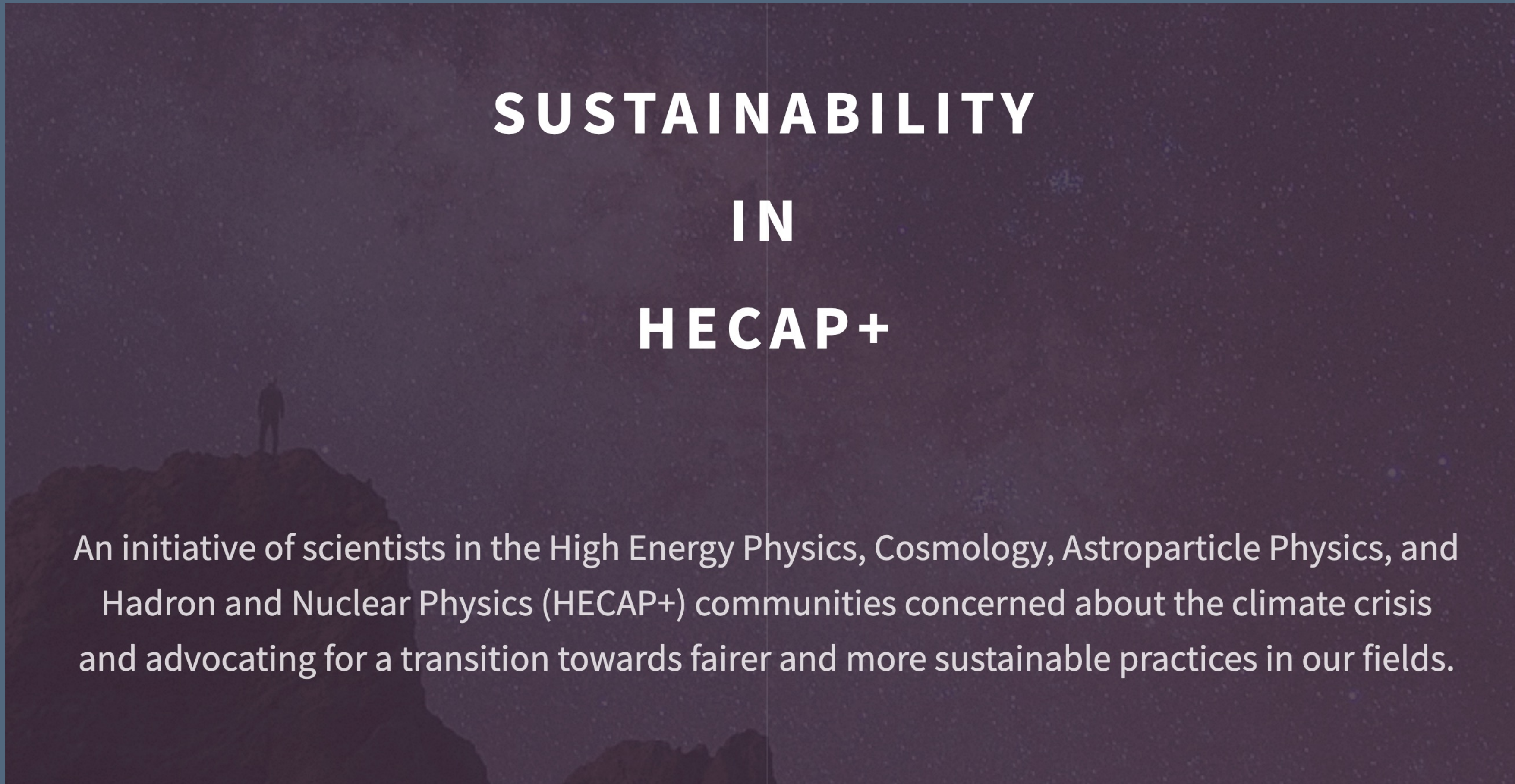


Released on 5th June 2023: Full report available

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 Main Linac study
- 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

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
- 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

Recommendations — Mobility

Individual actions:

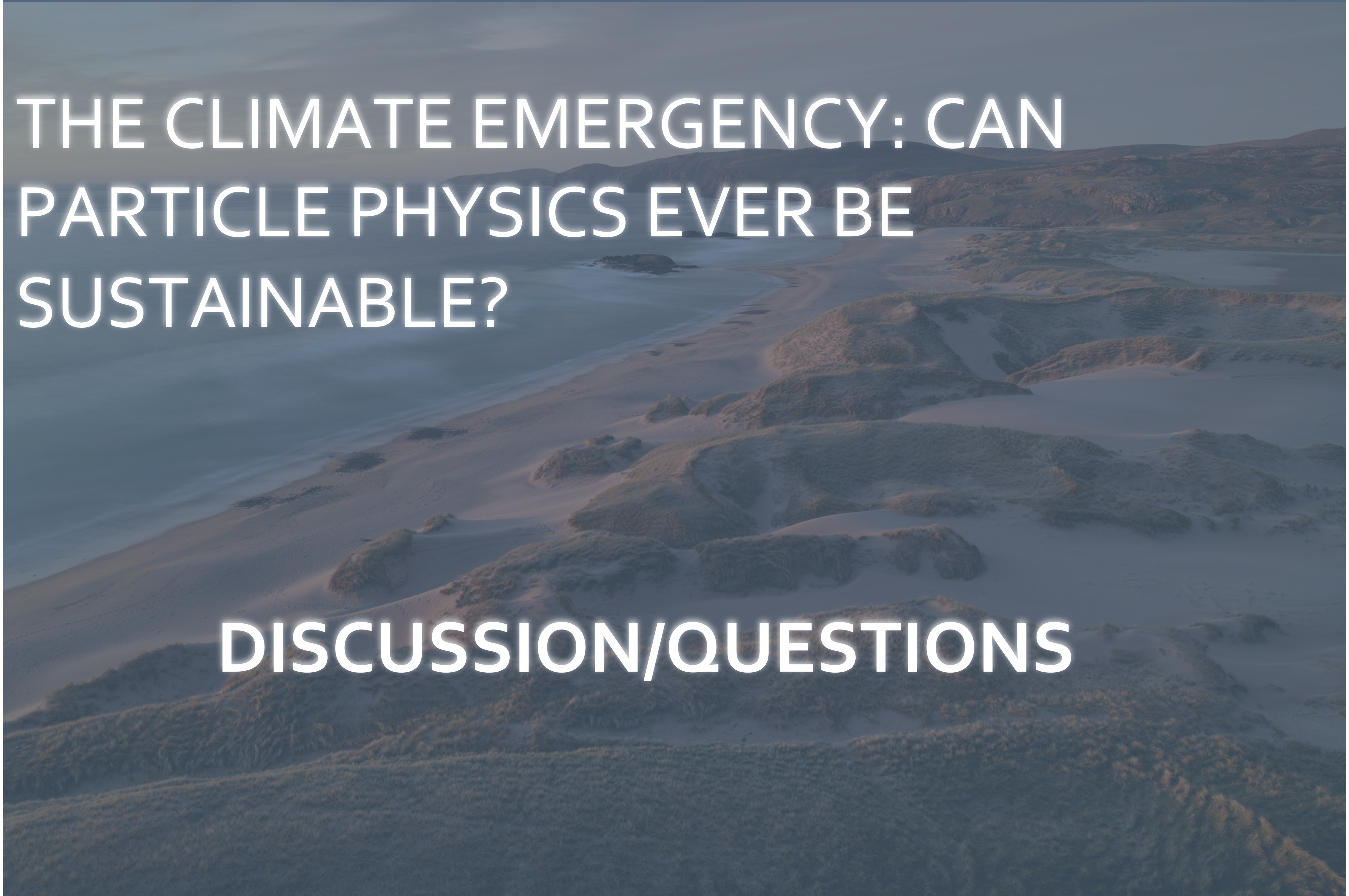
- Re-assess business travel needs, using remote technologies wherever practicable.
- Choose environmentally sustainable means of transport for daily commutes as well as unavoidable business travel, amalgamating long-distance trips where possible.

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.



THE CLIMATE EMERGENCY: CAN PARTICLE PHYSICS EVER BE SUSTAINABLE?

DISCUSSION/QUESTIONS