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Life cycle assessment of linear colliders and future opportunities

SCE technical seminar

Sustainability seminar | 24/11/2023

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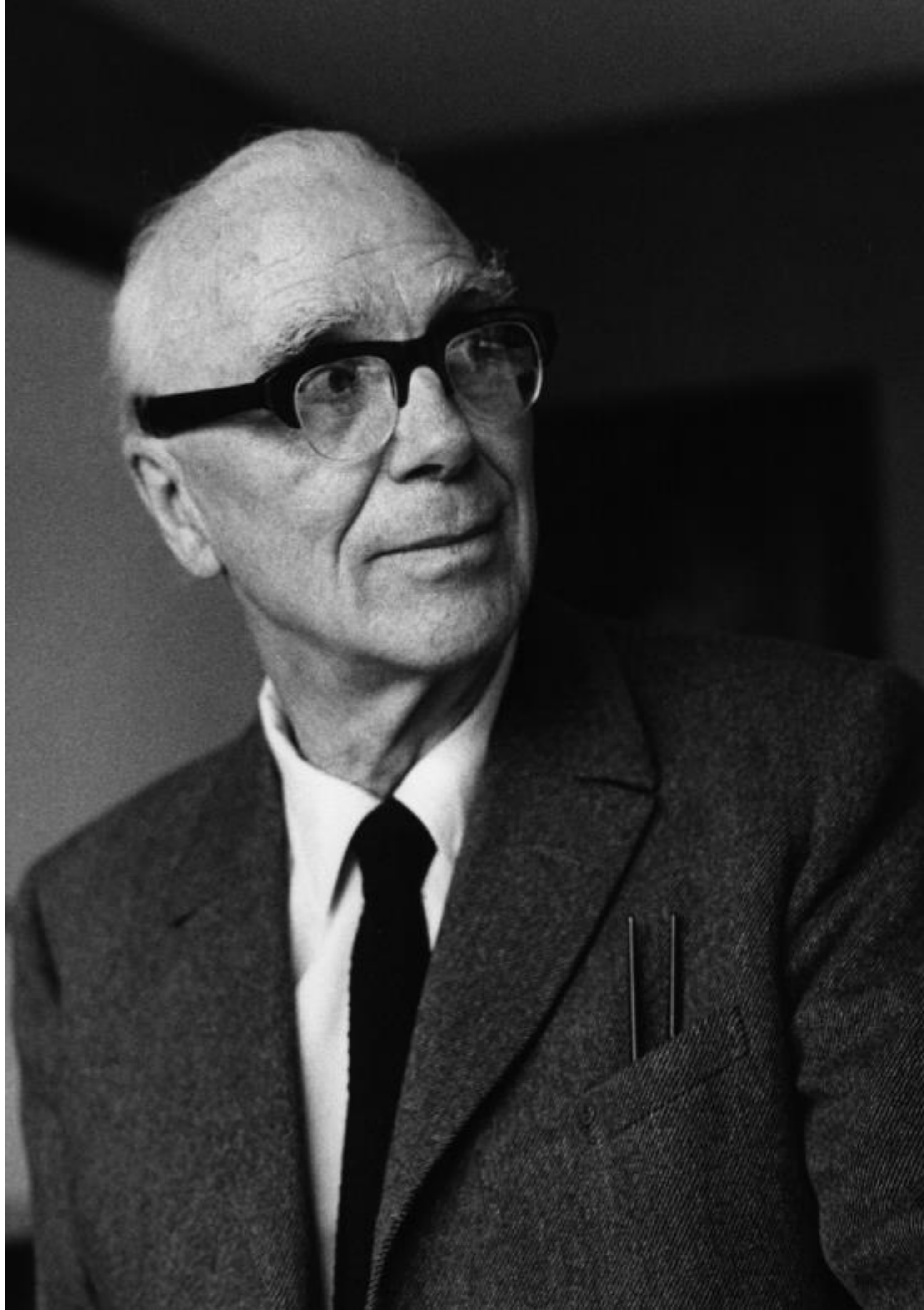

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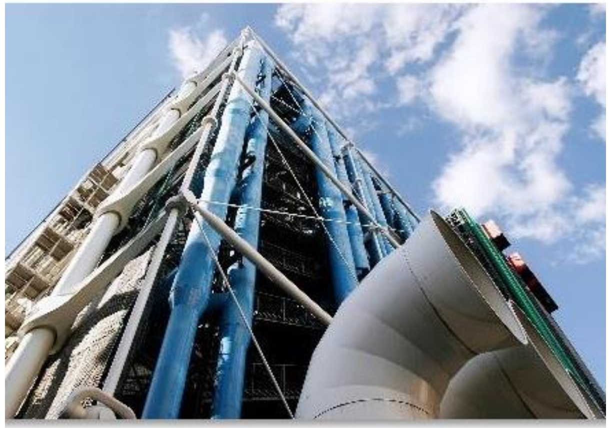
Jan Valach

Associate Director
Arup Zurich, Switzerland



Pompidou Centre

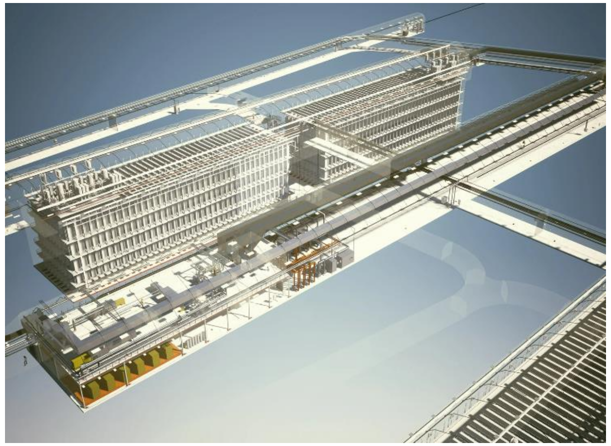
Paris, France

Sydney Opera House

Sydney, Australia

LBNF

South Dakota, USA



Swiss National Supercomputing Centre

Lugano, Switzerland

COP26

Glasgow, UK

The Earthshot Prize

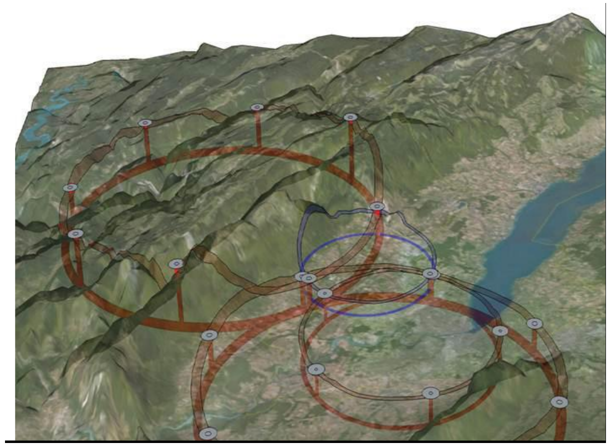
Global Alliance

Science Gateway

Structural Engineering

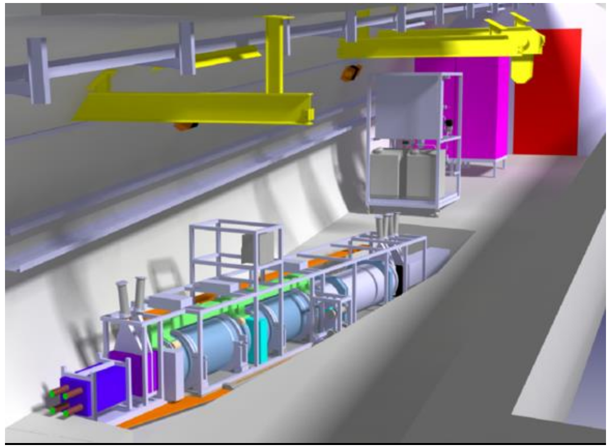
Hi-Lumi LHC

Independent Engineer



FCC

Engineering Feasibility, optioneering, EIS GIS

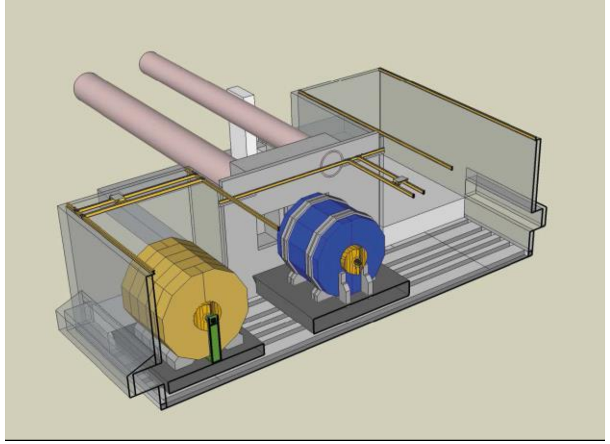


Physics Beyond Colliders

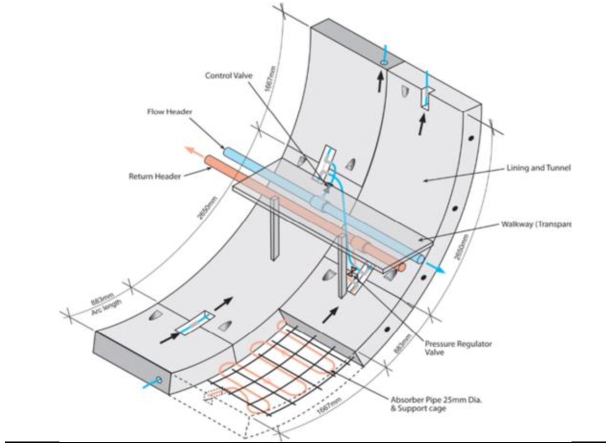
FASER, BDF, FPF, TAM

CLIC/ILC

Engineering Feasibility



Energy Tunnels



Purpose of seminar

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Knowledge sharing of linear collider life cycle assessments and to explore the ambition for decarbonisation of CERN and possible interventions towards net zero by 2050

What is Decarbonisation to CERN?

Waiting for responses

Decarbonisation context

Global GHG Emissions

(tCO_2e)

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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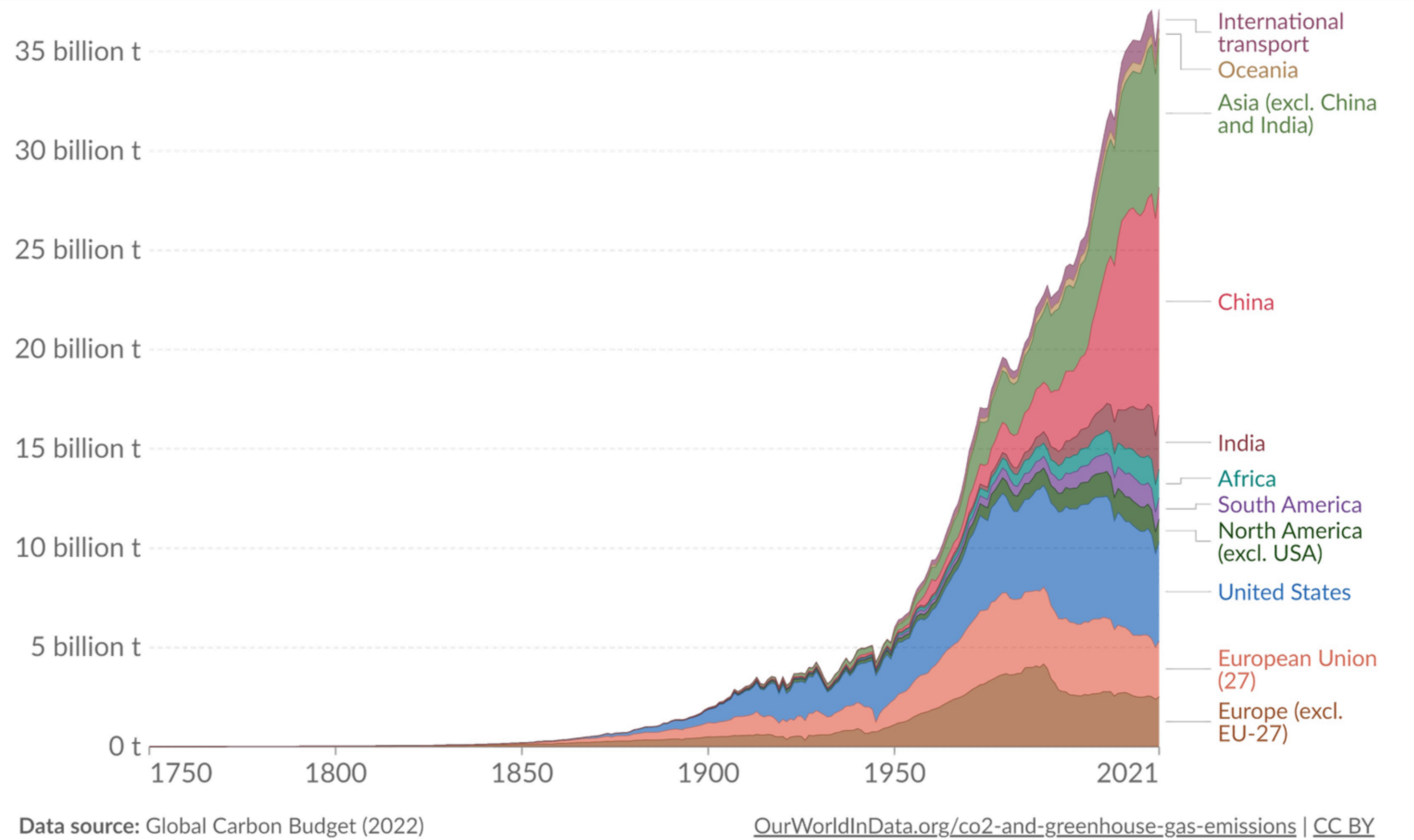
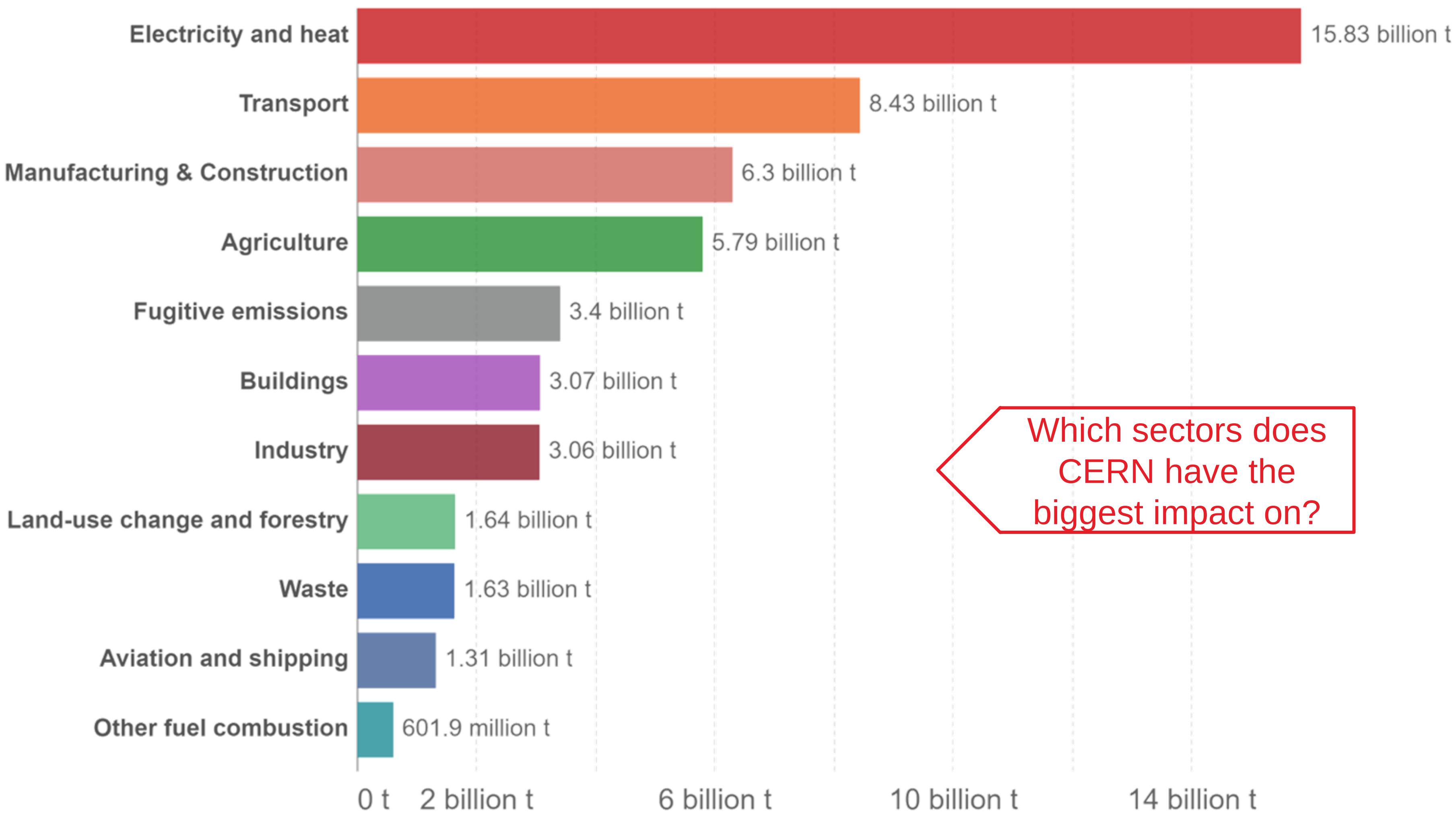


Global GHG Emissions

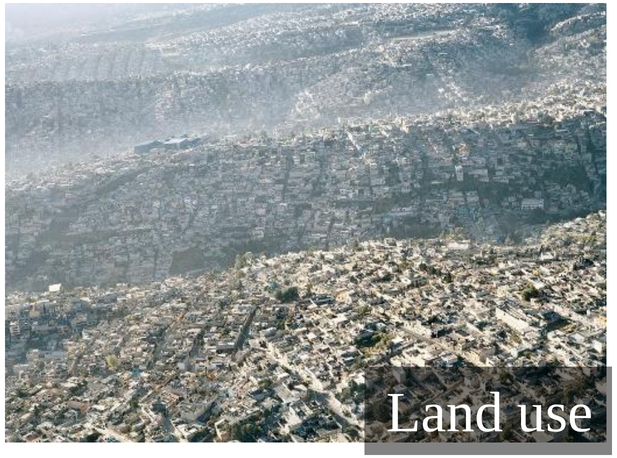
(tCO_2e)

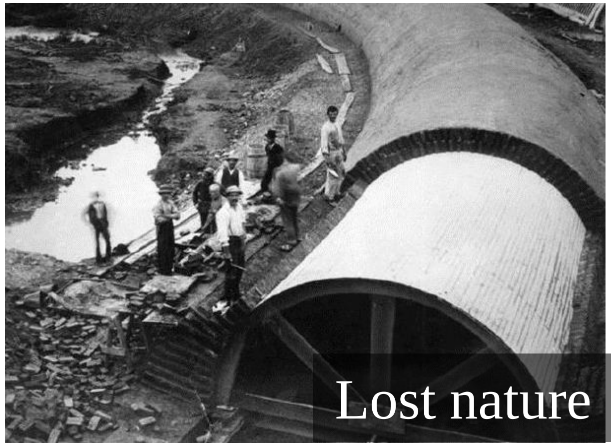


Which sectors does CERN have the biggest impact on?

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

Where is the carbon?

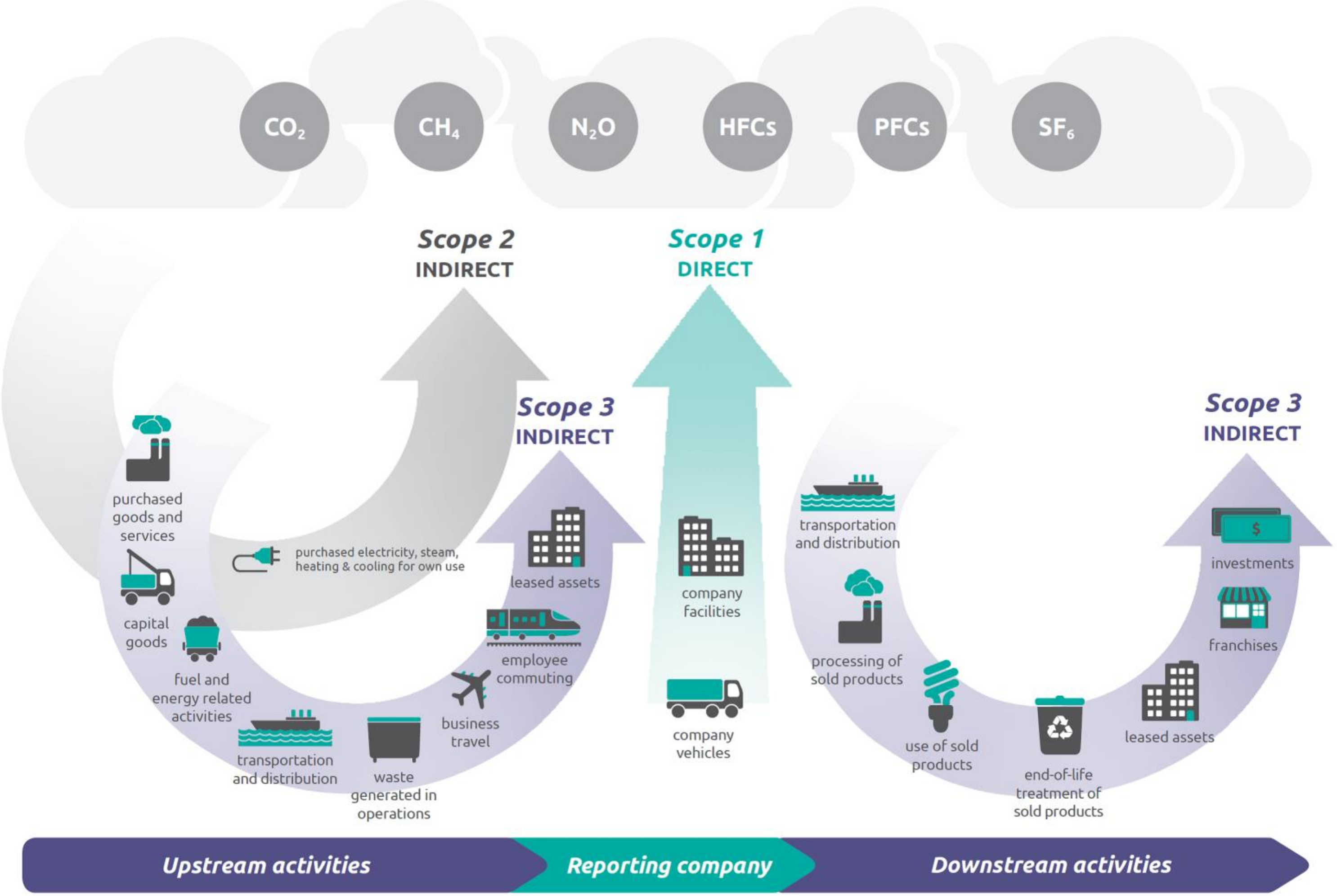




Scope 1, 2 and 3 emissions

Corporate reporting of carbon

- CERN reports scope 1 and 2 since 2017
- Downstream scope 3 since 2019
- No reporting of upstream scope 3 (construction activities)



Source: WRI/WBCSD Corporate Value Chain (Scope 3) Accounting and Reporting Standard (PDF), page 5.

UN Breakthrough Outcomes for 2030

Built environment

100% of projects due to be completed in **2030** or after are **net zero carbon in operation** with at least **40% less** embodied carbon compared to current practice

2030 Breakthroughs UNFCCC

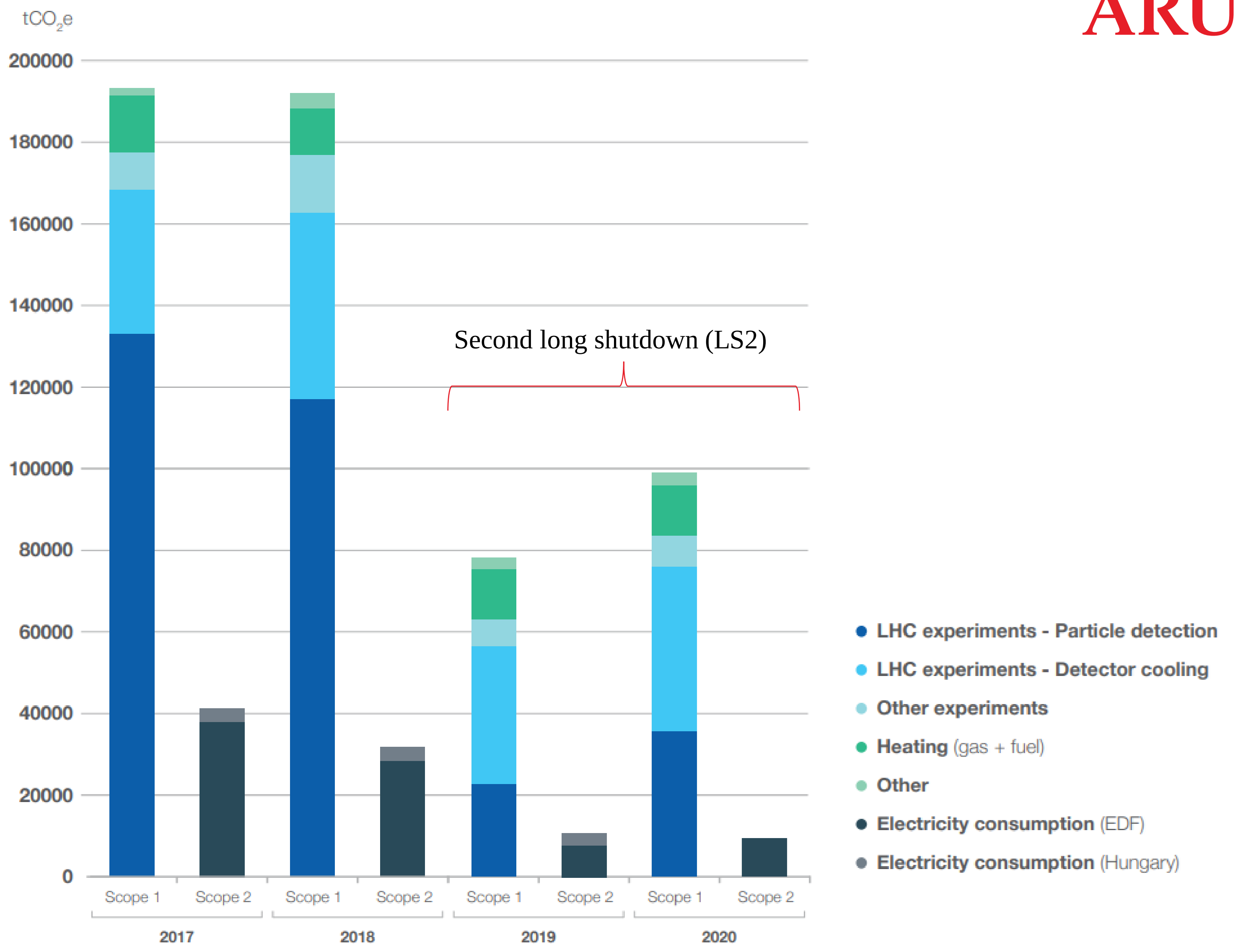
CERN target

Reduce scope 1 emissions by 28% by end of 2024 (baseline year 2018)

CERN Environment Report 2019 - 2020

CERN GHG Emissions

(tCO_2e)



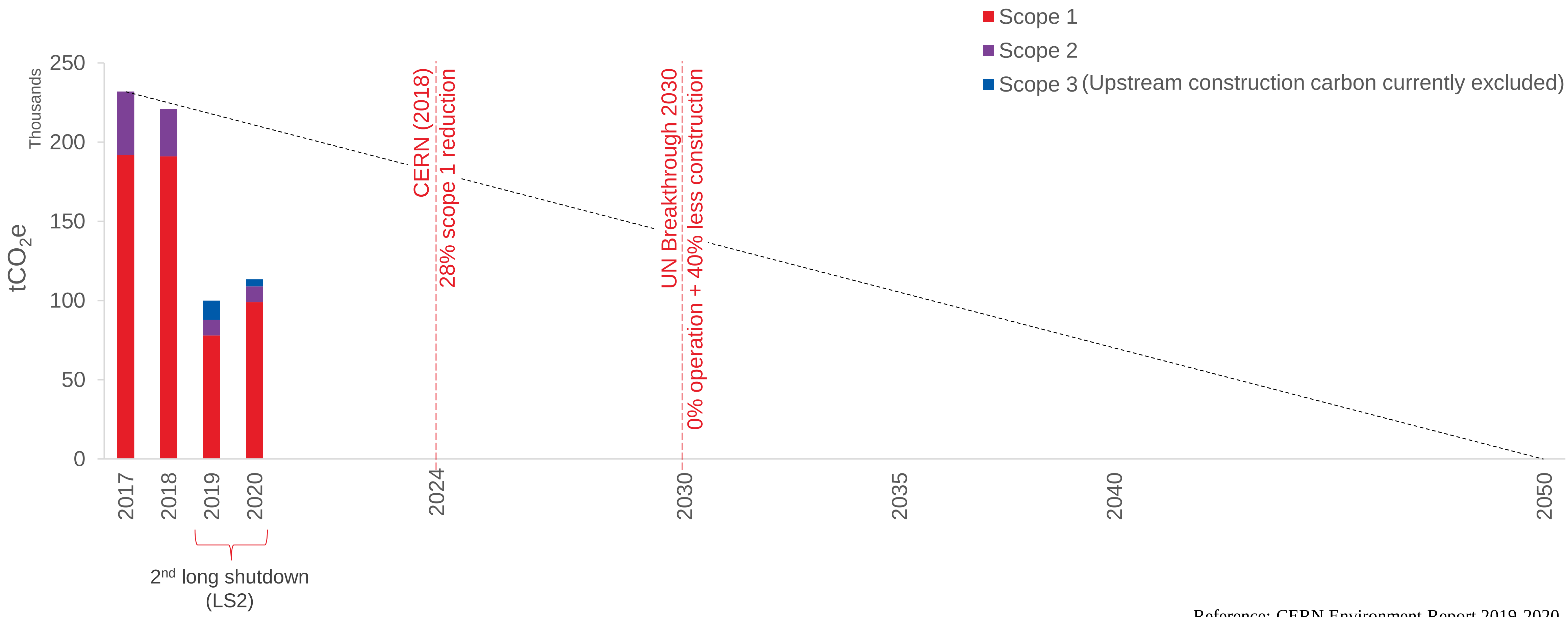
Reference: CERN Environment Report 2019-2020

CERN SCOPE 1 AND SCOPE 2 EMISSIONS FOR 2017-2020 BY CATEGORY.

Other includes air conditioning, electrical insulation, emergency generators and CERN vehicle fleet fuel consumption. Emission factors for electricity: EDF Bilan des émissions de GES 2002-2020 for EDF and Bilan Carbone® V8 for Hungary.

What is required for net zero 2050?

Future decarbonisation of CERN



Reference: CERN Environment Report 2019-2020

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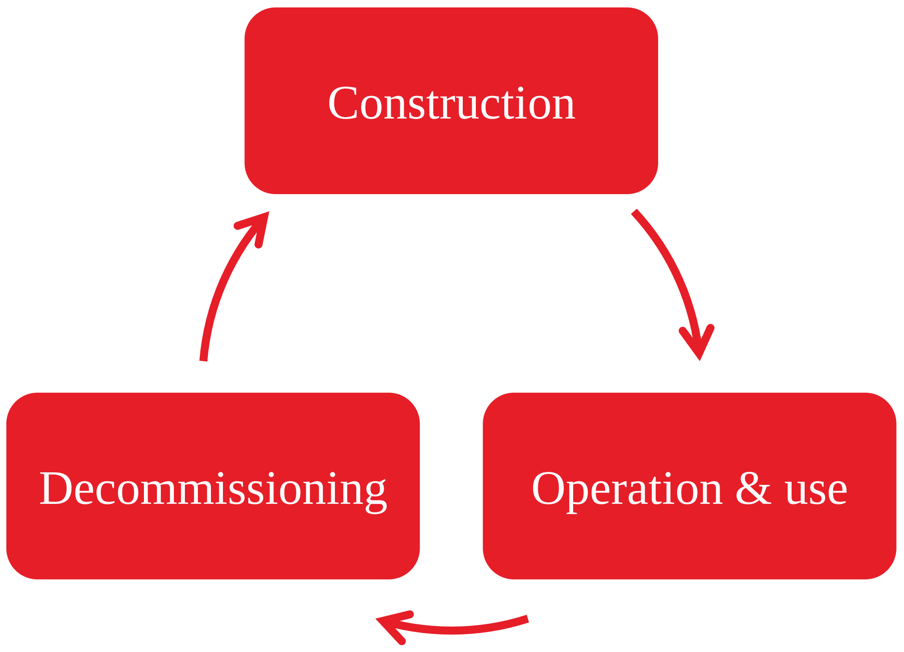
Life cycle assessment of CLIC and ILC

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



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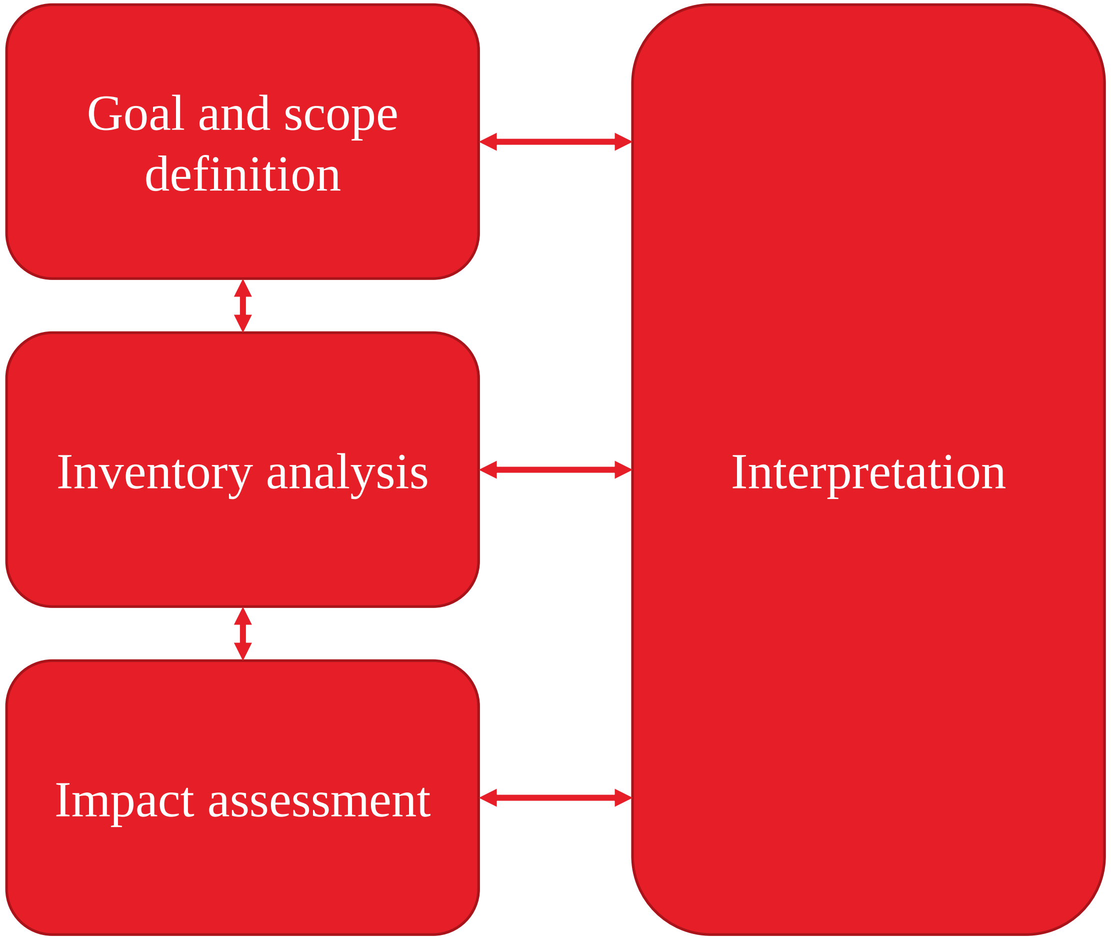
Life cycle assessment

Intended application
Reasons for carrying out study
System boundaries
Assumptions and limitations

Data collection
Data validation
Data aggregation

Evaluate potential environmental and human health impacts



Conclusions, limitations and recommendations

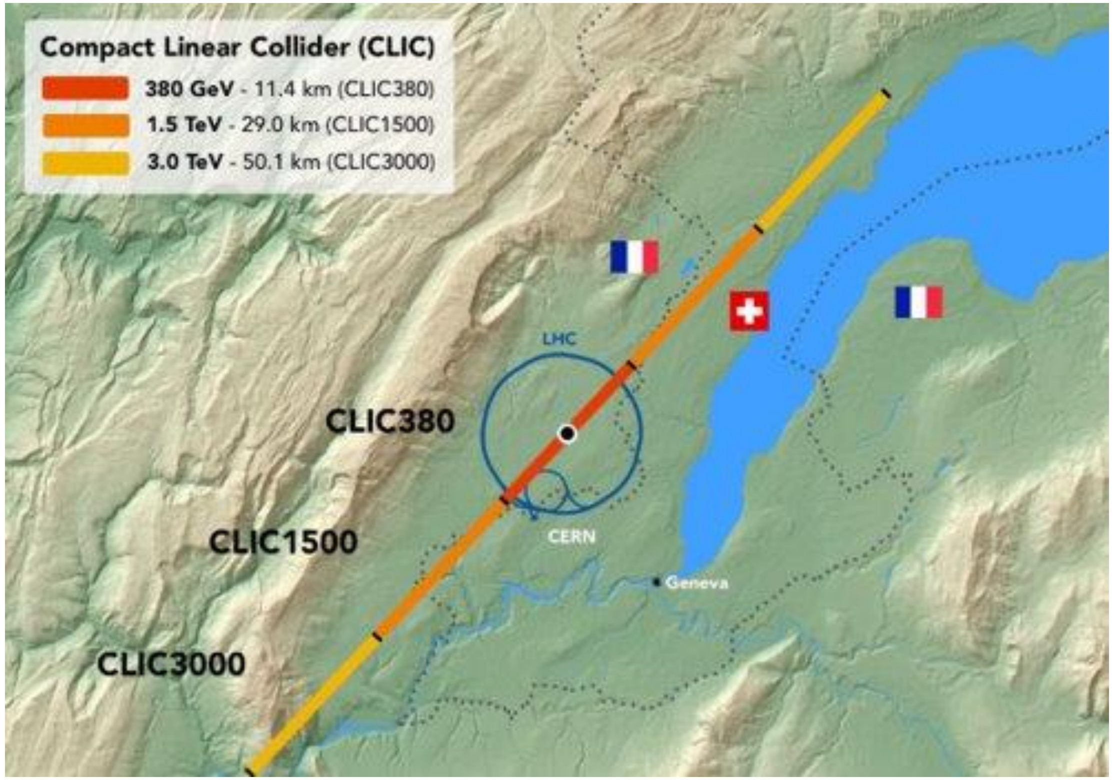
ISO 14040:2006

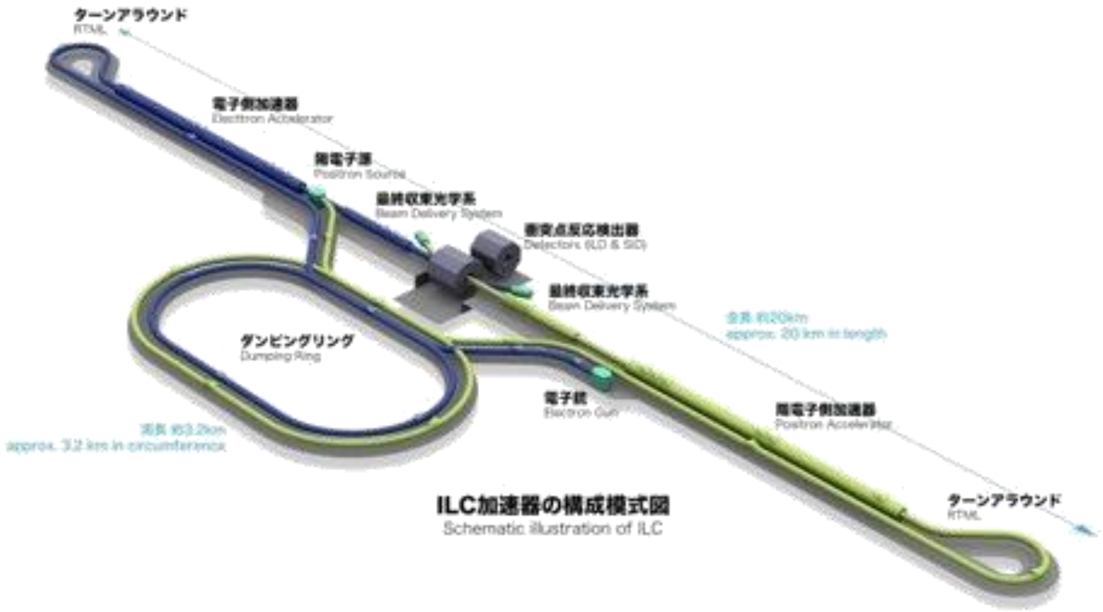
Linear collider options

Compact Linear Collider (CLIC)

a) Drive Beam   b) Klystron

International Linear Collider (ILC)





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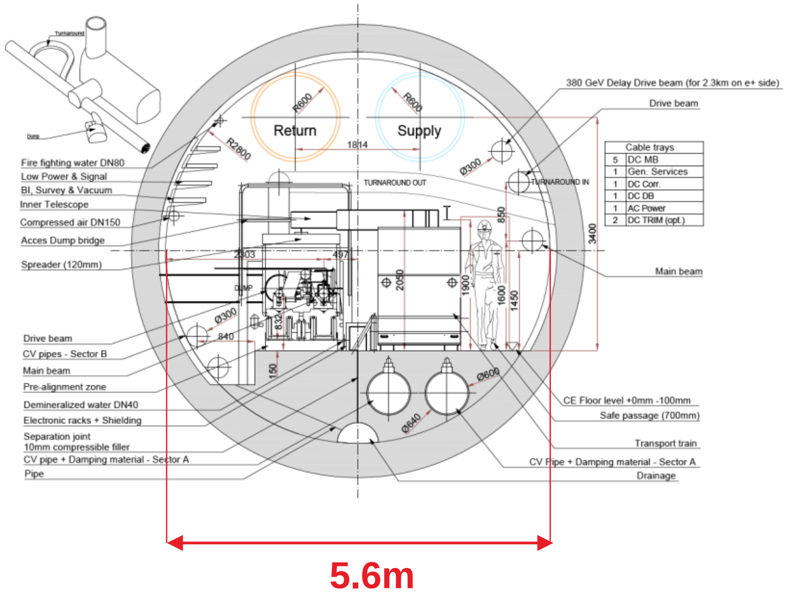
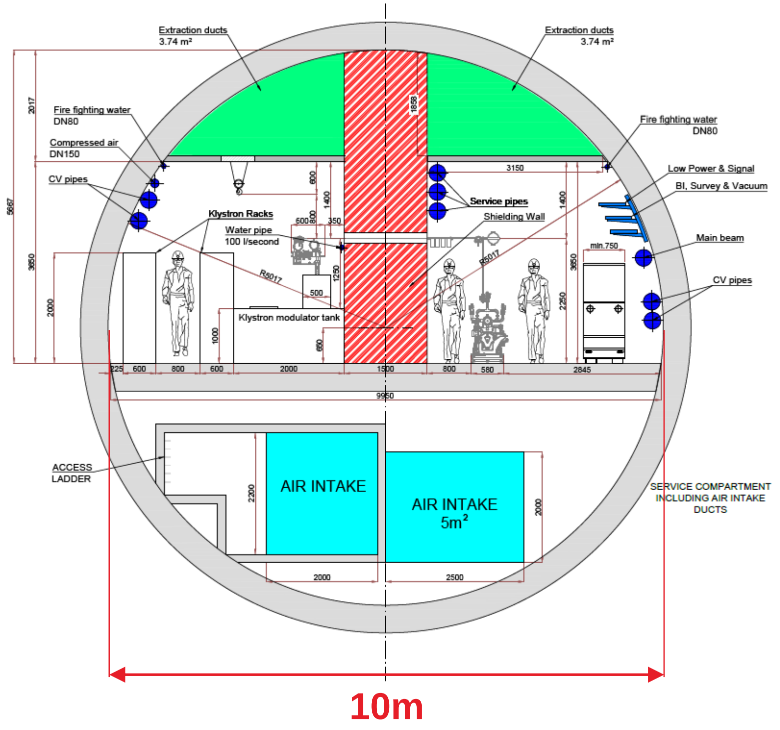
Linear collider options

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



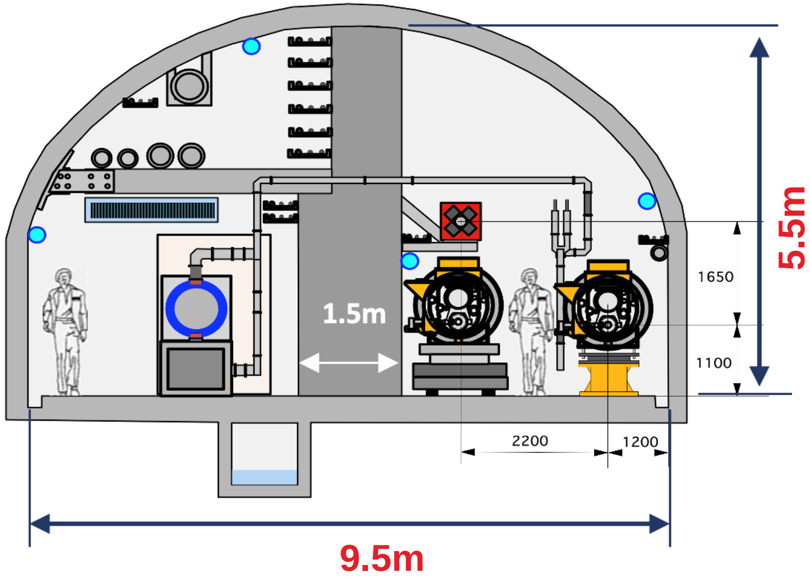
Reference: CLIC Drive Beam tunnel cross section, 2018

CLIC Klystron
10m internal dia. Geneva.
(380GeV)



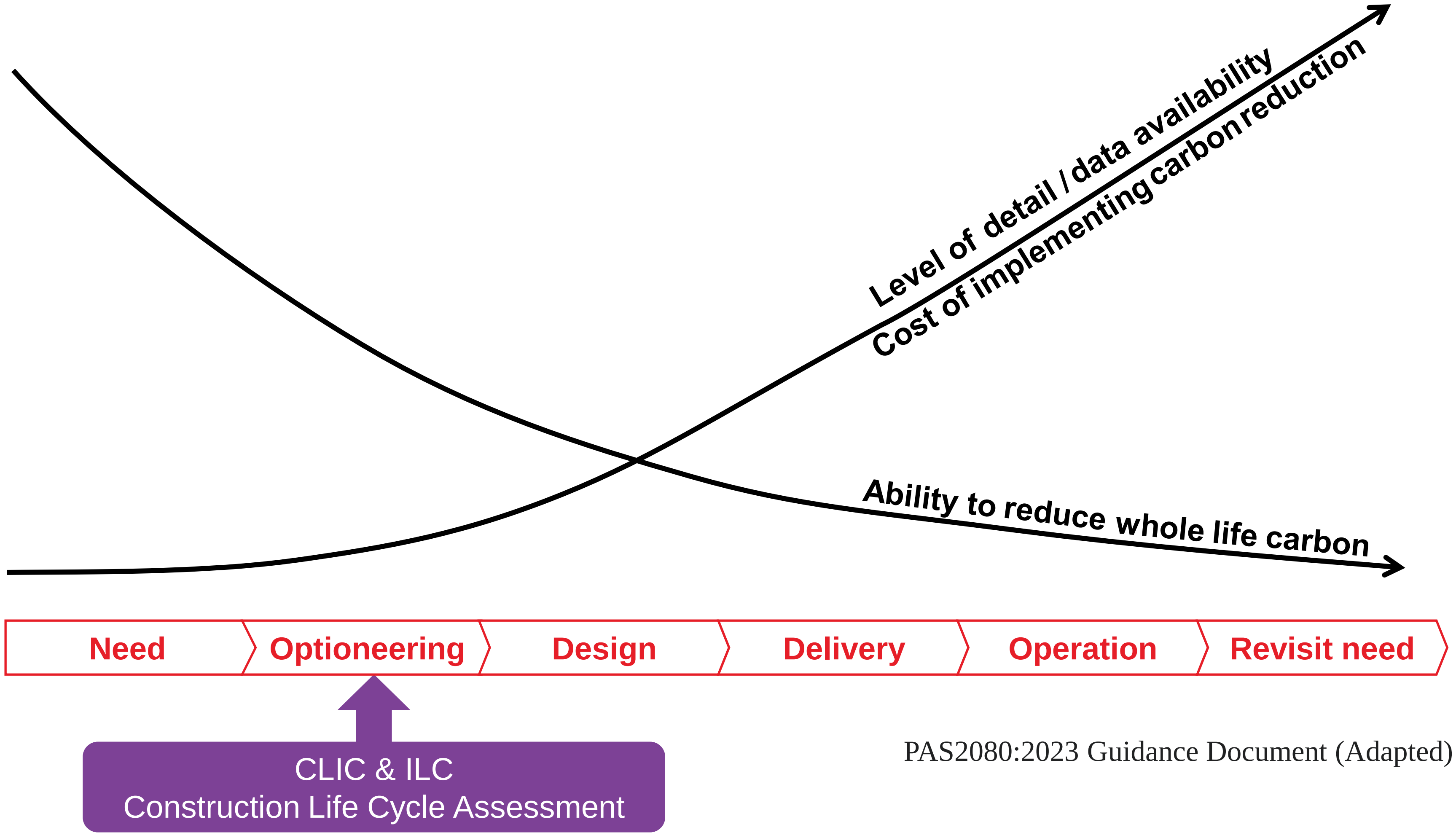
Reference: CLIC Klystron tunnel cross section, 2018

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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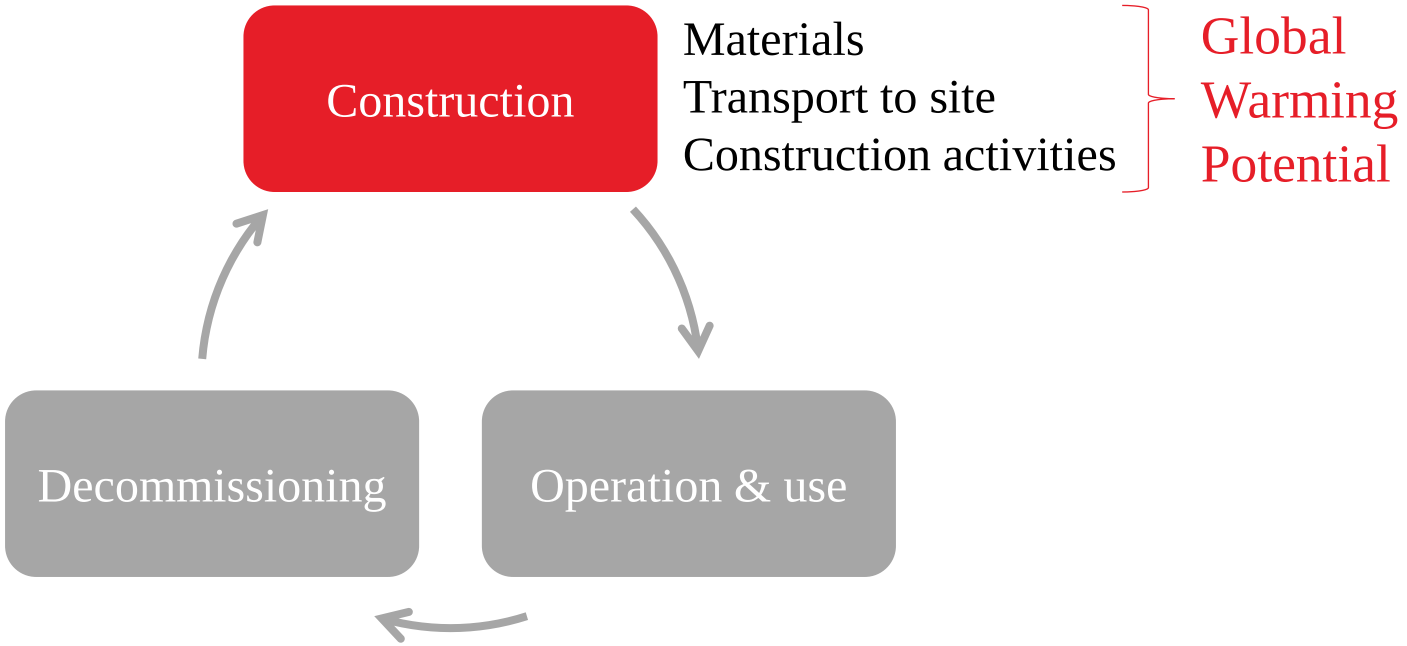
Goal and scope

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



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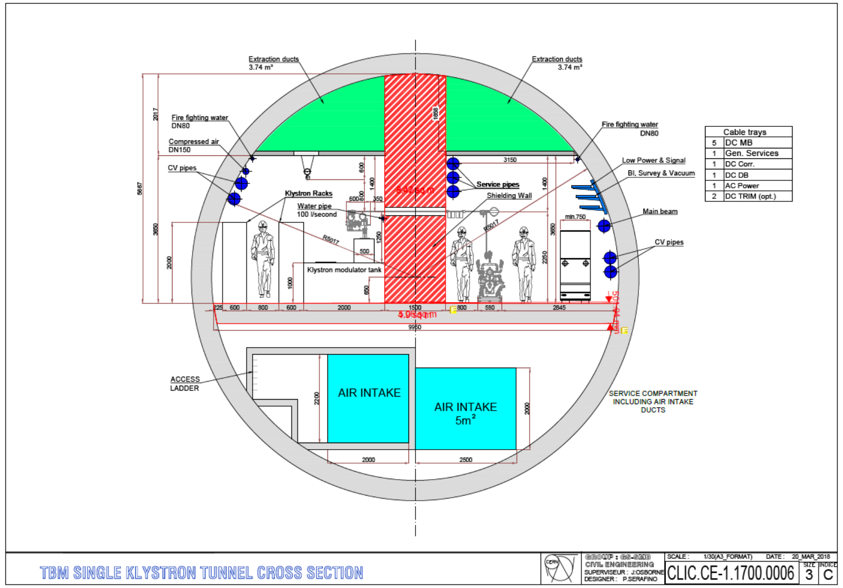
Inventory analysis

- 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

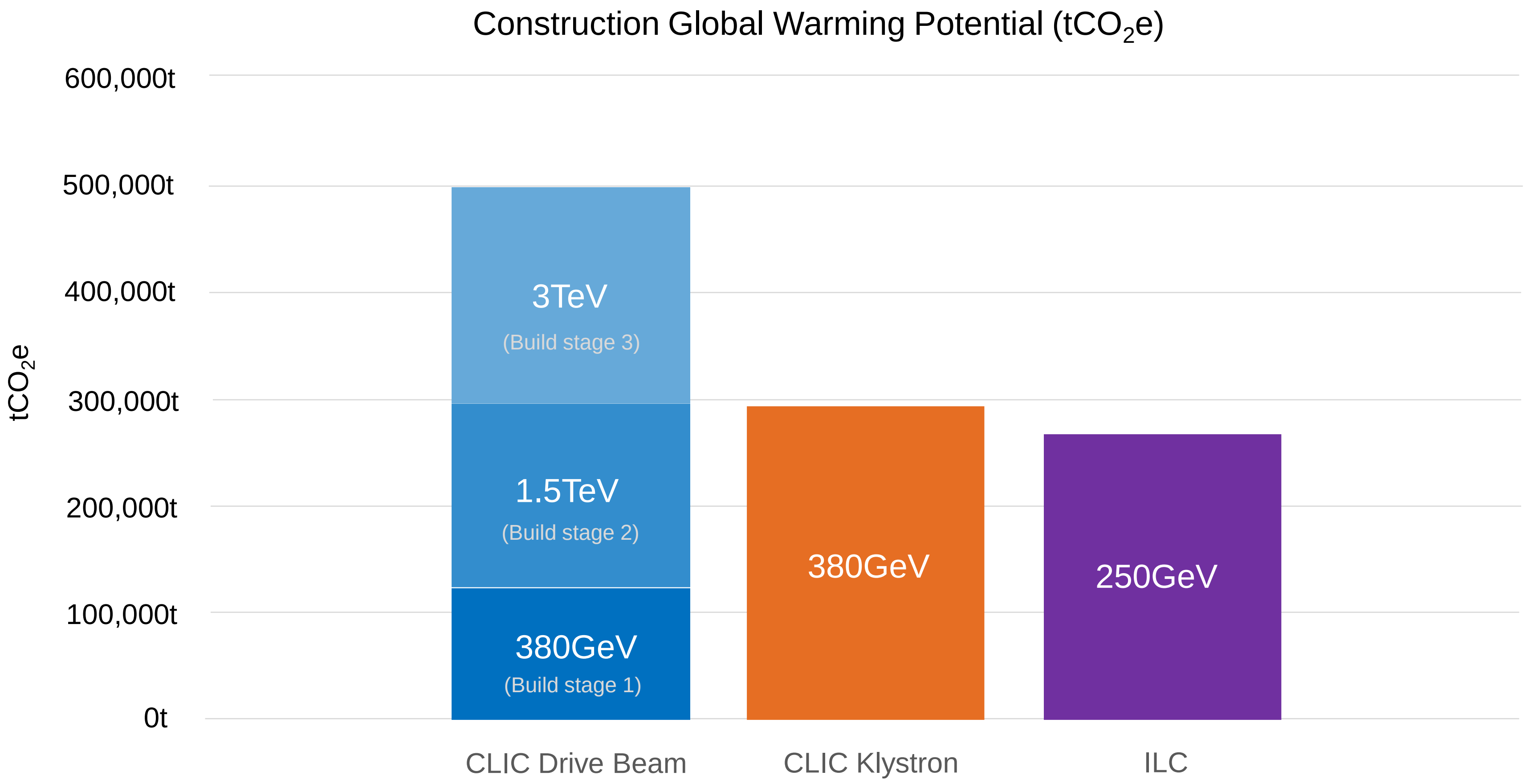
System	Sub-system	Components	Sub-components
CLIC Drive Beam 380GeV			
	Tunnels		
		Main accelerator tunnel	
			Primary Lining Permanent Lining Invert
		Turnarounds	
			Primary Lining Permanent Lining Invert
	Shafts		
		9-18m dia.	
			Primary Lining Permanent Lining
	Caverns		
		BDS, UTRC, UTRA, BC2,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

2030 Baseline assumptions

Construction LCA		CLIC Drive Beam	CLIC Klystron	ILC
Materials		Concrete (CEMI) & Steel (80% recycled)		
Transport of materials to site		Concrete: Local by road (50km) Steel: European by road (1500km)		Concrete: Local by road (50km) Steel: National by road (300km)
Construction activities	Material wasted in construction	Concrete insitu: 5% Precast concrete: 1% Steel reinforcement: 5%		
	Transport of disposal materials off site	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.*		
	Construction process	Tunnel Boring Machine (TBM)		Drill & Blast* — *Explosives excluded due to lack of data
	Electricity mix 2021/2022	Fossil: 12% Non-fossil: 88%		Fossil: 71% Non-fossil: 29%

Impact assessment

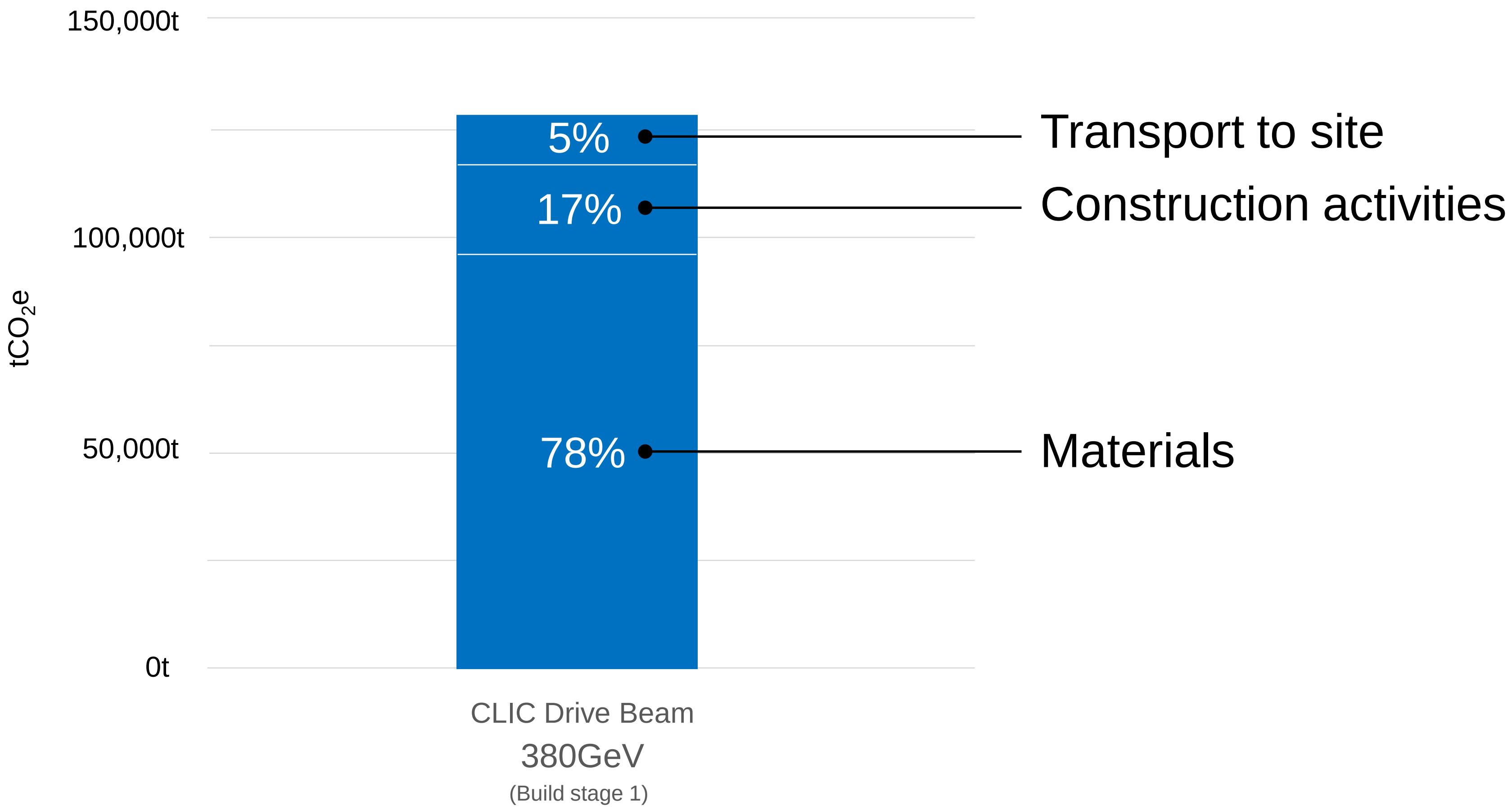
CLIC & ILC



Impact assessment

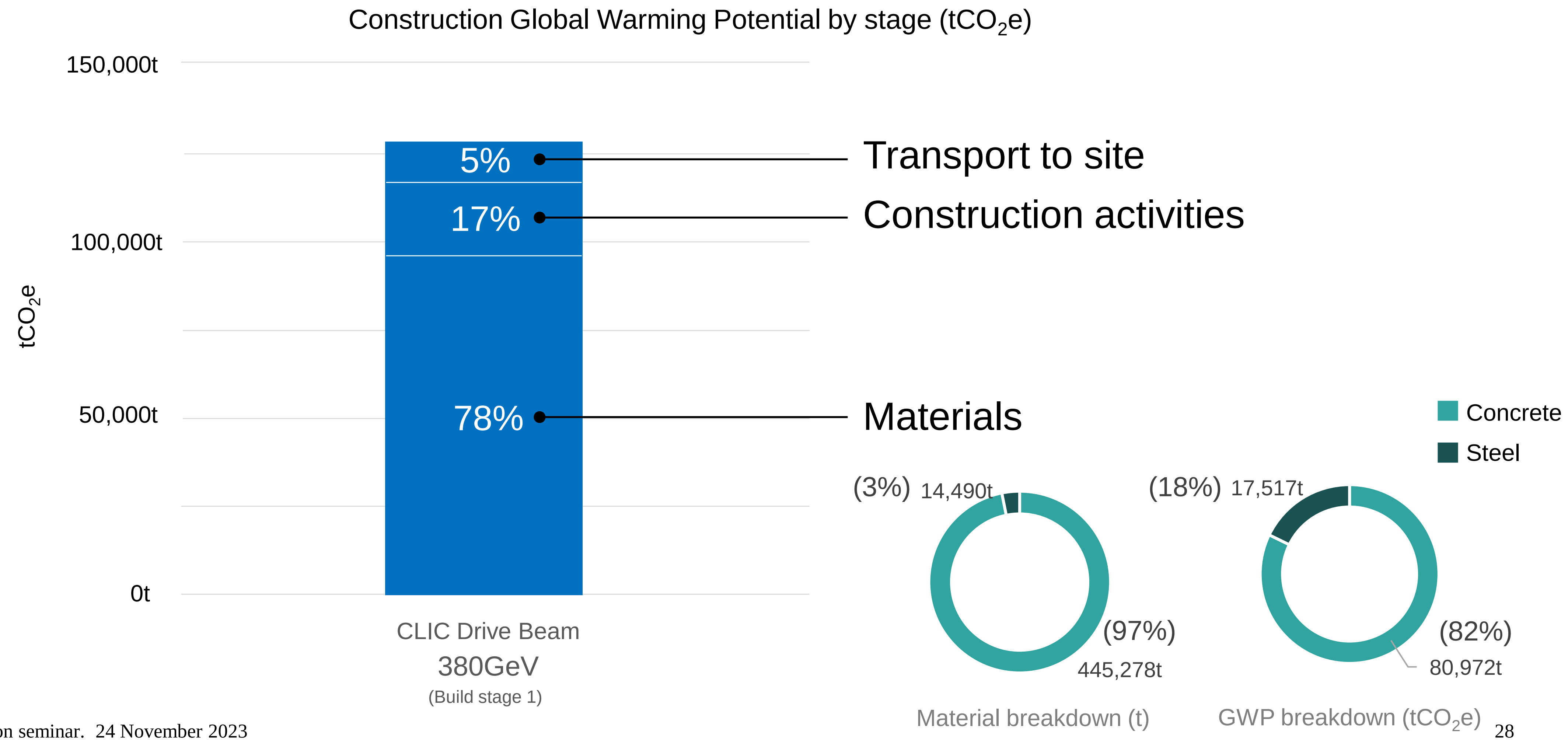
CLIC Drive Beam 380GeV

Construction Global Warming Potential by stage (tCO_2e)



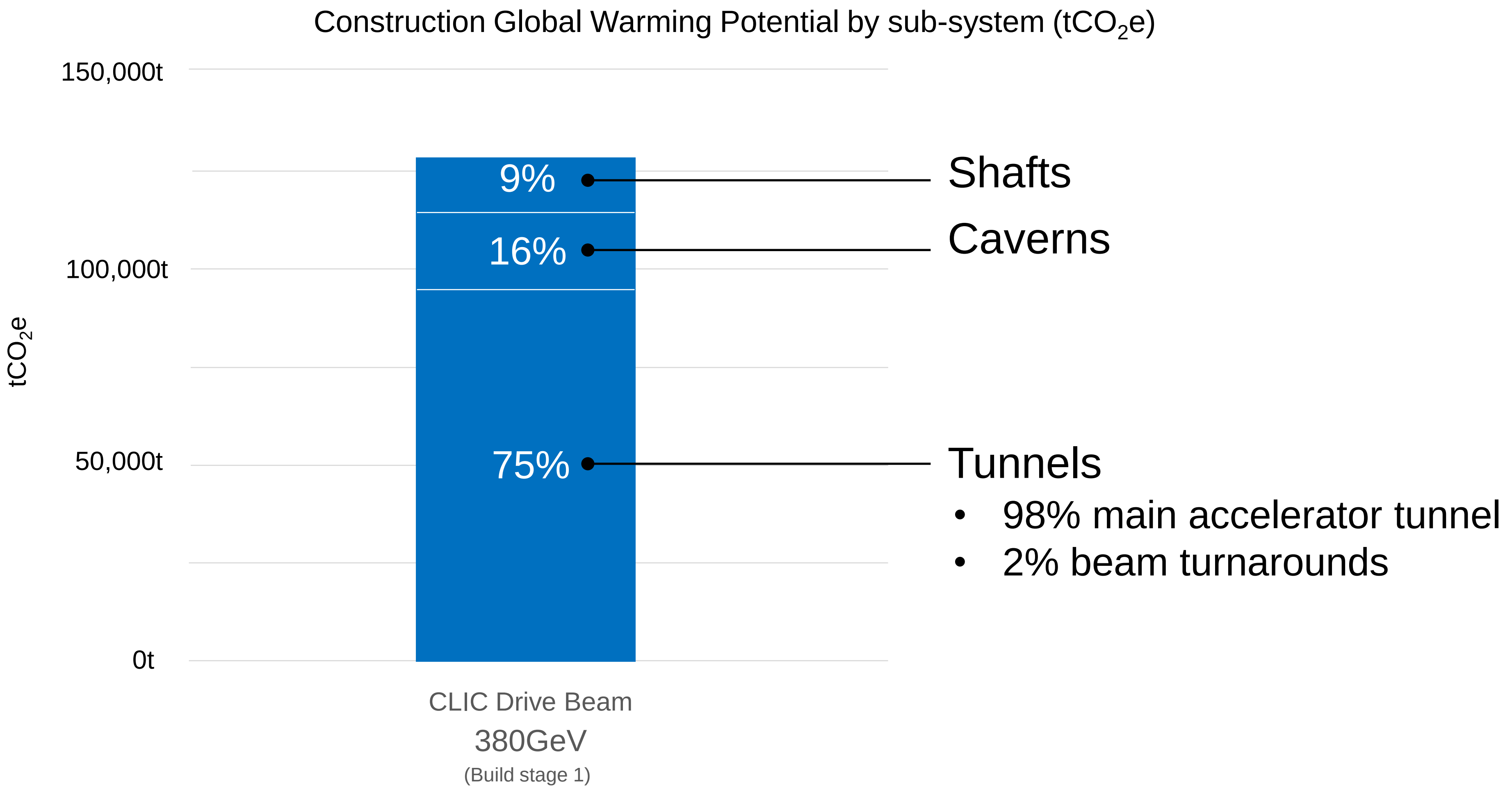
Impact assessment

CLIC Drive Beam 380GeV



Impact assessment

CLIC Drive Beam 380GeV



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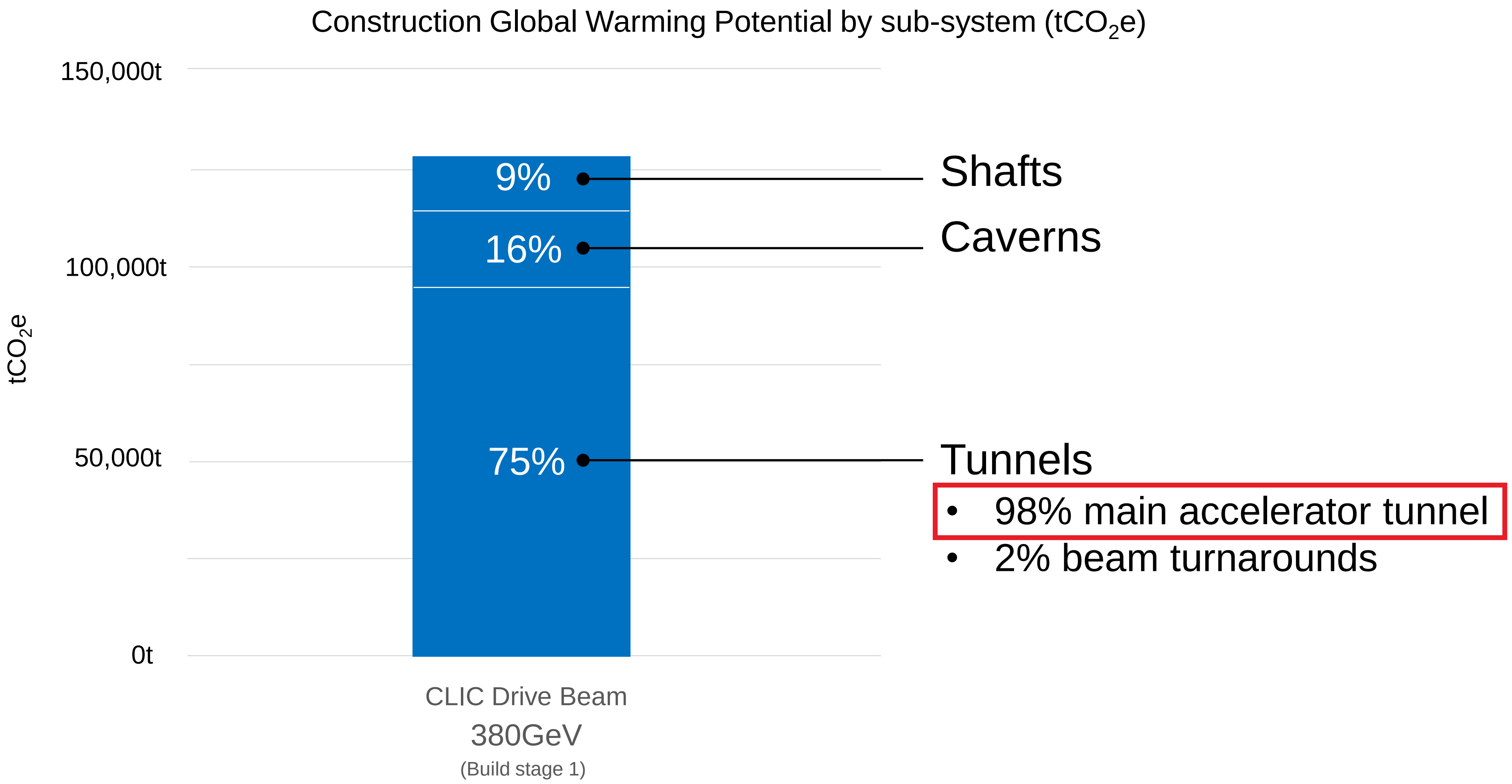
Impact assessment

CLIC Drive Beam 380GeV



Hotspots

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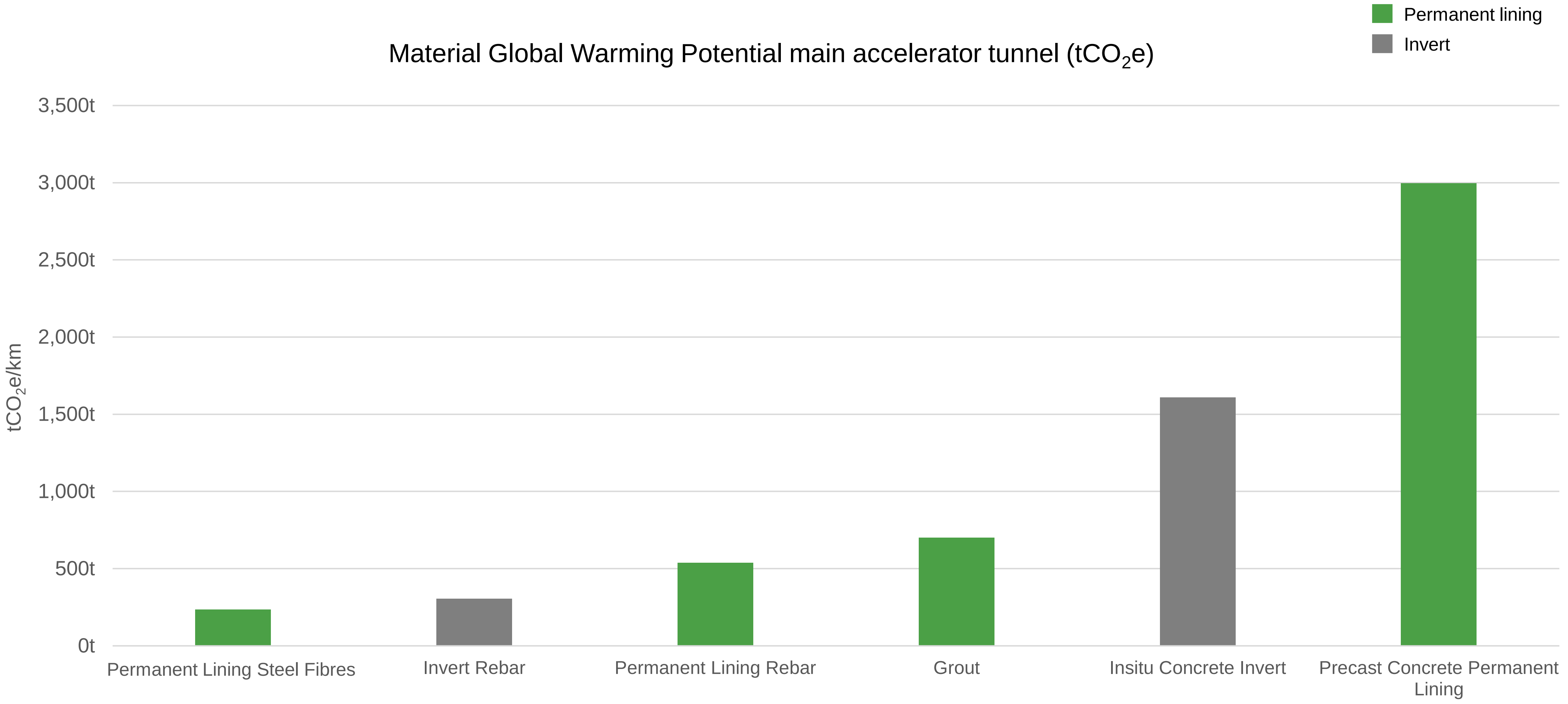
CLIC Drive Beam 380GeV main accelerator tunnel



Benchmarks

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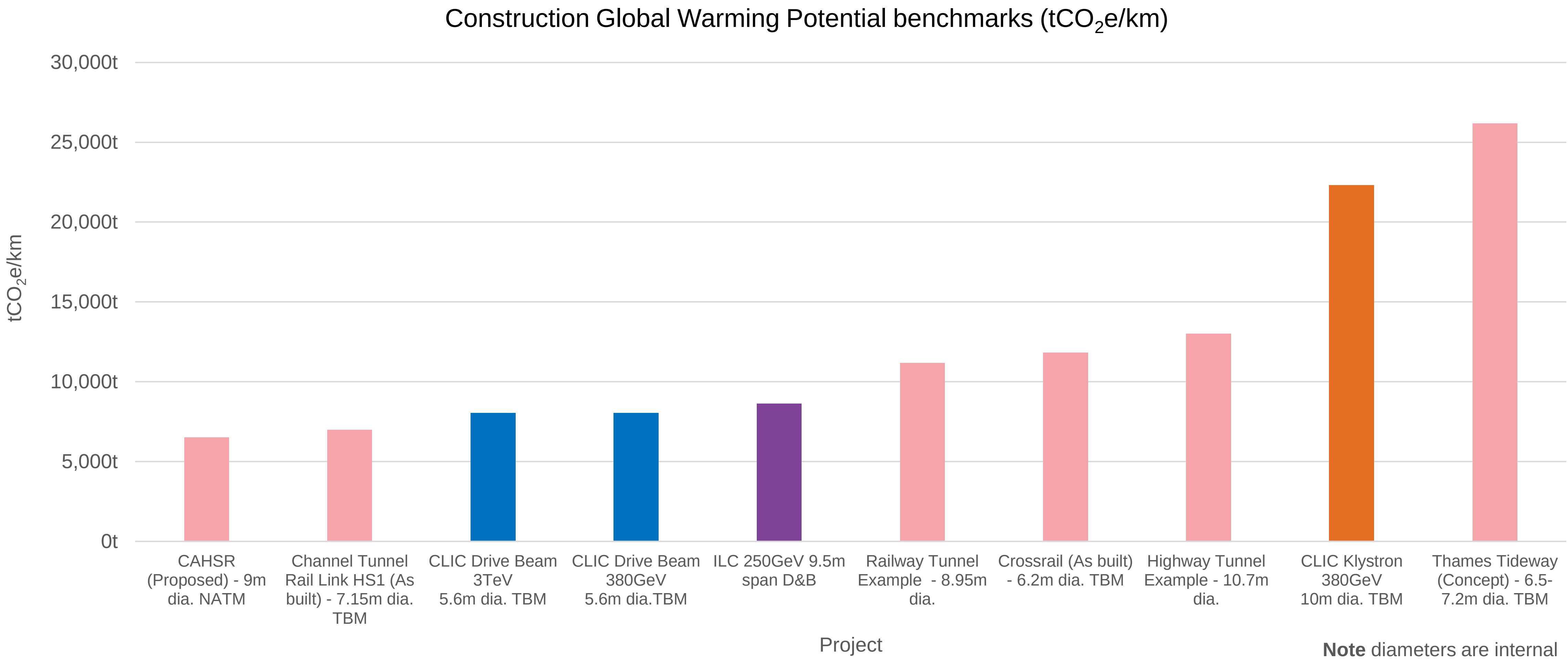
CLIC & ILC main accelerator tunnel



Note diameters are internal

Reduction opportunities

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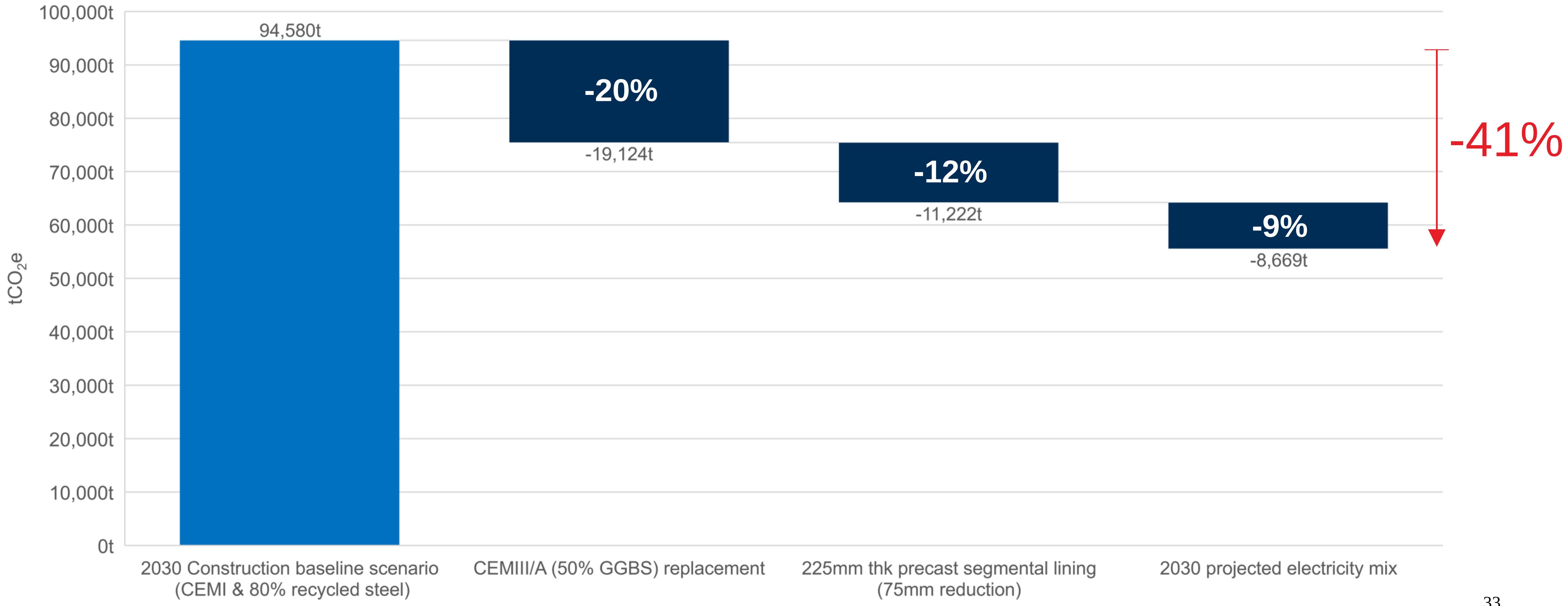
CLIC Drive Beam 380GeV tunnels

Construction GWP possible reduction opportunities (tCO_2e)



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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…

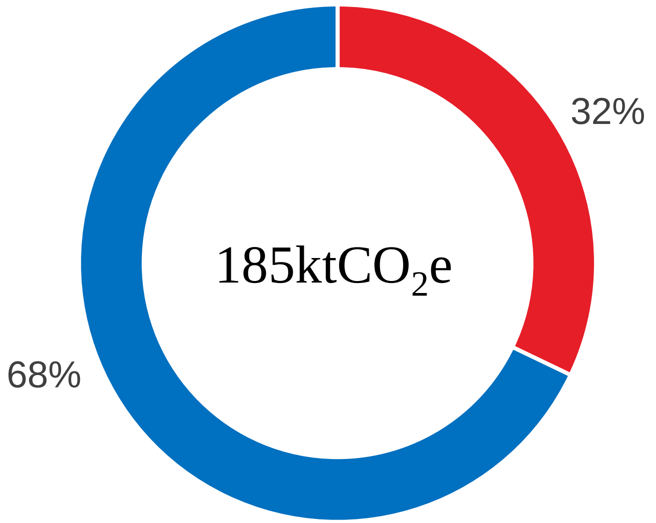
Construction and operation carbon

CLIC Drive Beam

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

380GeV

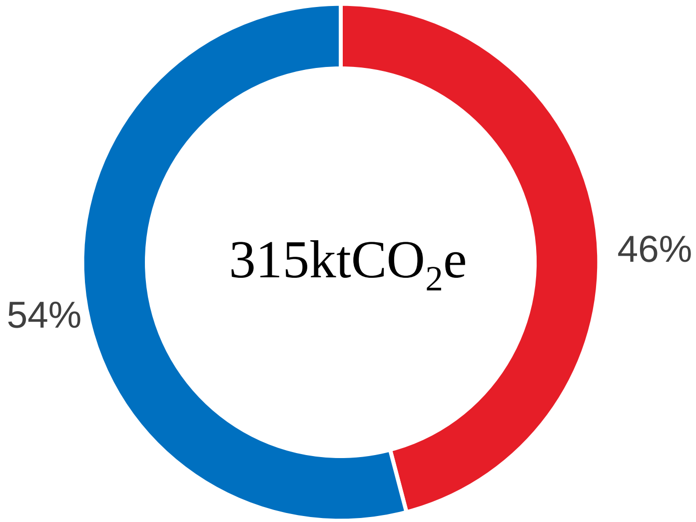
Construction GWP is equivalent to 1.7 decades of running accelerator



- A1-A5 Construction (tunnel: 11.47km)
- Operation over 8 years

1.5TeV

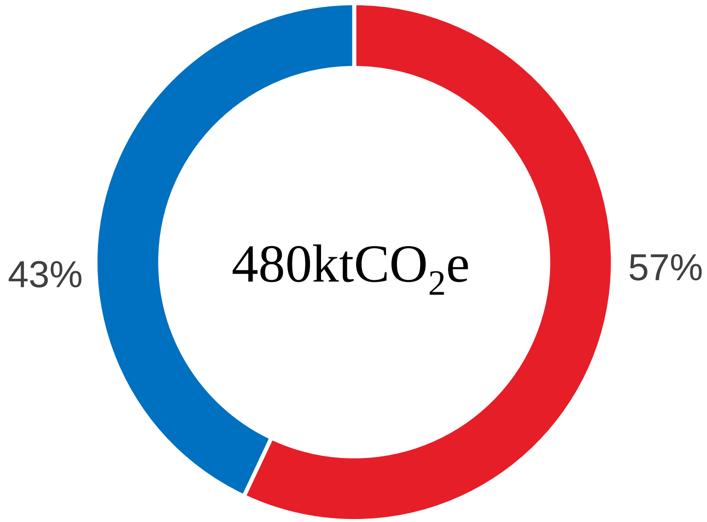
Construction GWP is equivalent to 0.8 decades of running accelerator



- A1-A5 Construction (tunnel: 17.56km)
- Operation over 7 years

3TeV

Construction GWP is equivalent to 0.6 decades of running accelerator



- A1-A5 Construction (tunnel: 21.08km)
- Operation over 8 years

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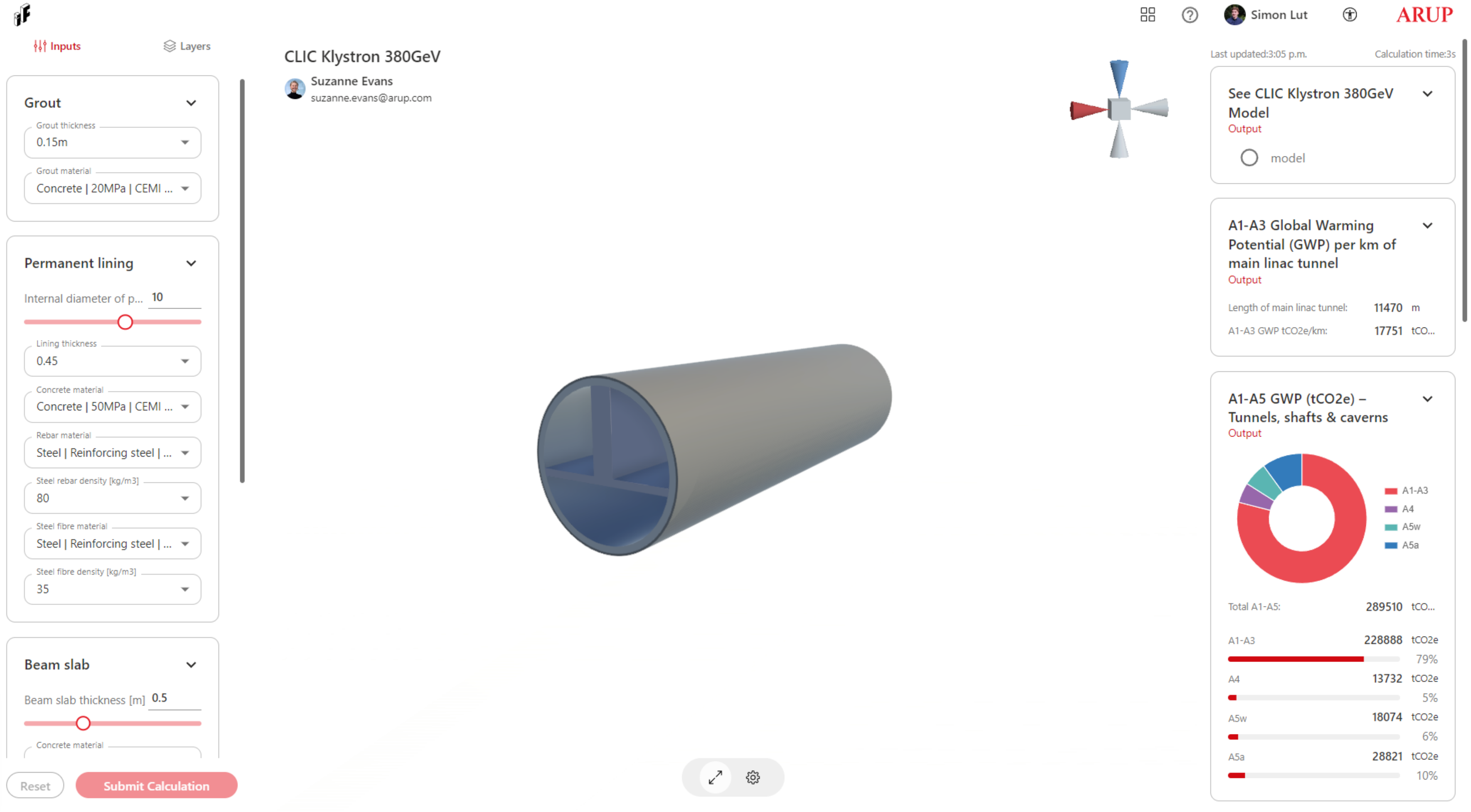
Learning points

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

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Policy timeline – UK

News story

UK becomes first major economy to pass net zero emissions law

New target will require the UK to bring all greenhouse gas emissions to net zero by 2050.

Climate Change Act 2008

PARIS2015

UK Net Zero

Biodiversity Net Gain

2008 — 2013 — 2015 — 2016 — 2019 — 2020 — 2021 — 2022 — 2023

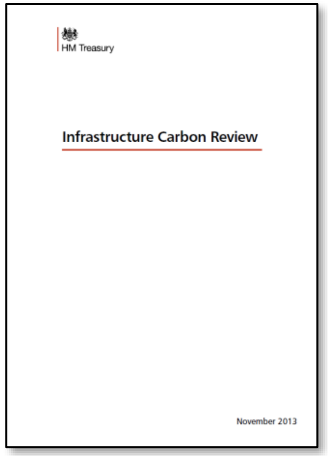
ICR

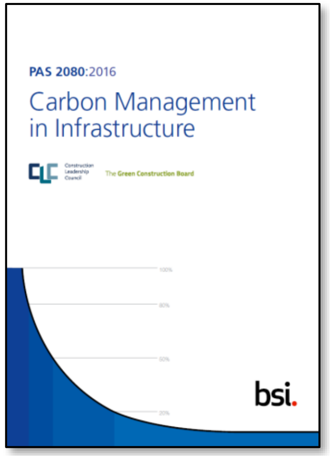
PAS 2080

6th Carbon Budget

COP26

PAS 2080:2023





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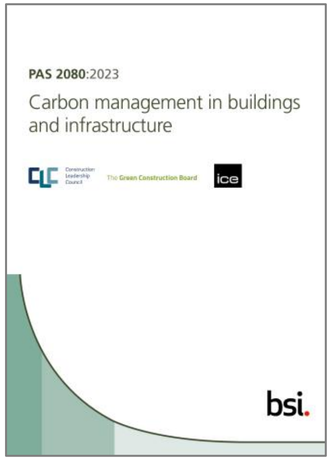
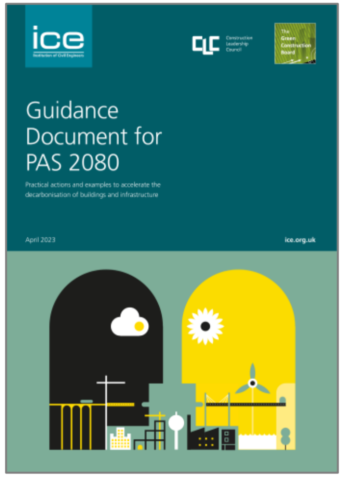
What is it?

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

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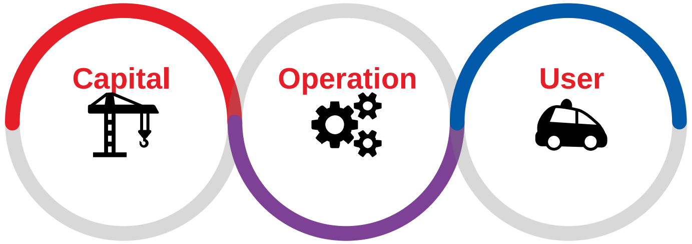
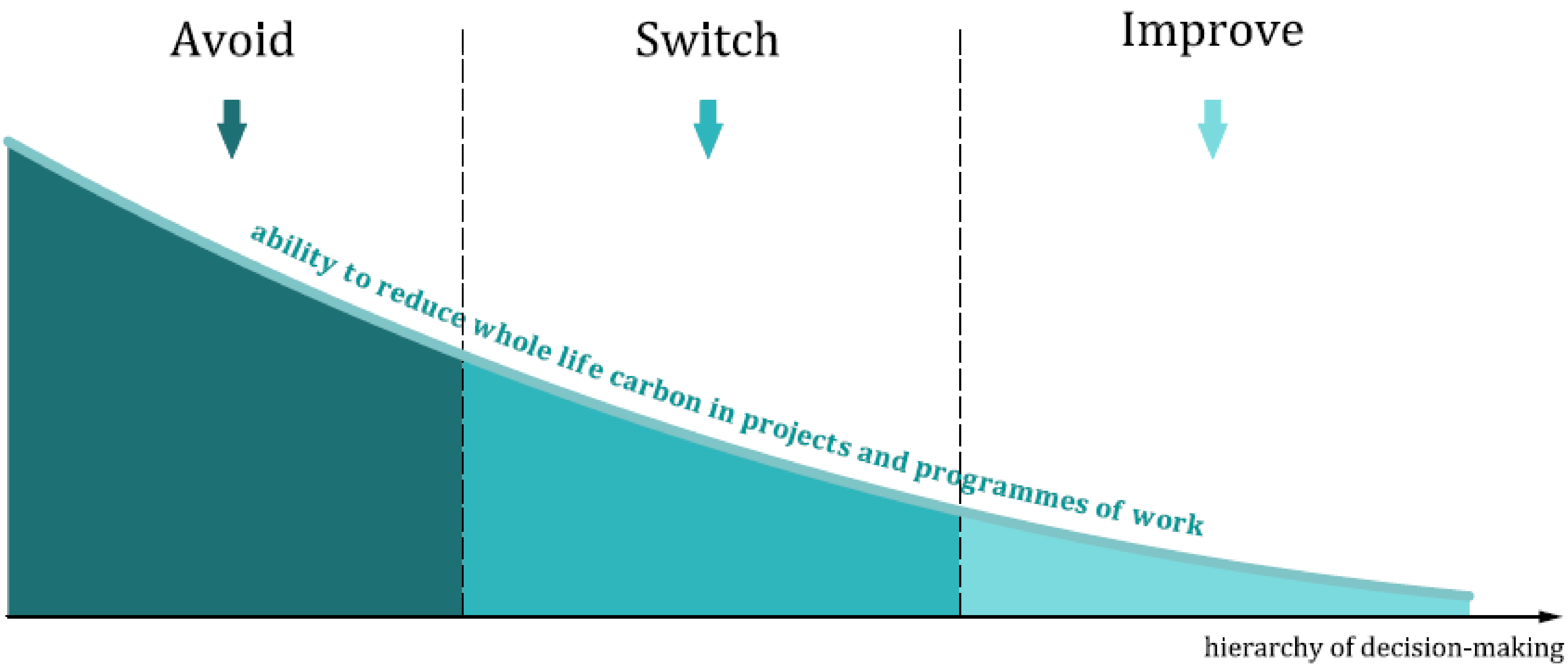
Carbon hierarchy

Prioritise meaningful decarbonisation





Previous work

Research community and carbon:

- UKRI - operational carbon support wave 3
- UKRI - facilitating workshop wave 4
- STFC – Scoping a decarbonisation implementation plan

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Carbon reduction examples

Ground energy potential

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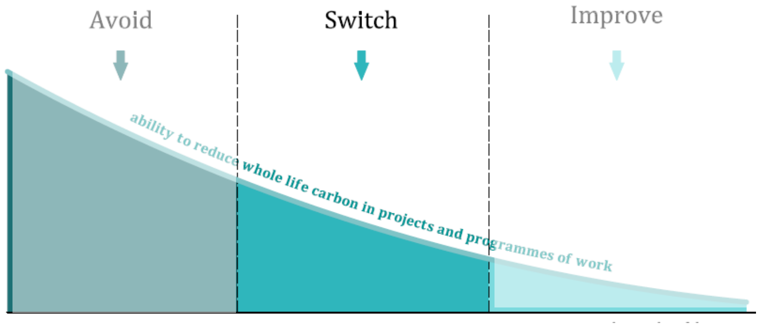
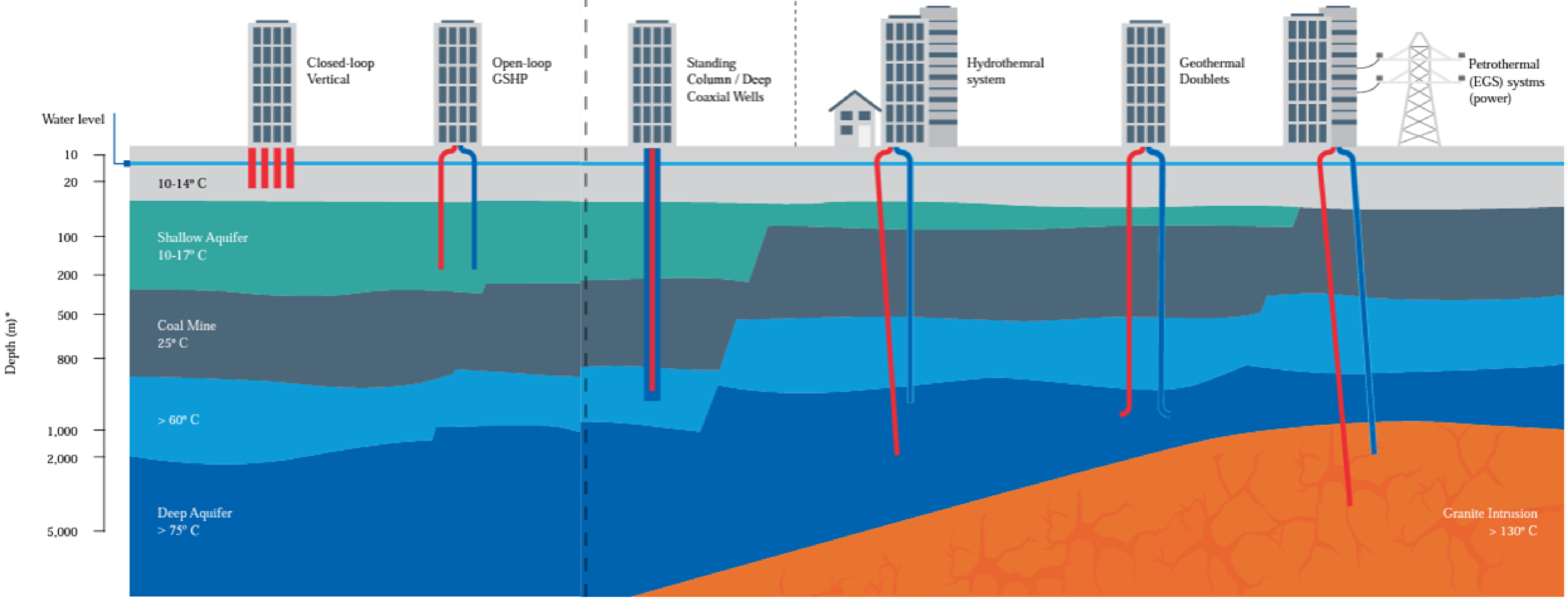


Heating and cooling ground source heating

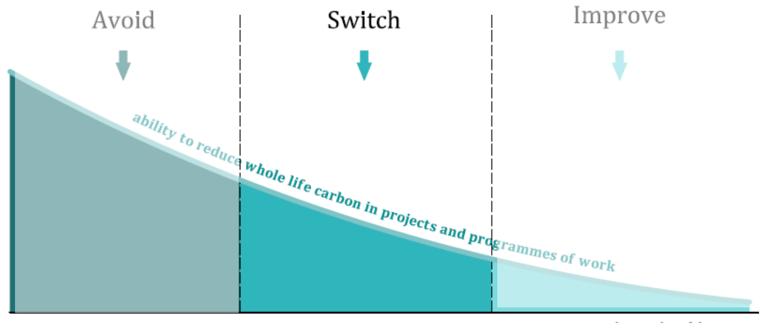
District heating and power generation (Direct use of heat & steam)



Shallow ground source energy systems

Deep geothermal energy systems

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



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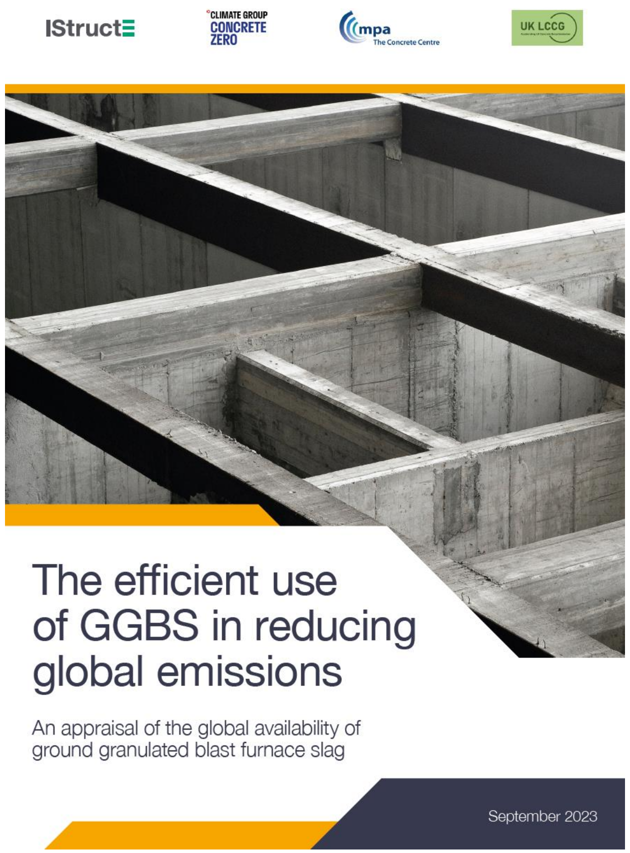
Concrete technologies

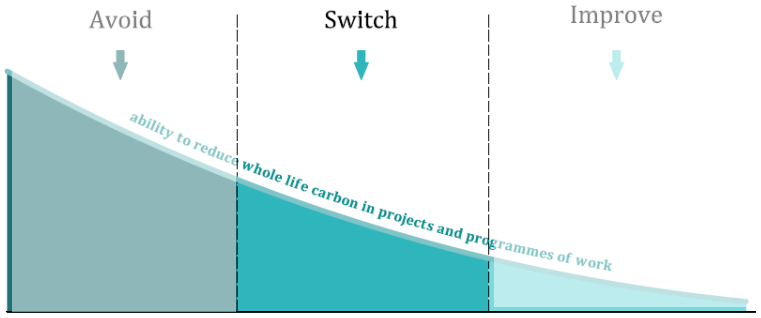
Global availability of GGBS is constrained

- Global production of **Portland Cement clinker** is **10 × GGBS** production.
- GGBS is a limited and constrained resource that is almost fully utilised globally.
- Locally increasing GGBS use is unlikely to decrease global emissions.
- Alternative options exist for reducing emissions in concrete.



https://www.istructe.org/resources/guidance/efficient-use-of-ggbs-in-reducing-global-emissions/

Concrete technologies



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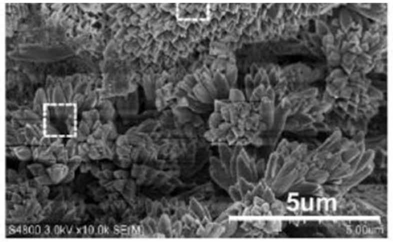
Indicative performance of alternatives to Portland cement

Property	Partial cement replacement									Total replacement		Carbon process
	GGBS	FA	SF	MK	NP	CNP	EMC	LS	LC³	AAMs	ANPC#	CCure
Embodied carbon	↓	↓	↓	~↓	↓	~↓	↓/~↓	↓	~↓	↓/~↓	↓/~↓	~~↓
Fresh properties	~↑	~↑	~↓	~↓	~↓	~↓	U	↑*/↓**	~↓	→	U	~↓
Strength (early)	~↓	~↓	~↑	~↑	~↓	~↓	~↓	~↓	U	U	~↓	~↑
Strength (long-term)	~↑	~↑	~↑	~↑	~↑	~↑	~↑	~↓	→	→	→	~↑
E-modulus	→	→	→	→	U	U	U	→	U	~↓	U	U
Shrinkage	~↑/→	~↑/→	↑	~↓/→	U	U	U	~↓	U	~↑	U	~↑
Creep	~↑/→	~↑/→	~↓	~↓/→	U	U	U	U	U	~↑	U	U
Durability -chlorides	↑	↑	↑	~↑	~↑	~↑	~↑	~↑	~↑	~↑	U	→
Durability-carbonation	↑*/↓**	↑*/↓**	~↑/→	~↓	U	U	U	~↓	~↑	~↑	U	U
Durability (ASR, DEF.)	↑	↑	↑	↑	↑	↑	~↑	↑	~↑	U	U	U
Standardisation	G	G	G	M	M	M	L	L	L	L	L	L
Availability	M	M	M	M	G	M	L	G	L	L	L	L
Cost	→	→	~↑	~↑	~↓	~↑	~↑	↓	→	~↑	U	~↑

GGBS = Ground granulated blastfurnace slag; FA = Fly ash; SF = silica fume; MK = metakaolin; NP = natural pozzolan; CNP = calcined natural pozzolan; EMC = energetically-modified cement; LS = limestone; LC3 = LC3 cement; AAMs = alkali-activated materials; ANPC = alternative non-Portland cements #; CCure = Carbon Cure
"G", "M", "L" and "U" are used for good, moderate, low and unknown, respectively

bioMASON

Biocement that grows with natural microorganisms in ambient temperatures



Concretene

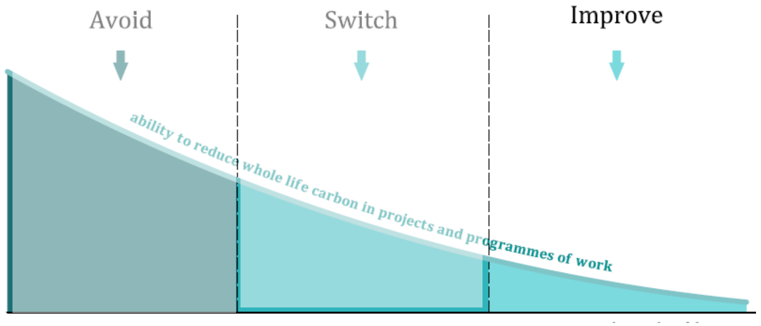
Cement innovation with graphene as an additive

Spoil to resource

Calcined clay arisings for use as Supplementary Cementitious Material (SCM)

CarbonCure

Cement innovation where carbon is injected to accelerate curing



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Turning spoil into resource

Calcined clay for cementitious material aggregates or bricks!

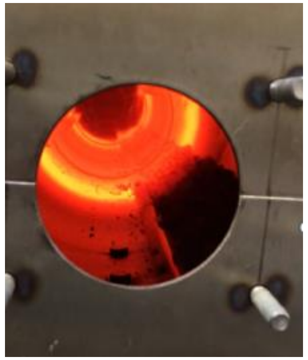

HS2

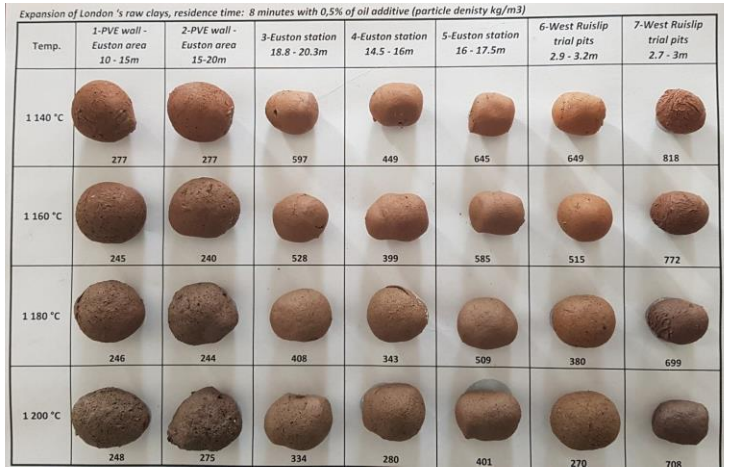
How HS2 waste clay could be conjured into concrete to cut emissions

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

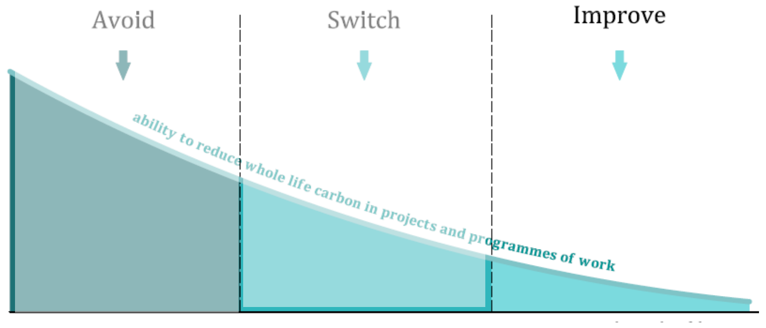



Expansion of London 's raw clays, residence time: 8 minutes with 0,5% of oil additive (particle denisty kg/m3)

Temp.	1-PVE wall - Euston area 10 - 15m	2-PVE wall - Euston area 15-20m	3-Euston station 18.8 - 20.3m	4-Euston station 14.5 - 16m	5-Euston station 16 - 17.5m	6-West Ruislip trial pits 2.9 - 3.2m	7-West Ruislip trial pits 2.7 - 3m
1 140 °C	277	277	597	449	645	649	818
1 160 °C	245	240	528	399	585	515	772
1 180 °C	246	244	408	343	509	380	699
1 200 °C	248	275	334	280	401	270	708

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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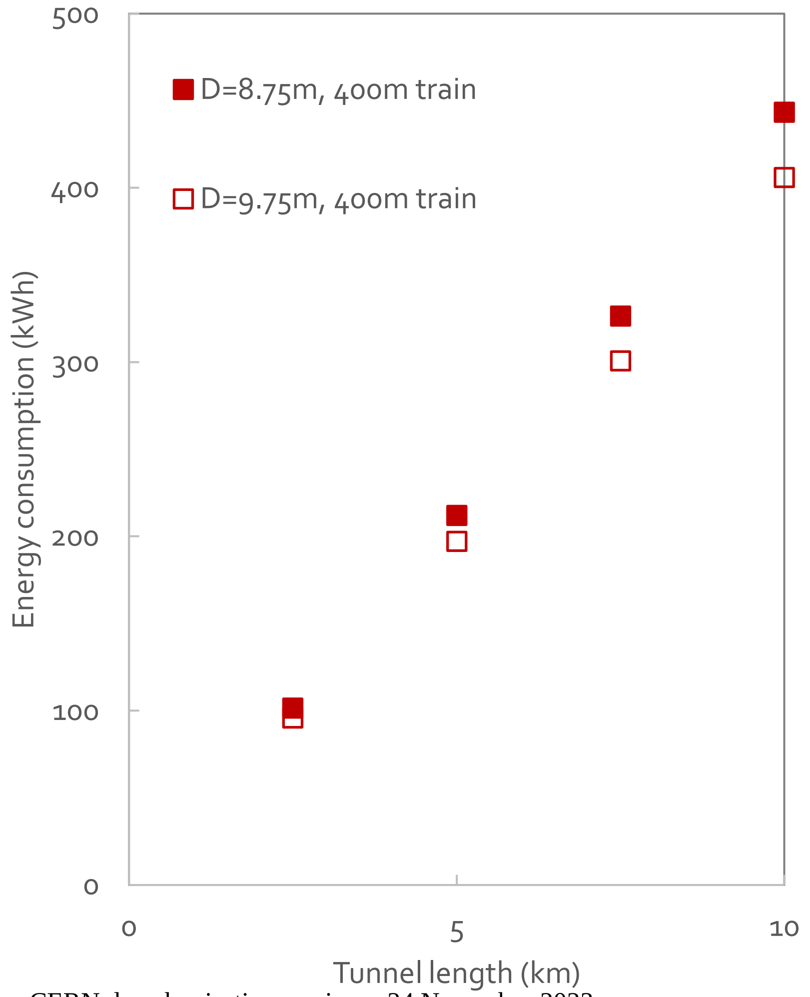
Capital v whole life carbon

Balance between capital carbon investment and operational savings



Railway Engineering-2017 railwayengineering.com doi: 10.25084/raileng.2017.0124

DESIGNING TUNNELS FOR WHOLE LIFE VALUE

H. Pantelidou, S. Stephenson, J. Alexander, R. Sturt

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Conclusions

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Conclusions

- Ambitious decarbonisation targets
- Carbon management to help meet targets
- Managing whole life carbon