Can particle physics ever be sustainable?

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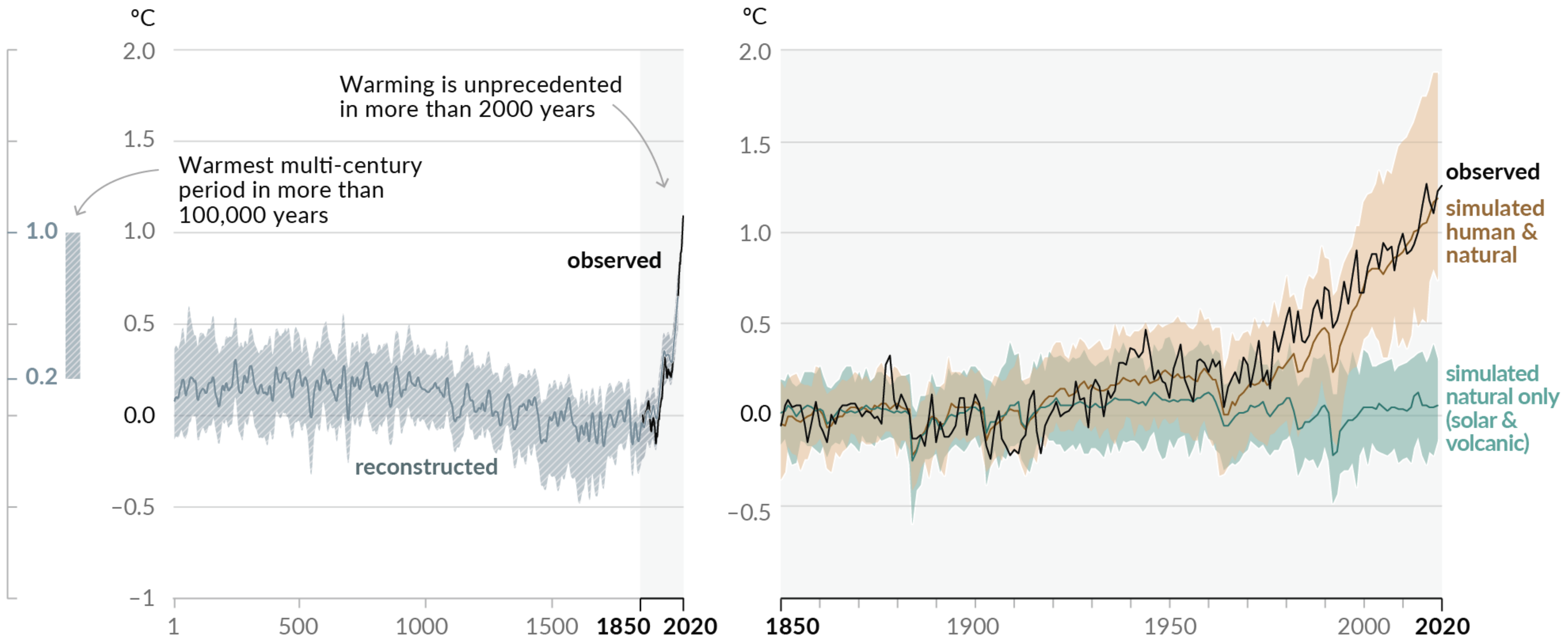
Climate change is real

Human influence has warmed the climate at a rate that is unprecedented in at least the last 2000 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)

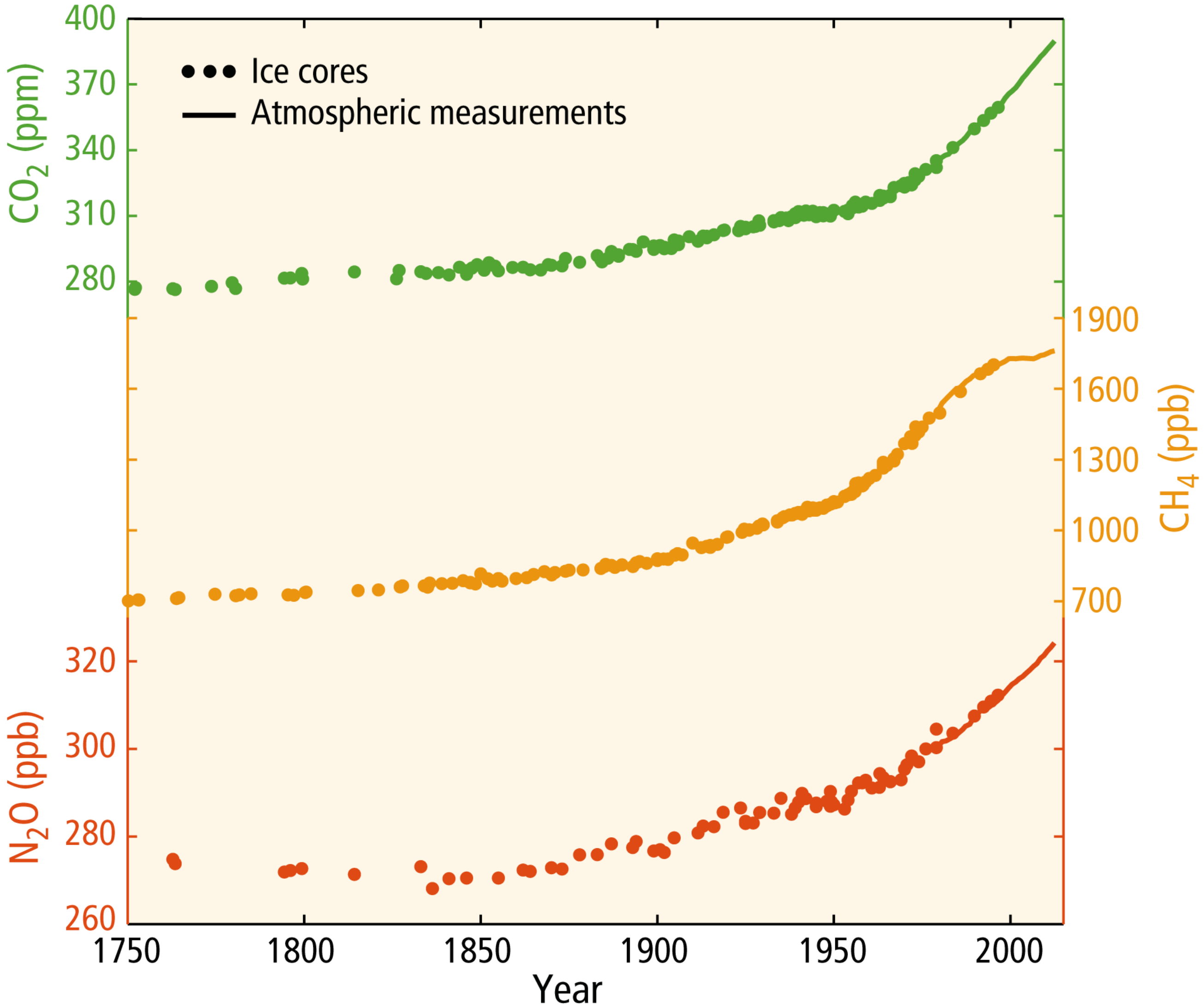
(b) Change in global surface temperature (annual average) as **observed** and simulated using **human & natural** and **only natural** factors (both 1850–2020)



(IPCC AR6)

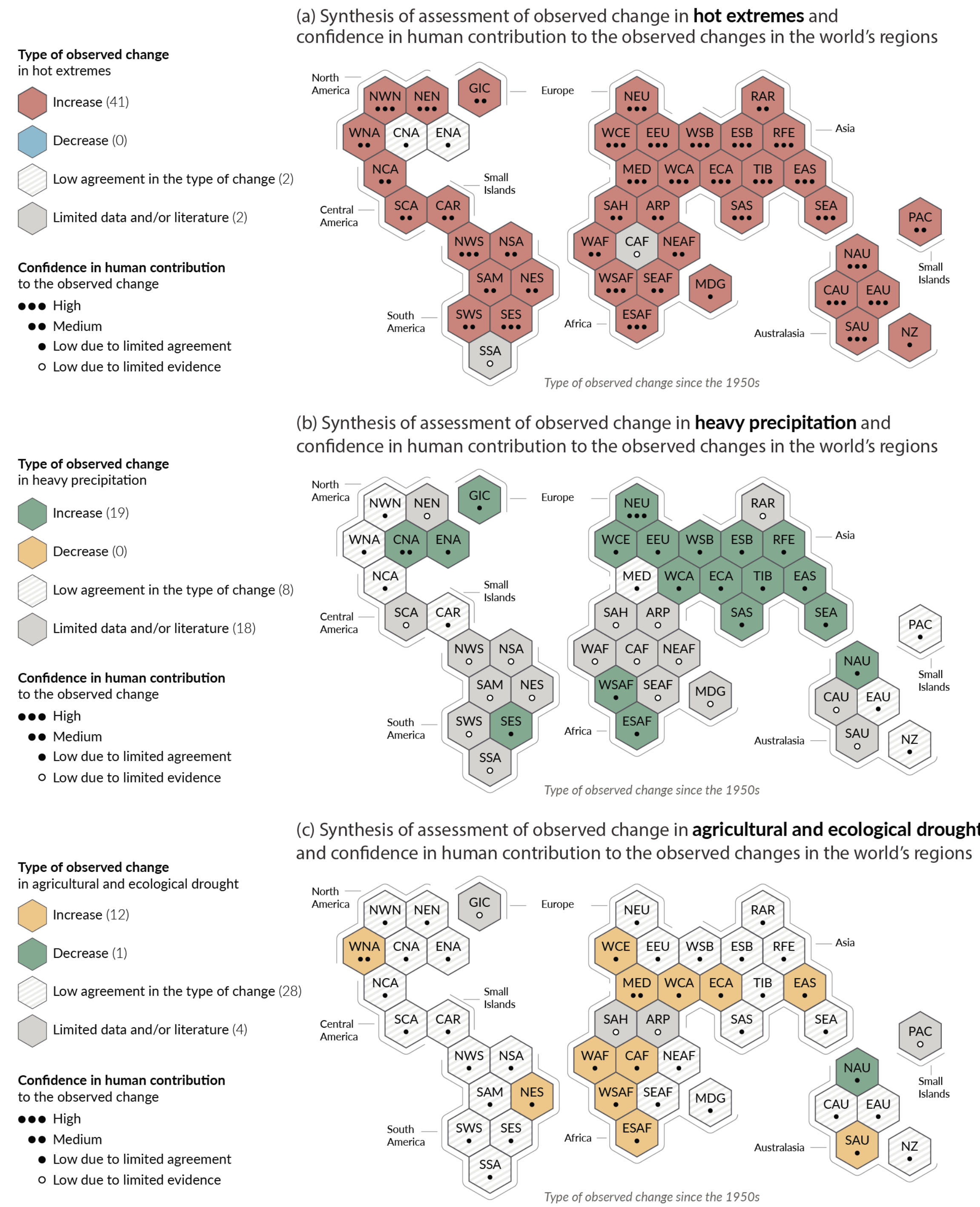
Climate change is real

Globally averaged greenhouse gas concentrations



(IPCC AR5)

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



(IPCC AR6)

Particle physics on a (carbon) budget

- Every 1000 gigaton of cumulative CO_2 emissions leads to 0.27-0.63 C increase in warming.
- To limit warming to < 1.5 C, emissions need to be limited to ~1 ton CO2e (CO_2 equivalent) per capita per year until 2050.
- Current per capita per year rate in U.S. ≃ 14.2 tCO2e, was ≃ 20 tCO2e in 2005, but still ~3x global average.
- Particle physics activities have the potential for scientists to have a carbon impact well above that of average citizens, so we must pay attention.
  - Moral reason: Responsibility for leaving behind a habitable planet.
  - Practical reason: Future major projects will have significant carbon impact and will be scrutinized for it.
- Particle physics is a world leader in international cooperation for common goals — can we do the same here?
- How can we pursue the science we love sustainably?

Astronomy impacts

nature astronomy

ARTICLES

https://doi.org/10.1038/s41550-022-01612-3

Check for updates

Estimate of the carbon footprint of astronomical research infrastructures

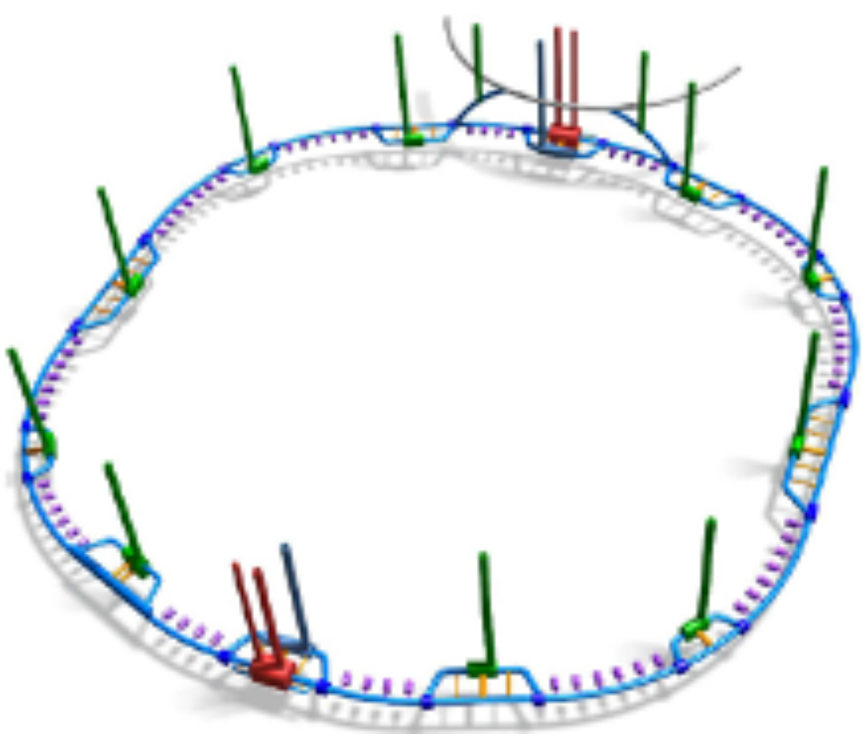
Jürgen Knödlseder ✉, Sylvie Brau-Nogué, Mickael Coriat, Philippe Garnier, Annie Hughes, Pierrick Martin and Luigi Tibaldo

The carbon footprint of astronomical research is an increasingly topical issue with first estimates of research institute and national community footprints having recently been published. As these assessments have typically excluded the contribution of astronomical research infrastructures, we complement these studies by providing an estimate of the contribution of astronomical space missions and ground-based observatories using greenhouse gas emission factors that relates cost and payload mass to carbon footprint. We find that worldwide active astronomical research infrastructures currently have a carbon footprint of 20.3 ± 3.3 $MtCO_2$ equivalent (CO_2e) and an annual emission of 1,169 ± 249 $ktCO_2e\ yr^{-1}$ corresponding to a footprint of 36.6 ± 14.0 tCO_2e per year per astronomer. Compared with contributions from other aspects of astronomy research activity, our results suggest that research infrastructures make the single largest contribution to the carbon footprint of an astronomer. We discuss the limitations and uncertainties of our method and explore measures that can bring greenhouse gas emissions from astronomical research infrastructures towards a sustainable level.

"Just to give you some perspective — 20 million tonnes of CO2 — this is the annual carbon footprint of countries like Estonia, Croatia, or Bulgaria," says Jürgen Knödlseder, an astronomer at IRAP, an astrophysics laboratory in France.

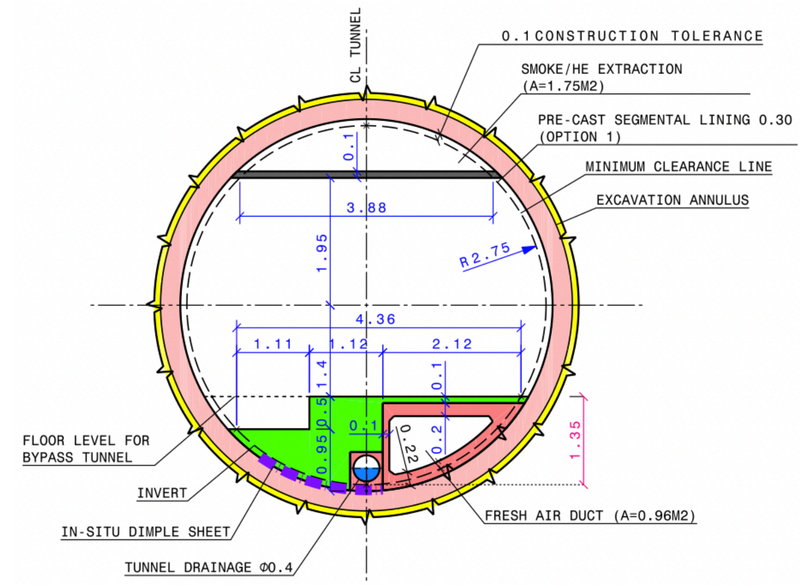
Emissions from construction

- Building construction industry contributes 10% of world's total carbon emissions.
  - Cement made via $CaCO_3$ + heat → $CaO + CO_2$, 1 ton CO_2 per 1 ton cement, hard to decarbonize.
- Assumption: the electric grid will be decarbonized by ~2040, so new HEP facilities will be operating on decarbonized energy.
  - Facility construction rather than operation could dominate carbon impacts!
- Example: FCC(-ee,-hh), 97.75 km tunnel would be one of the world's largest, plus many bypass tunnels, access shafts, experimental caverns, surface facilities….



Emissions from construction

- Carbon impact of main tunnel?
- Bottom up: calculate volume of tunnel walls, concrete is 15% cement → ~240 kt CO_2.
- Top down: studies of road tunnel construction give rule of thumb of 5,000-10,000 kg CO_2/km of tunnel → > ~500 kt CO_2.
- 6 million trees required for carbon offset!



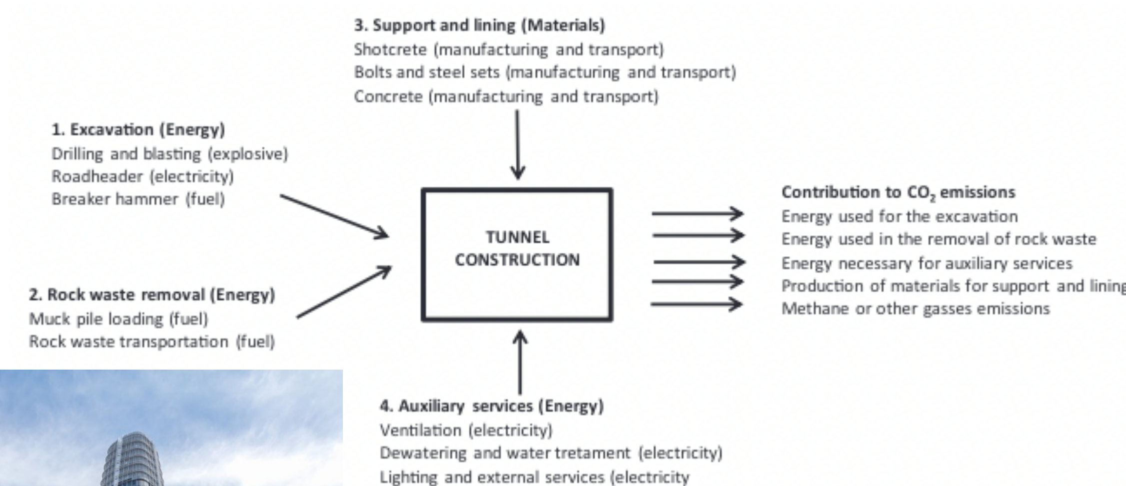
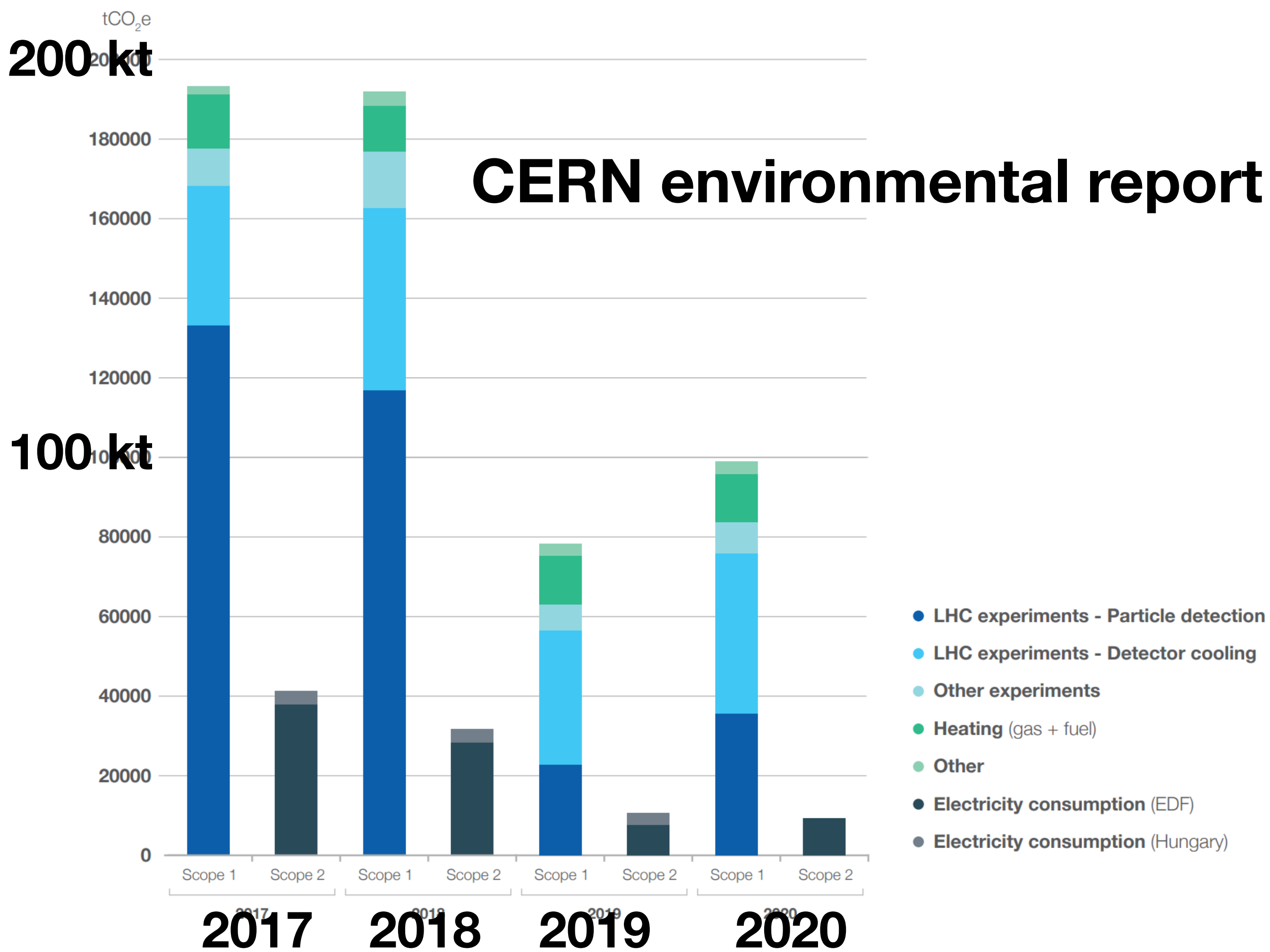


Fig. 1. Schematic overview of the system boundary.

- Salesforce Tower: 1.4M ft^2, ~550 kg embodied carbon/m^2 → ~79 kt CO2e.

Emissions from detectors

- CERN emissions are dominated by experiment gases!



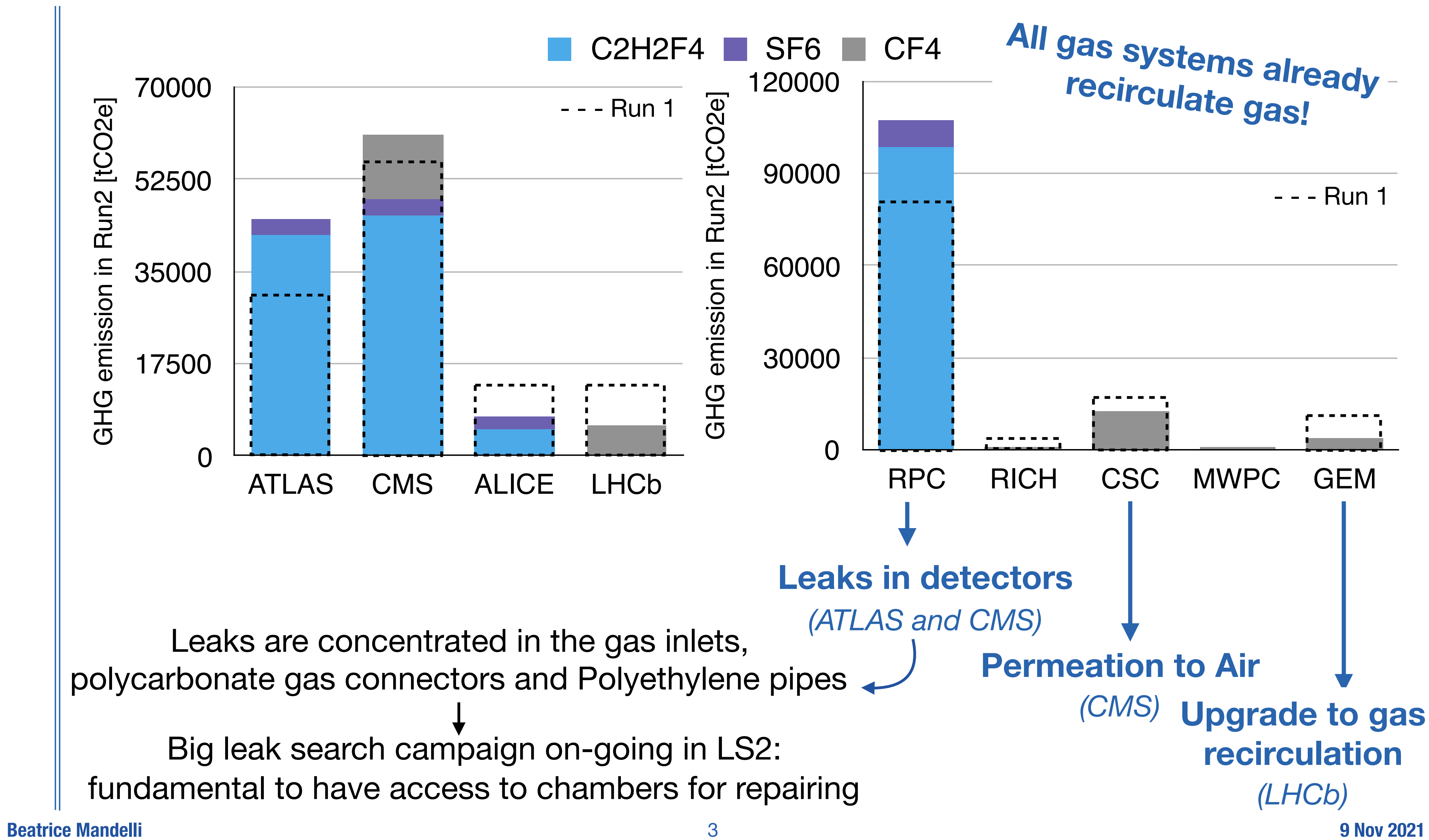
- Scope 1: direct emissions from organization
- Scope 2: indirect emissions from electricity, heating, etc.
- Scope 3: all other emissions upstream and downstream (business travel, commuting, catering etc.); harder to quantify

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

Scope 1 emissions by gas type

- Gases used for particle detection, cooling, etc.
- $C_2H_2F_4$ (78% of detector emissions) has 1300x global warming potential (GWP) of CO_2.
- CF_4 (15%) has 6630x GWP, SF_6 (8%) has 23500x GWP!

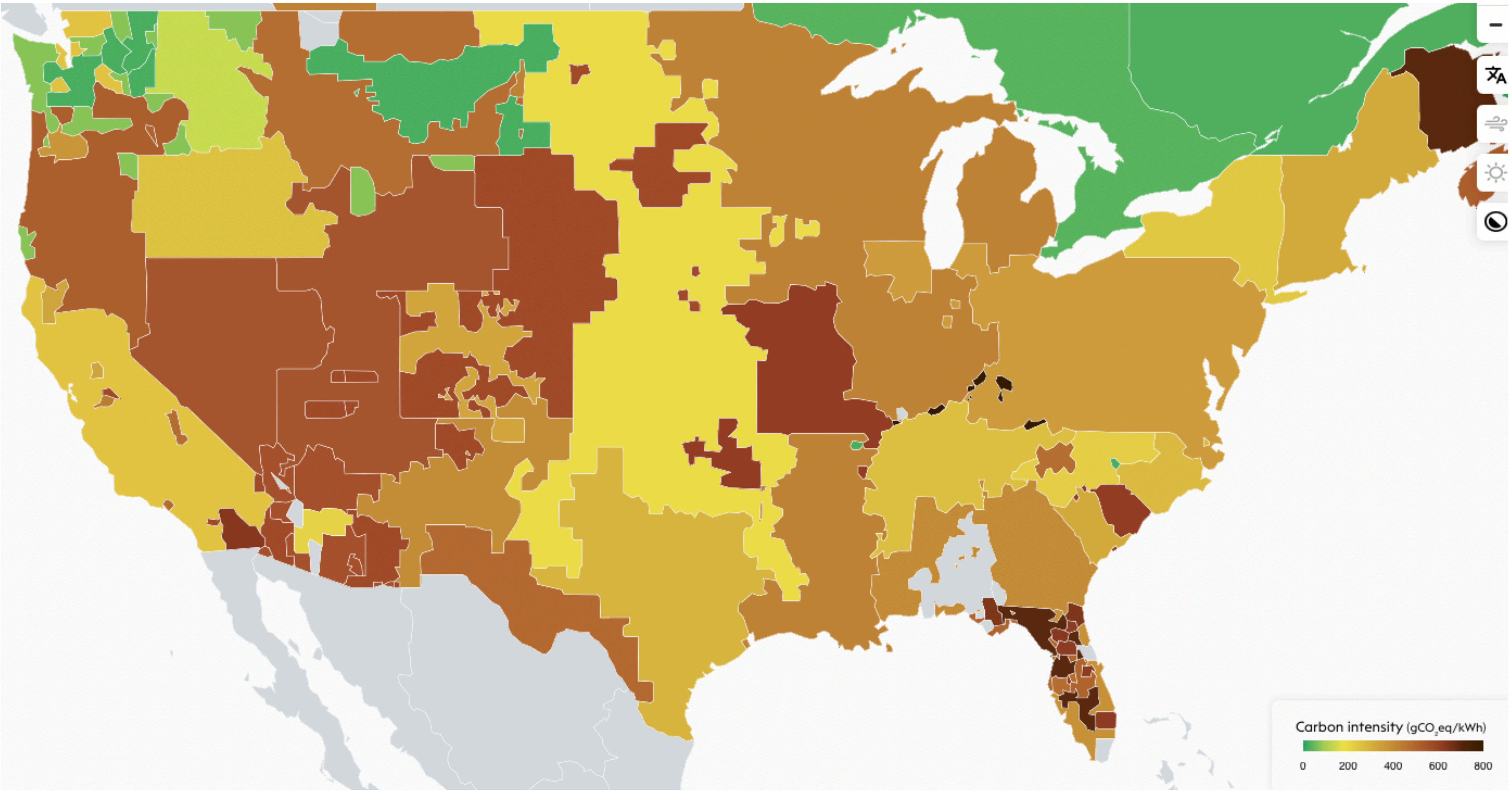
Emissions from detectors



- F-gases are good for detector operations, but highly regulated in the EU (phased-down sales → more expensive), mandatory reporting in the US.
- Procurement subject to availability and price increases → potential threat to long-term LHC program.
- New eco-friendly gases good for refrigerants, not so much for particle detection.

Emissions from computing

- Data centers and computing contribute 2-4% of global GHG emissions, only expected to grow.
- Up-front considerations: where do we place computing facilities and how are they powered? Electricity emissions vary significantly across regions.
- But if electric grid is decarbonized, electricity supply might be biggest concern.



electricitymap.org

Emissions from laboratories

- DOE requires annual reports from labs on emissions.
- From SLAC <u>2021 Annual Site Environmental Report</u>:

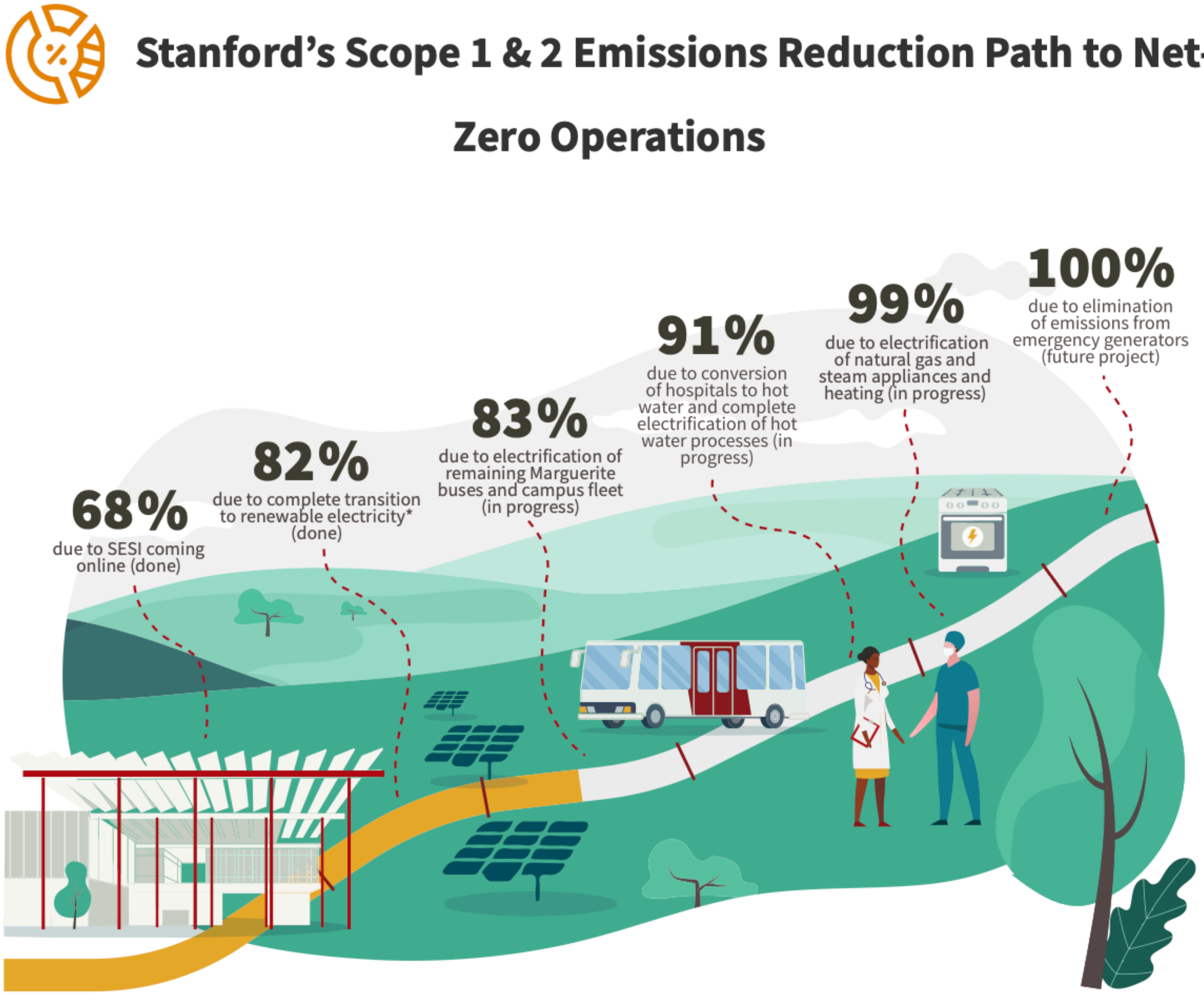
Executive Order EO 14008 engages the federal government in greenhouse gas reduction to combat climate change and EO 14057 seeks to reduce U.S. greenhouse gas emission by at least 50 percent from 2005 levels by 2030. By the end of CY 2021, implementing instructions had yet to be issued. SLAC continues to track and take action to reduce GHGs. In 2021, SLAC achieved a cumulative reduction in Scope 1 and 2 emissions of 64 percent, a reduction from 92,000 to 40,000 of metric tons of carbon dioxide (CO2) equivalent (MTCO2e). Scope 3 emissions were reduced by 52 percent relative to the 2008 baseline, a reduction from 12,000 to 6,000 MTCO2e. The reduction is attributed to SLAC iteratively re-starting accelerator operations of the LCLS II, and reduced on-site occupancy related to the pandemic.

As part of its GHG management program, CARB established a program that specifically addresses gas-insulated switchgear (GIS), electrical equipment filled with sulfur hexafluoride (SF_6). This compound is the most powerful GHG known, having a Global Warming Potential (GWP) of 23,900 relative to carbon dioxide, which has a GWP of 1. SLAC monitors all purchase and use of SF_6 closely; explores less potent GHG alternatives; and emissions, if any, are tracked and reported to CARB. Both the annual SF_6 GIS inventory report and the annual SF_6 Research Report were submitted to CARB by the March 2021 and June 2021 deadlines, respectively.

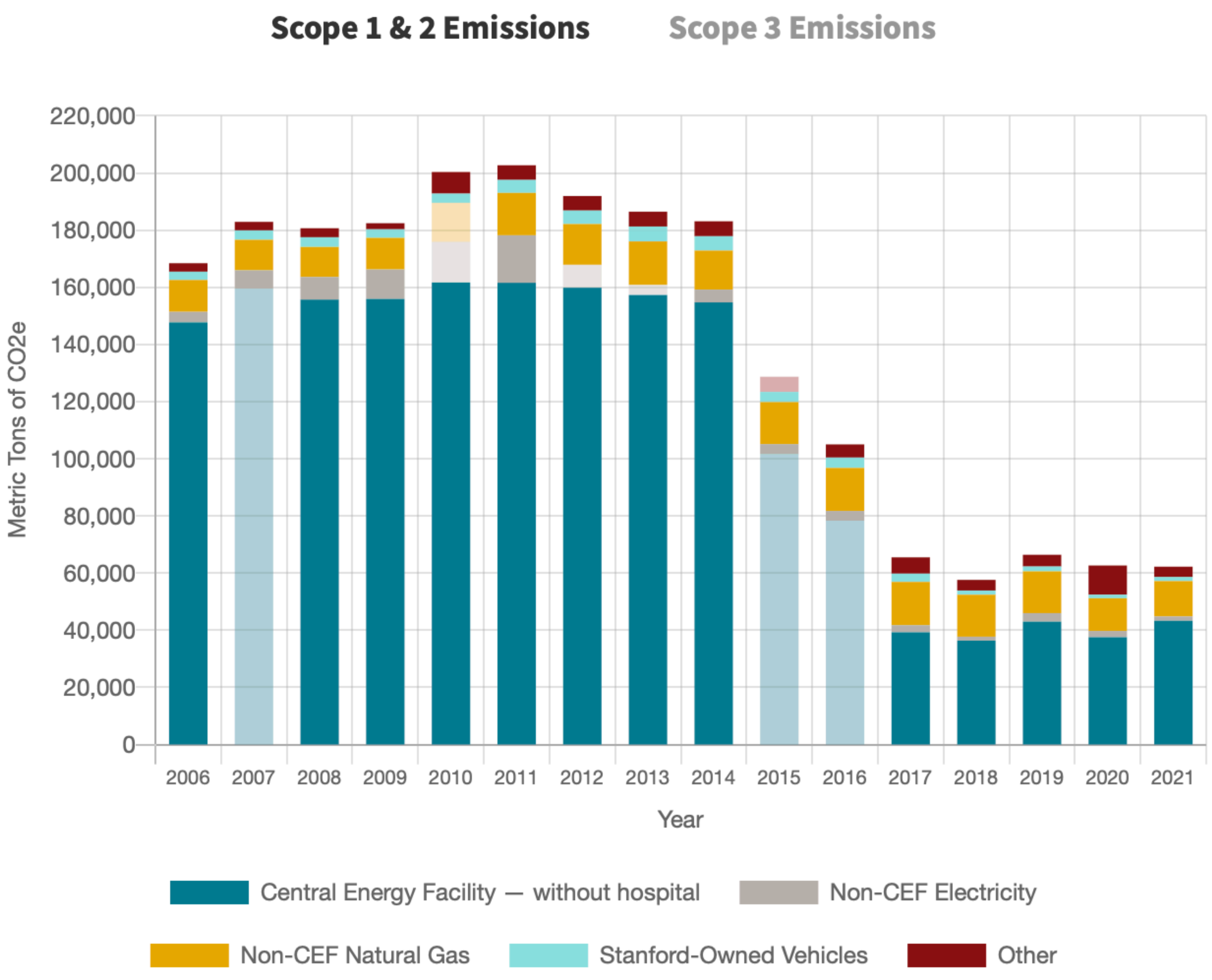
Emissions from campuses

- Stanford has many sustainability efforts:
  - New Doerr School of Sustainability!
  - One of only ten U.S. institutions with a platinum rating from Association for Advancement of Sustainability in Higher Education.
  - As of last year, 100% of electricity is from renewable sources.
  - Heat recovery system in Central Energy Facility.
  - Reduced Scope 1 and Scope 2 emissions by 69% over past decade, starting to focus on Scope 3.

Emissions from campuses



Emissions from campuses



Why am I here?

Rethinking travel

- Particle physicists are famous for their travel!
- Air travel is “only” 2.4% of global emissions (2018), but rising rapidly (up 32% in 5 years) and hard to de-carbonize.
- The pandemic has taught us a lot about what can be done remotely…and what *can’t* be done remotely.
- Optimizing experiment work: remote control rooms, improved meeting technology, rely more on regional centers.
- What about conferences? Is in-person appearance necessary for career development, or just for fun?
  - Estimate 1 ton CO2e per conference participant!
  - Improvements: accessible venues, virtual attendance, reduce frequency, multiple regional hubs
- Judicious choices can have an impact.

What to do?

- Be prepared!
  - Expect more stringent review of environmental impacts.
  - Set concrete emissions reduction goals and define pathways to meet them.
  - Consider the evolving context, e.g. a decarbonized electric grid by 2040.
- Invest for a zero-carbon future by letting particle physicists spend some of their research time on directly tackling challenges related to climate change in the context in particle physics.
  - Less carbon-intensive construction materials, better gases for particle detection, energy-efficient accelerators and computing, improved remote meeting technology.
- Addressing climate change requires a societal response, but particle physics should be leaders in sustainable science.
- It's not too late, if we start acting now.