Environmental Impact of Future Colliders

Perspective from the Snowmass ITF

Spencer Gessner, SLAC
Marlene Turner, LBNL

September 5, 2022

Outline

- Snowmass Implementation Task Force: Objectives and Results
- Carbon Impact of Facility Construction
- Carbon Impact of Facility Operation
- Mitigation Strategies

Snowmass ITF

The Snowmass Implementation Task Force (ITF) was tasked with analyzing future collider facilities for:

- Cost
- Time of development
- Size
- Power consumption

The size and power consumption parameters can be used to determine environmental impact.

Steve Gourlay (LBNL)

Philippe Lebrun (CERN)

Thomas Roser (BNL, Chair)

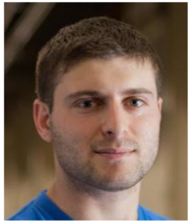
Tor Raubenheimer (SLAC)

Katsunobu Oide (KEK)

Jim Strait (FNAL)

Early Career Members

Marlene Turner (LBNL)



Spencer Gessner (SLAC)

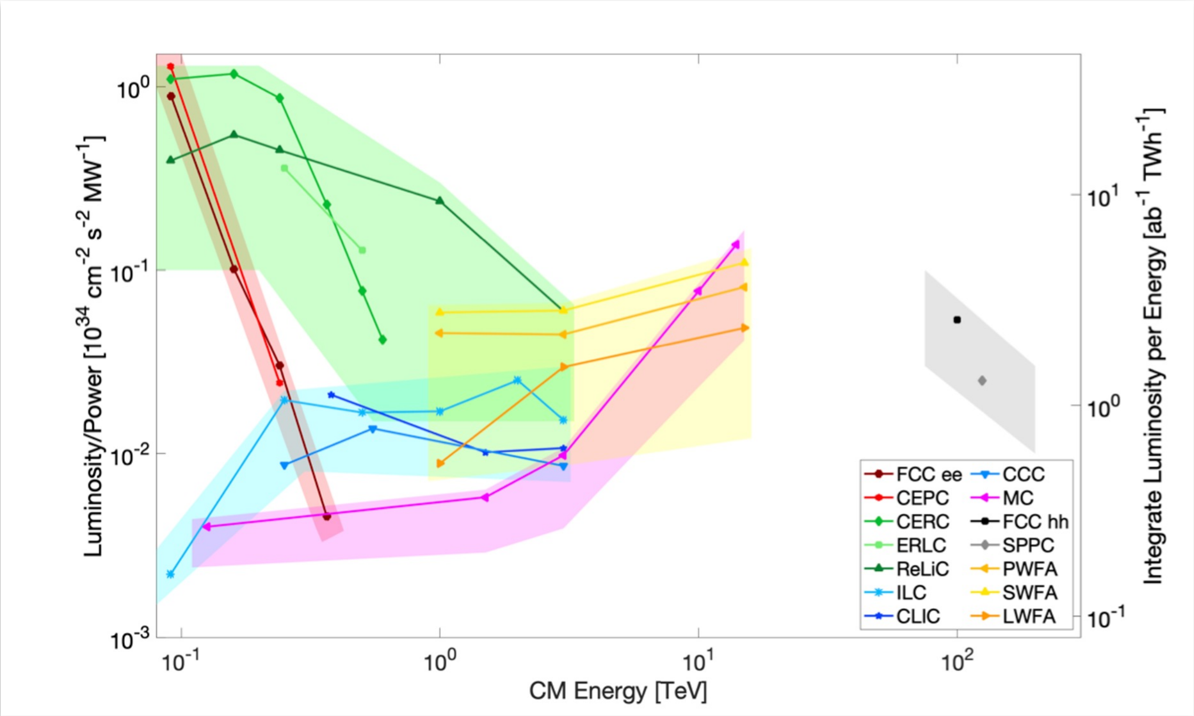
Sarah Cousineau (ORNL)

Vladimir Shiltsev (FNAL)

Reinhard Brinkmann (DESY)

John Seeman (SLAC)

Snowmass ITF Report



ITF Report: https://arxiv.org/abs/2208.06030

Tunneling

Tunneling and Construction

Drill and Blast

Tunnel Boring Machine

~0.4 Tonnes CO_2/m @ 5.5 m diameter
(includes loading and hauling)

Environmental impact of drill and blast tunnelling: life cycle assessment.
http://dx.doi.org/10.1016/j.jclepro.2014.08.083

~1.8 MWh/m -> 0.09-0.9t CO_2/m @ 5.5 m diameter
(additional 0.15 CO_2/m for loading and hauling)

Performance Analysis of Tunnel Boring Machines for Rock Excavation.
https://doi.org/10.3390/app11062794

Tunneling and Construction

Excavation emissions per meter

Total CO2 Emissions

Concrete emissions per kg

$$E_{CO_2} = L\left[XE(r) + \pi\left((r+t)^2 - r^2\right)\rho_{concrete}CE\right]$$

Tunnel length

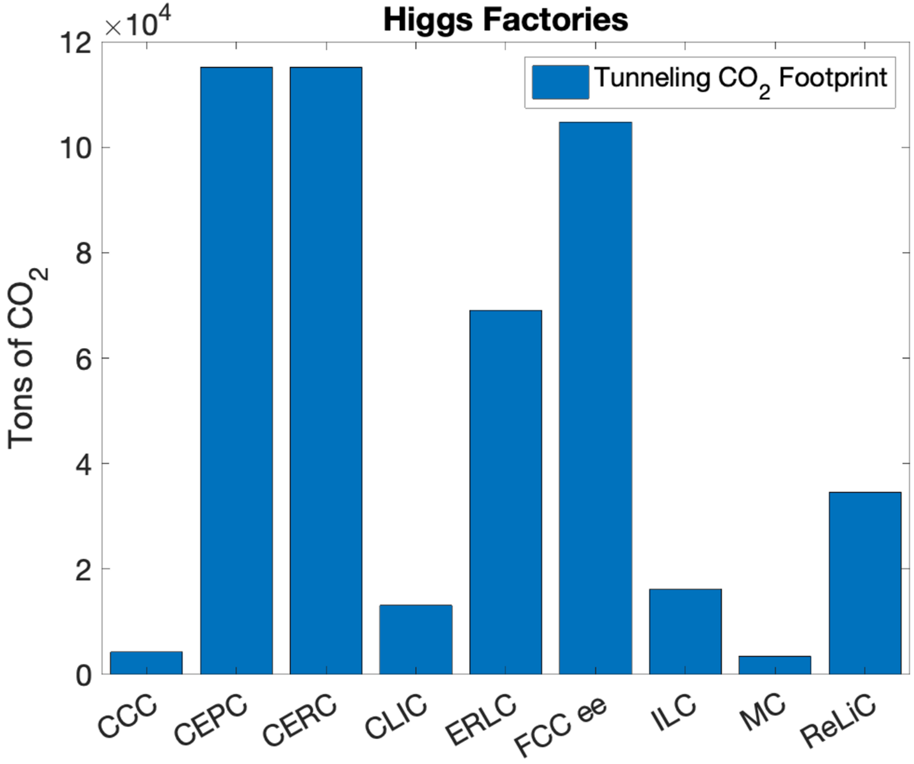
Tunnel radius

Tunneling and Construction

Calculation based on length of main tunnel and assumes 0.4t CO_2/m (independent of site or technique).

Assumes a 5 meter diameter and considers emissions from concrete as well.

Emissions may be lower for projects at CERN (nuclear energy) or C^3 (surface-level tunnel).




Power Consumption

Power Consumption

Power consumption estimates provided by proponents of the collider.

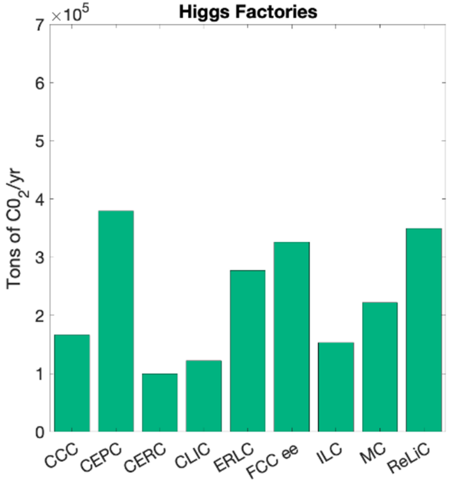
For our analysis of carbon emissions, we assume:

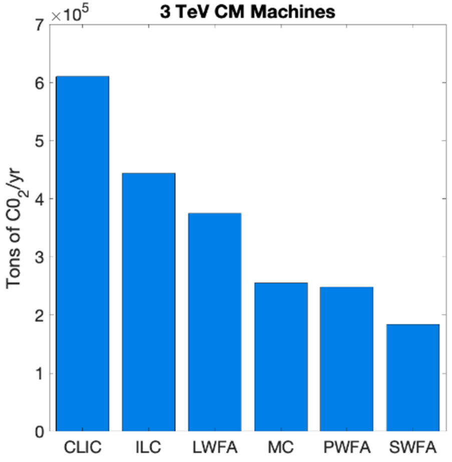
- 370g CO_2/kWh (US average)
- 1E7 seconds/year operation

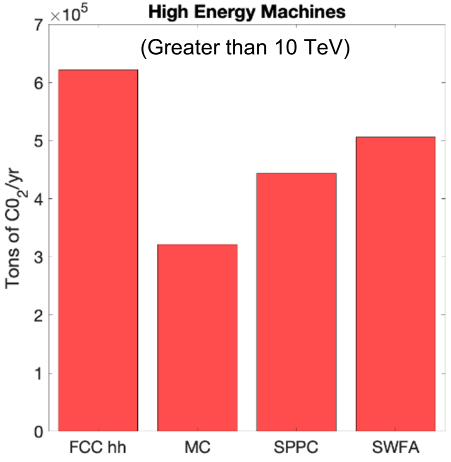
Proposal Name	Power Consumption	Size	Complexity	Radiation Mitigation
FCC-ee (0.24 TeV)	290	91 km	I	I
CEPC (0.24 TeV)	340	100 km	I	I
ILC (0.25 TeV)	140	20.5 km	I	I
CLIC (0.38 TeV)	110	11.4 km	II	I
CCC (0.25 TeV)	150	3.7 km	I	I
CERC (0.24 TeV)	90	91 km	II	I
ReLiC (0.24 TeV)	315	20 km	II	I
ERLC (0.24 TeV)	250	30 km	II	I
XCC (0.125 TeV)	90	1.4 km	II	I
MC (0.13 TeV)	200	0.3 km	I	II
ILC (3 TeV)	~400	59 km	II	II
CLIC (3 TeV)	~550	50.2 km	III	II
CCC (3 TeV)	~700	26.8 km	II	II
ReLiC (3 TeV)	~780	360 km	III	I
MC (3 TeV)	~230	10-20 km	II	III
LWFA (3 TeV)	~340	1.3 km (linac)	II	I
PWFA (3 TeV)	~230	14 km	II	II
SWFA (3 TeV)	~170	18 km	II	II
MC (14 TeV)	~300	27 km	III	III
LWFA (15 TeV)	~1030	6.6 km	III	I
PWFA (15 TeV)	~620	14 km	III	II
SWFA (15 TeV)	~450	90 km	III	II
FCC-hh (100 TeV)	~560	91 km	II	III
SPPC (125 TeV)	~400	100 km	II	III

ITF Report: https://arxiv.org/abs/2208.06030

Emissions from Power Consumption







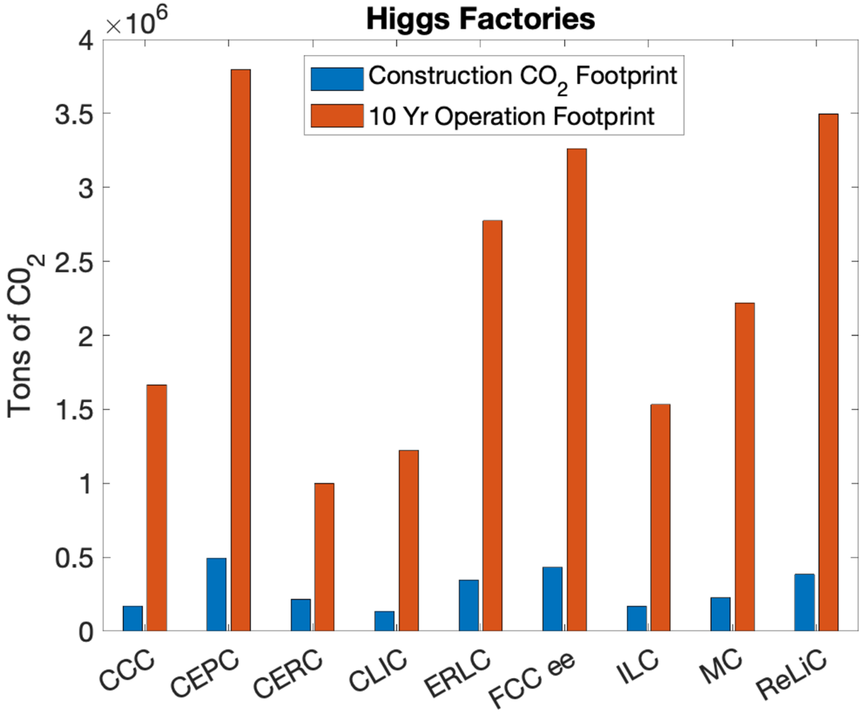
Site-independent estimate of emissions due to power consumption.

Emissions from Power Consumption

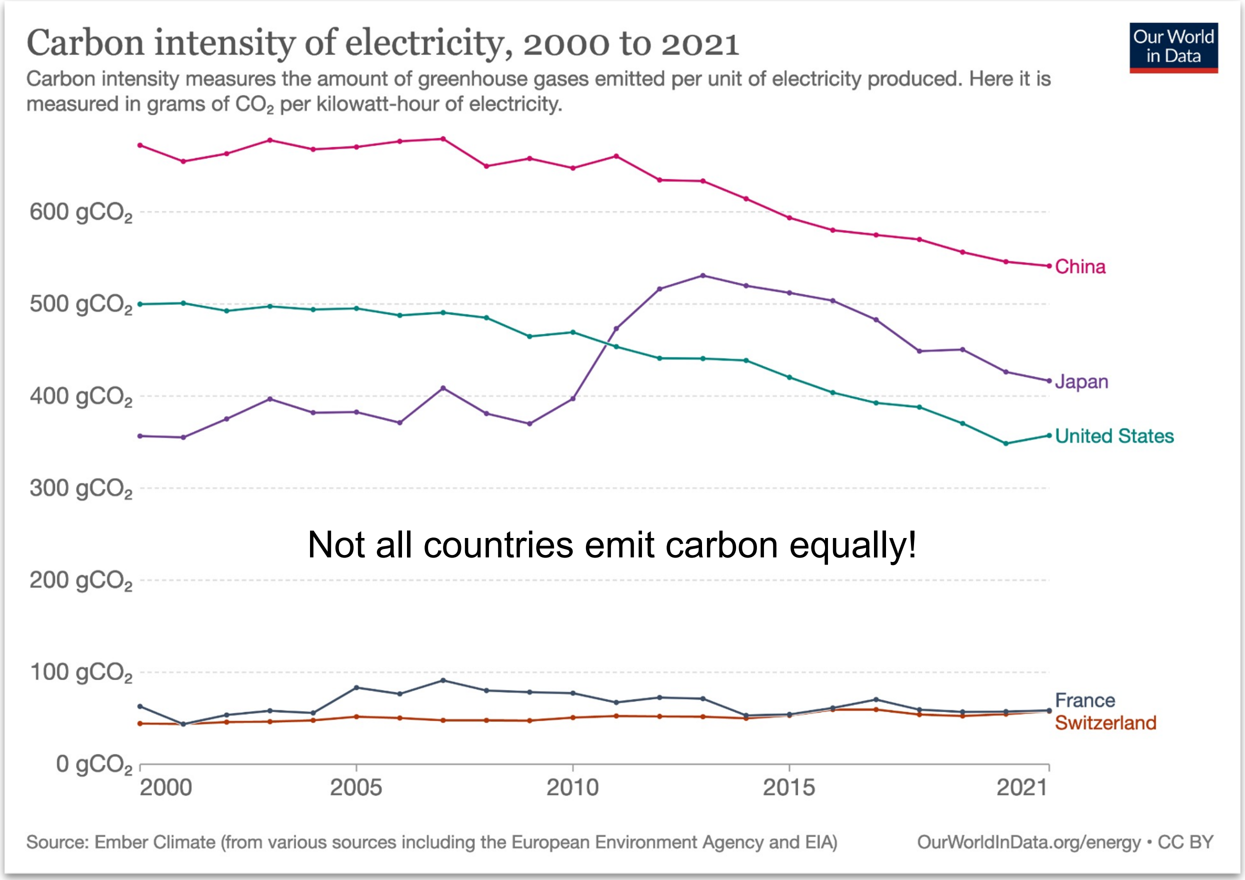
Construction footprint includes:

- Emissions due to tunneling.
- Emissions from concrete.
- Assumes that the lab uses 10% of full operating power during construction phase.

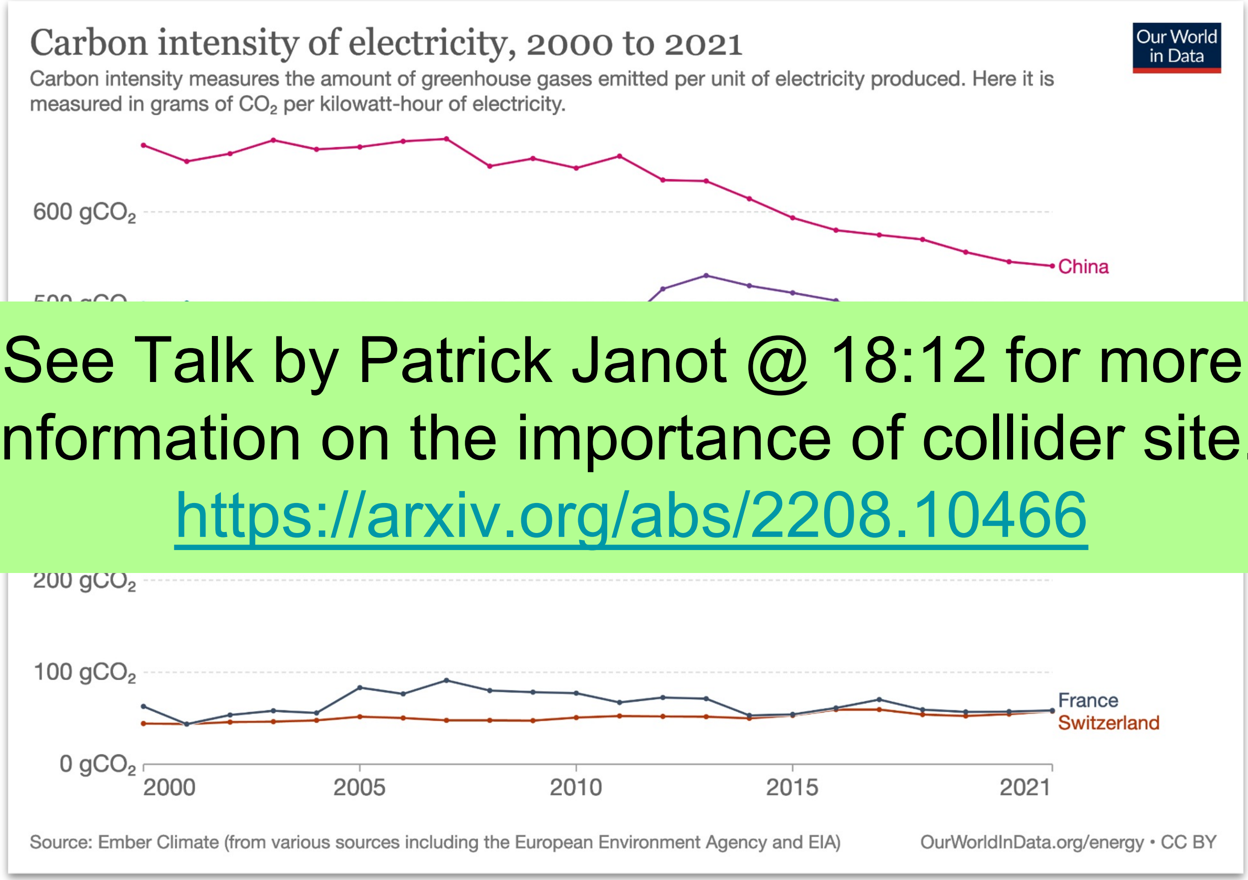
In all cases, emissions from power consumption during operation dominate over construction emissions.



Carbon Intensity Varies Around the World



Carbon Intensity Varies Around the World



See Talk by Patrick Janot @ 18:12 for more information on the importance of collider site.
https://arxiv.org/abs/2208.10466

Mitigation

Green Accelerator Technology

Energy recovery:

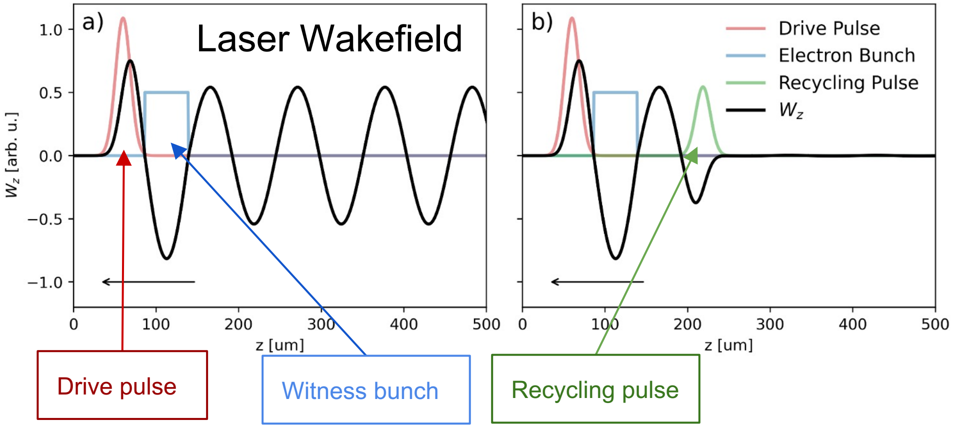
- Superconducting energy-recovery linac ERL already demonstrated.
- DOE funded project to develop this concept for plasma accelerators. (M. Turner ECA)

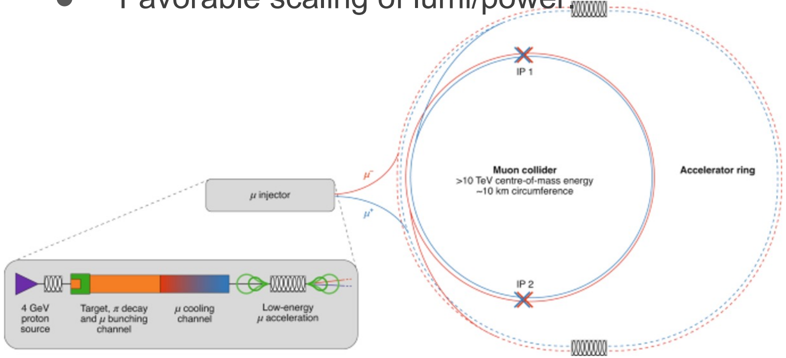
Emittance reduction:

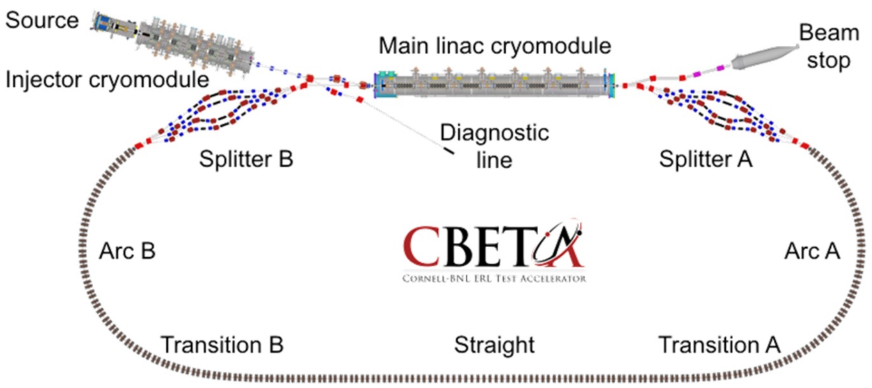
- Novel damping ring design or particle sources would reduce power requirements of linear colliders.

Muons colliders:

- Favorable scaling of lumi/power







Carbon Taxes and Offsets

Carbon taxes:

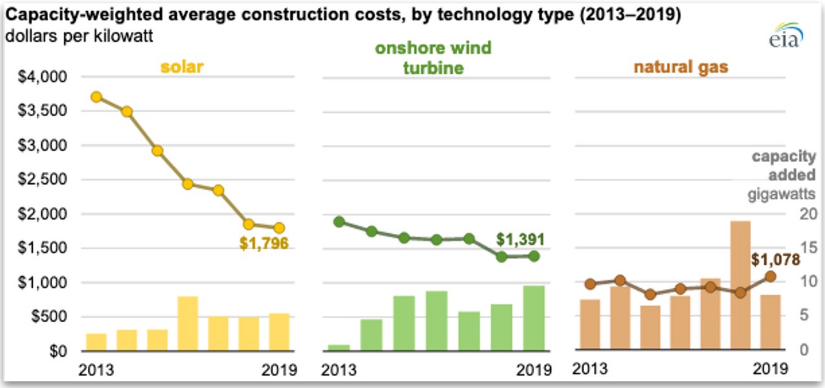
- Represents “cost” of emissions.
- Switzerland proposes 130 CHF/tonne.
    - Approximately 7.3 CHF/year CO_2 taxes for FCC.
    - Approximately 80 CHF/year CO_2 taxes for CEPC (if China taxed at same rate).

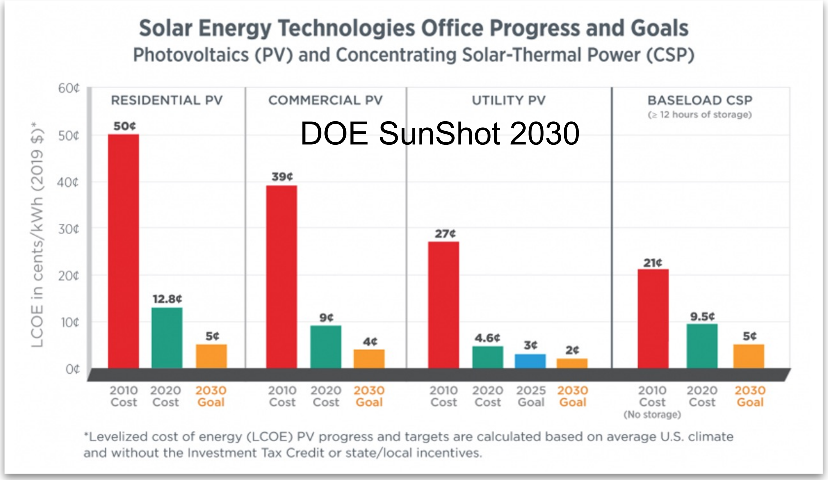
Carbon offsets: aim for zero net emissions.

- This concept is easy to abuse.
    - See John Oliver.
- But it is possible to do it right with strategic investment.

Building Green Power

- The price of new renewable energy sources is dropping rapidly.
  - In the U.S., hope to achieve $1000/kW solar installed in 2030.
- A new collider could provide a benefit to the community by funding new power sources.
- Take C³ as an example:
  - 150 MW operating power for Higgs.
  - $150M investment to create solar energy.
  - Only 2% of project cost!





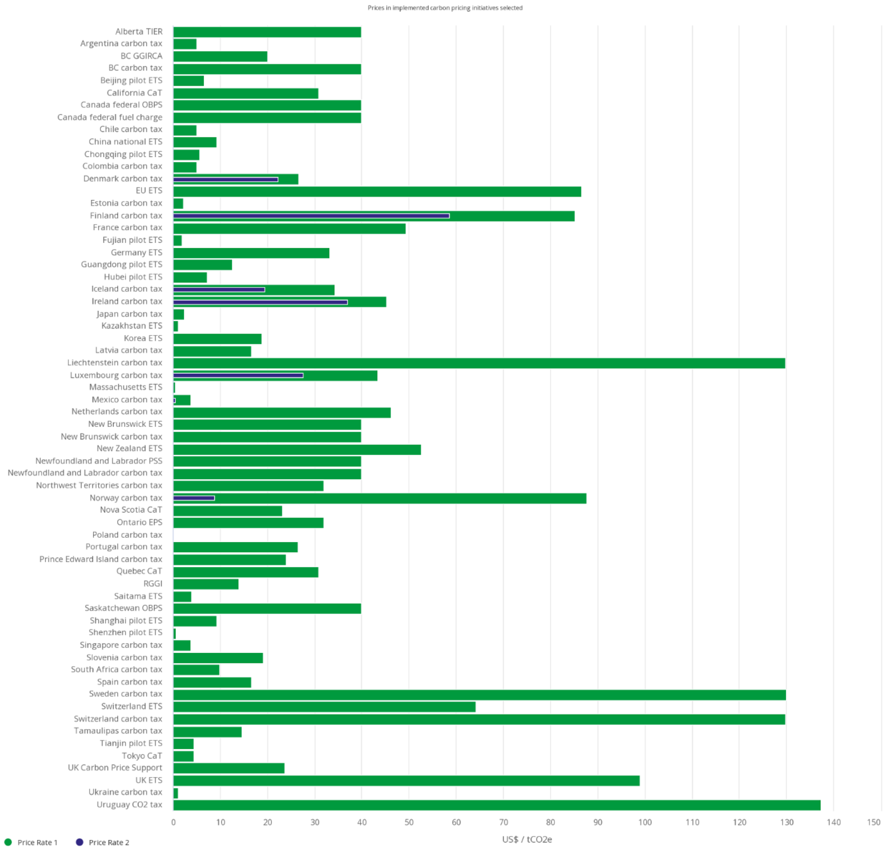
Conclusions

- We consider the effect of future colliders on the environment.
  - Collider power consumption is the biggest single factor.

- Site choice is important.
  - See Patrick Janot's talk next.

- Regardless of site choice, it is possible to mitigate the effect of carbon emissions by either investing in offsets or building renewable power sources.

Carbon Tax



Note: Nominal prices on April, 01 2022
Prices are not necessarily comparable between carbon pricing initiatives because of differences in the number of sectors covered and allocation methods applied, specific exemptions, and different compensation methods. Due to the dynamic approach to continuously improve data quality and fluctuating exchange rat may not always be comparable and could be amended following new information from official government sources. In addition, data for a limited number of initiatives may be incomplete as they are in the process of being validated and will be updated following confirmation from official government sources.