Life cycle assessment of linear colliders

Sustainable HEP

12/06/2024

Suzanne Evans

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Decarbonisation context

Annual CO_2 emissions by world region

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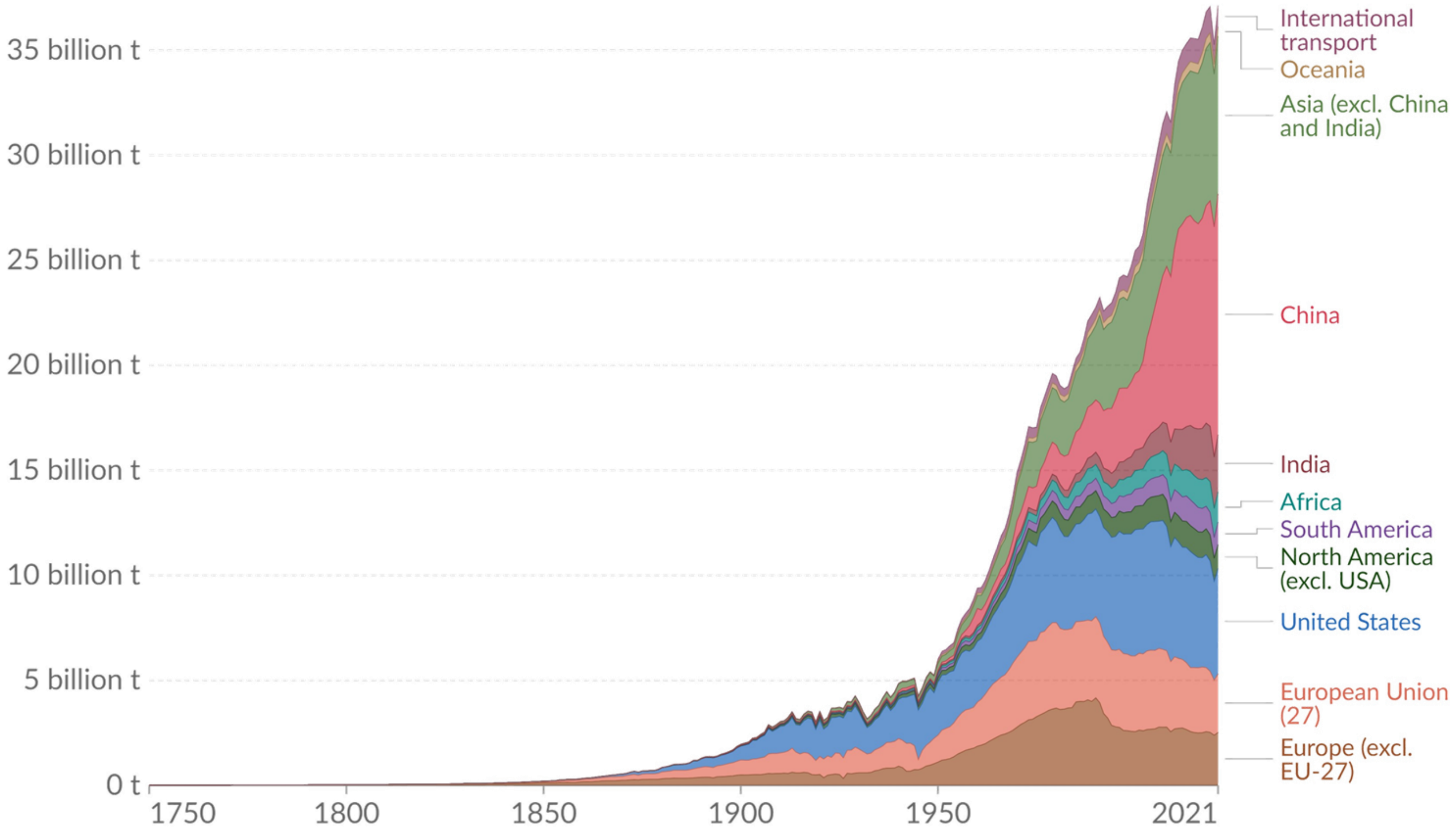
To limit global warming to 1.5°C (relative to 1900), the estimated remaining carbon budget from the beginning of 2020 is **< 300 billion t** *https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_SPM_final.pdf*



Data source: Global Carbon Budget (2022)

To limit global warming to 1.5°C (relative to 1900), the estimated remaining carbon budget from the beginning of 2020 is **< 300 billion t** https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_SPM_final.pdf

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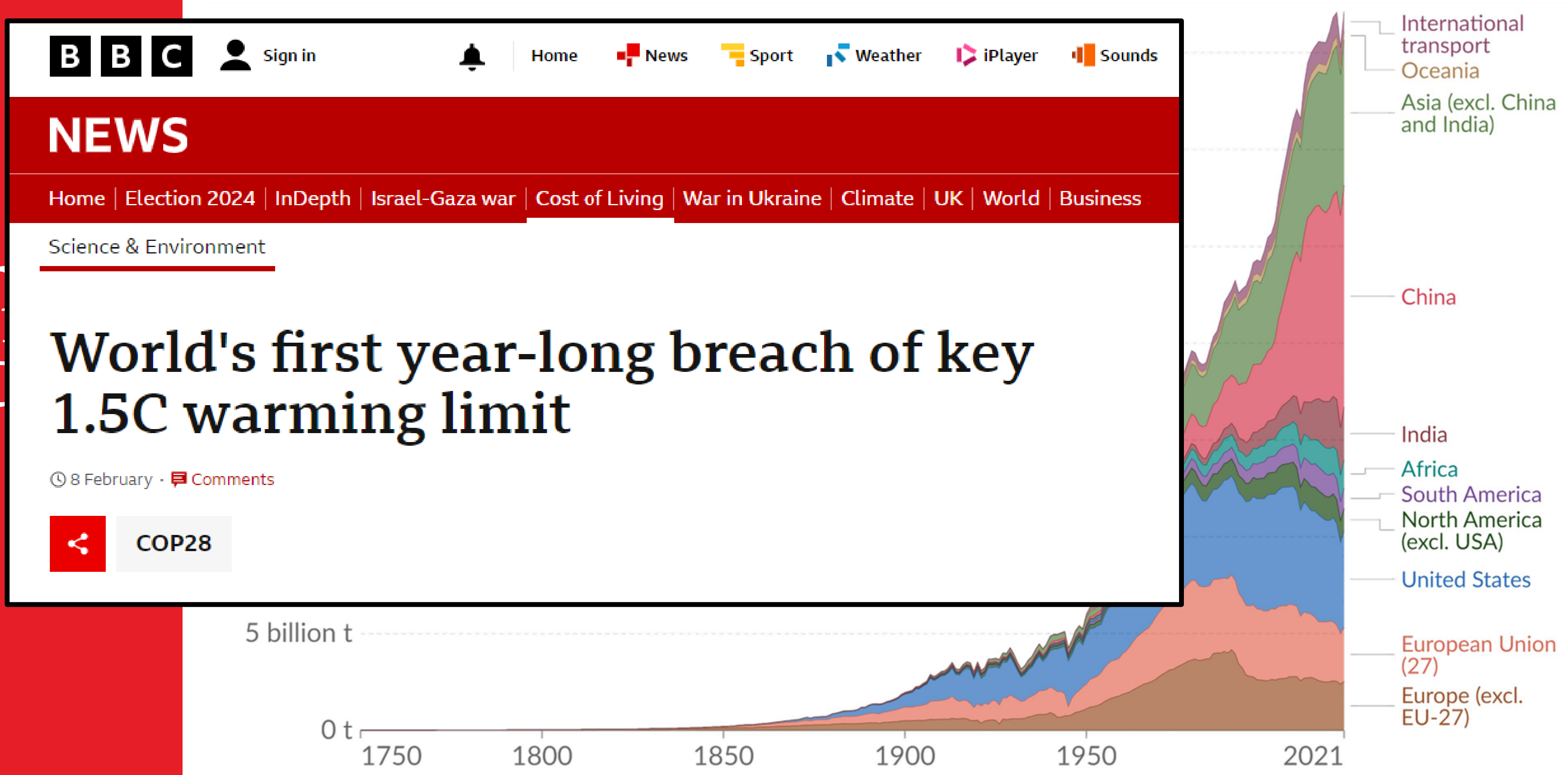
Annual CO_2 emission by worl region



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Science & Environment

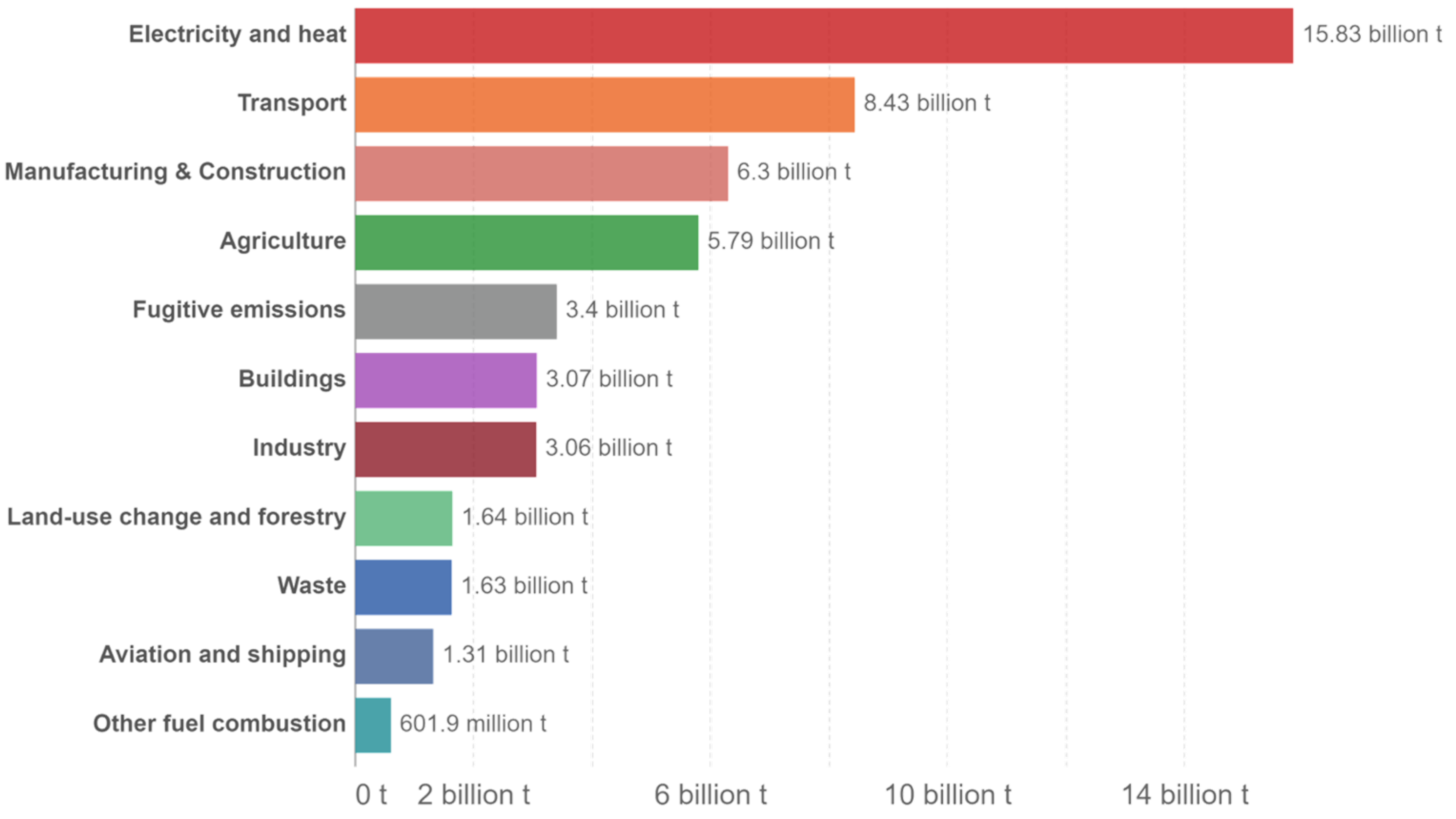
World's first year-long breach of key 1.5C warming limit

8 February · Comments

COP28

Data source: Global Carbon Budget (2022) OurWorldInData.org/co2-and-greenhouse-gas-emissions | CC BY

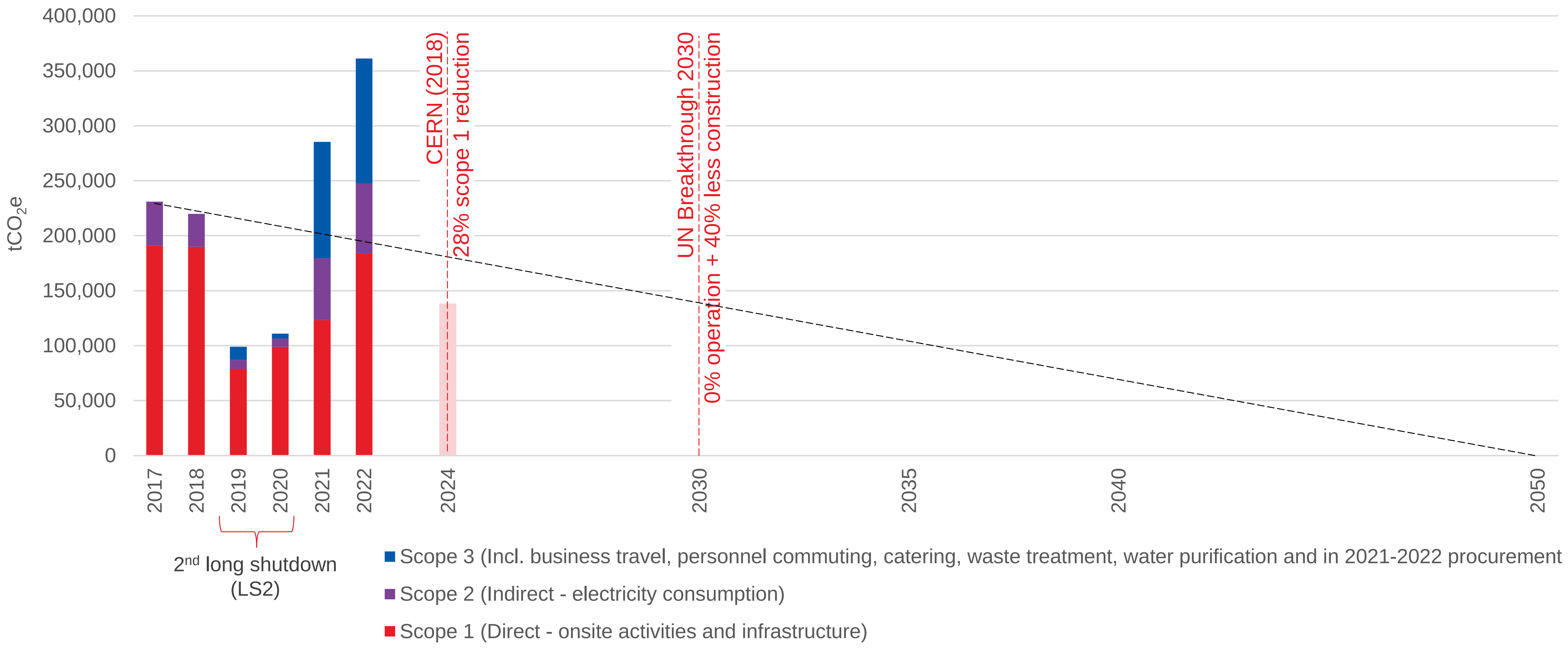
Global GHG Emissions (tCO_2e)



Our World in Data based on Climate Analysis Indicators Tool (CAIT) 2019

What is required for net zero 2050?

Future decarbonisation of CERN



Reference: CERN Environment Report 2021-2022

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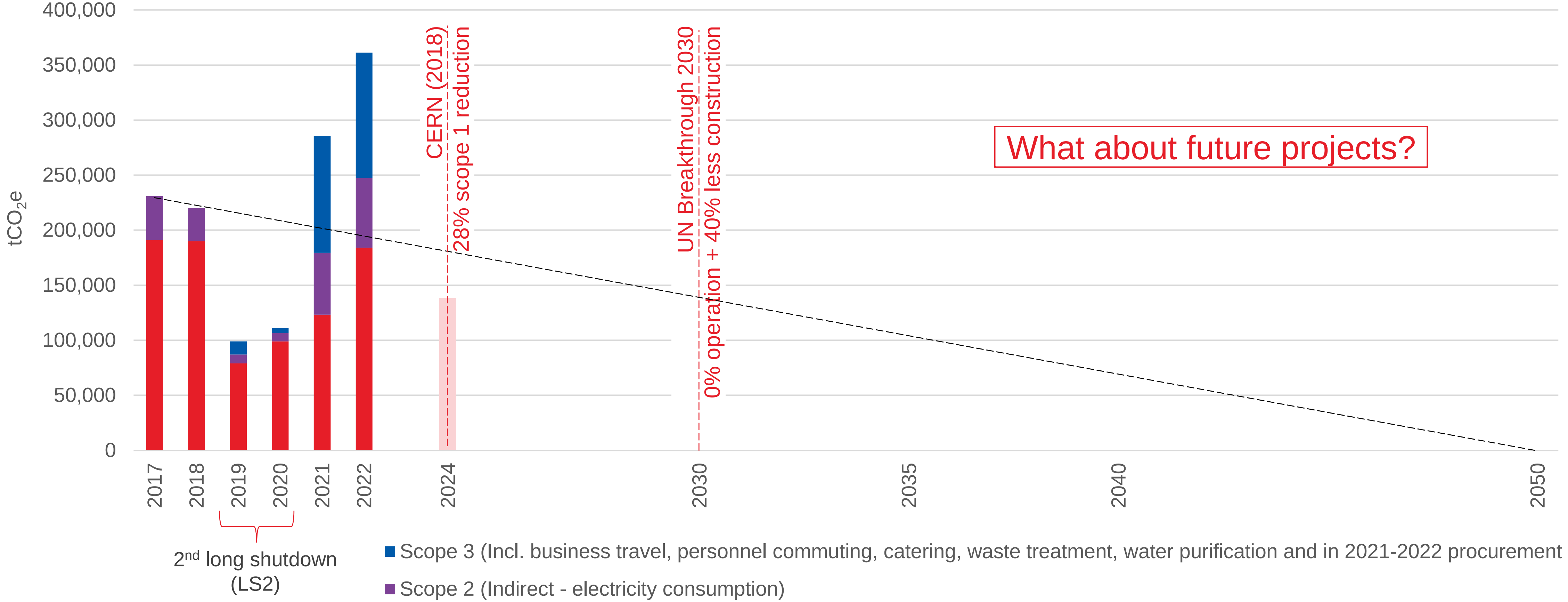
What is required for net zero 2050?

Future decarbonisation of CERN



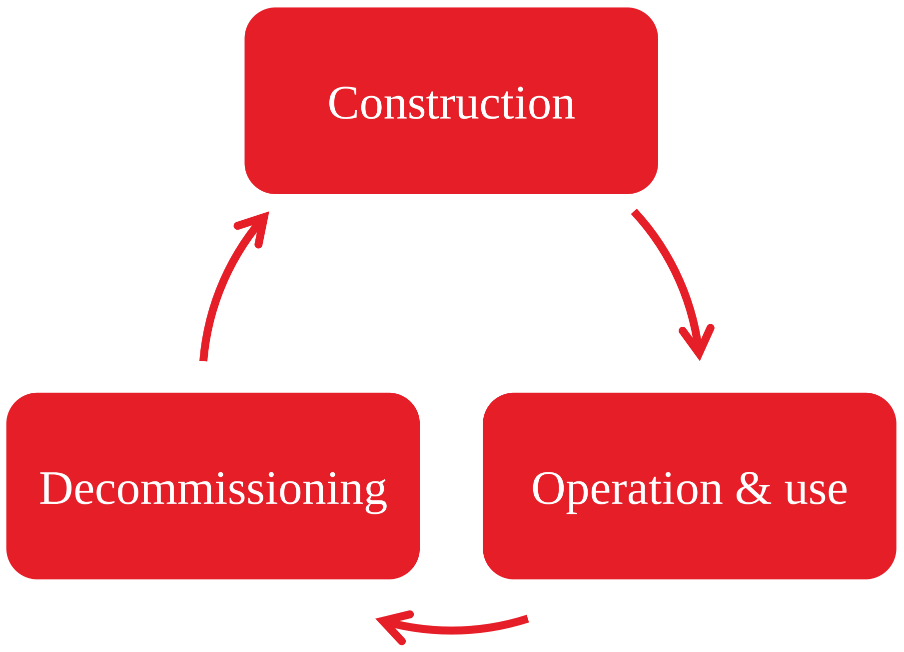
Reference: CERN Environment Report 2021-2022

Life cycle assessment of CLIC and ILC

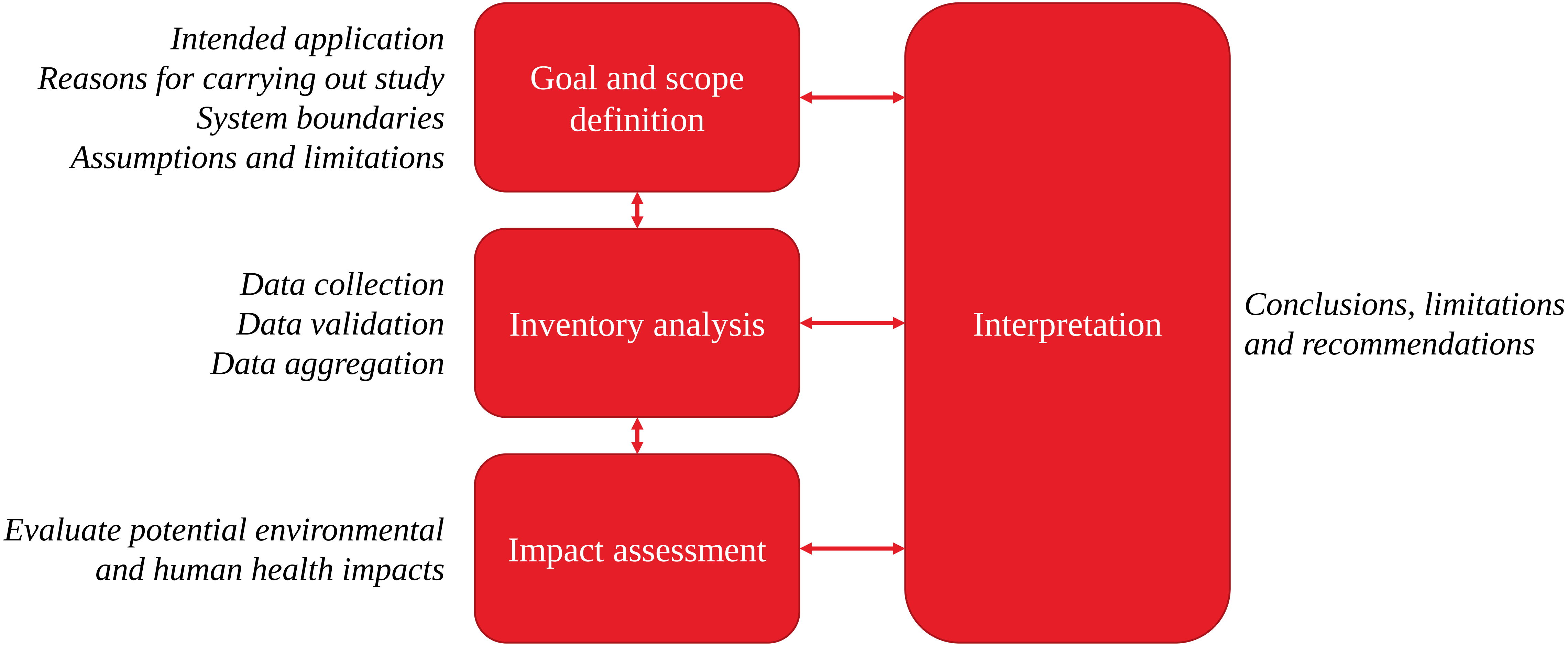
ARUP: Suzanne Evans, Yung Loo, Heleni Pantelidou, Ben Castle, Jin Sasaki
CERN: John Osborne, Steinar Stapnes, Liam Bromiley
DESY: Benno List
KEK: Nobuhiro Terunuma, Akira Yamamoto, Tomoyuki Sanuki

Life cycle assessment

A life cycle assessment systematically assesses the environmental impact of a product or asset throughout its life cycle



Life cycle assessment



ISO 14040:2006

Linear collider options

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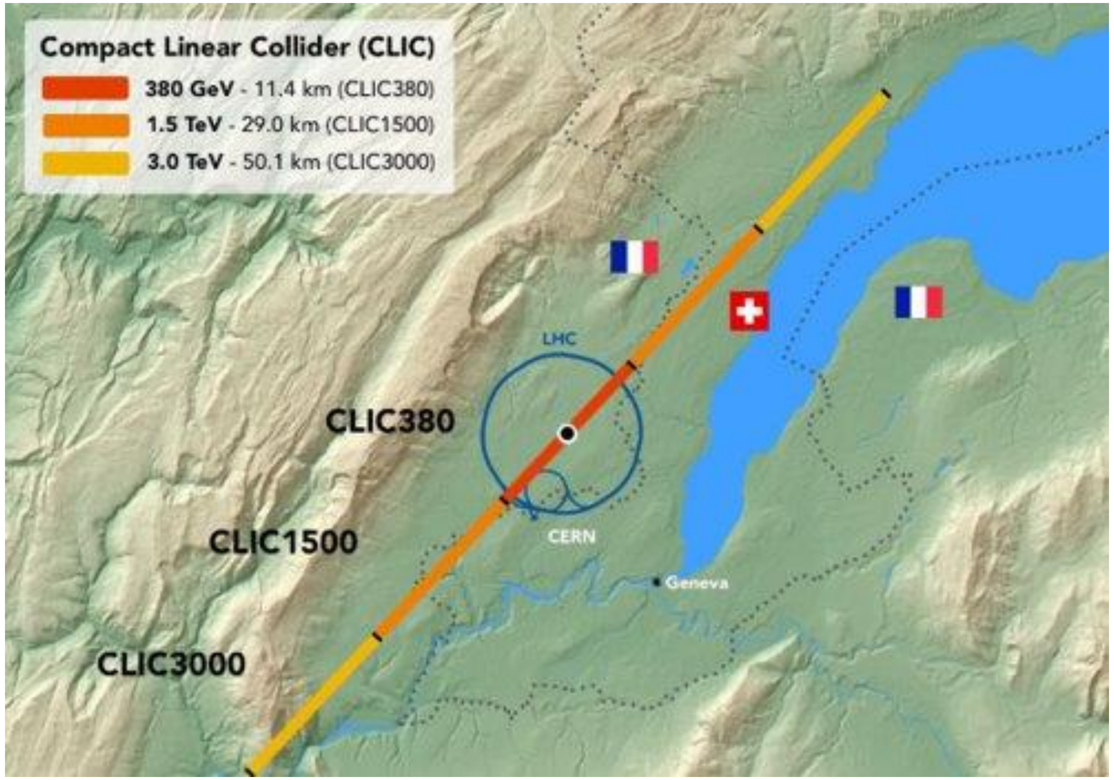
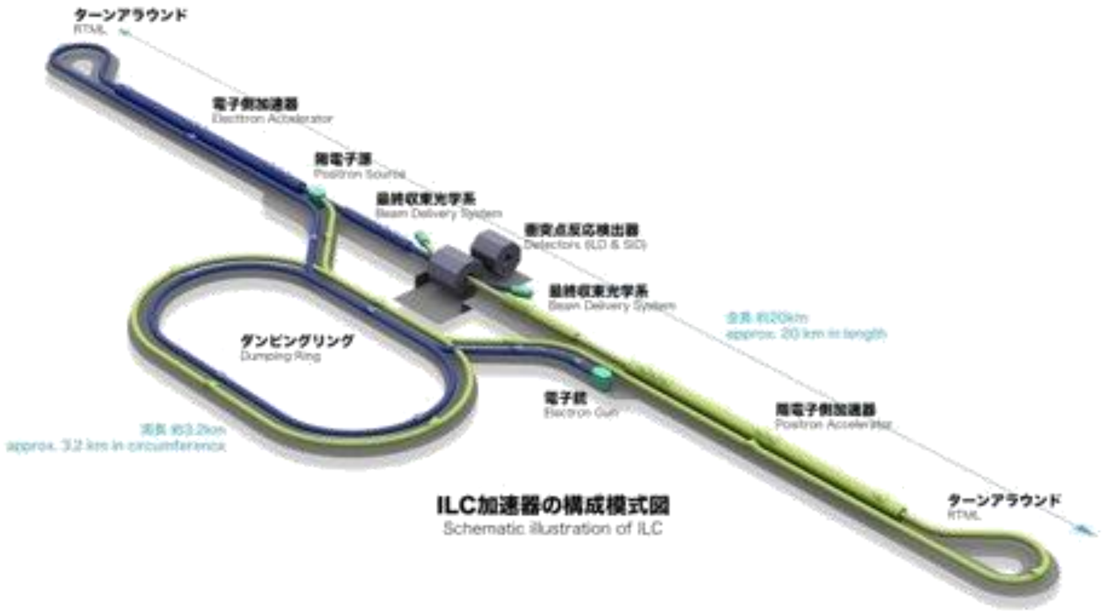
Compact Linear Collider (CLIC)

a) Drive Beam b) Klystron



International Linear Collider (ILC)



Linear collider options

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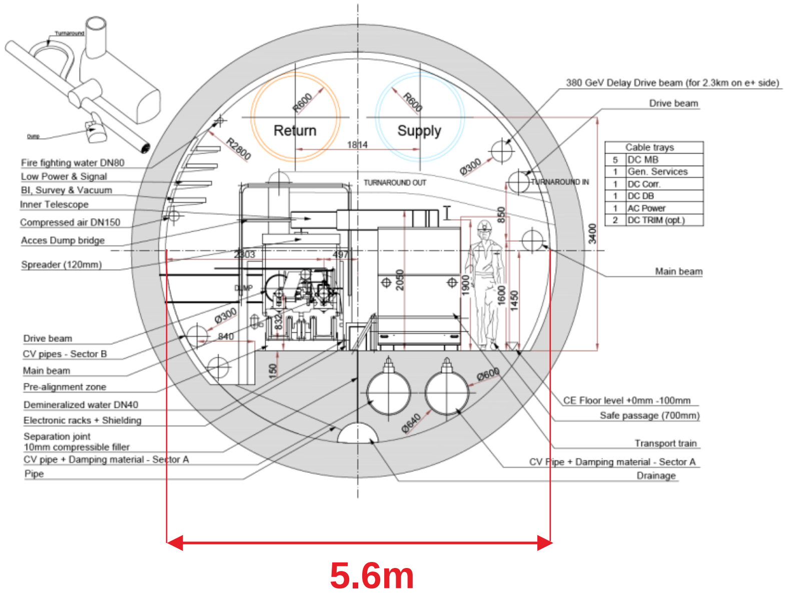
CLIC Drive Beam

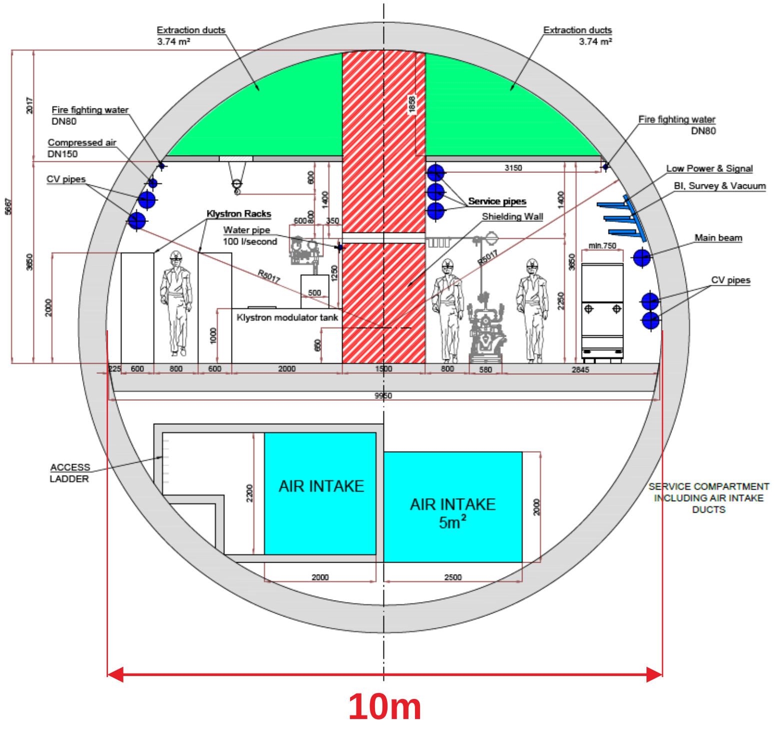
5.6m internal dia. Geneva.
(380GeV, 1.5TeV, 3TeV)



Reference: CLIC Drive Beam tunnel cross section, 2018

CLIC Klystron

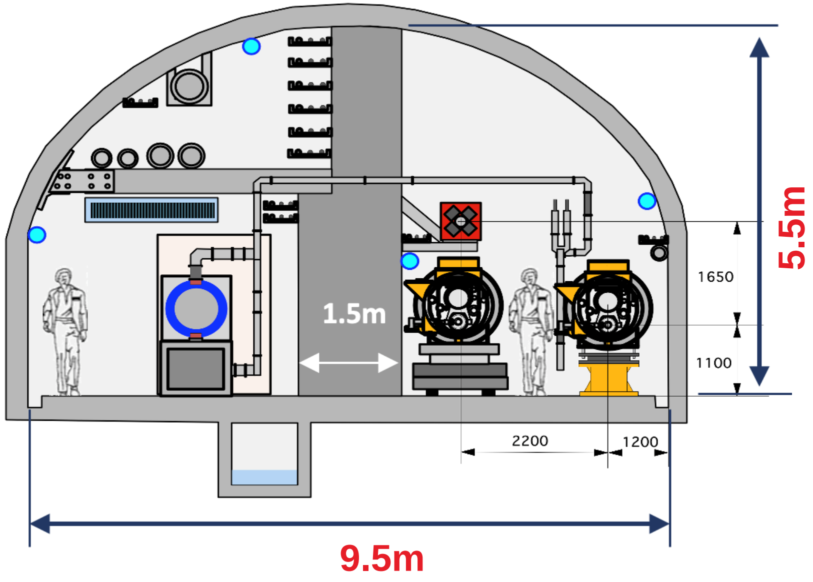
10m internal dia. Geneva.
(380GeV)



Reference: CLIC Klystron tunnel cross section, 2018

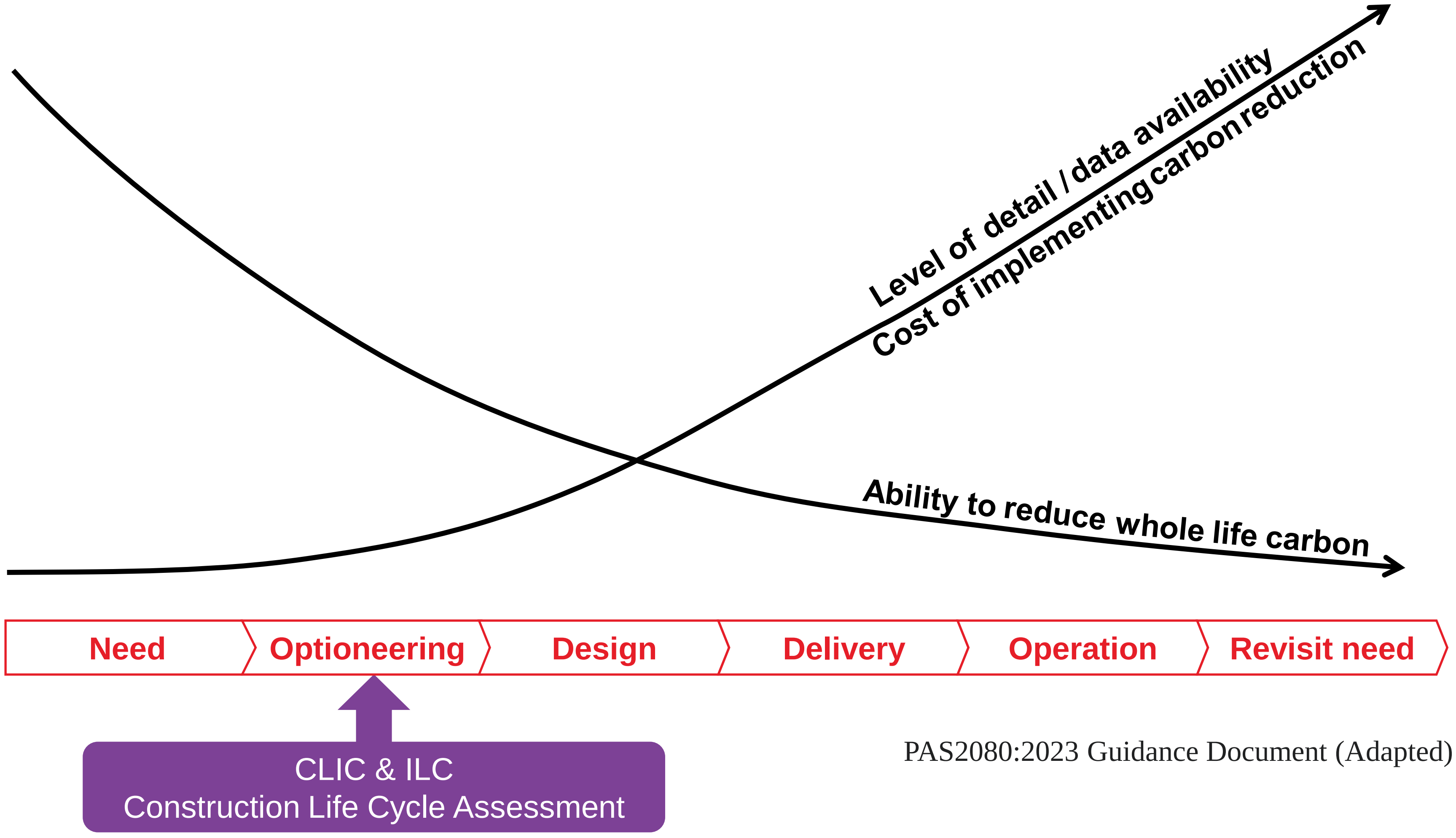
ILC

Arched 9.5m span. Tohoku region, Japan.
(250GeV)



Reference: Tohoku ILC Civil Engineering Plan, 2020

Early stage Influence



PAS2080:2023 Guidance Document (Adapted)

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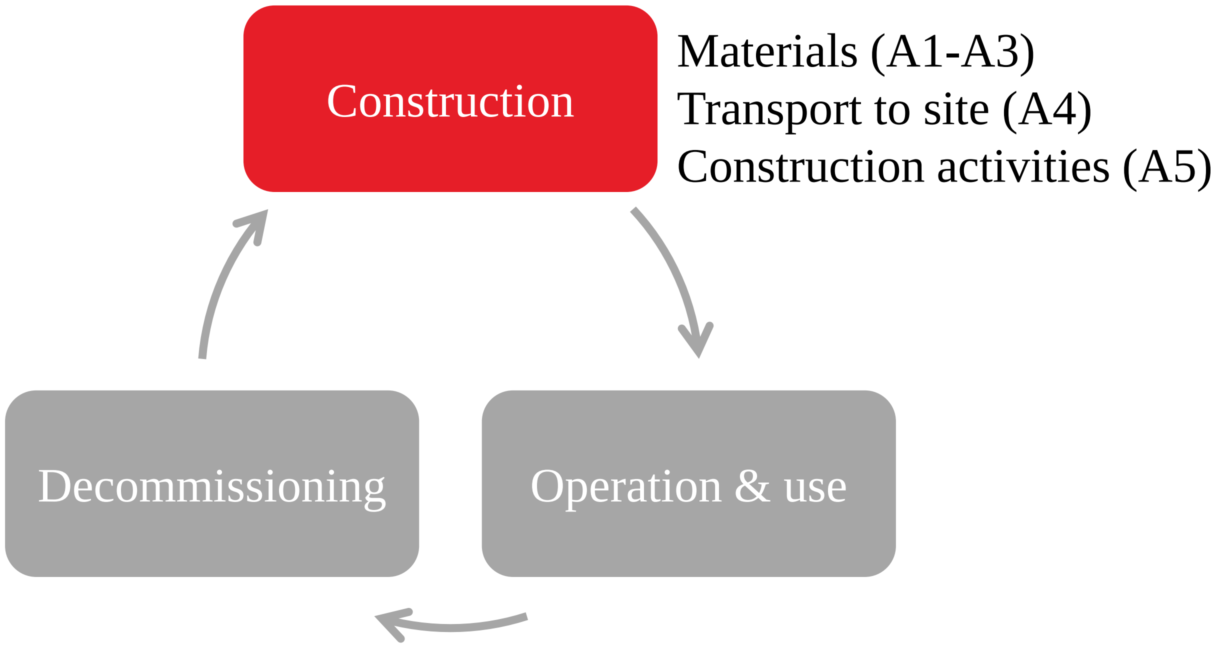
Goal and scope

Evaluate the construction environmental impacts of the 3 proposed linear collider options, identifying hotspots and potential reduction opportunities



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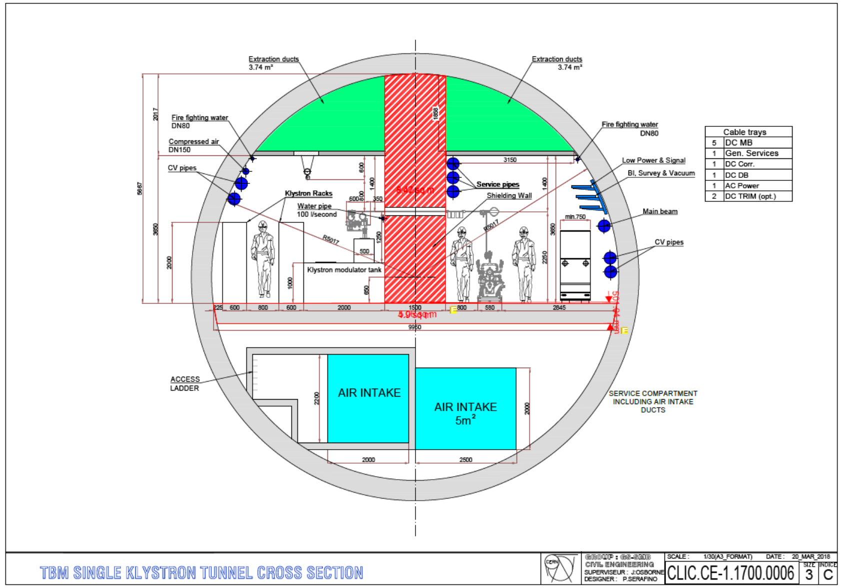
Inventory analysis

- Data collected through design reports and drawings
- Assumptions provided by CERN and KEK in absence of information



Specification	5.6m TBM tunnel	10m TBM tunnel	3m beam turnaround	Caverns	Drive beam dump caverns	9m shafts	18 m shafts	12 m shafts
Precast concrete thickness, mm	300	450	-	-	-	-	-	-
Precast concrete compressive strength, MPa	50	50	-	-	-	-	-	-
Grout lining thickness, mm	100	150						
Steel fibre density per vol. concrete, kg/m³	35	35	-	-	-	-	-	-
Rebar density, kg/m³	80	80	-	-	-	-	-	-
Shotcrete thickness, mm	-	-	200	400	200	300	500	400
Shotcrete compressive strength, MPa	-	-	30	30	30	30	30	30
Shotcrete rebar density per vol. concrete, kg/m³	-	-	60	55	55	20	50	50
Rock bolting length (grid layout), m	-	-	2.5m (3 x 3 m)	10m (3 x 3 m)	10m (3 x 3 m)	7m (3 x 3 m)	7m (3 x 3 m)	7m (3 x 3 m)
In-situ concrete lining thickness, mm	-	-	200	110	45	300	600	500
In-situ compressive strength, MPa	-	-	40	40	40	40	40	40
In-situ rebar density per vol. concrete, kg/m³	-	-	100	120	120	60	130	110

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Data Hierarchy

System	Sub-system	Components	Sub-components
CLIC Drive Beam 380GeV			
	Tunnels		
		Main accelerator tunnel	
			Primary Lining Permanent Lining Invert
		Turnarounds	
			Primary Lining Permanent Lining Invert
	Shafts		
		9-18m dia.	
			Primary Lining Permanent Lining
	Caverns		
		BDS, UTRC, UTRA, BC2, DBD, service cavern, IR cavern, detector and service hall	
			Primary Lining Permanent Lining

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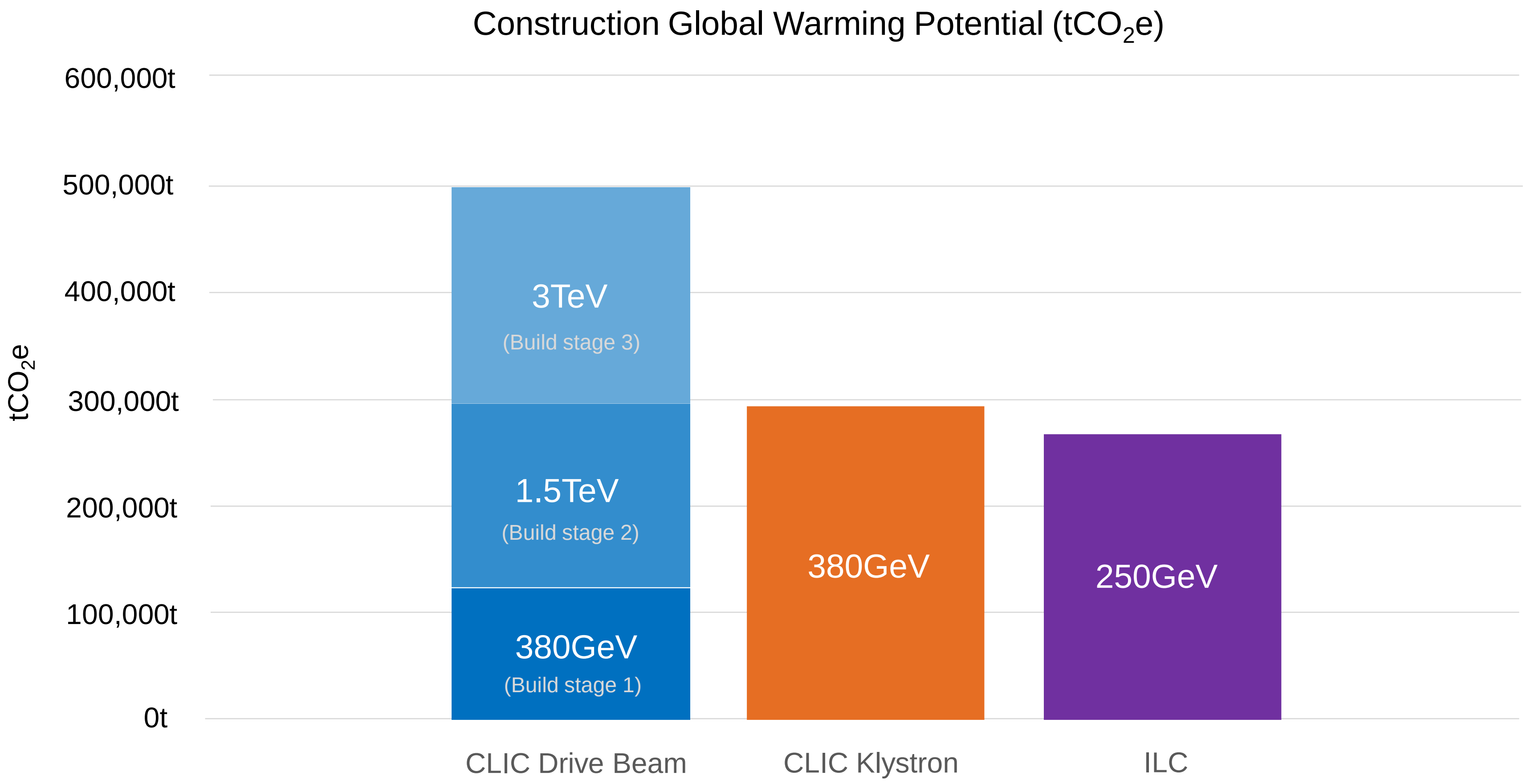
2030 Baseline assumptions

<table>
<tr><th colspan="2">Construction LCA</th><th>CLIC Drive Beam</th><th>CLIC Klystron</th><th>ILC</th></tr>
<tr><td colspan="2">Materials (A1-A3)</td><td colspan="3">Concrete (CEMI) & Steel (80% recycled)</td></tr>
<tr><td colspan="2">Transport of materials to site (A4)</td><td colspan="2">Concrete: Local by road (50km)
Steel: European by road (1500km)</td><td>Concrete: Local by road (50km)
Steel: National by road (300km)</td></tr>
<tr><td rowspan="4">Construction activities (A5)</td><td>Material wasted in construction</td><td colspan="3">Concrete insitu: 5%
Precast concrete: 1%
Steel reinforcement: 5%</td></tr>
<tr><td>Transport of disposal materials off site</td><td colspan="3">Concrete and steel recycling: 30km by road
Concrete and steel landfill: 30km by road
Spoil: 20km by road
Assumed that 90% of EoL construction materials are recycled or repurposed and 10% is in landfill.</td></tr>
<tr><td>Construction process</td><td colspan="2">Tunnel Boring Machine (TBM)</td><td>Drill & Blast*   *Explosives excluded due to lack of data</td></tr>
<tr><td>Electricity mix 2021/2022</td><td colspan="2">Fossil: 12%
Non-fossil: 88%</td><td>Fossil: 71%
Non-fossil: 29%</td></tr>
</table>

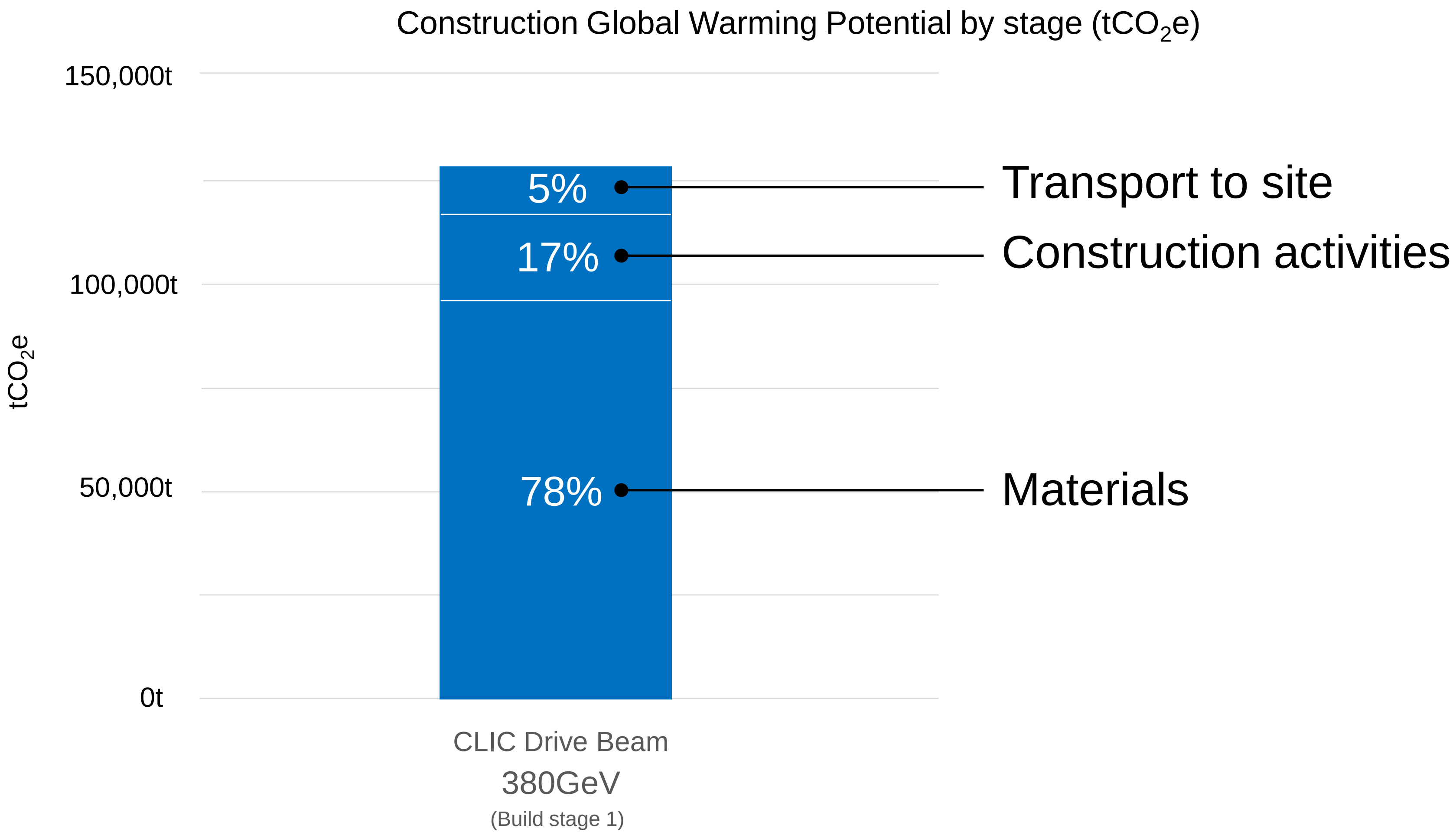
Impact assessment

CLIC & ILC



Impact assessment

CLIC Drive Beam 380GeV



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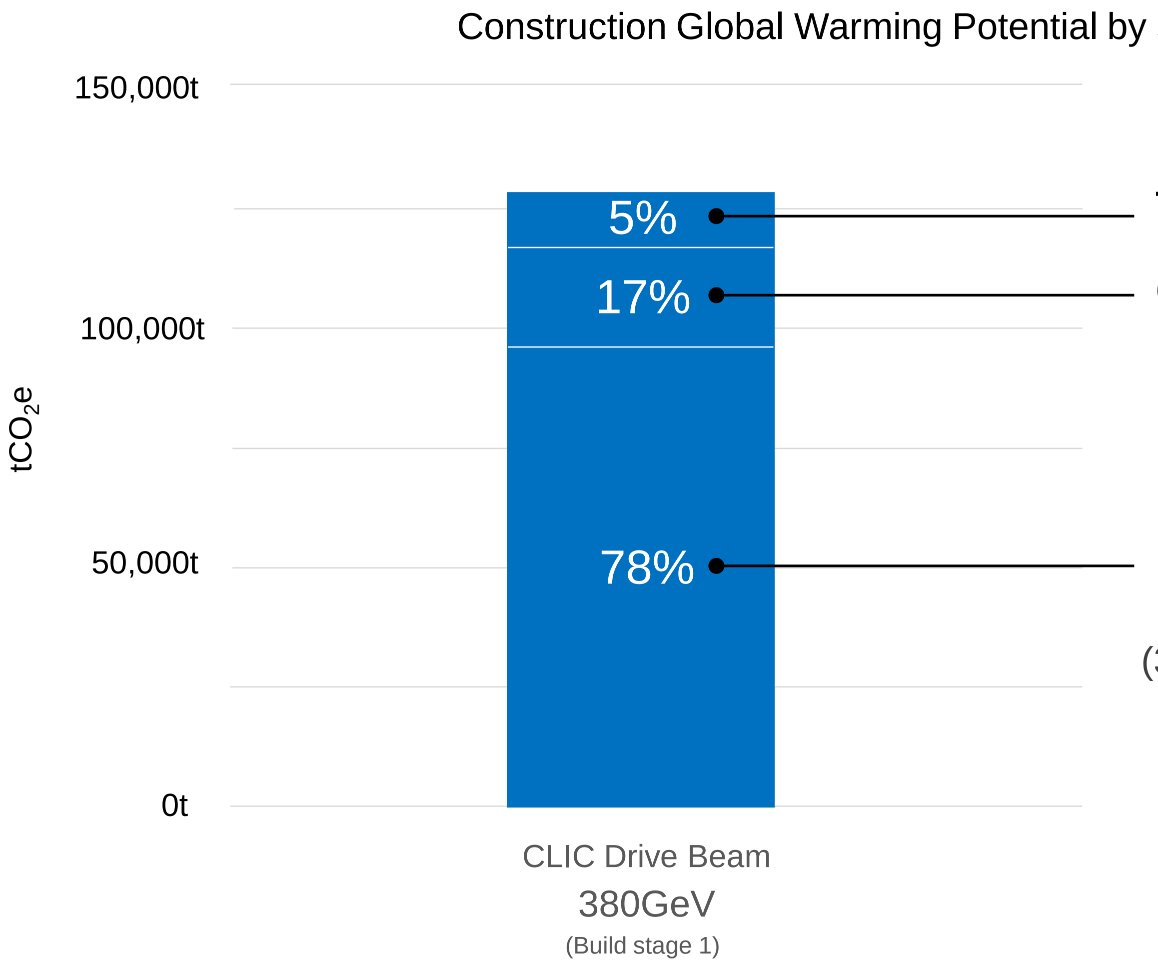
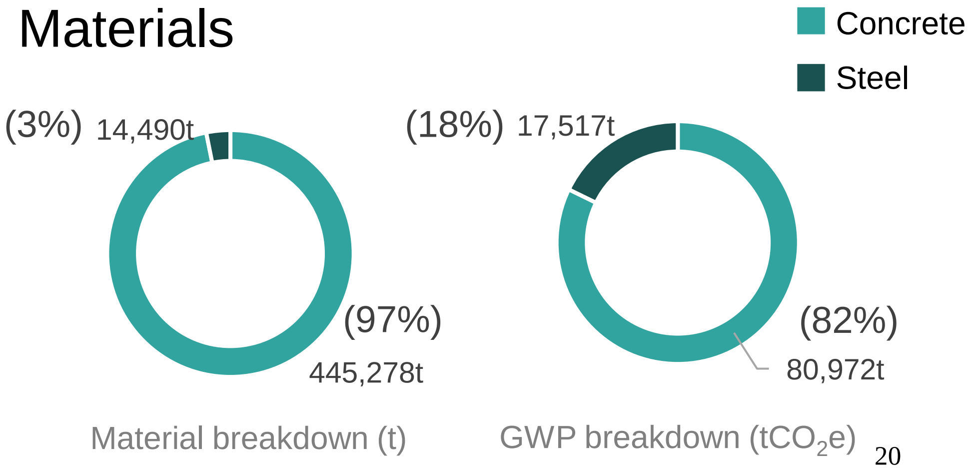
Impact assessment

CLIC Drive Beam 380GeV





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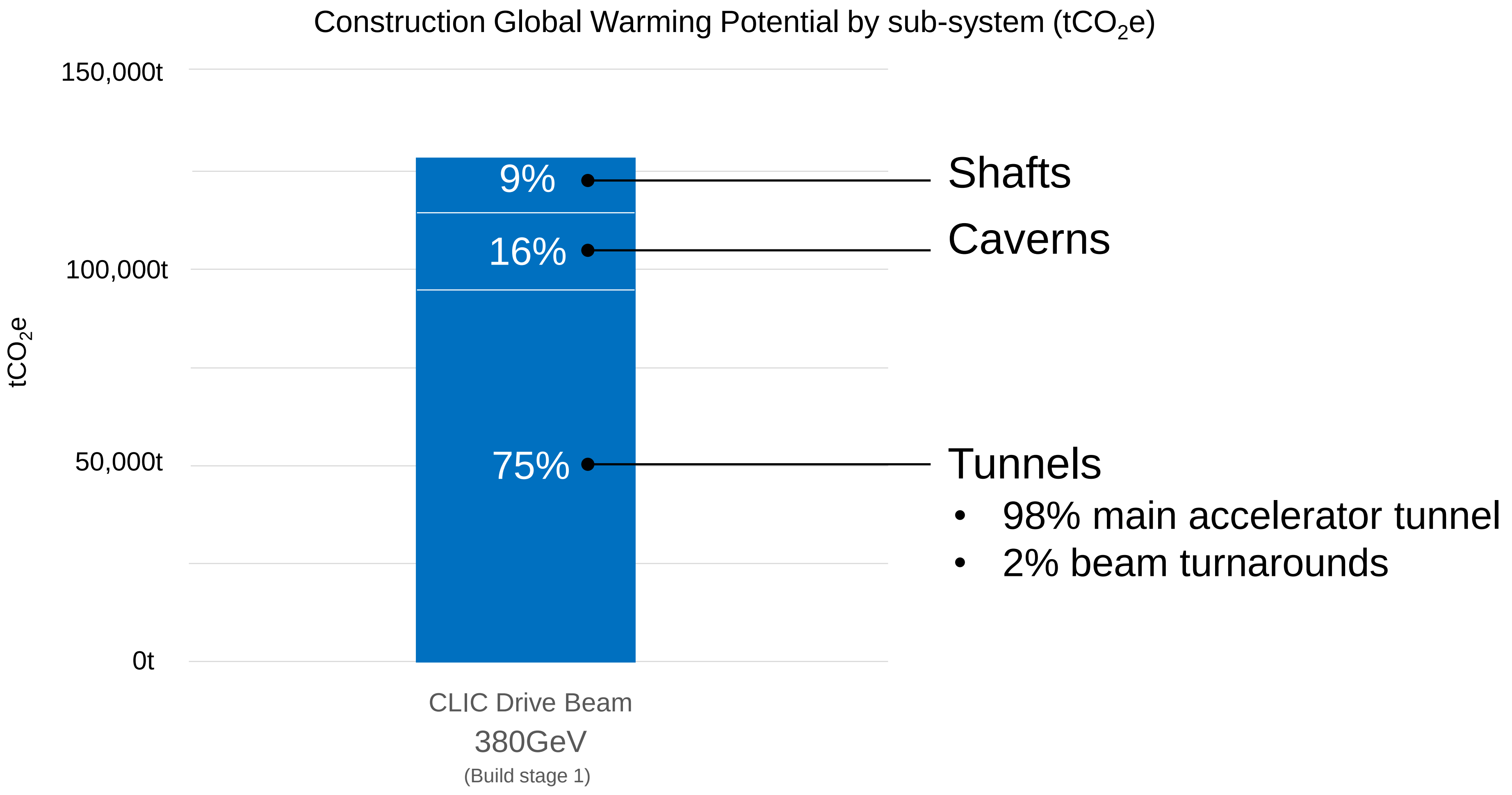
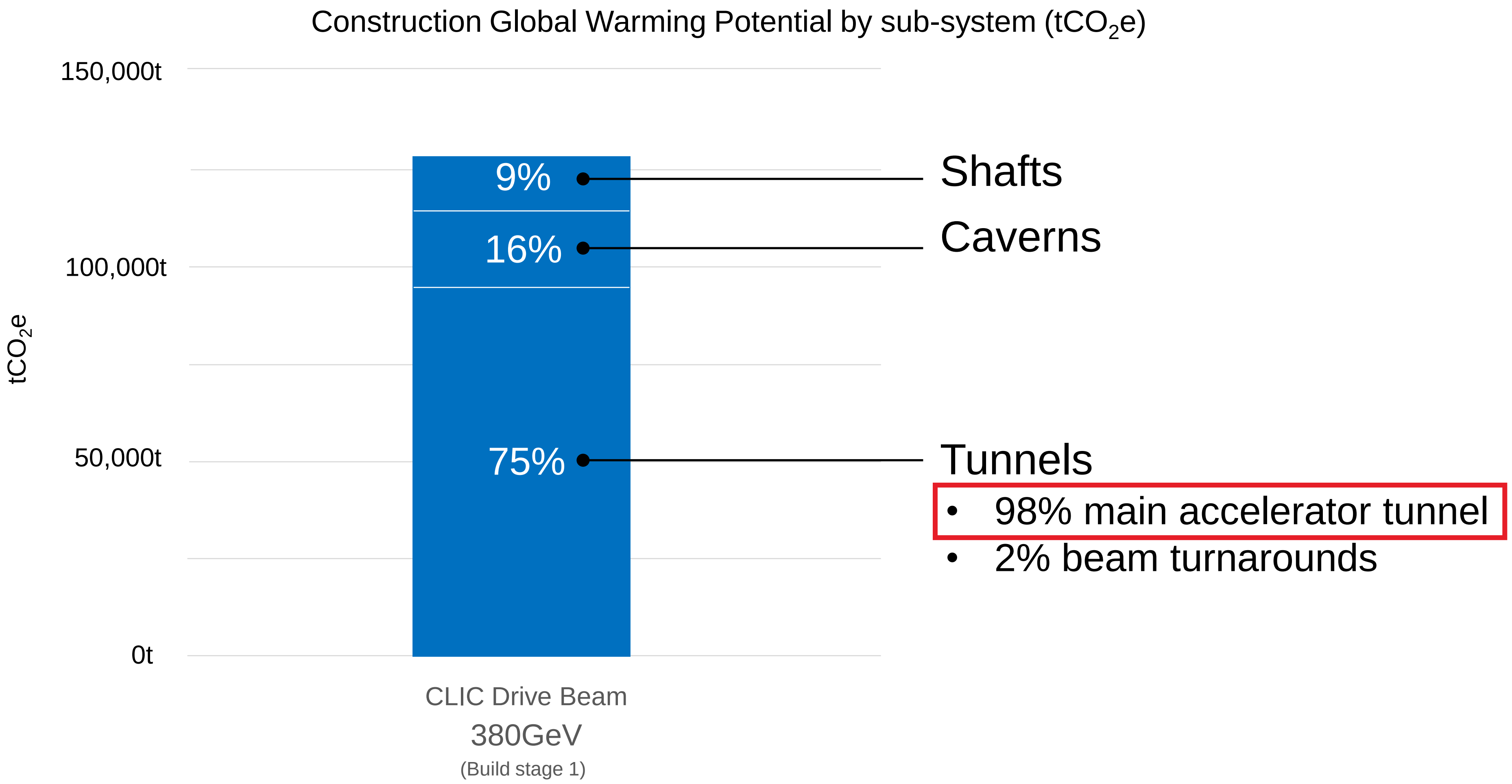


Impact assessment

CLIC Drive Beam 380GeV



Hotspots

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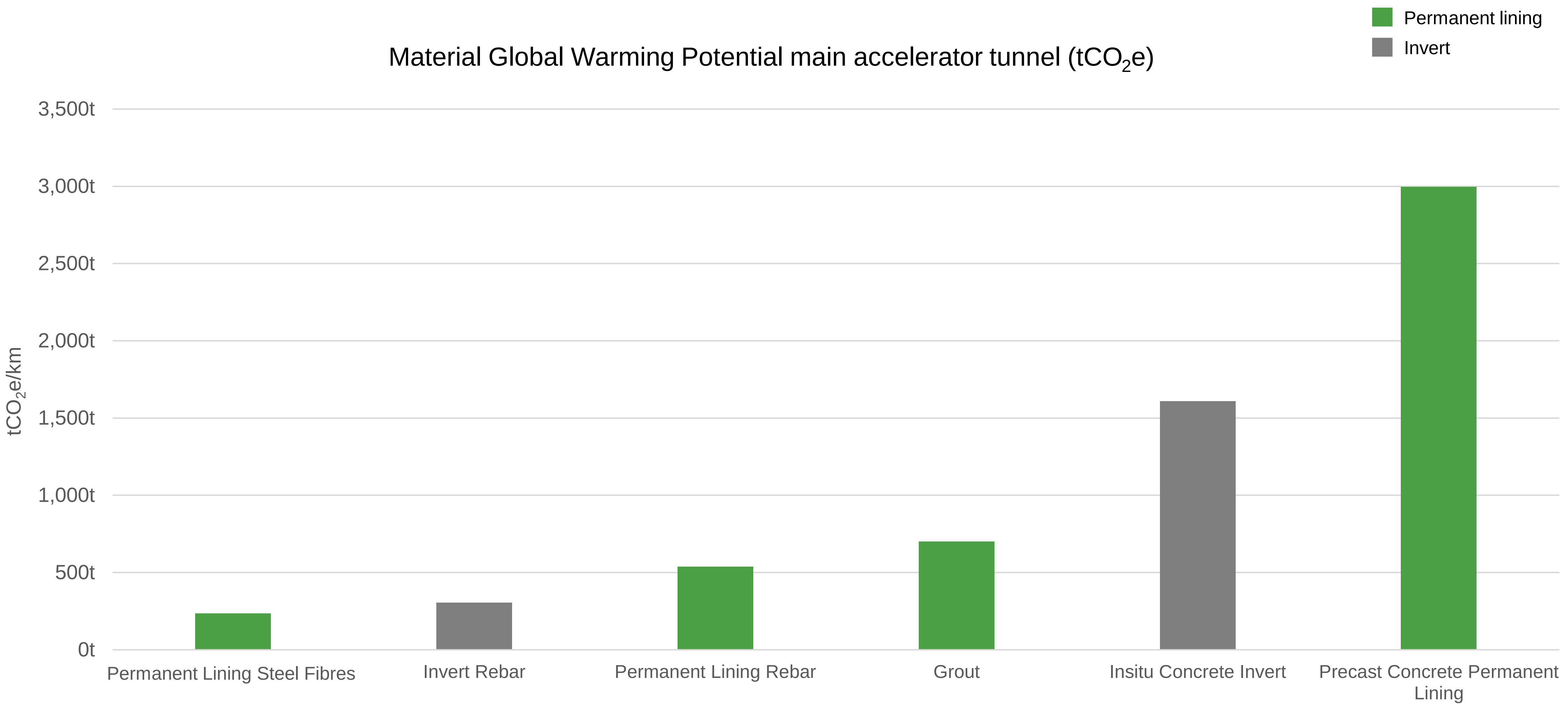
CLIC Drive Beam 380GeV main accelerator tunnel



Benchmarks

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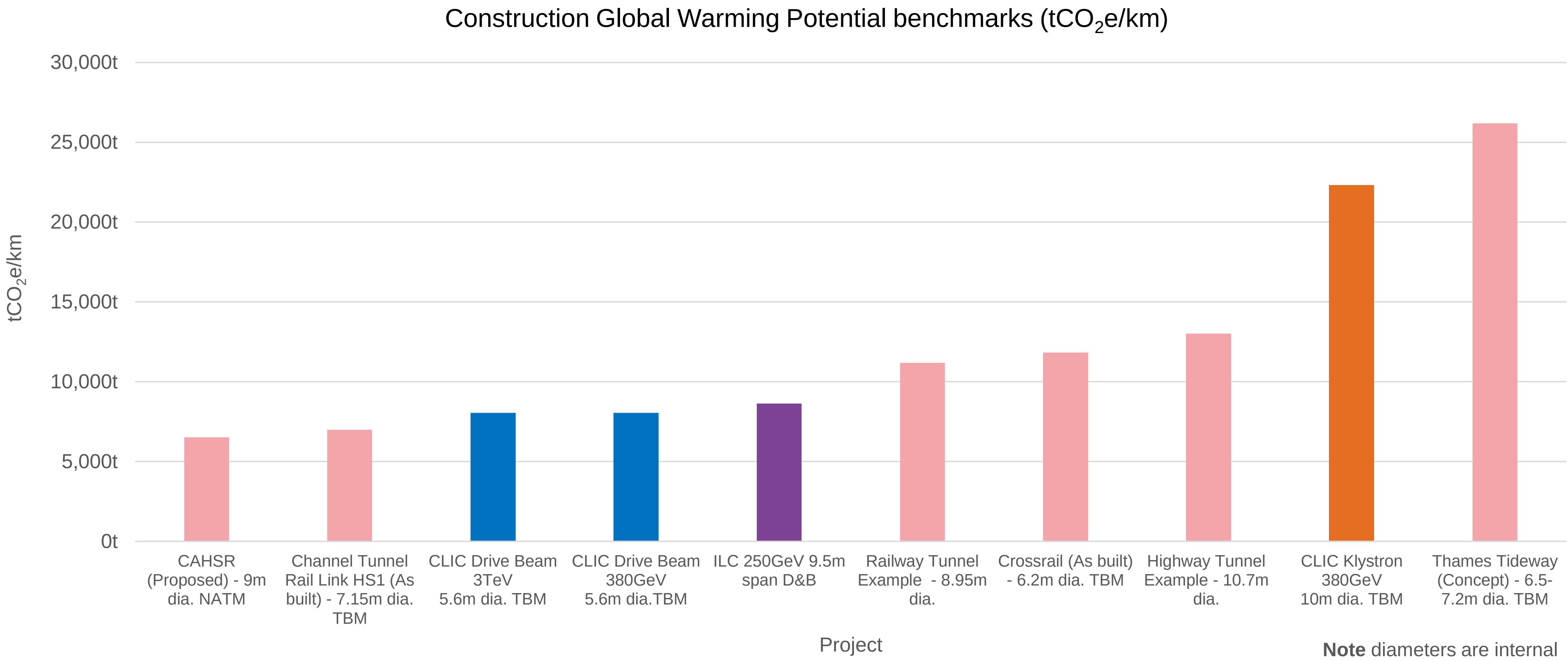
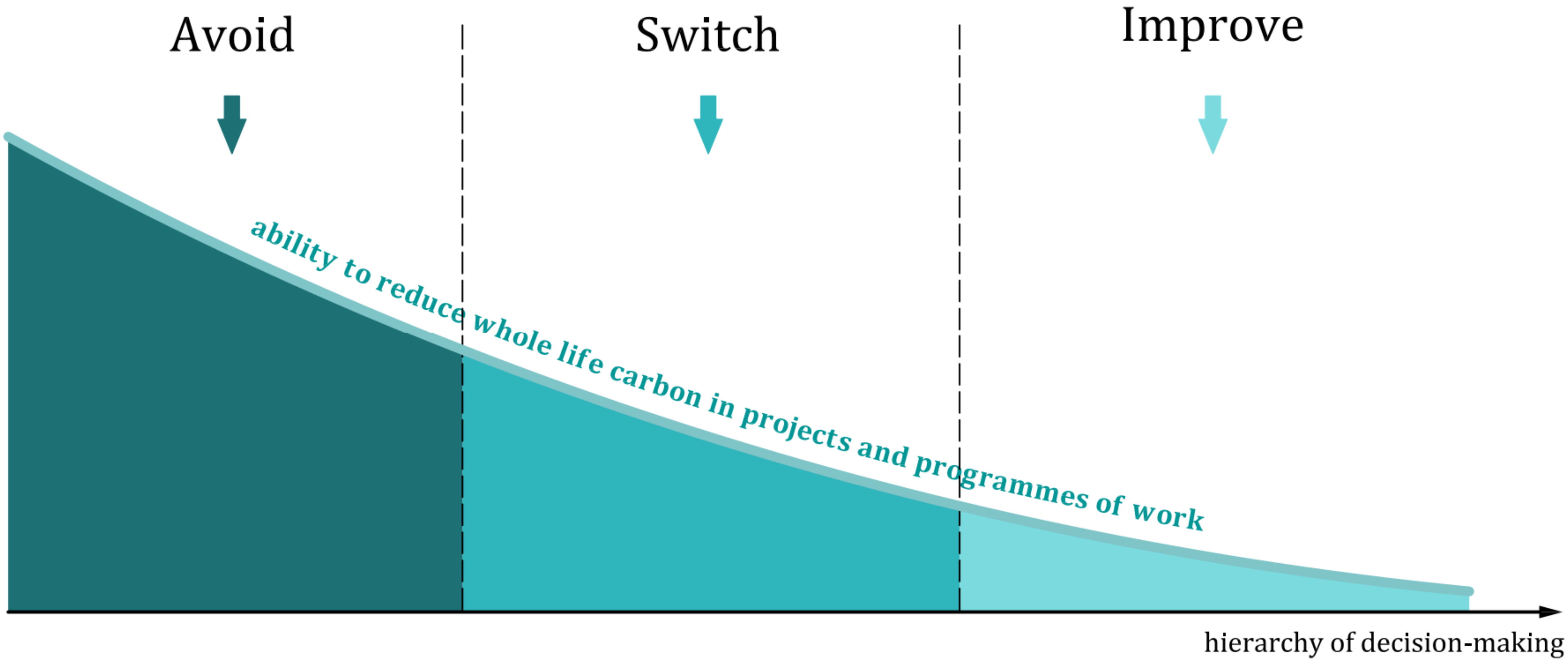
CLIC & ILC main accelerator tunnel



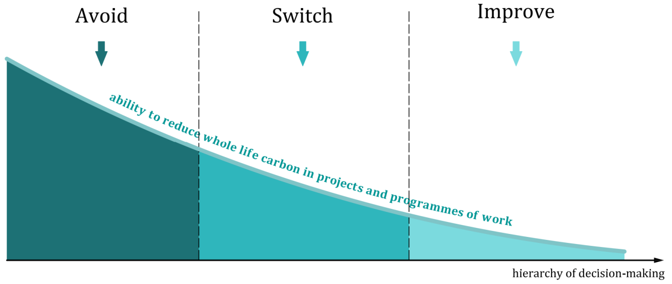
Note diameters are internal

Carbon reduction hierarchy

Prioritise meaningful decarbonisation



Reduction opportunities



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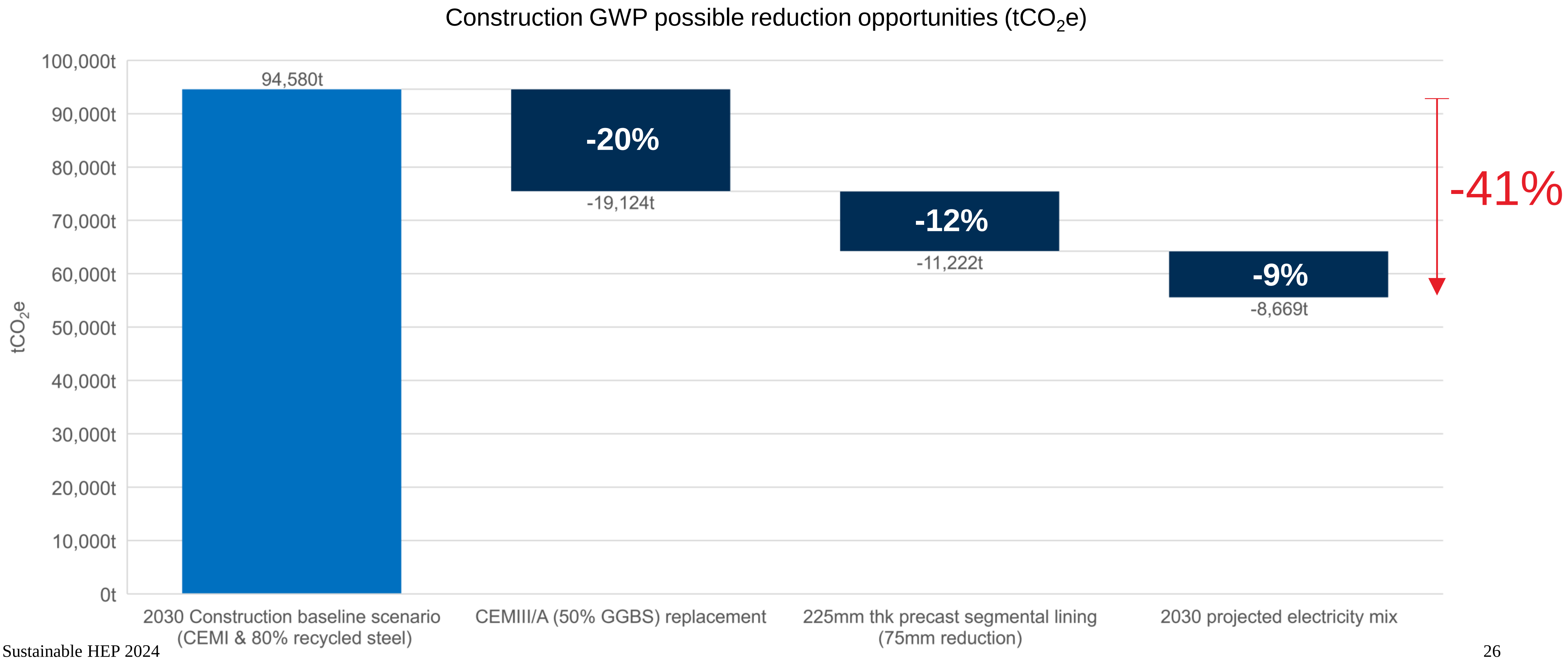
CLIC Drive Beam 380GeV tunnels



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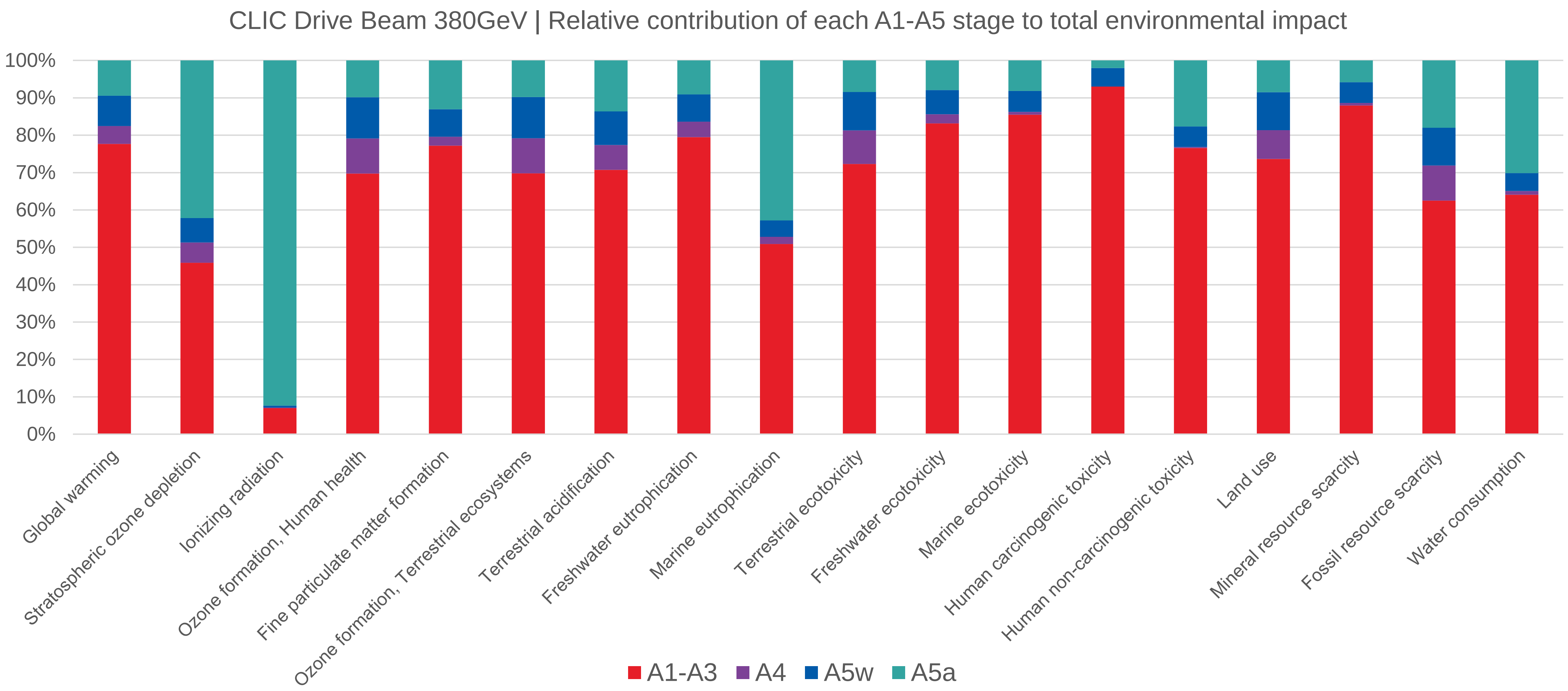
Reduction opportunities

What else?

- Partially replacing Portland cement (CEMI)
- Totally replacing Portland cement with “Portland cement-free”
- Carbon sequestering in concrete
- Plant fibres
- Rubber tyre steel fibres
- & more…

ReCiPe 2016 Midpoint (H) Impact Categories

CLIC Drive Beam 380GeV



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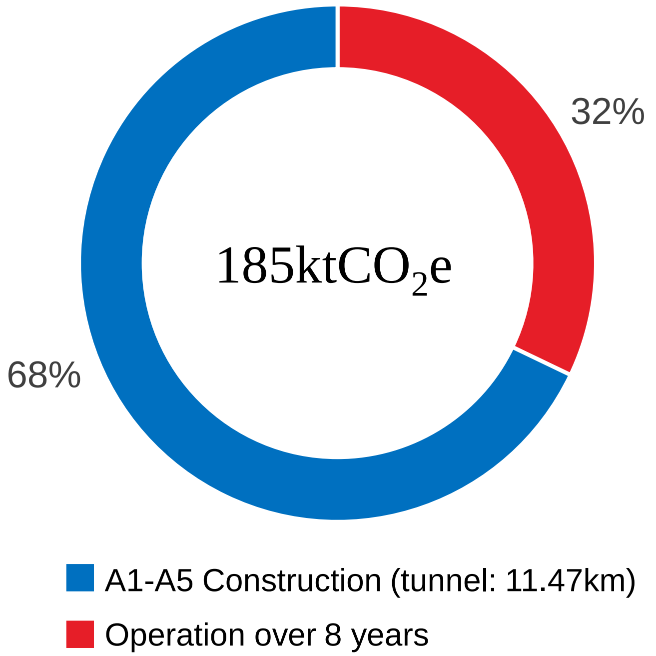
Construction and operation carbon

CLIC Drive Beam

Operational estimates provided by CERN. Based on a projected electricity mix in 2050 (50% nuclear, 50% renewables).

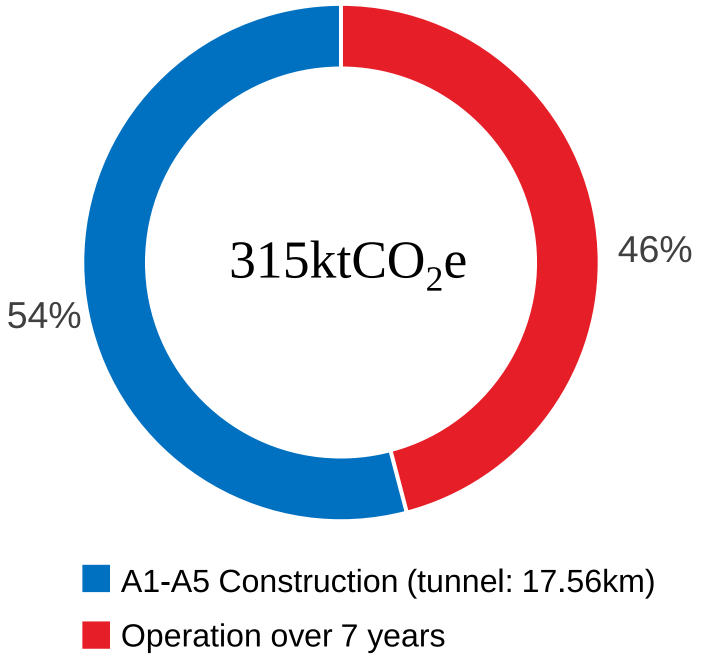
380GeV

Construction GWP is equivalent to 1.7 decades of running accelerator



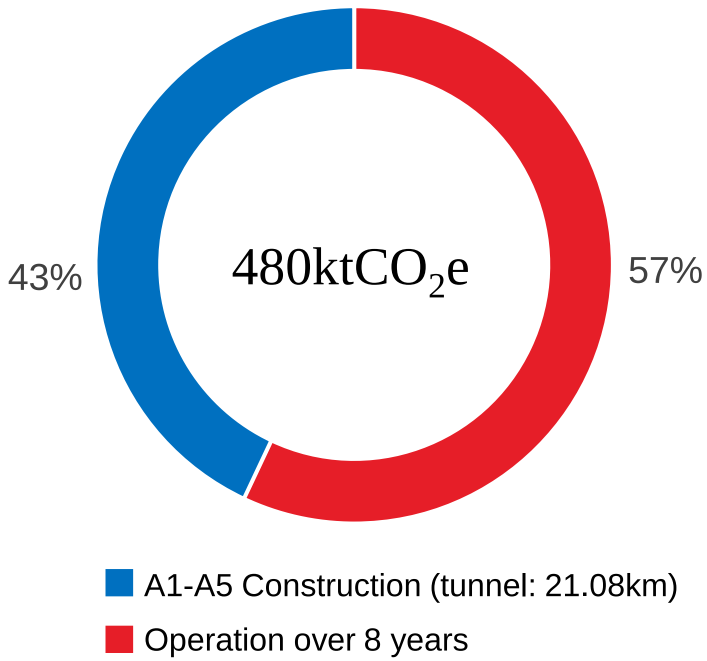
1.5TeV

Construction GWP is equivalent to 0.8 decades of running accelerator



3TeV

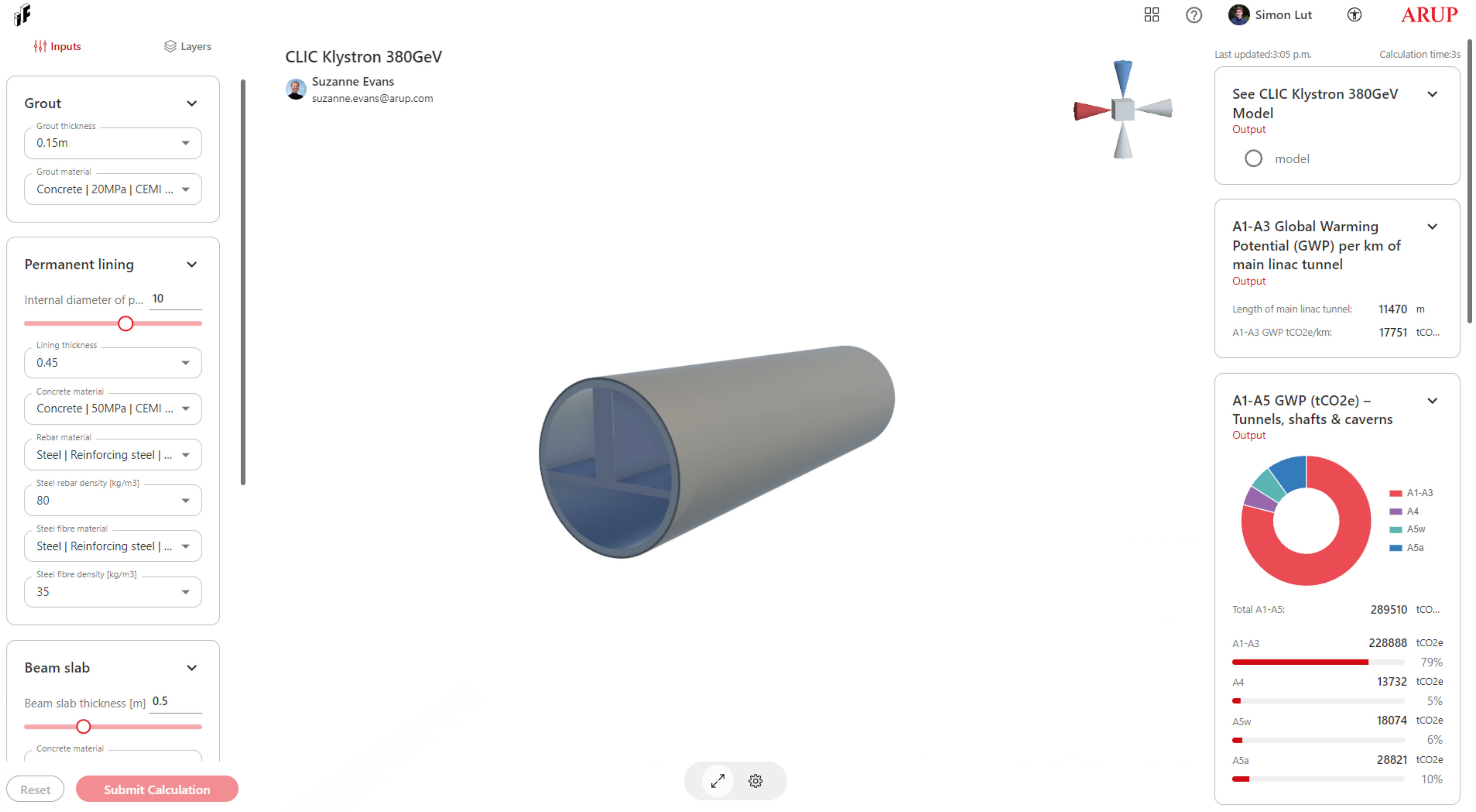
Construction GWP is equivalent to 0.6 decades of running accelerator



Learning points

- Establish baseline and consistent methodology for LCA
- Design changes e.g. replace the shielding wall with excavated fill in casing
- Design optimisation e.g. reduce lining thickness
- Alternative materials e.g. low carbon concrete and steel technologies
- Influencing operational /whole life carbon
- Carbon quantification integrated into project development
- Managing carbon is integral to decision making

Parametric LCA Tool



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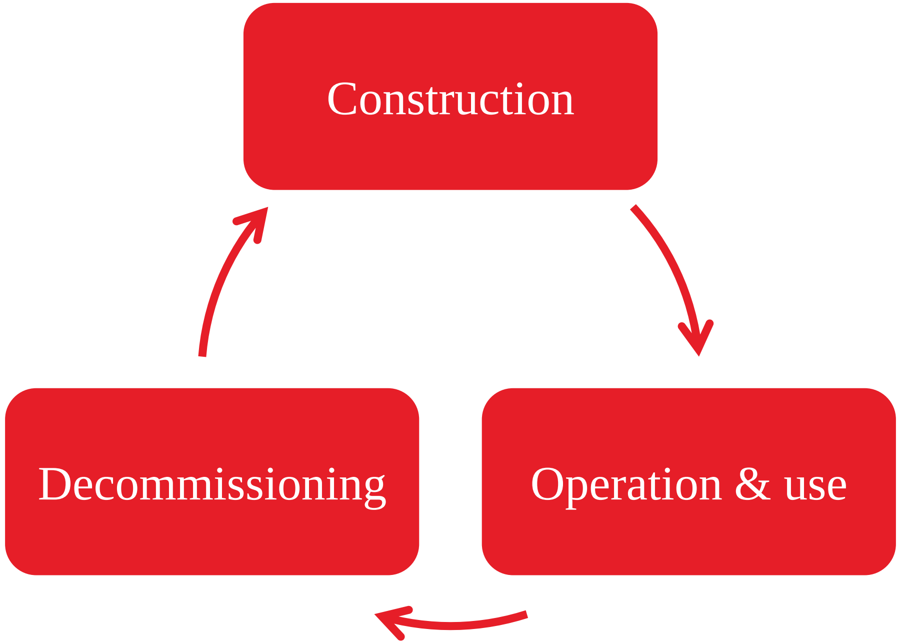
Next steps

Phase 2

- Whole life cycle assessment of the machine componentry for CLIC & ILC (Construction, operation & use, decommissioning)

- Construction life cycle assessment of CLIC injector complex and CLIC & ILC tunnel services systems (Construction)

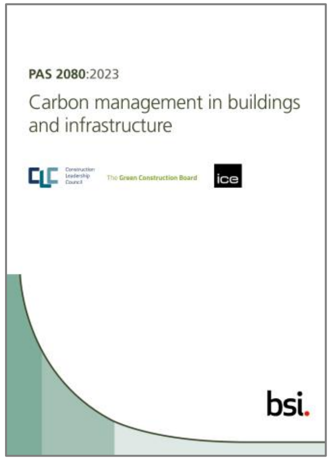


What is carbon quantification for?
Managing to reduce whole life carbon

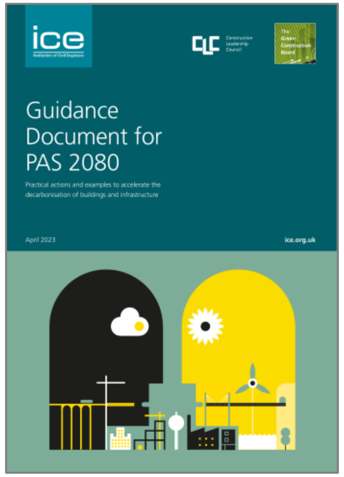
Accelerating decarbonisation

PAS2080:2023 Carbon management in buildings and infrastructure

- Managing to reduce whole life carbon
- Consistency in framing emissions under the control and influence of the value chain
- Integrating carbon into decision-making



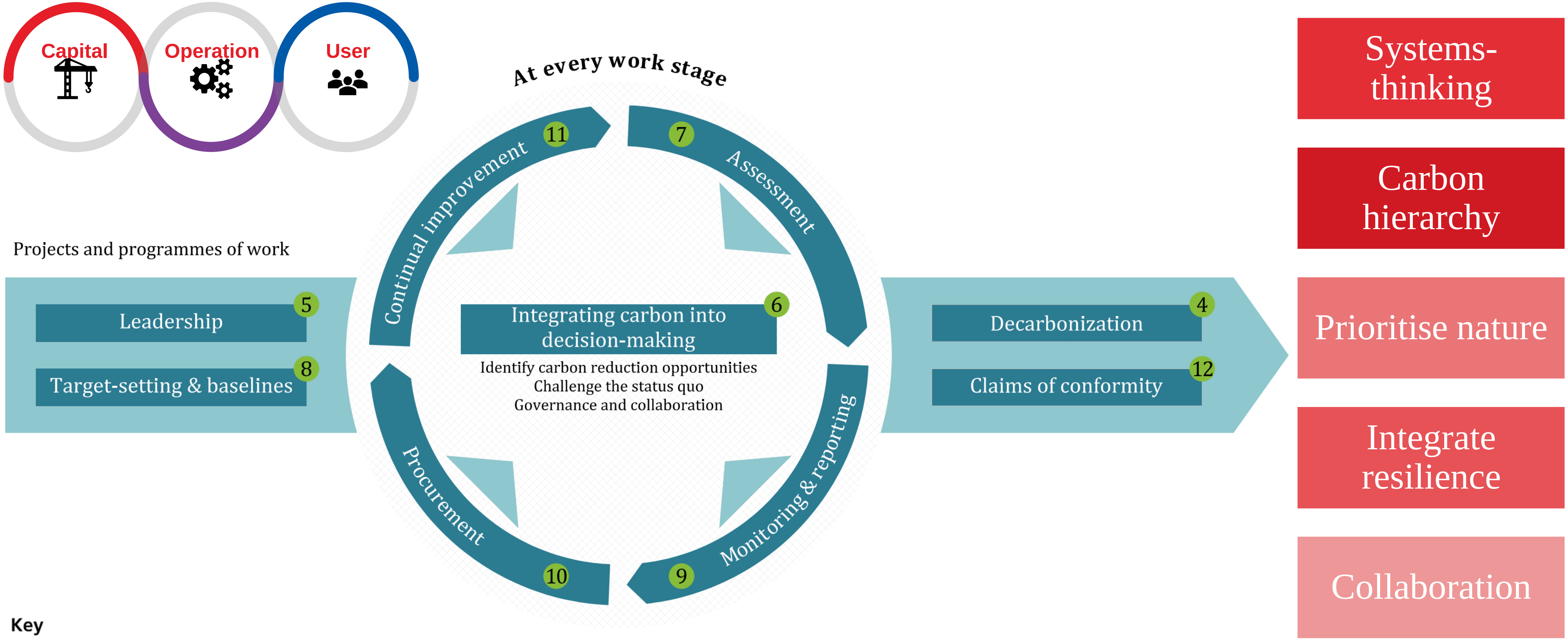
https://www.bsigroup.com/en-GB/standards/pas-2080/



https://www.ice.org.uk/engineering-resources/briefing-sheets/guidance-document-pas2080

Carbon management process

PAS2080:2023



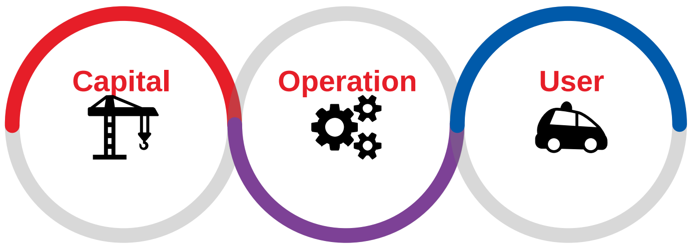
Key

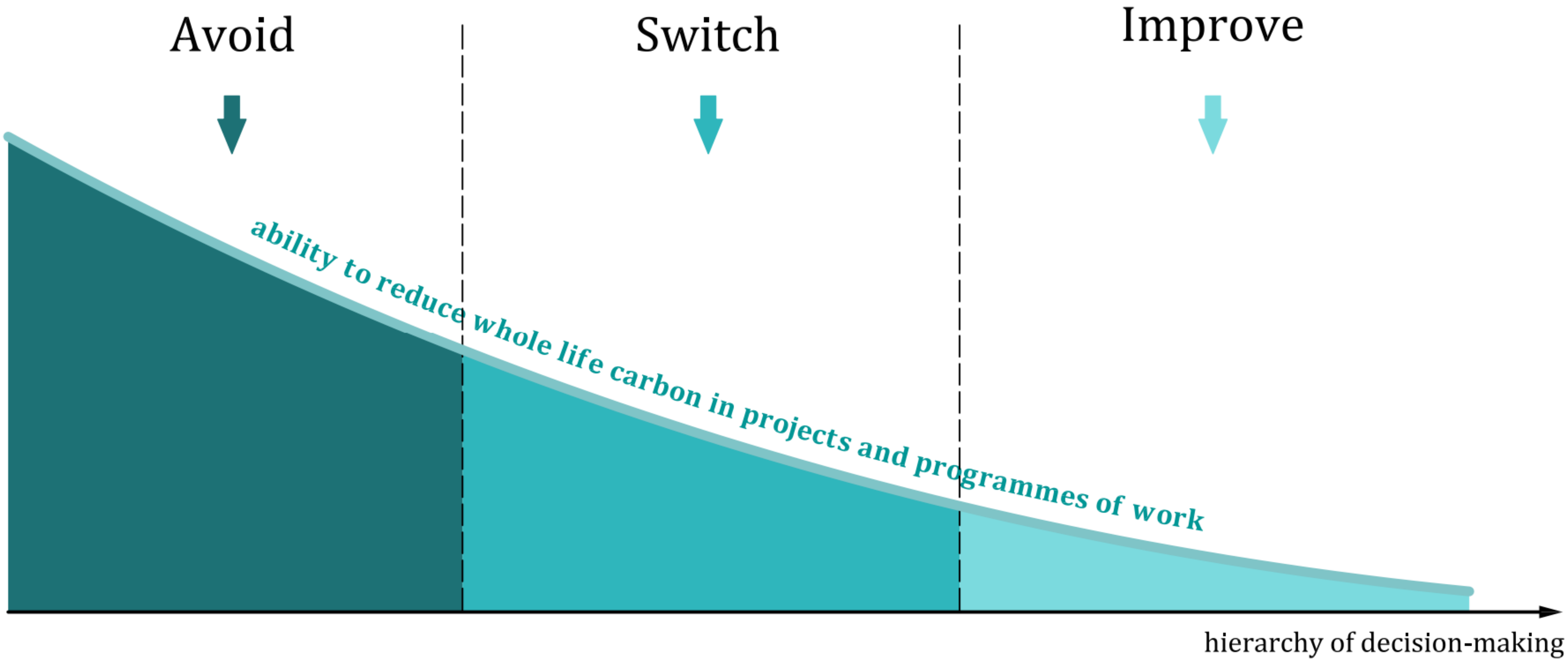
X PAS 2080 clause number

PAS 2080: 2023 Carbon management in buildings and infrastructure: https://www.bsigroup.com/en-GB/standards/pas-2080/

Carbon reduction hierarchy

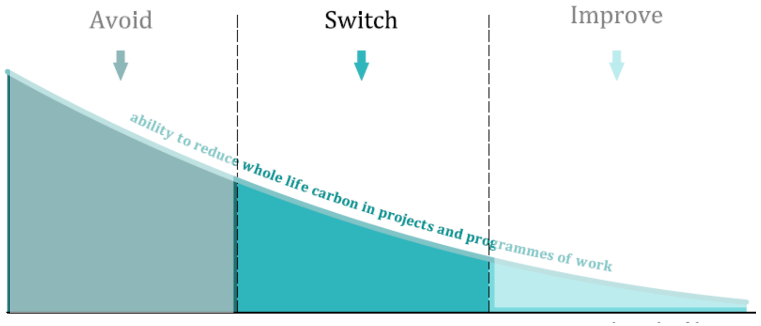
Prioritise meaningful decarbonisation





Carbon reduction examples

Ground energy potential



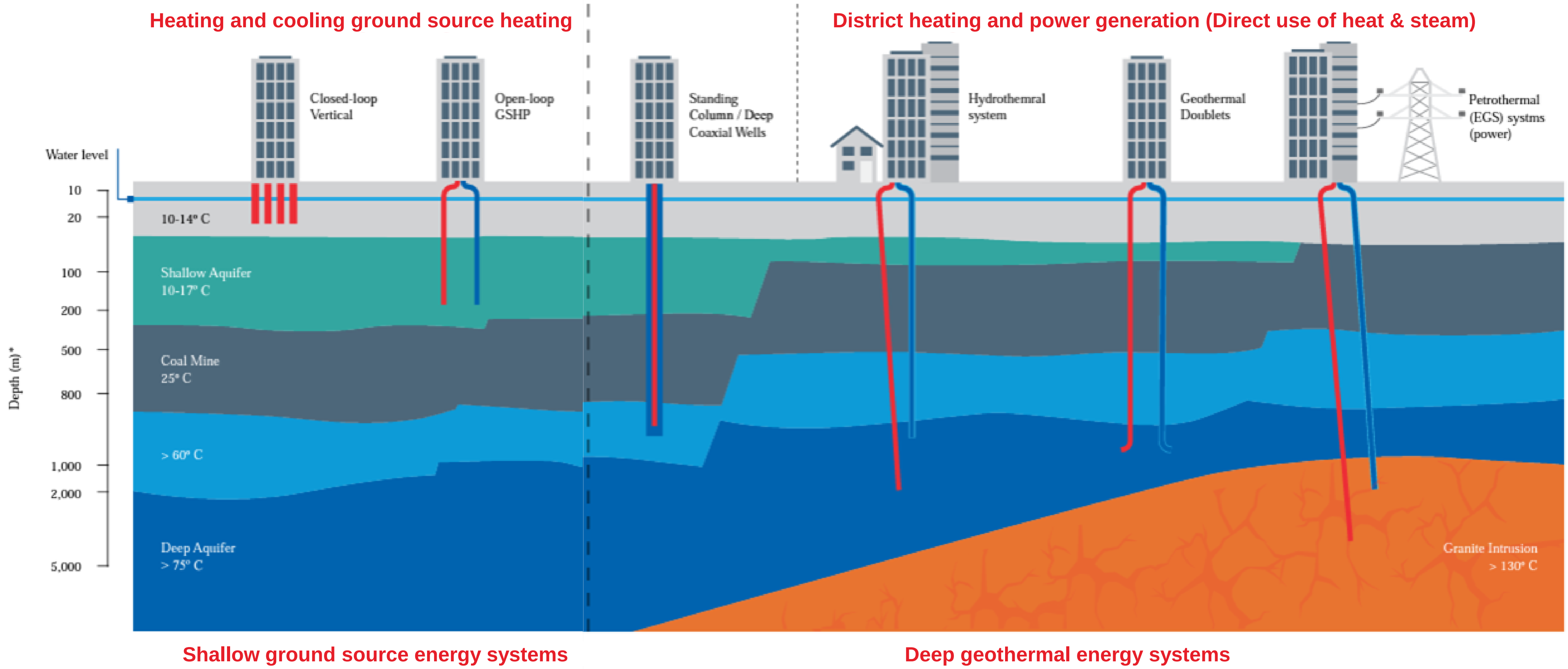
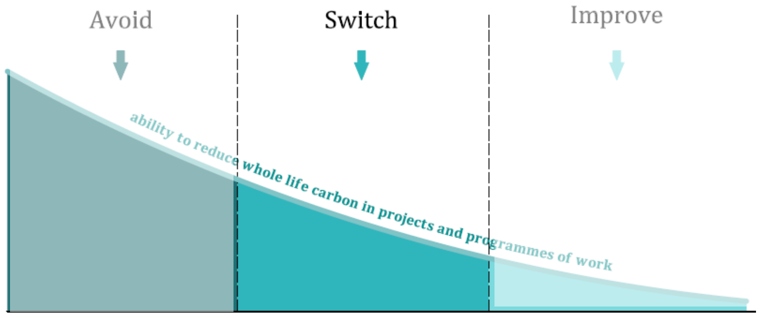


Illustration of geothermal project types, modified from British Geological Survey UKRI 2021

Turning spoil into resource

Calcined clay for cementitious material aggregates or bricks!



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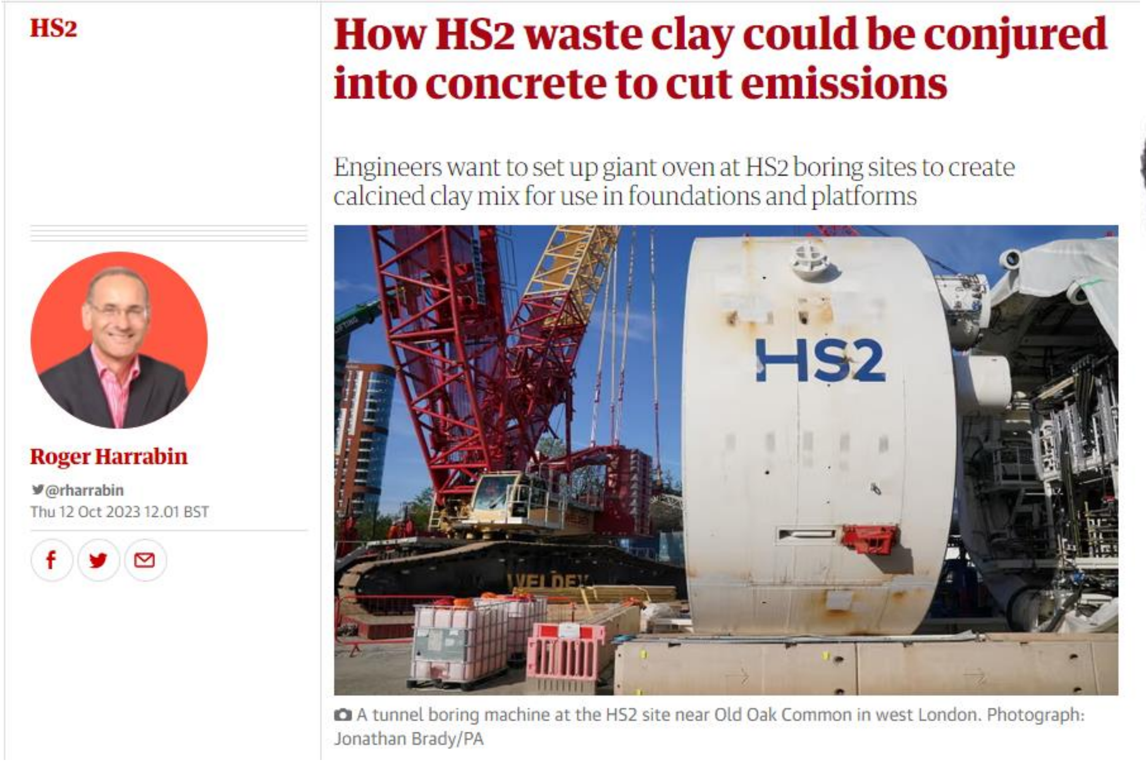


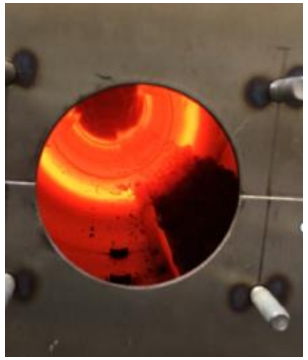
HS2

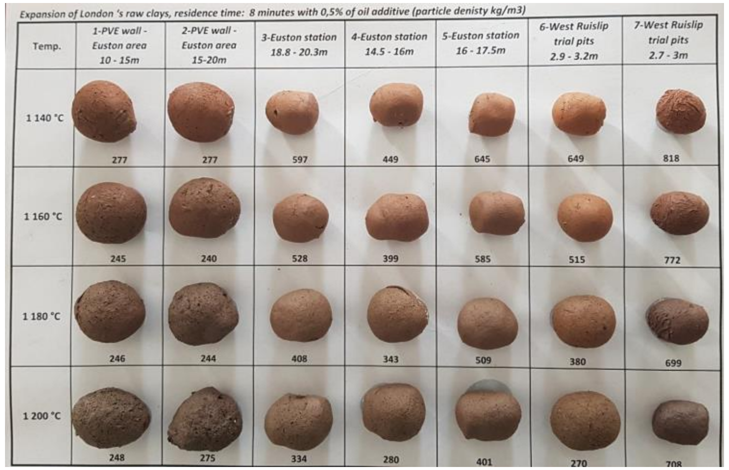
How HS2 waste clay could be conjured into concrete to cut emissions

Engineers want to set up giant oven at HS2 boring sites to create calcined clay mix for use in foundations and platforms

Roger Harrabin
@rharrabin
Thu 12 Oct 2023 12.01 BST

A tunnel boring machine at the HS2 site near Old Oak Common in west London. Photograph: Jonathan Brady/PA





https://www.theguardian.com/uk-news/2023/oct/12/how-hs2-waste-clay-could-be-conjured-into-concrete-to-cut-emissions?ref=biztoc.com

https://learninglegacy.hs2.org.uk/document/transformation-of-london-clay-into-construction-resources-supplementary-cementitious-material-and-lightweight-aggregate/

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Conclusions

Conclusions

- Carbon management to help meet decarbonisation targets
- Managing whole life carbon – *whole life carbon LCA*

Thank you and questions

Contact

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