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Life Cycle Assessment

Comparative environmental footprint for future linear colliders CLIC and ILC

LCWS 2023 - SLAC | 16/05/2023

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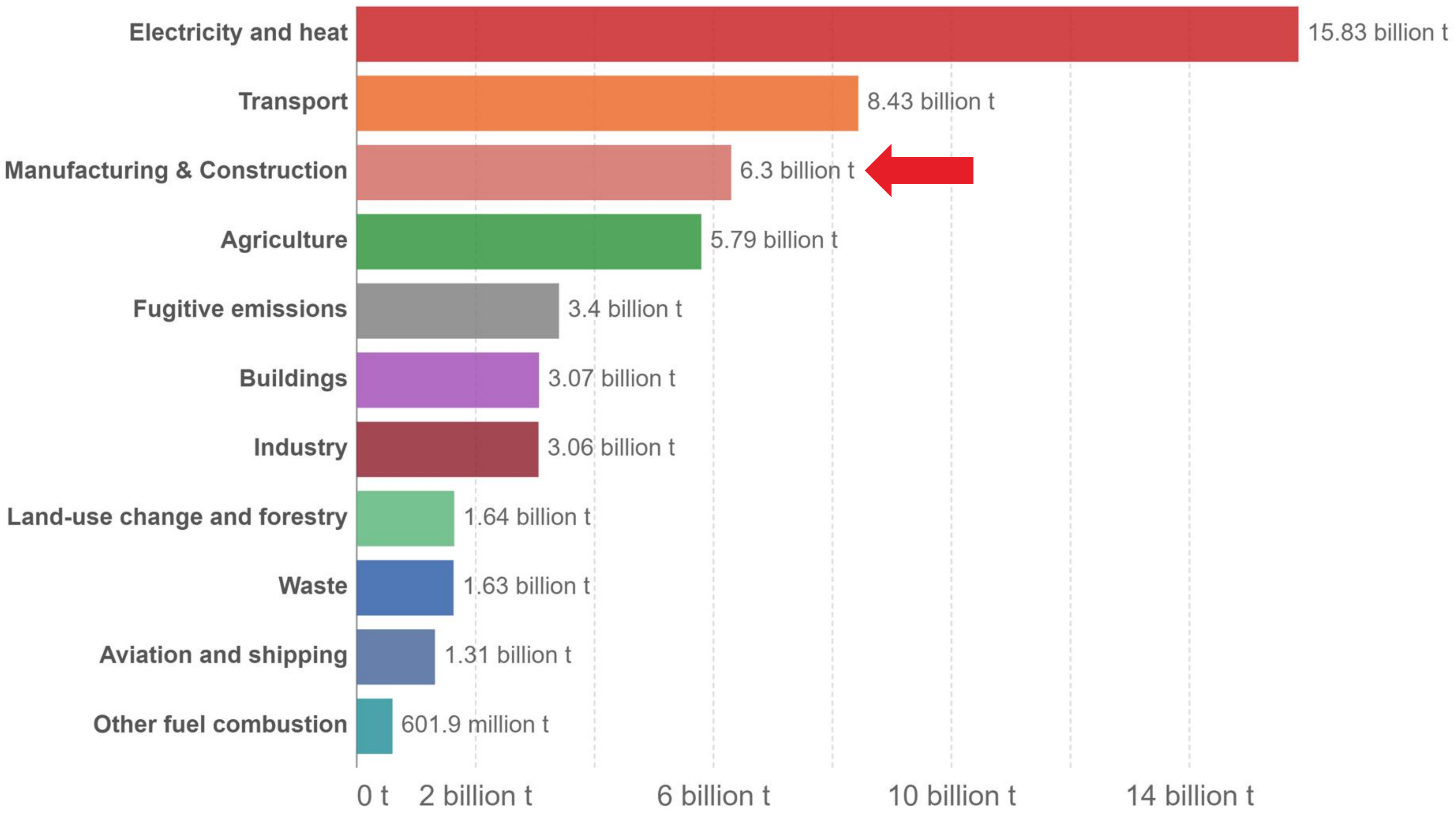
LCWS2023
INTERNATIONAL WORKSHOP ON LINEAR COLLIDERS

Global GHG Emissions

(tCO_2e)



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

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

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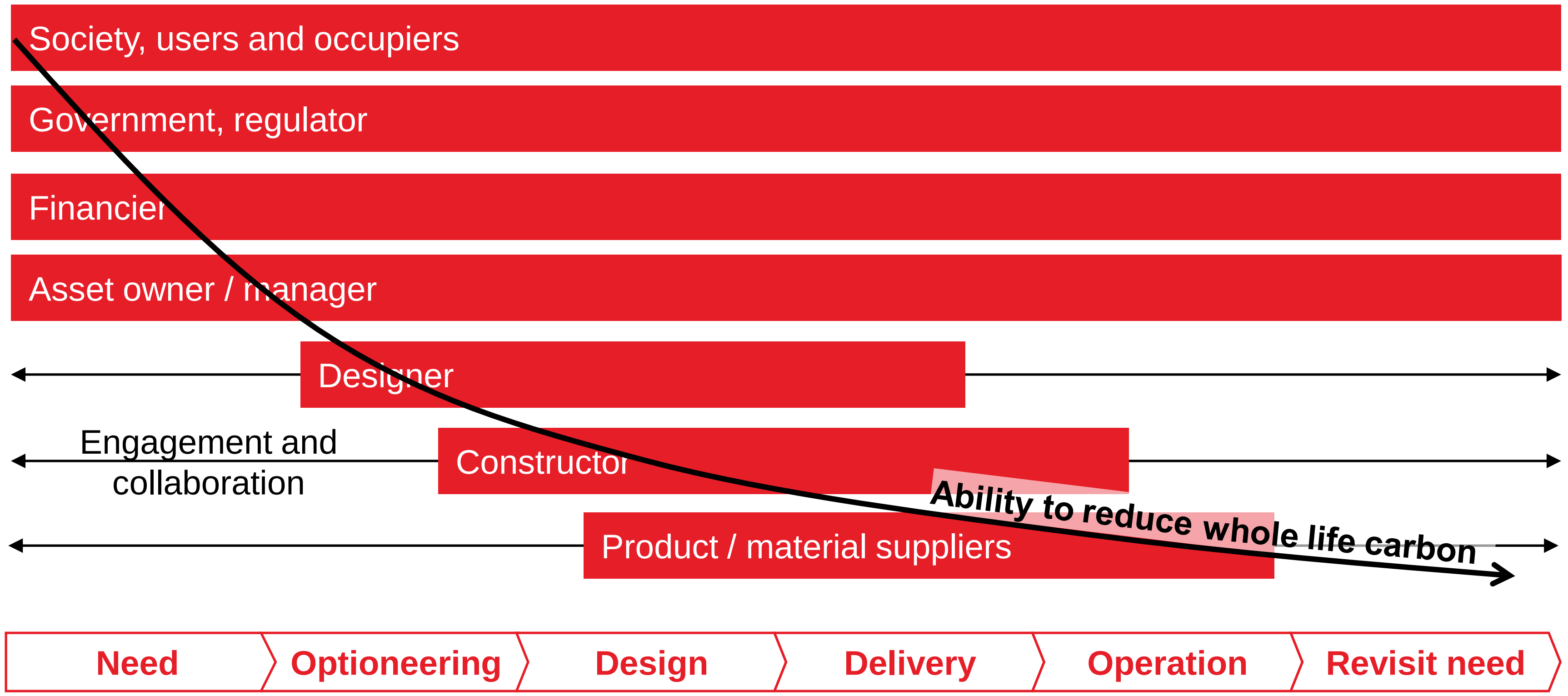
UN Breakthrough Outcomes for 2030

Our Influence



PAS2080:2023 Guidance Document (Adapted)

Our Influence

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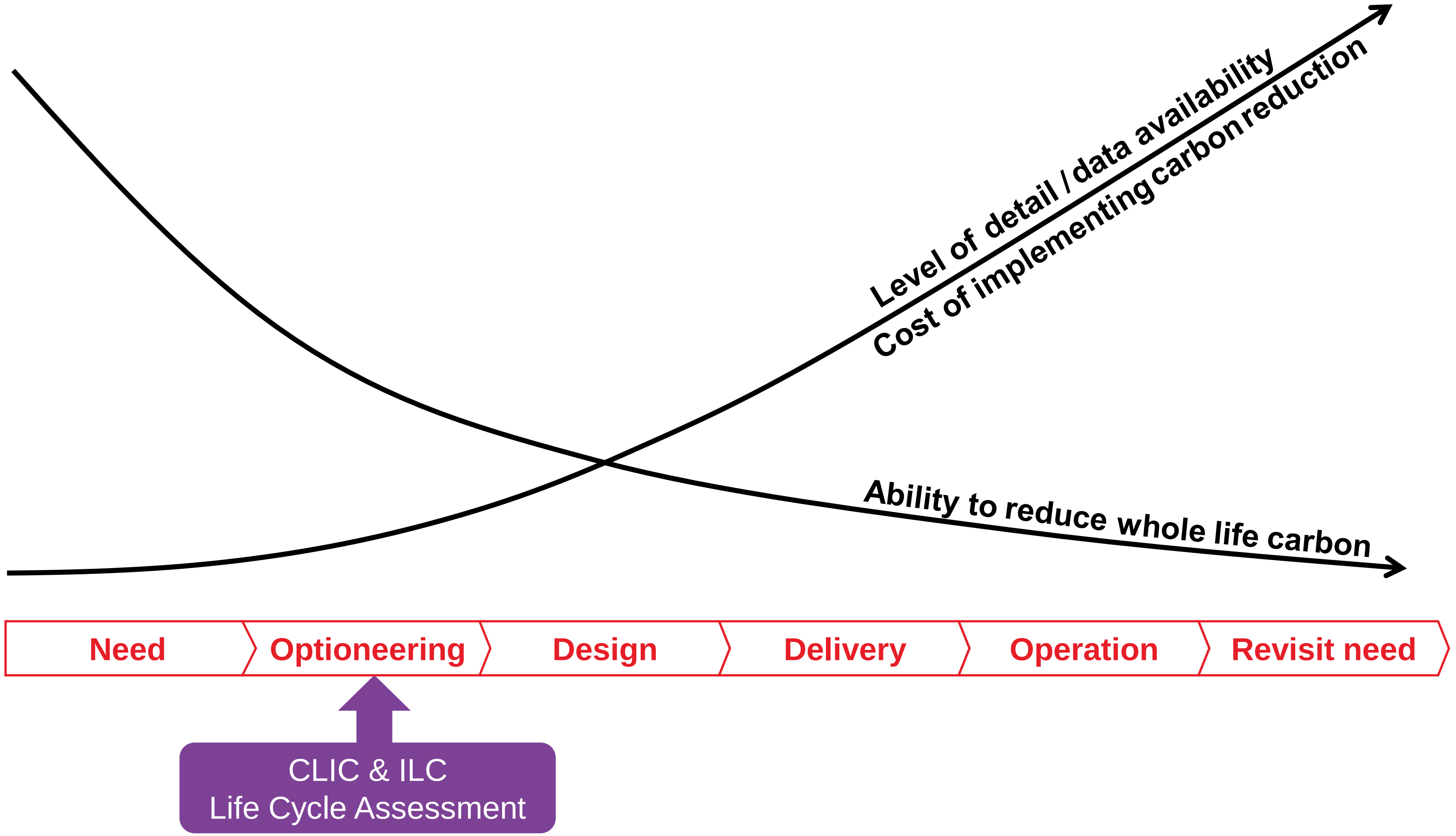

PAS2080:2023 Guidance Document (Adapted)

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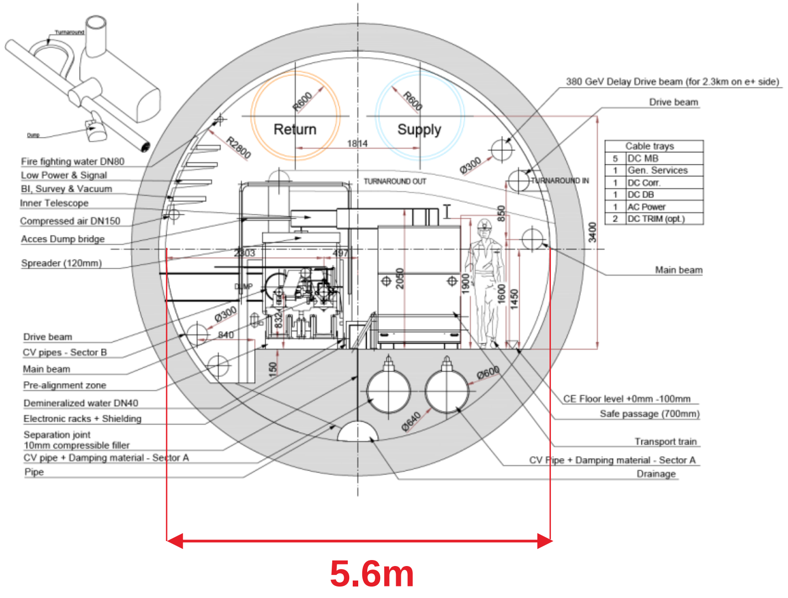
Linear Collider Options

1. CLIC Drive Beam

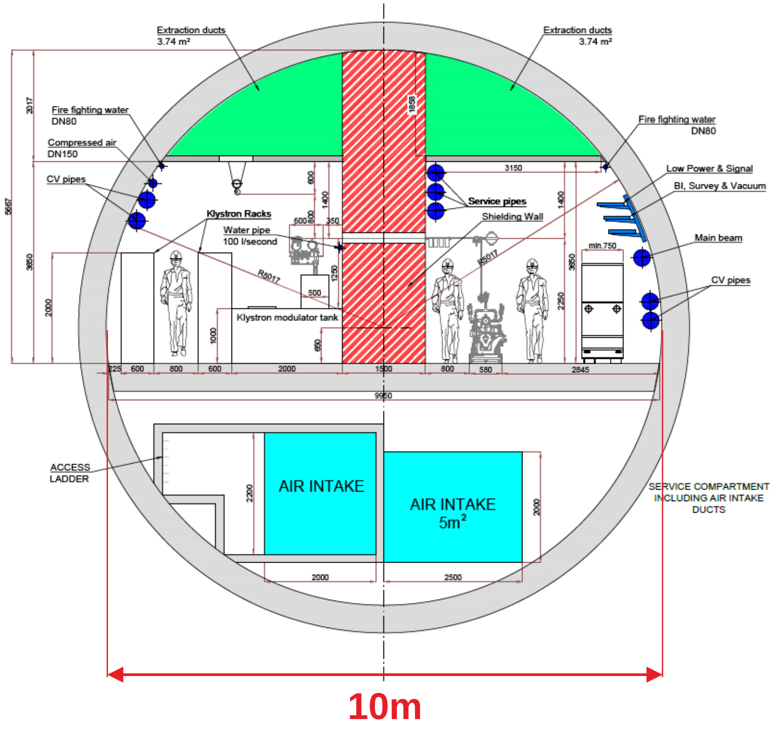
5.6m internal dia. Geneva.
(380GeV, 1.5TeV, 3TeV)



Reference: CLIC Drive Beam tunnel cross section, 2018

2. CLIC Klystron

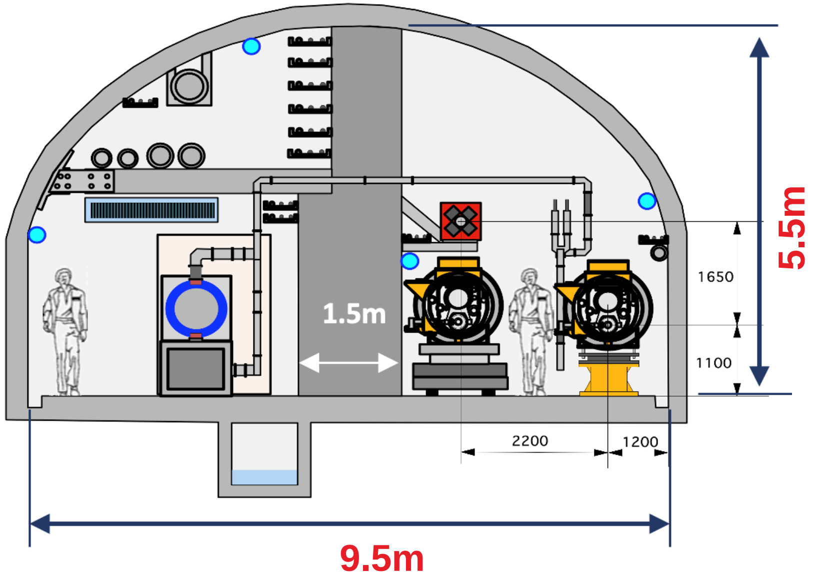
10m internal dia. Geneva.
(380GeV)



Reference: CLIC Klystron tunnel cross section, 2018

3. ILC

Arched 9.5m span. Japan.
(250GeV)



Reference: Tohoku ILC Civil Engineering Plan, 2020

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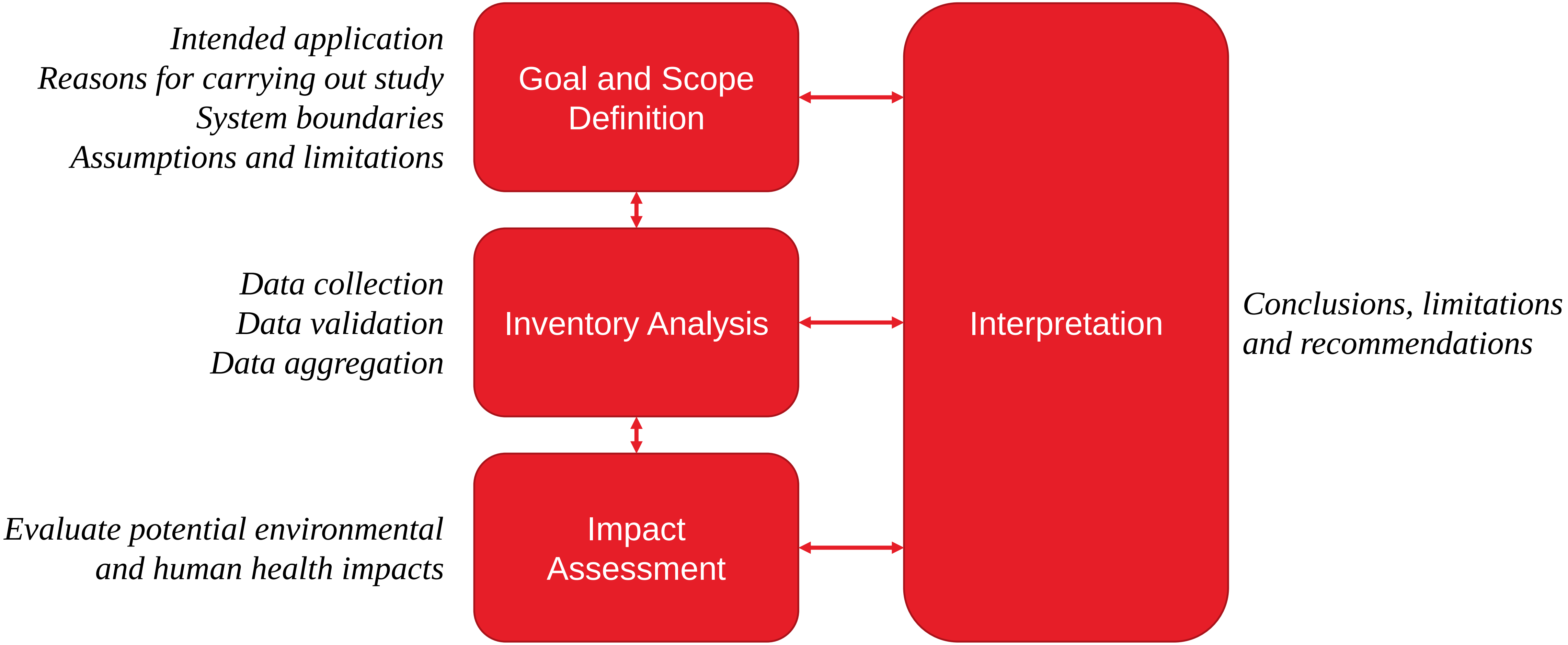
Life Cycle Assessment Framework



ISO 14040:2006

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Goal and Scope

- **Goal:** Evaluate the material and construction environmental impacts of the three proposed linear collider options, identifying hotspots and potential reduction opportunities.

- **Scope:** CLIC & ILC options (tunnels, caverns & access shafts).

- **Methodology:** Evaluates 18 environmental impact categories, including Global Warming Potential (GWP), using ReCiPe 2016 Midpoint (H) Method. LCA tool is Simapro with Ecoinvent database.

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System boundaries

Before use stage
[A0-A5]

- A0 Preliminary studies
- **A1** Raw material supply
- **A2** Transport
- **A3** Manufacture
- **A4** Transport to works site
- **A5** Construction process

Materials: A1–A3

Transport & construction activities: A4–A5

Use stage
[B1-B8]

- B1 Use
- B2 Maintenance
- B3 Repair
- B4 Replacement
- B5 Refurbishment
- B6 Operational Energy Use
- B7 Operational Water Use
- B8 User utilisation of infrastructure

End of life stage
[C1-C4]

- C1 Deconstruction/ Demolition
- C2 Transport for Disposal
- C3 Waste Processing for recovery
- C4 Disposal

Benefits and Loads beyond the system boundary
[D]

Reuse
Recycling

Benefits and loads of additional infrastructure functions

BS EN 17472:2022

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2030 Baseline assumptions

LCA Modules		CLIC Drive Beam	CLIC Klystron	ILC
A1-A3	Materials	Concrete (CEMI) & Steel (80% recycled)		
A4	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)
A5	Material wasted in construction	Concrete insitu: 5% Precast concrete: 1% Steel reinforcement: 5%		
A5	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.*		
A5	Construction process	Tunnel Boring Machine (TBM)		Drill & Blast
A5	Electricity mix 2021/2022	Fossil: 12% Non-fossil: 88%		Fossil: 71% Non-fossil: 29%

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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

A1-A5 Results

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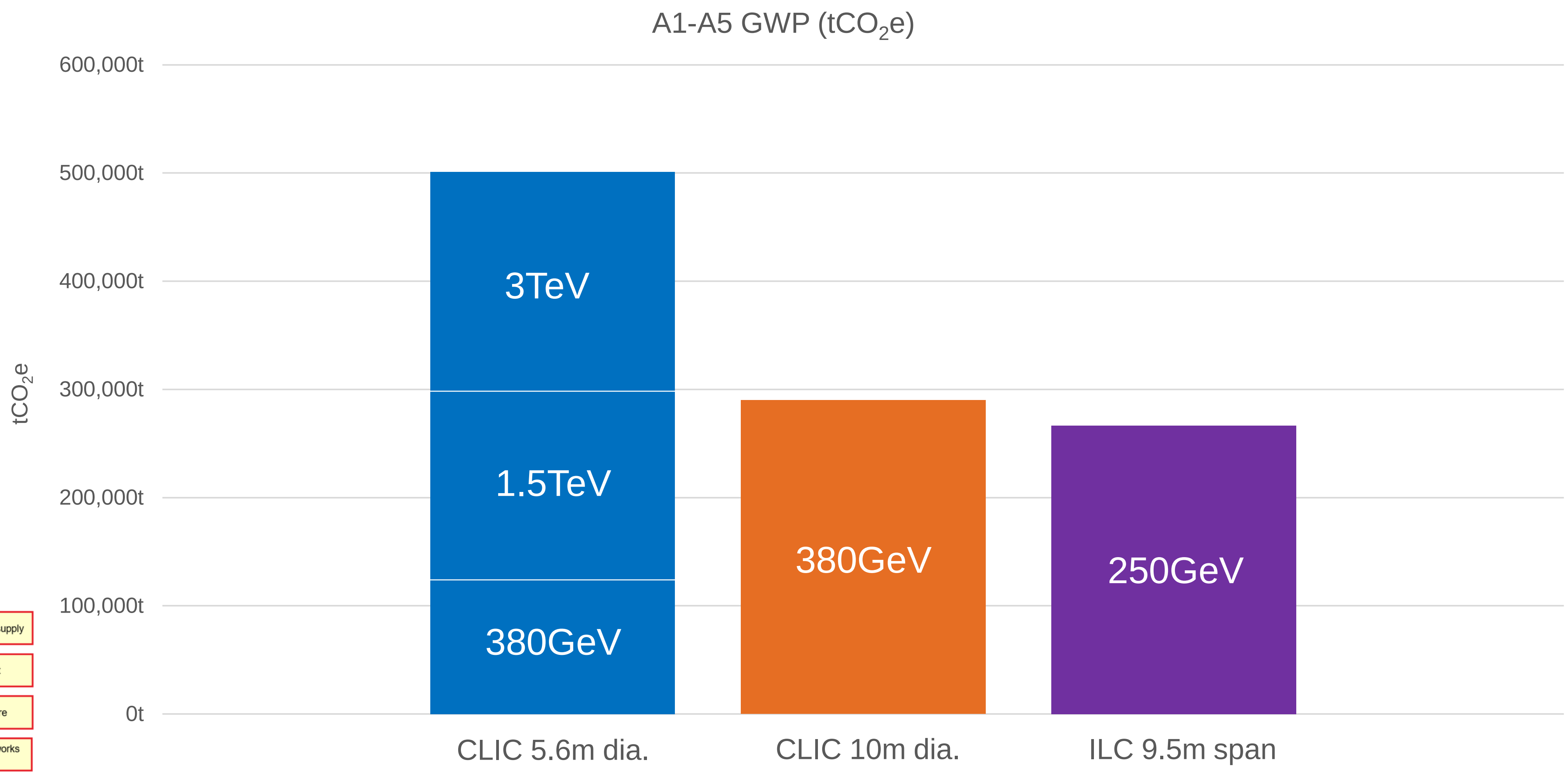
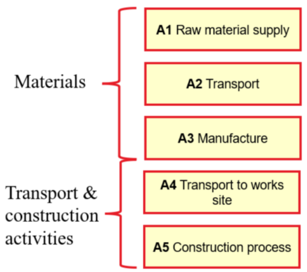
Global Warming Potential, GWP (tCO_2e)





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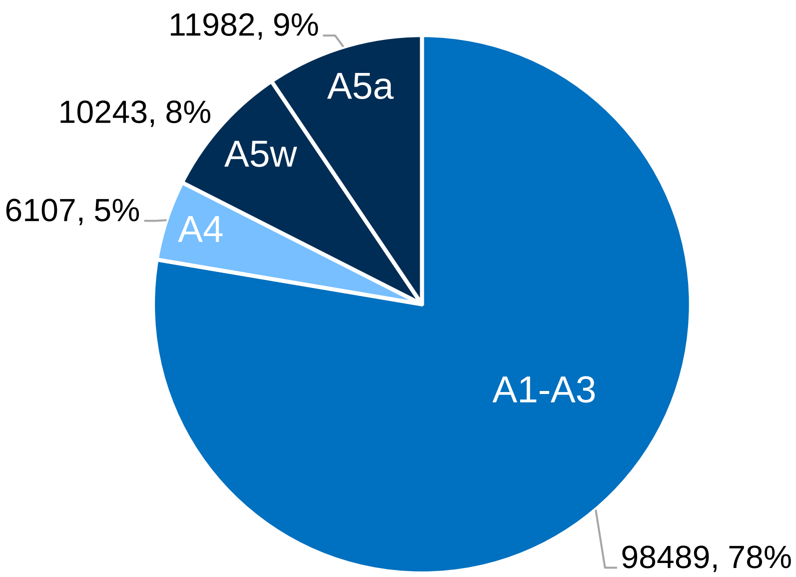
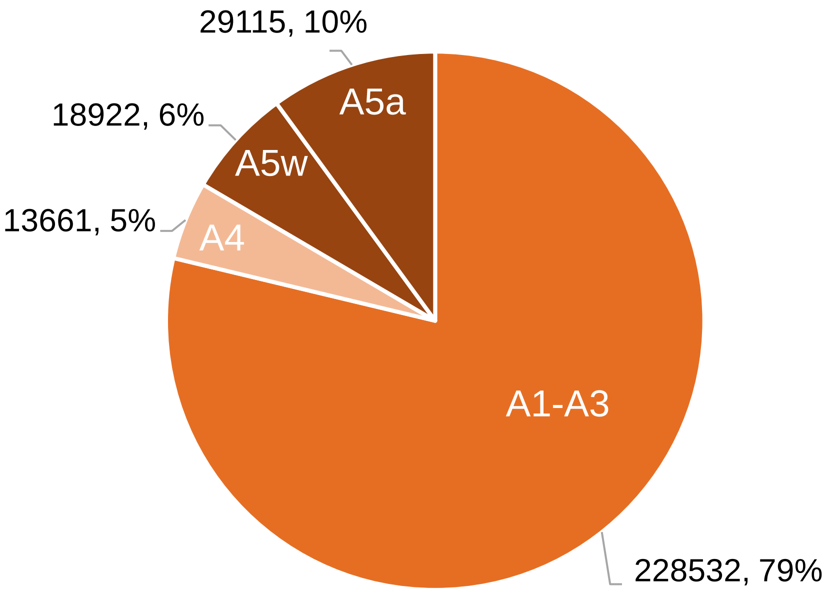
1. CLIC Drive Beam 380GeV
5.6m internal dia.
Geneva



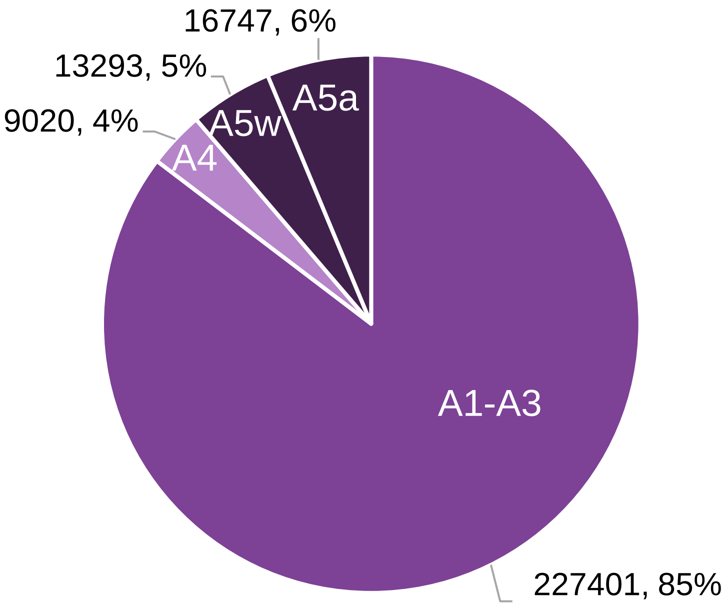
Total A1-A5 GWP: 127000 tCO_2e

2. CLIC Klystron 380GeV
10m internal dia.
Geneva



Total A1-A5 GWP: 290000 tCO_2e

3. ILC 250GeV
Arched 9.5m span
Japan



Total A1-A5 GWP: 266000 tCO_2e

*Total GWP results reported to 3 significant figures

Benchmarks

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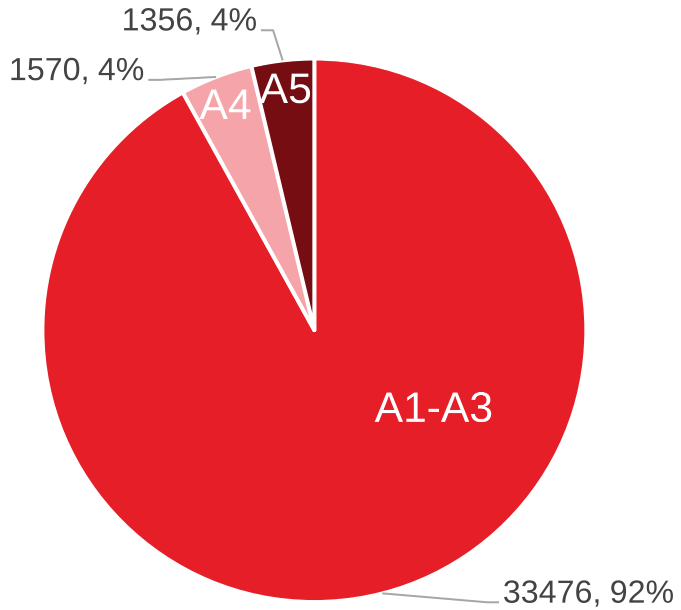
A1-A5 Global Warming Potential

Highway tunnel, UK
Concept stage

1.4km long, twin bore, 10.7m internal dia. TBM tunnel

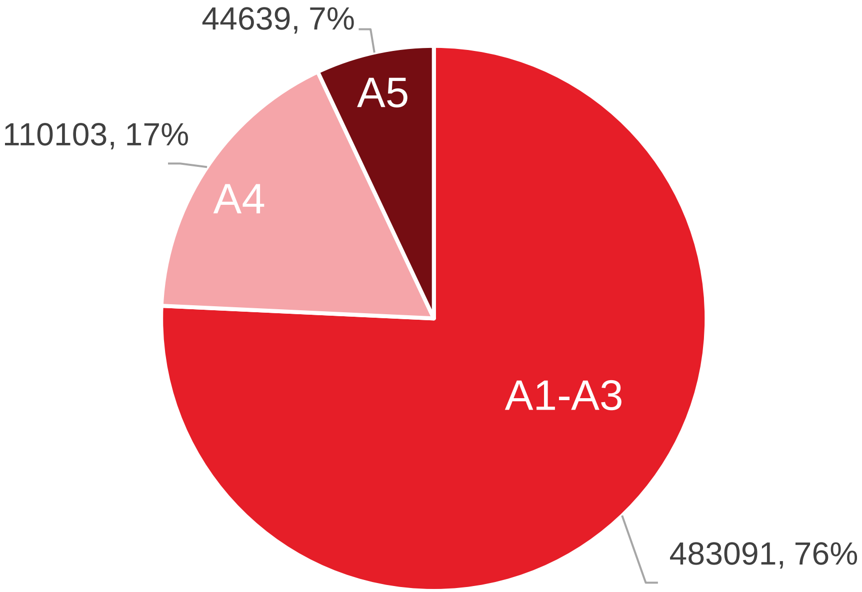


Total A1-A5 GWP: 36400 tCO_2e

Reference: Arup Highway tunnel carbon calculation internal study (2020)

Californian High-Speed Rail System
Proposed scheme

49km long, twin-bore, 9m internal dia. NATM tunnel

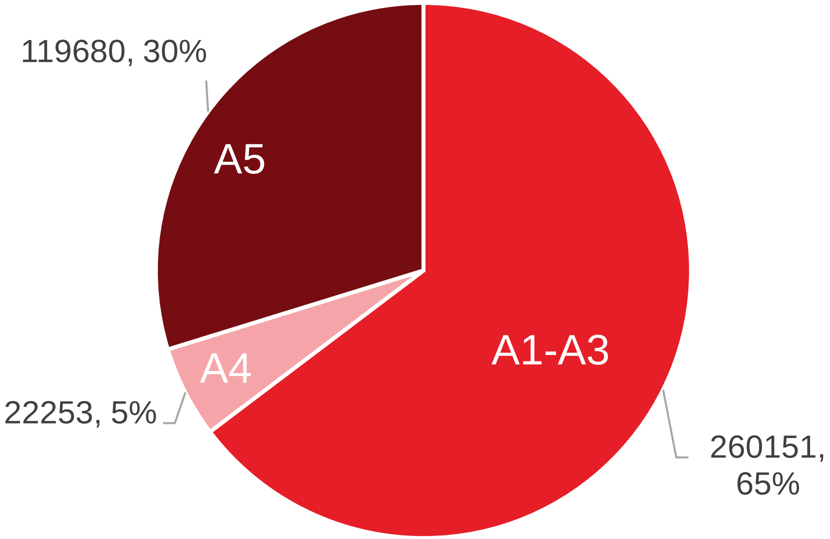


Total A1-A5 GWP: 213000 tCO_2

Note: Data is reported as CO_2 but is reasonable to compare against CO_2e.
Reference: Understanding the contribution of tunnels to the overall energy consumption of and carbon emissions from a railway J. A. Pritchard , J. Preston, Transportation Research Group, University of Southampton, (2018).

Crossrail, UK
As built

17km long, 5x twin-bore, 6.2m internal dia. TBM tunnel



Total A1-A5 GWP: 402000 tCO_2

Note: Data is reported as CO_2 but is reasonable to compare against CO_2e.
Reference:
Understanding the contribution of tunnels to the overall energy consumption of and carbon emissions from a railway J. A. Pritchard , J. Preston, Transportation Research Group, University of Southampton, (2018).

**Total GWP results reported to 3 significant figures*

CLIC & ILC

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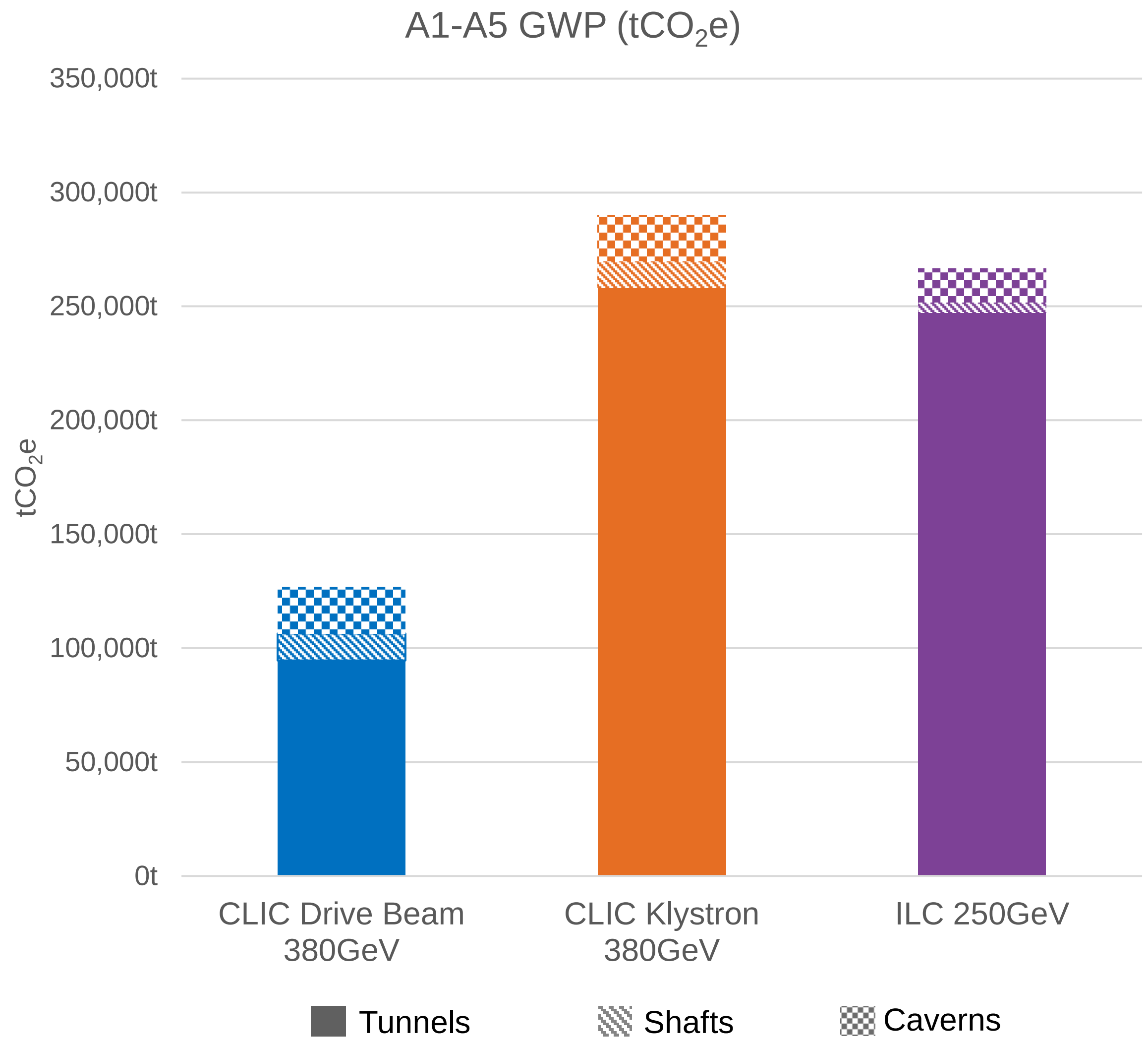
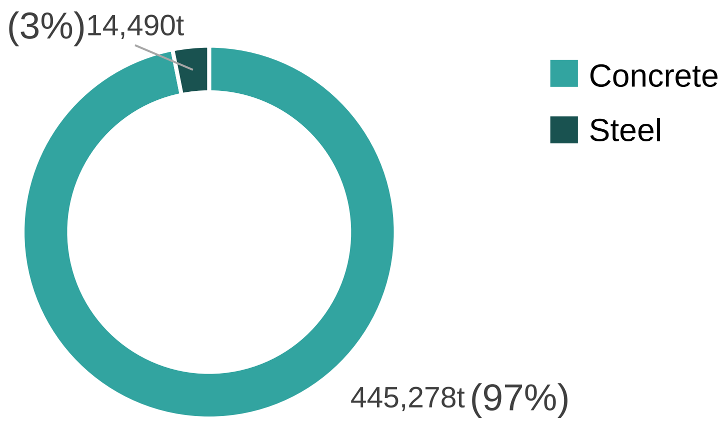
A1-A5 Global Warming Potential (tCO_2e)

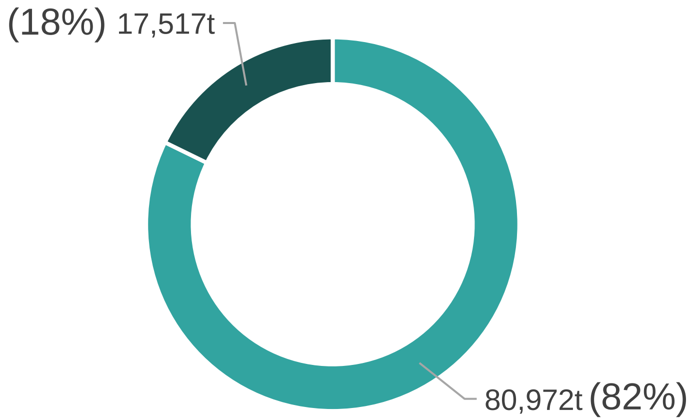


CLIC Drive Beam 380GeV

A1-A3 material breakdown (t)

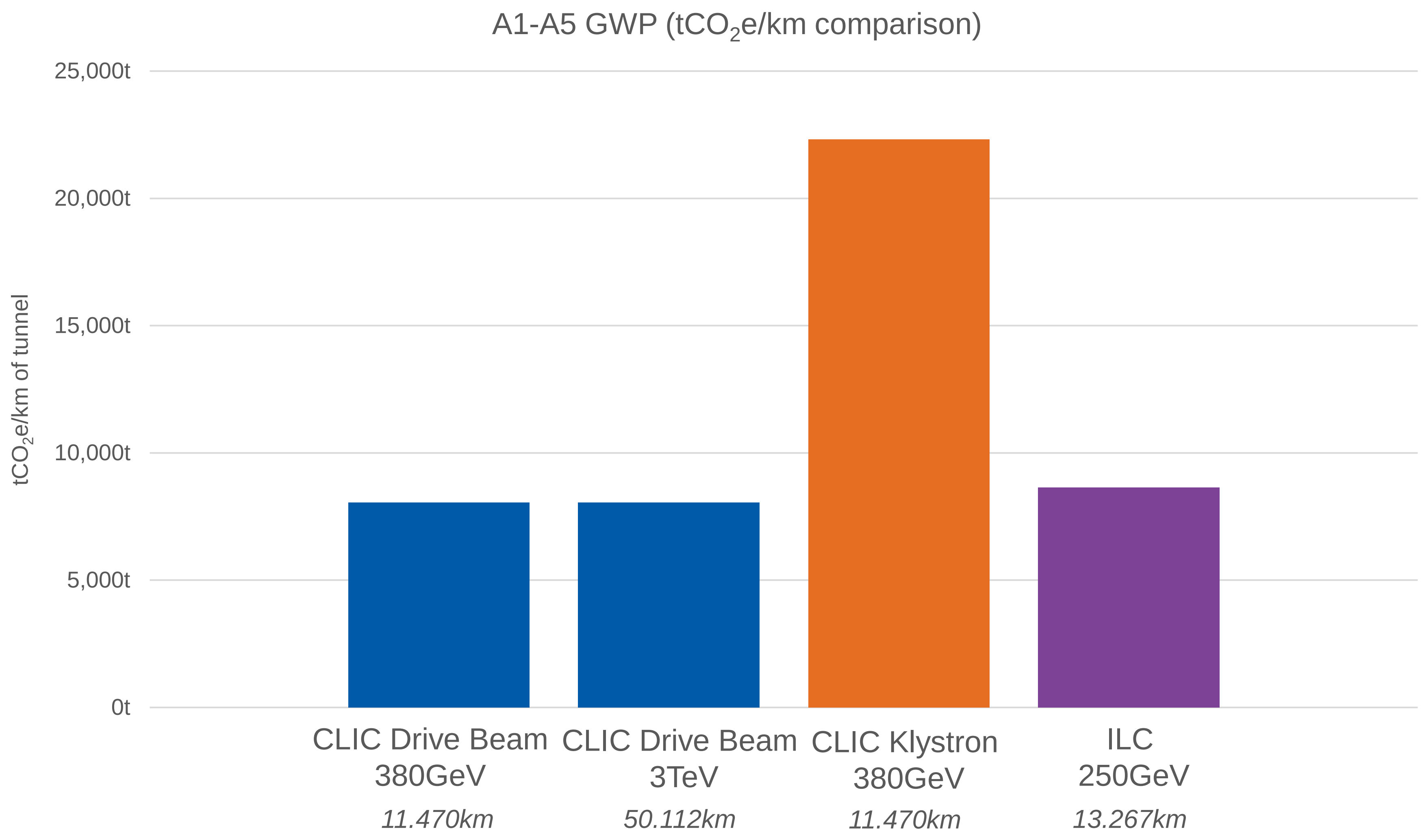


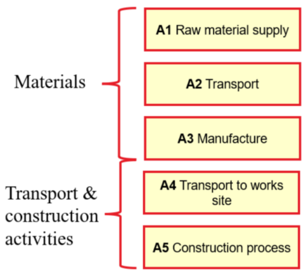
A1-A3 GWP breakdown (tCO_2e)



A1-A5 Results

Global Warming Potential, GWP (tCO_2e)





Main accelerator tunnel

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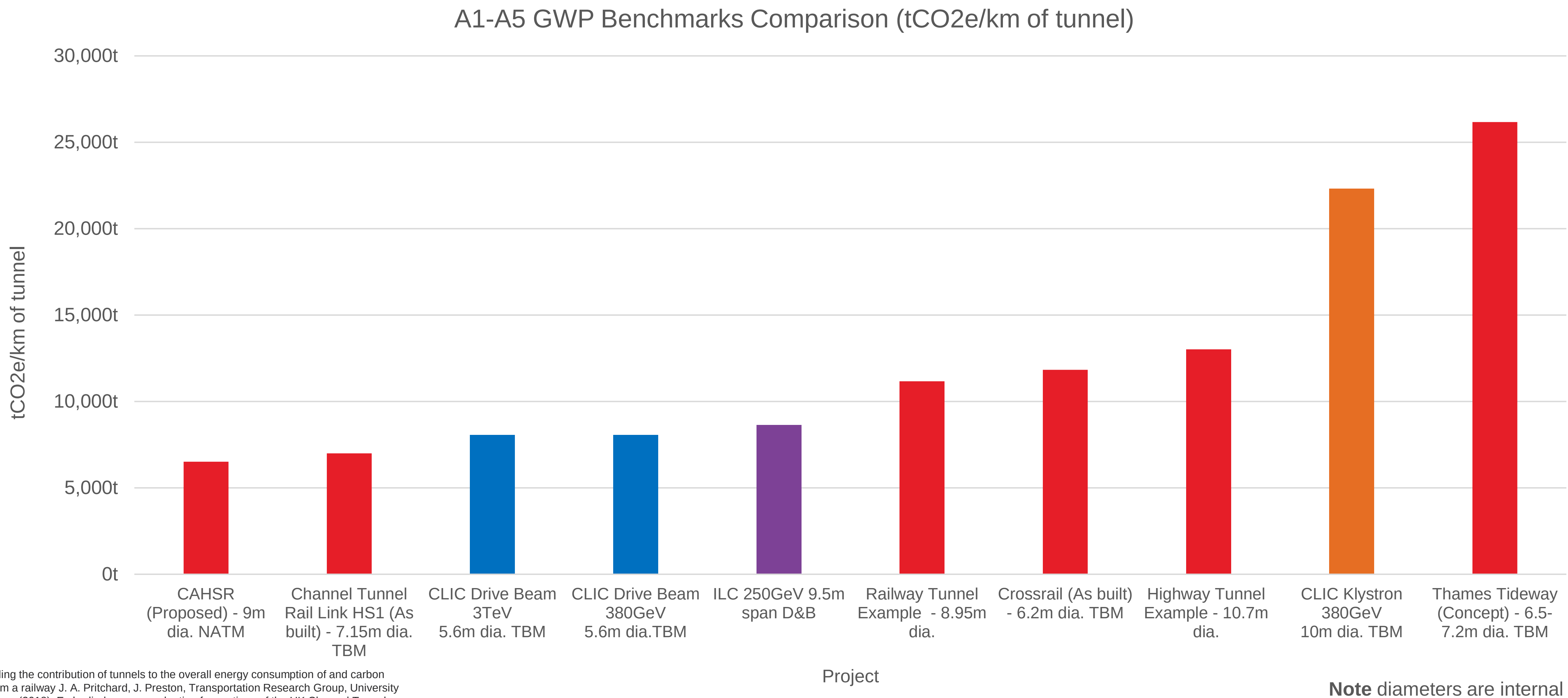
A1-A5 Global Warming Potential (tCO_2e/km)

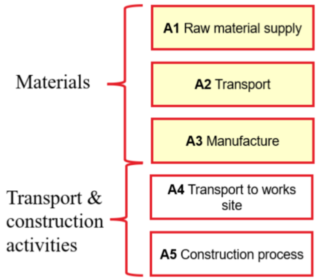


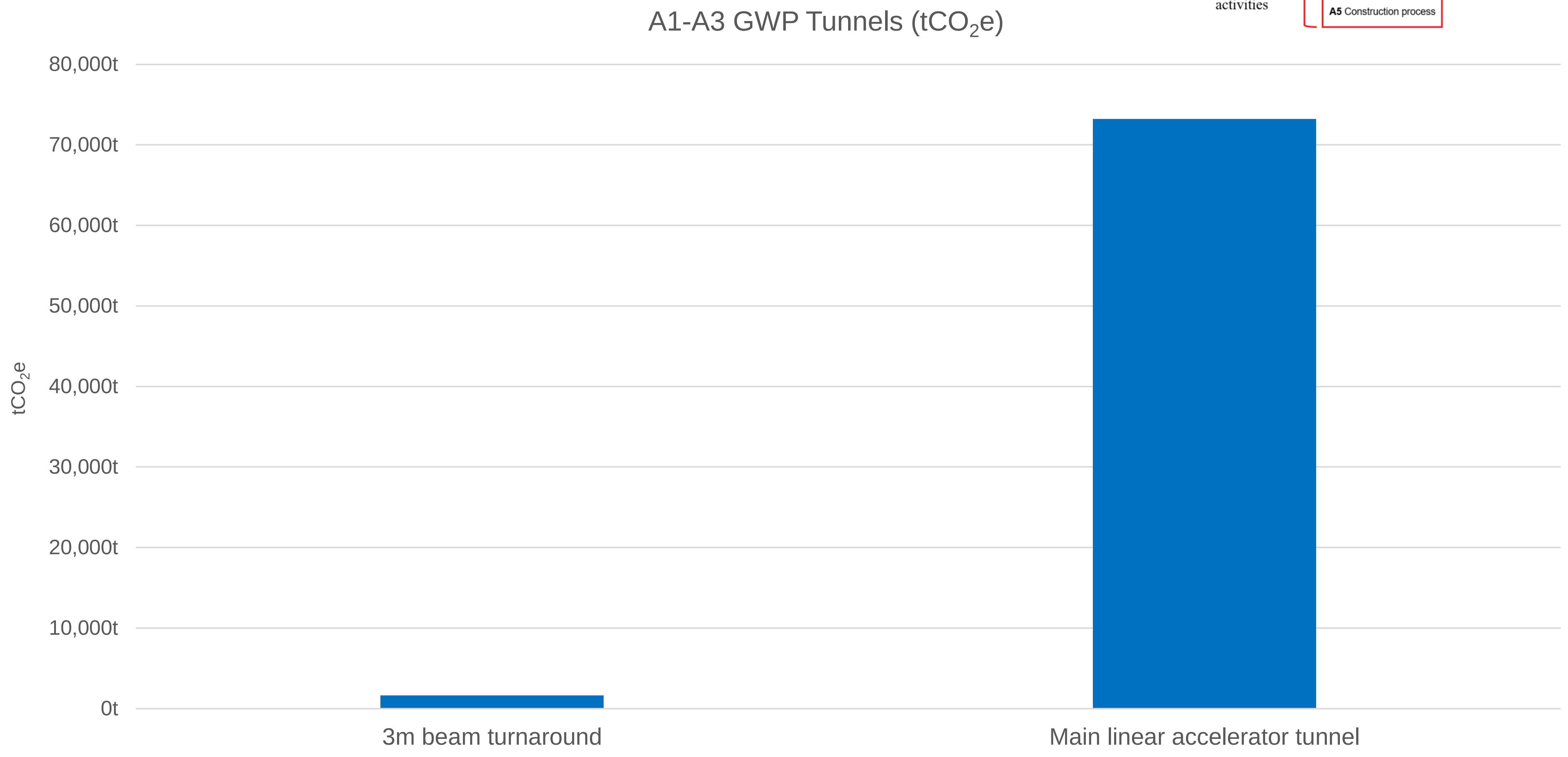
Note diameters are internal

1 Understanding the contribution of tunnels to the overall energy consumption of and carbon emissions from a railway J. A. Pritchard, J. Preston, Transportation Research Group, University of Southampton, (2018). Embodied energy evaluation for sections of the UK Channel Tunnel Rail link, Geotechnical Engineering, vol.165 Chau, Soga, O'Riordan and Nicholson (2011).
2 Arup Railway Tunnel Carbon Calculation internal study, (2022).
3 Thames Tideway Tunnel, Thames Water Utilities Limited, Application for Development Consent, Energy and Carbon Footprint Report, (2013).

CLIC Drive Beam 380GeV

A1-A3 Global Warming Potential (tCO_2e)





CLIC Drive Beam 380GeV

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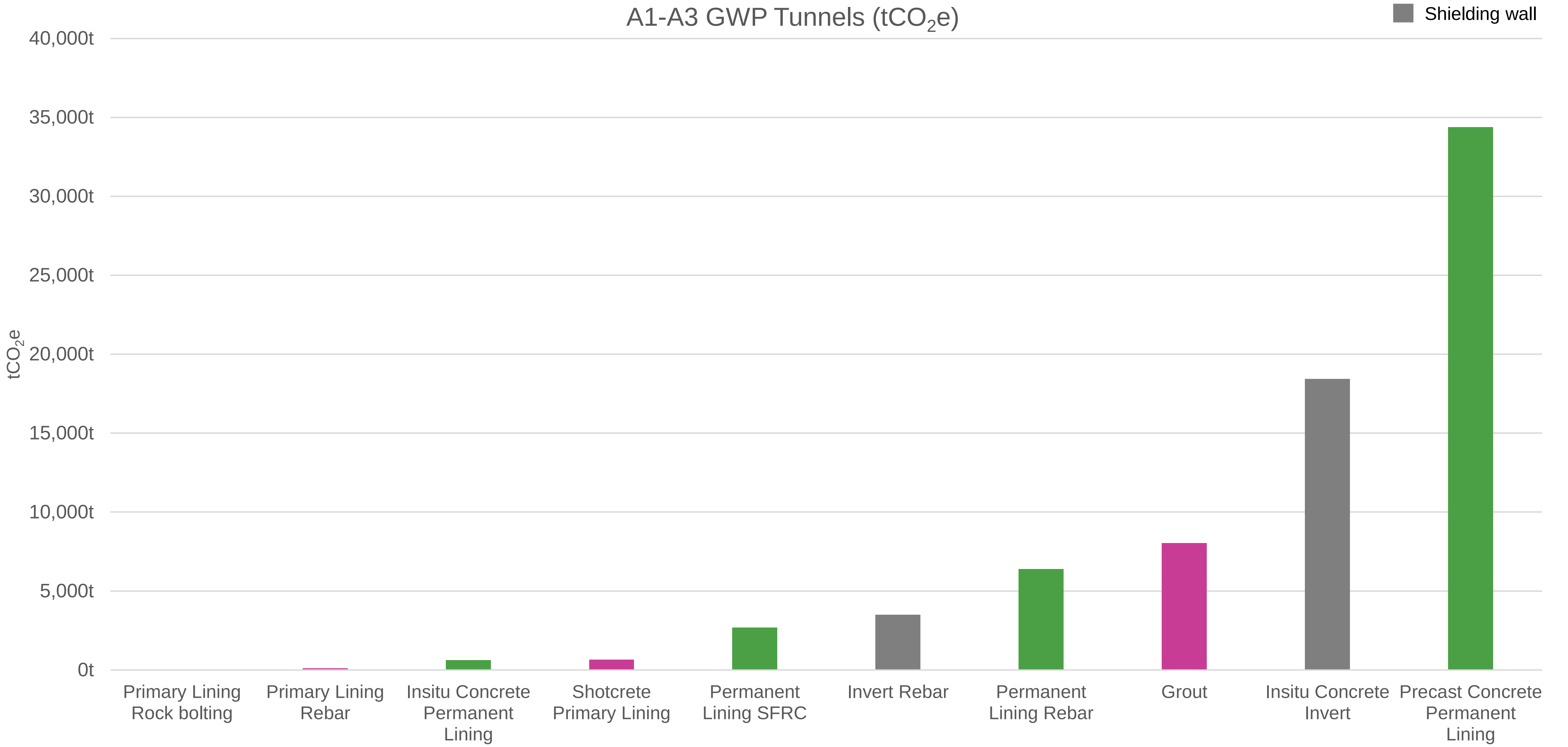
A1-A3 Global Warming Potential (tCO_2e)



ILC 250GeV

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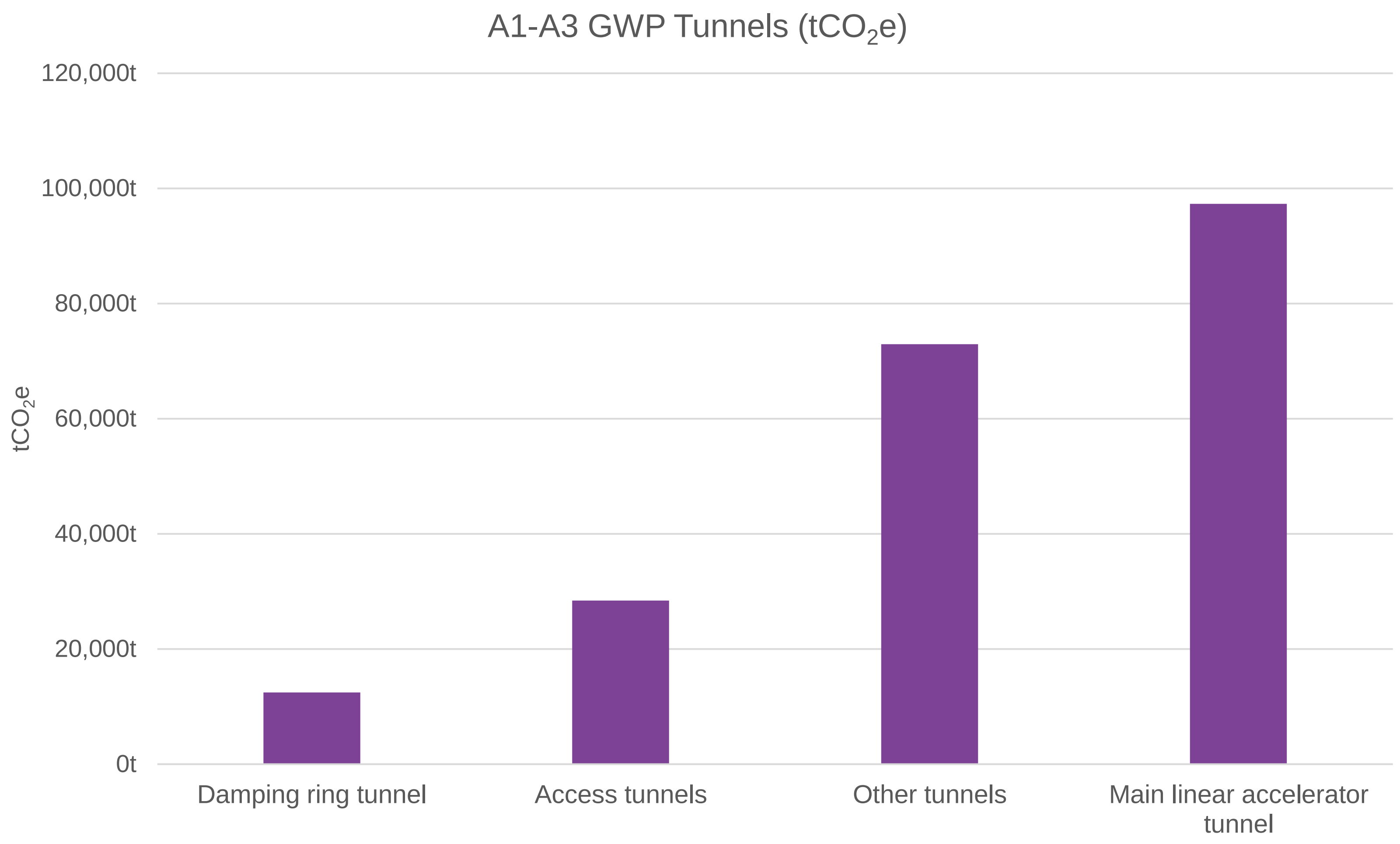
A1-A3 Global Warming Potential (tCO_2e)

Tunnels are inclusive of (total length: 33,042m)

Main accelerator tunnel
Damping ring tunnel

Access tunnels:
- Access tunnel CI
- Access tunnel CII
- Access tunnel DI
- Access tunnel DIII
- Access tunnel DI (EPZ)
- Access tunnel CII (EPZ)

Other tunnels:
- BDS beam tunnel Section A w9.5m
- BDS beam tunnel Section B w13m
- BDS beam tunnel Section C w17m
- BDS beam tunnel Section D w25m
- Loop sections at both ends
- Widening sections
- Reversal pits
- Peripheral tunnel 3.0m
- Peripheral tunnel 4.0m
- Peripheral tunnel 6.0m
- Peripheral tunnel 8.0m
- AT-DH and AT-DR tunnels
- RTML tunnels



ILC 250GeV

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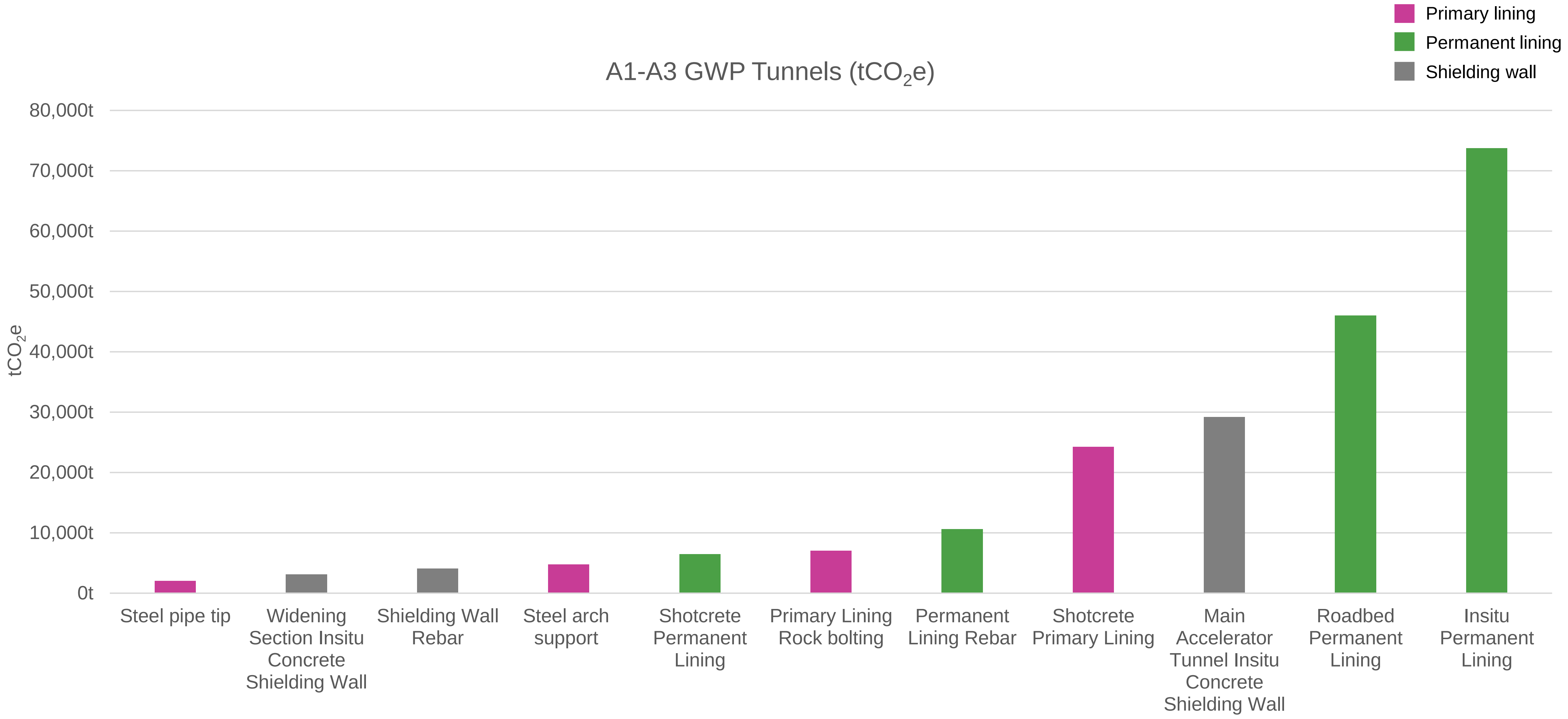
A1-A3 Global Warming Potential (tCO_2e)



CLIC Drive Beam 380GeV

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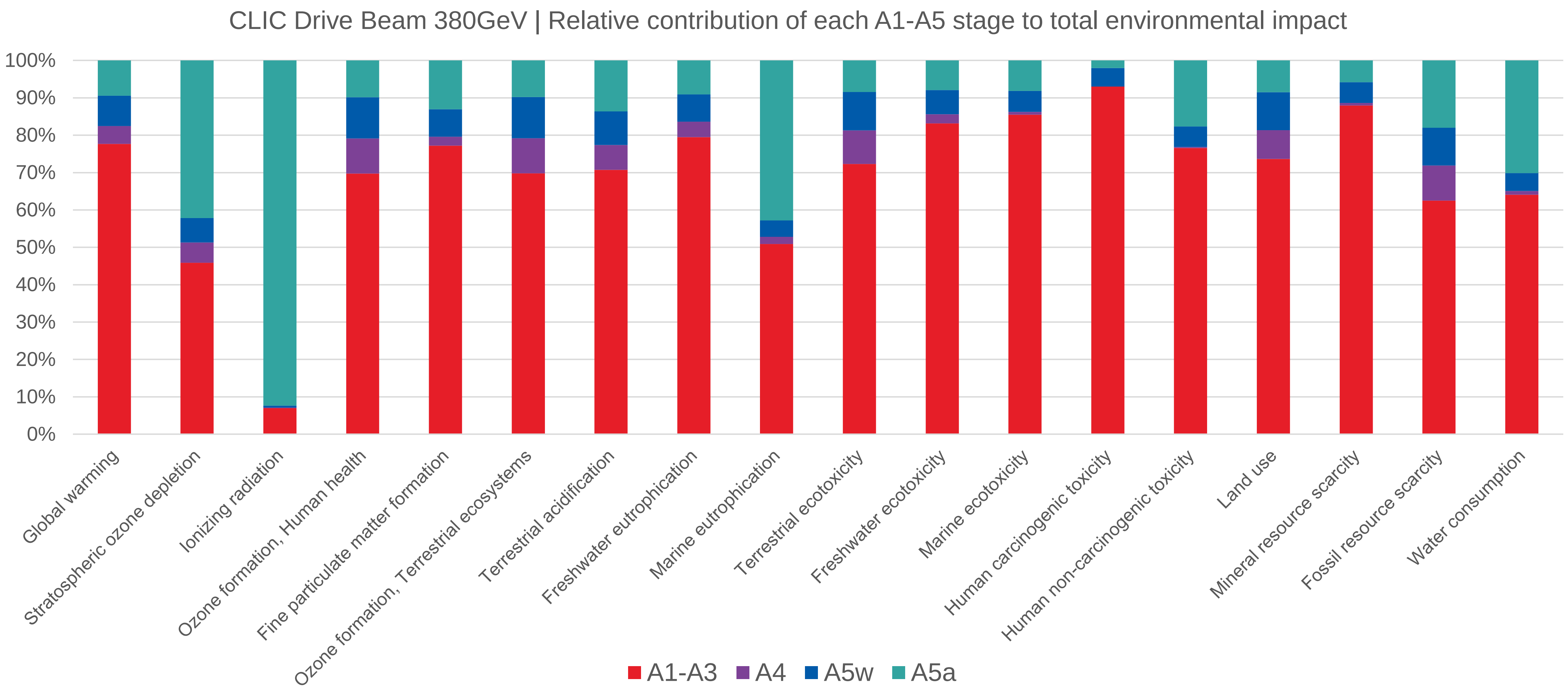
A1-A5 ReCiPe 2016 Midpoint (H) Impact Categories



ILC 250GeV

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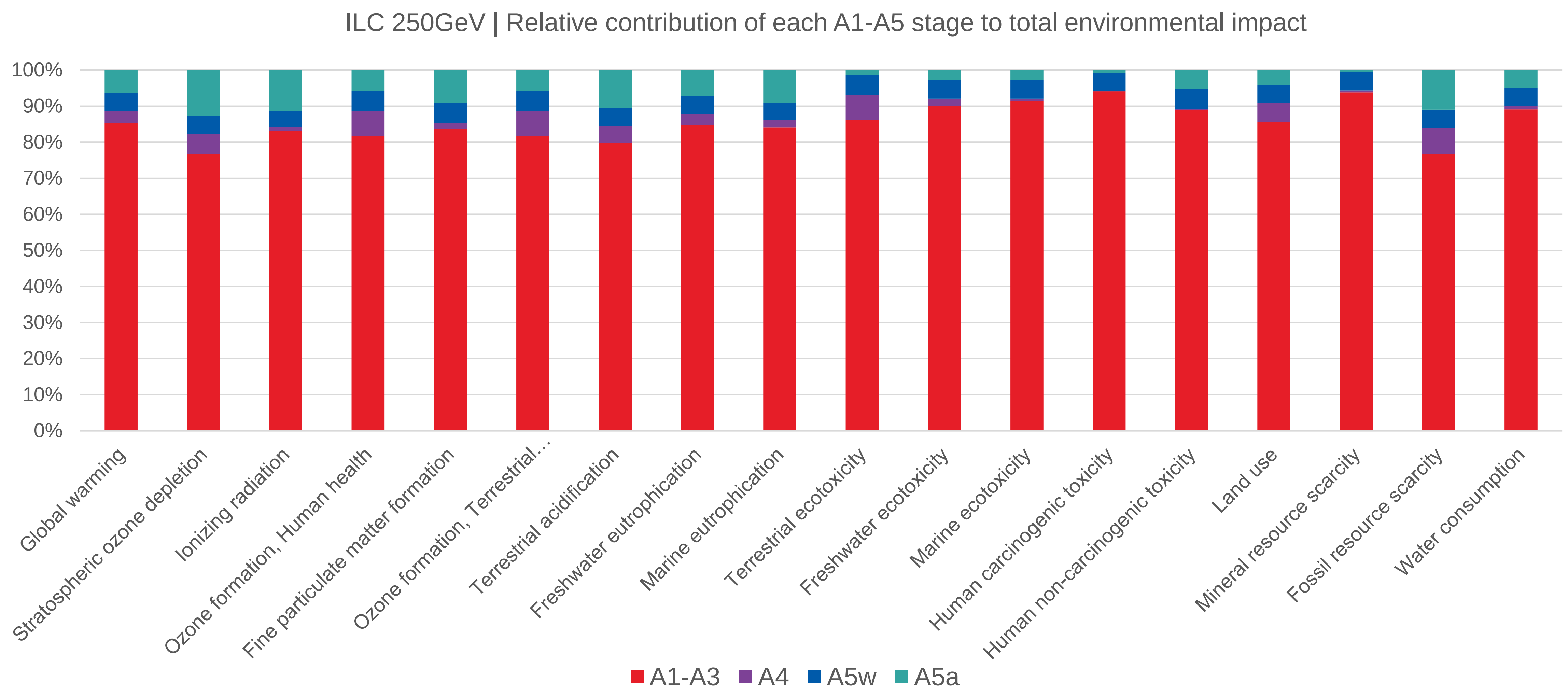
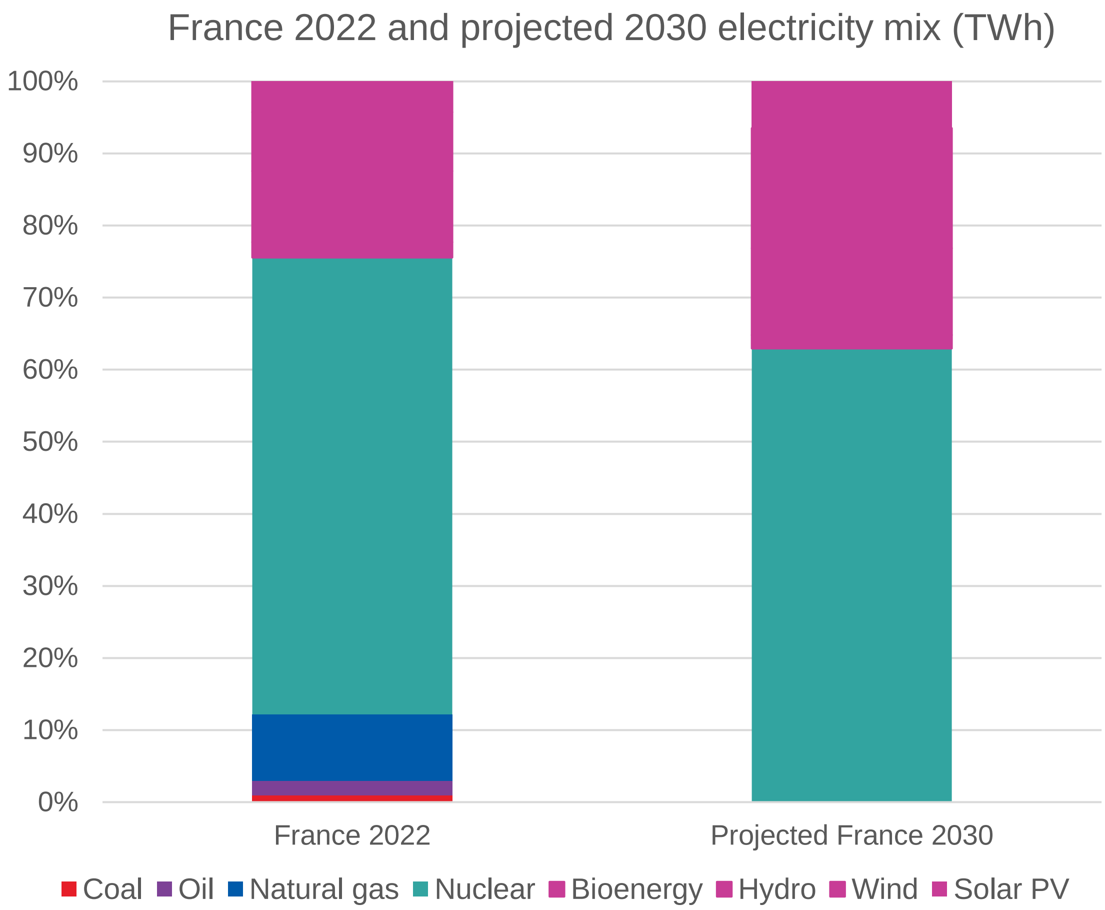
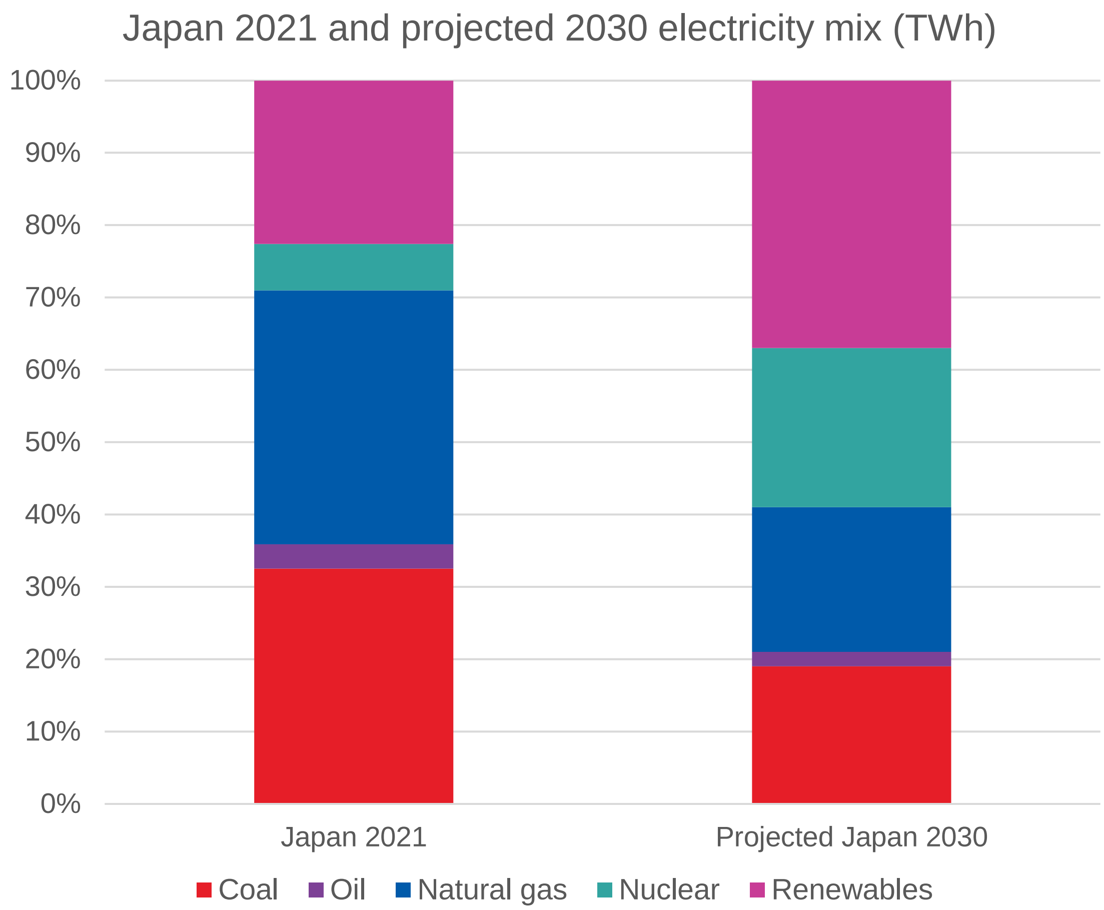
A1-A5 ReCiPe 2016 Midpoint (H) Impact Categories



Baseline and projected electricity mix

CLIC & ILC





Reference: Our World in Data, France 2022

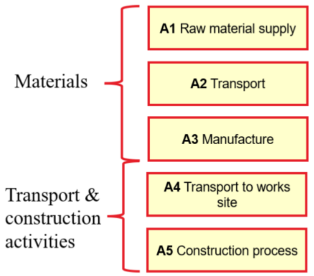
Reference: Energy pathways 2050 key results, RTE 2021

Reference: Our World in Data, Japan 2021

Reference: 6th Strategy Energy Plan, METI 2021

CLIC Drive Beam 380GeV

Tunnels reduction opportunities



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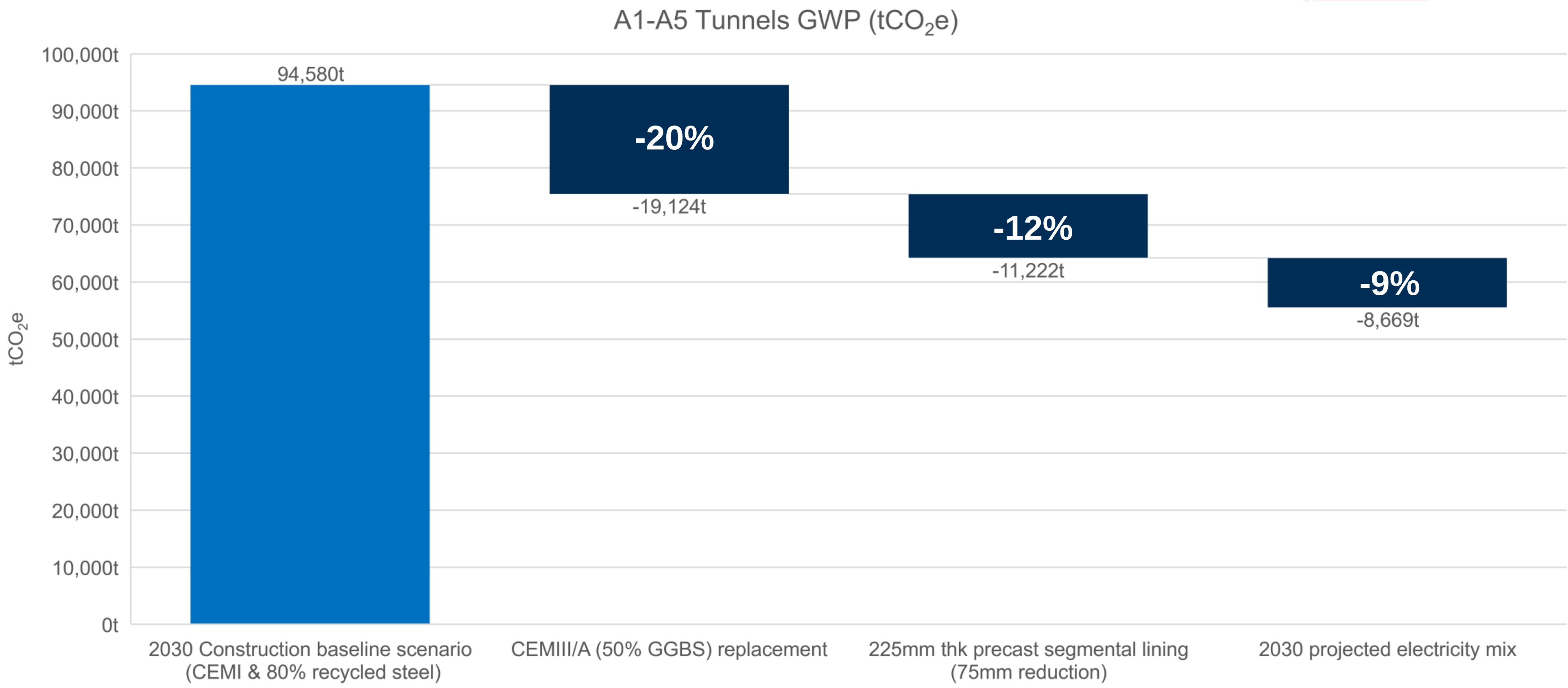
41% possible A1-A5 GWP reduction



ILC 250GeV

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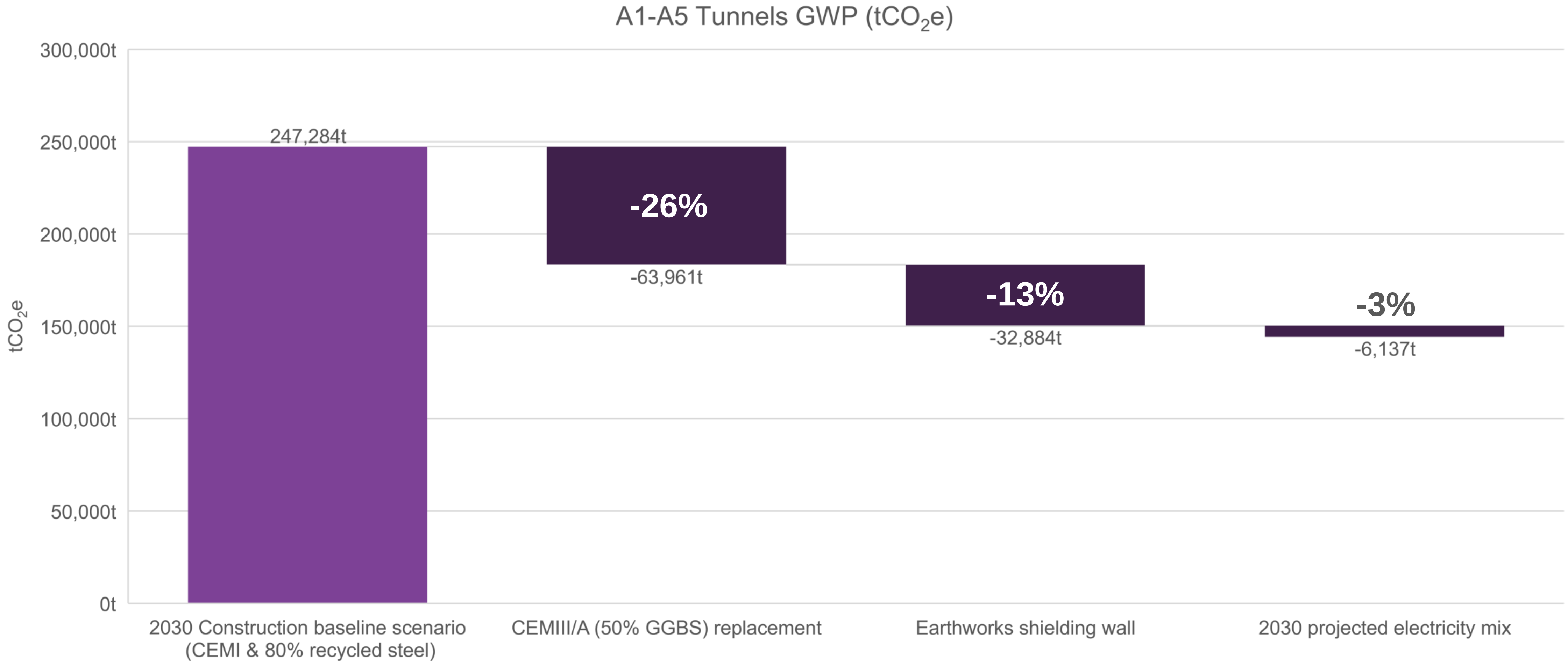
Tunnels reduction opportunities

42% possible A1-A5 GWP reduction



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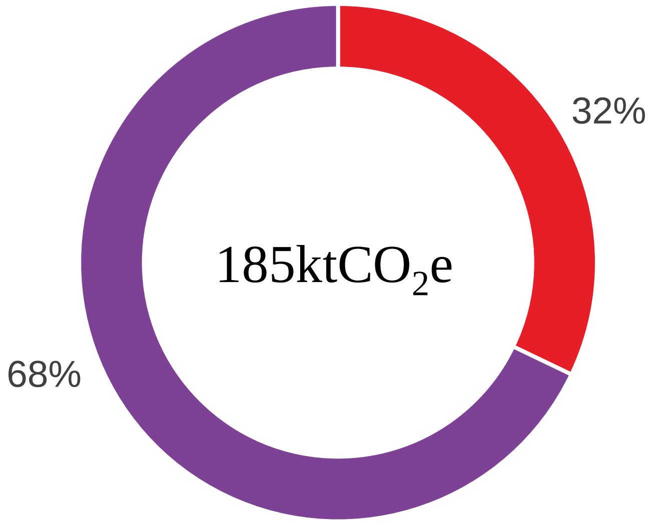
CLIC Drive Beam

A1-A5 Global Warming Potential (tCO_2e)

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

380GeV

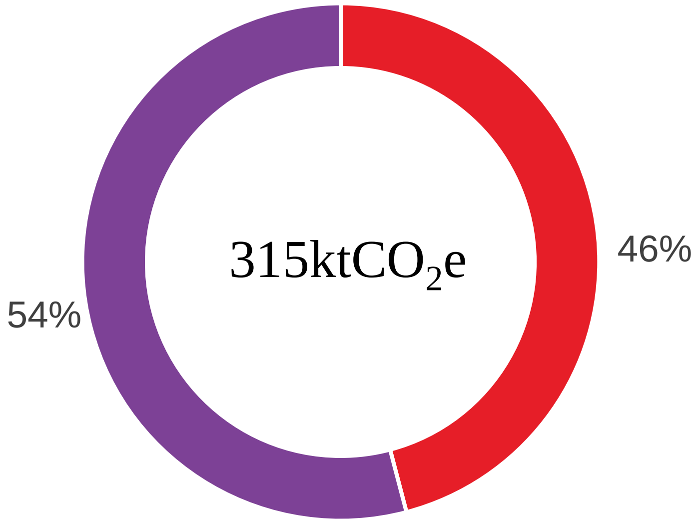
Annual CO_2e of operations is 6% of embodied carbon
A1-A5 GWP is equivalent to 1.7 decades of running accelerator



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

1.5TeV

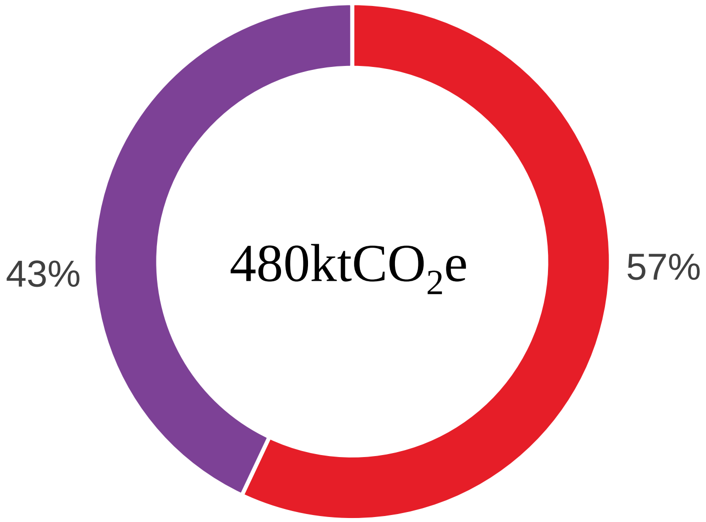
Annual CO_2e of operations is 12% of embodied carbon
A1-A5 GWP is equivalent to 0.8 decades of running accelerator



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

3TeV

Annual CO_2e of operations is 17% of embodied carbon
A1-A5 GWP is equivalent to 0.6 decades of running accelerator



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

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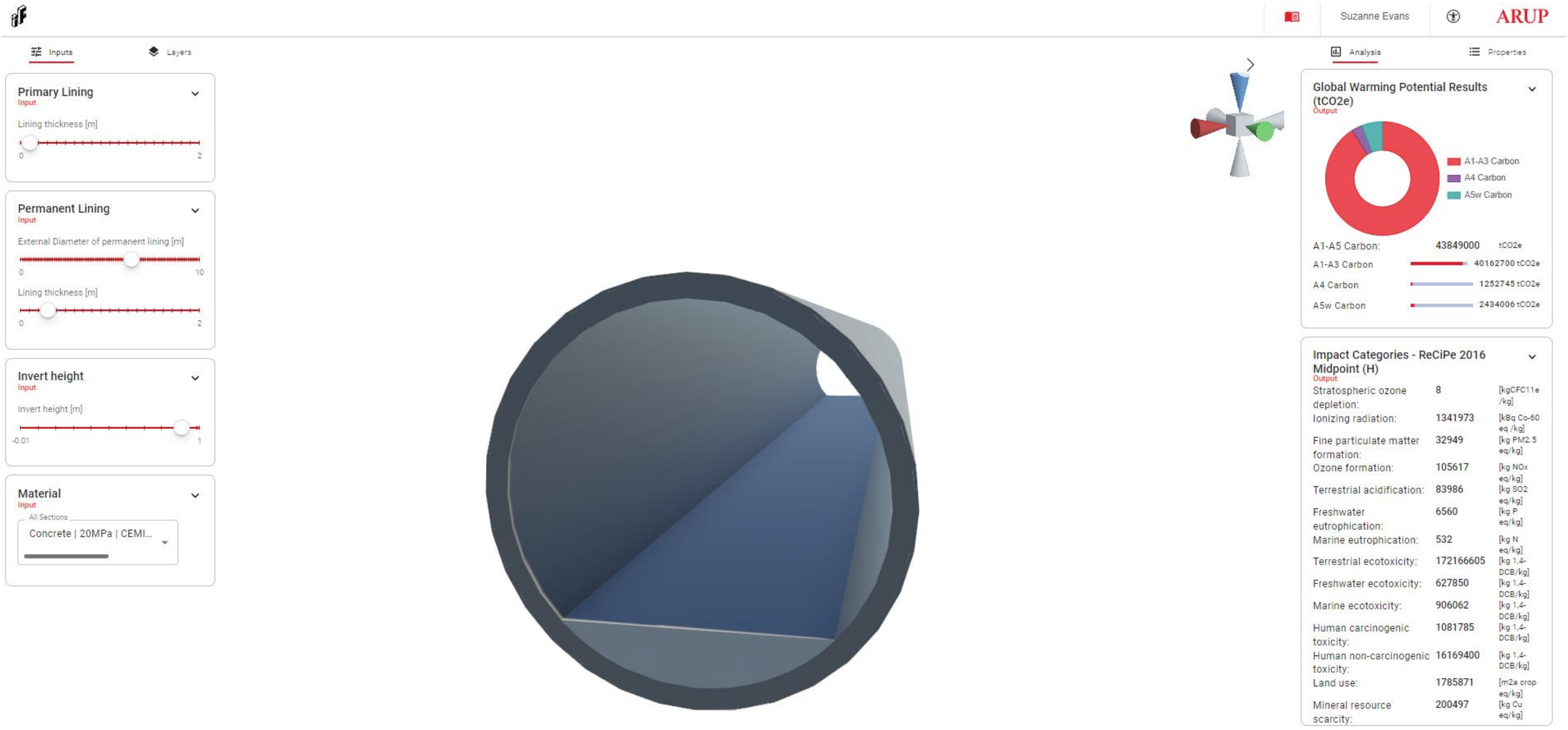
Parametric Visualisation

In development



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Summary of LCA

- Evaluates the environmental impact of CLIC and ILC for the first time
- Establishes a baseline quantification with hotspots and reduction opportunities identified
- Provides a stepping stone for optimising design based on GWP impact

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Key Takeaways

- **A1-A5 Global Warming Potential results:**
  - ~125-500 ktCO2e for CLIC Drive Beam 380GeV-3TeV
  - ~290 ktCO2e for CLIC Klystron 380GeV
  - ~270 ktCO2e for ILC 250GeV
- **A1-A3:** Key drivers are concrete and steel, driven by the scale of the proposed schemes.
- **A4-A5:** Use local manufacturers to reduce transport distances. Energy transition has less of a significance on construction GWP compared to A1-A3 possible reductions and optimisations.
- GWP is one indicator, but the impact of other environmental indicators and reduction opportunities should be recognised

Future Consider-ations

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- Challenge the community to target ambitious aims to drive down the environmental impact and carbon footprint.
- **Technical:** With the baseline established, design optimisation based on GWP and other impact categories can be made based on biggest impact; identify achievable technological advances; consideration of non-CE materials and equipment e.g. services, cooling.
- **Socio-economic:** Consideration of whole life impacts is important to provide the full picture, from construction to end of life. Consideration of the cost impact of carbon.
- **Governance:** Procurement for low carbon. Update the LCA to keep relevant with the expected changing net-zero aligned policies, legislations and governance that will drive standards.

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