ARUP

Linear Colliders | CLIC & ILC LCA

Phase 2: Progress meeting

9th September 2024

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Agenda

- Programme check-in
- Construction LCA results
  - Injector complex - Underground
  - Tunnel service systems
  - Surface buildings
- Machine LCA preliminary results
- Niobium modelling
- AOB

Programme

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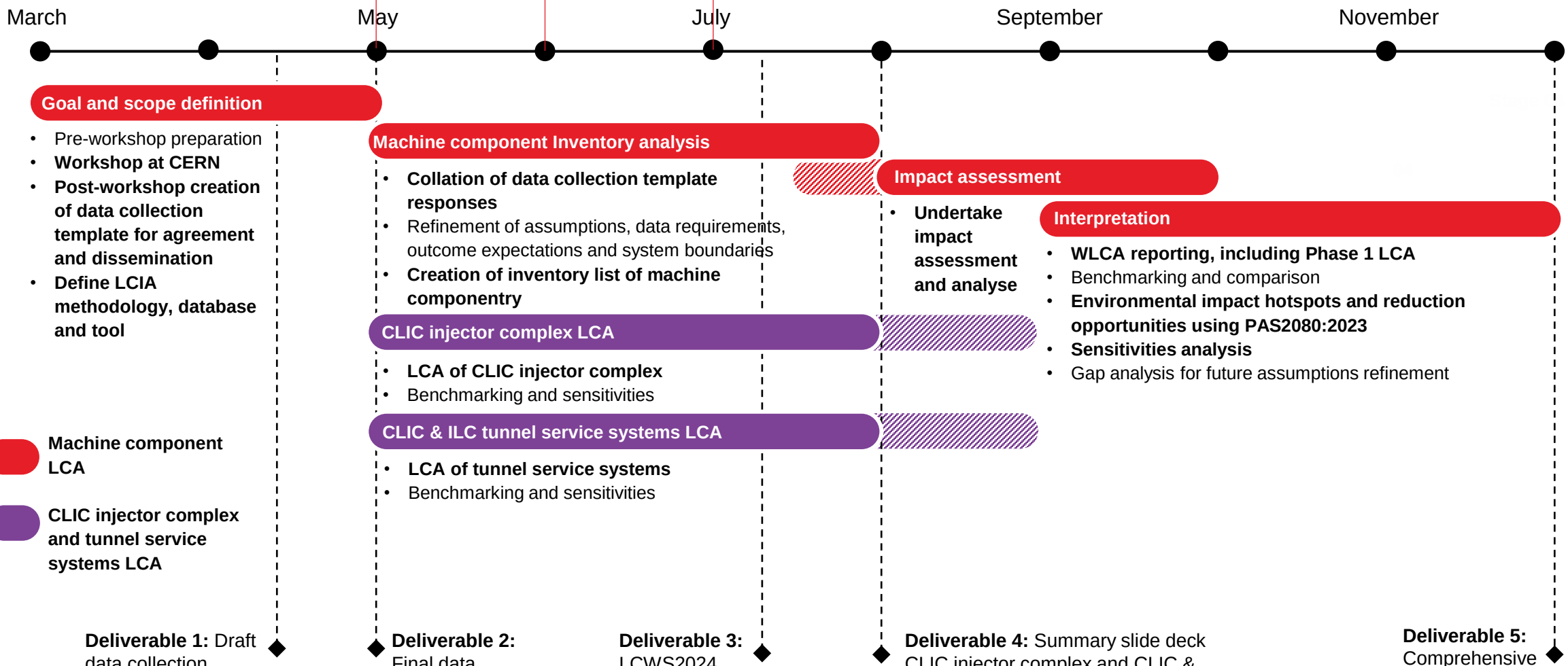
Receivable 1: Tunnel service systems information

Receivable 2: Detector high-level material quantities

Receivable 3: Draft machine inventory analysis

Receivable 4: Final machine inventory analysis

Note: *Regular progress meetings are expected, especially during inventory analysis phase.*



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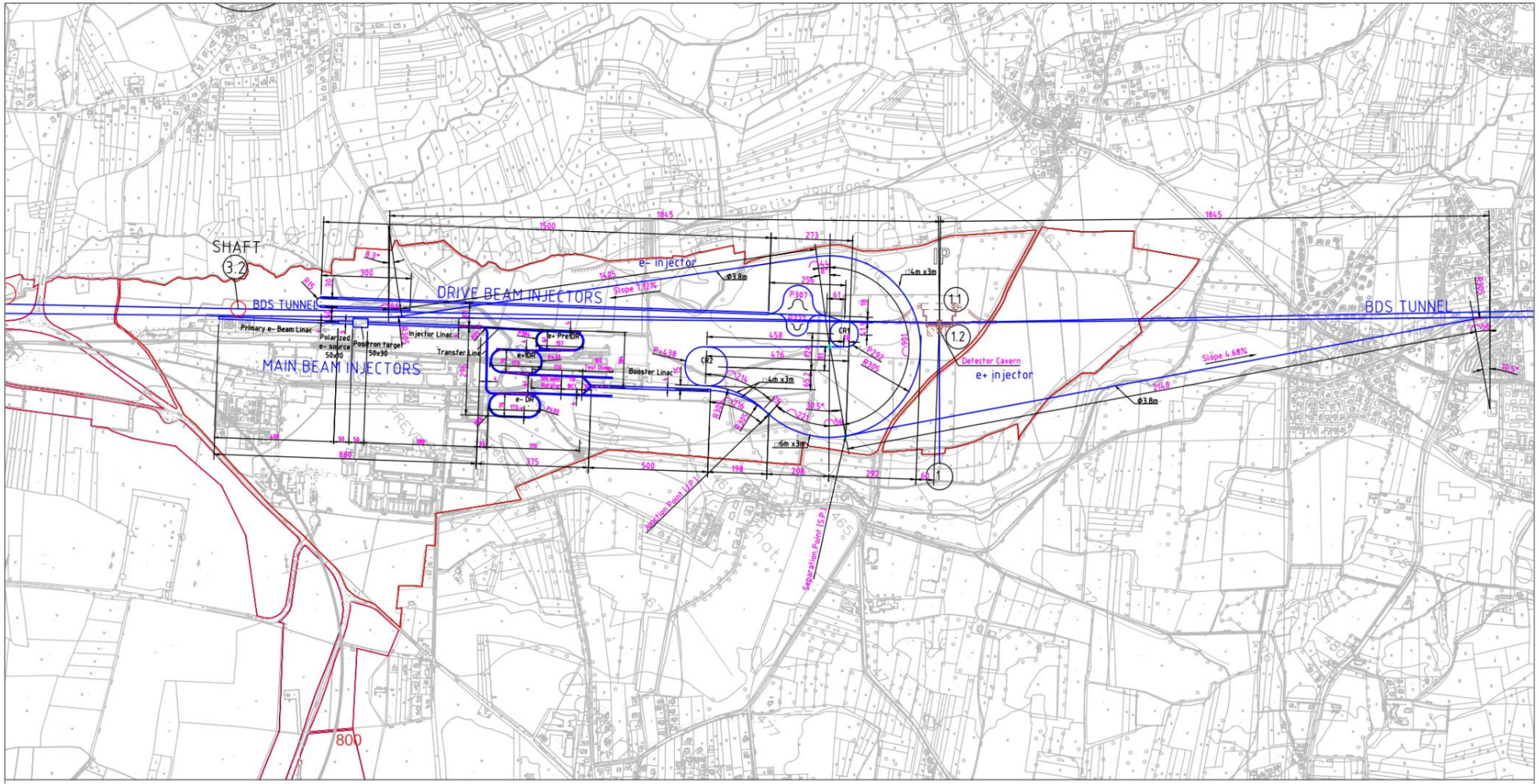
Construction LCA results



INJECTORS TUNNELS	DRIVE BEAM INJECTORS COMPLEX							MAIN BEAM INJECTORS COMPLEX									COMMON TRANSFER TUNNEL	FINAL TRANSFER TUNNELS ((From Separation Point)		
	LINAC	DL1	DL2	CR 1	CR 2	Transfer Lines	TT to Junction Point	Preliminary e- beam LINAC	Polarized e- source	Positron Target	Transfer Lines	e+ Pre DR	e+/e- DR	SpinRotator +BC1+TD	Booster LINAC	TT to Junction Point	J.P. to S.P.	e- TT		e+ TT
Length (l) m	1500 +48+300	227	307	292	438	518	239	400	50	50	482	384	2x433	2 x 313	500	216	277	945	1449	2196
Section (w x h) m	6 x 3	4 x 3	4 x 3	4 x 3	4 x 3	4 x 3	4 x 3	4 x 3	5 x 3	30 x 3	4 x 3	4 x 3	4 x 3	4x 3	4 x 3	4 x 3	6 x 3	4 x 3	ϕ 3.8	ϕ 3.8
Surface Buildings (l x w x h) m	1800 x 30 xh 9	-	-	30x30 x h 5	30x30 x h 5	-	-	400 x 7 x h 3	ComptonR. 30x30x h3	Linac1+2. 30x30xh5(x2)	-	30x30 xh5(x2)	30x30 xh5(x2)	-	500 x 5 x h 3	-	Inject.Hall 30x30xh5	delta e-/e+ = 198m		

CLIC- MAIN / DRIVE BEAM INJECTORS AND EXPERIMENTAL AREA LAYOUT

CERN

GROUP : GS-SE
CIVIL ENGINEERING
SUPERVISOR : J.OSBORNE
DESIGNER : P.SERAFINO

SCALE : 1/8000(A3_FORMAT) DATE : 16-MAY-2024

CLIC.CE-1.1799.0002 | SIZE 3 | INDICE M

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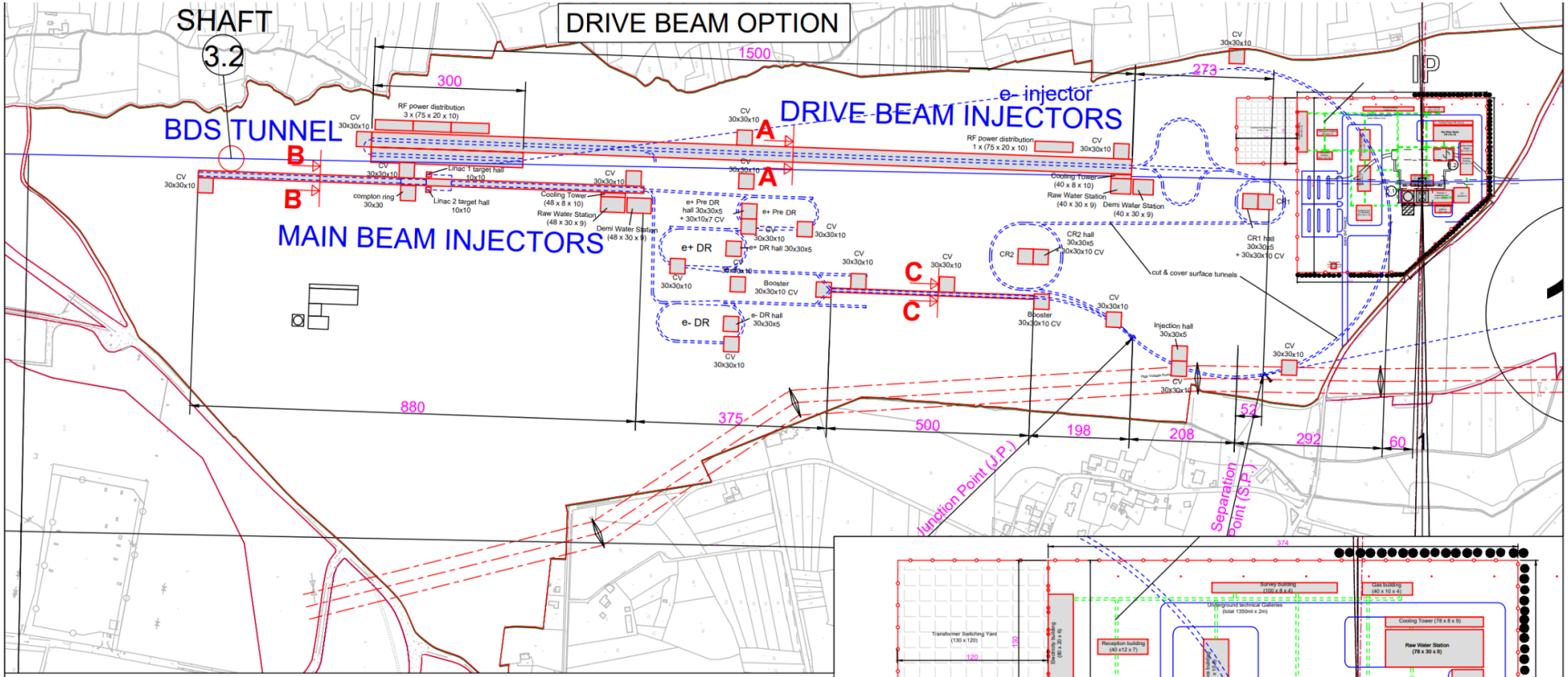
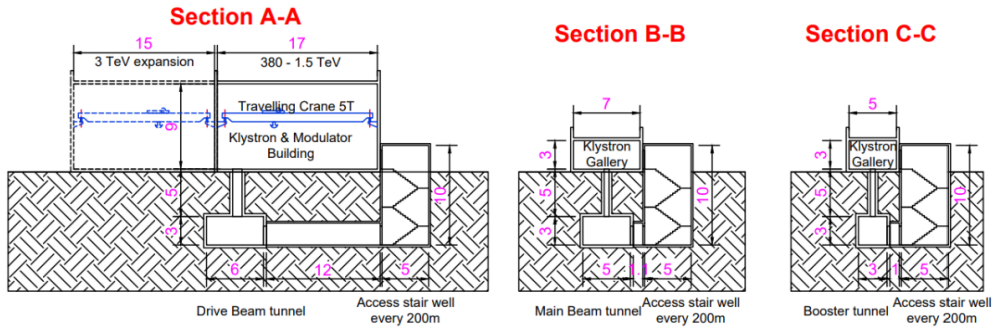
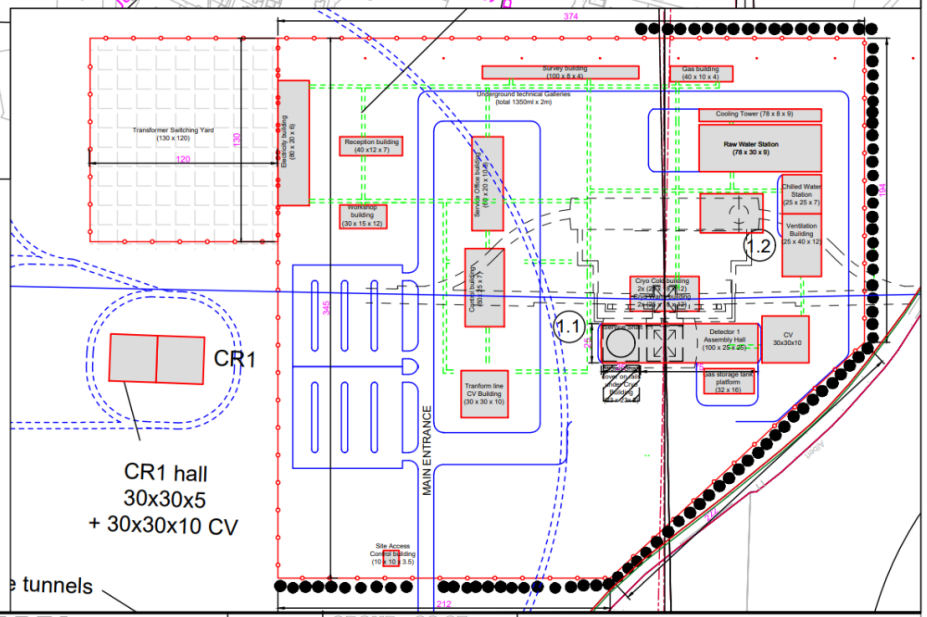


Main Beam & Drive Beam Injector Cross Sections





CLIC- MAIN / DRIVE BEAM INJECTORS AND EXPERIMENTAL AREA SURFACE BUILDINGS LAYOUT

CERN

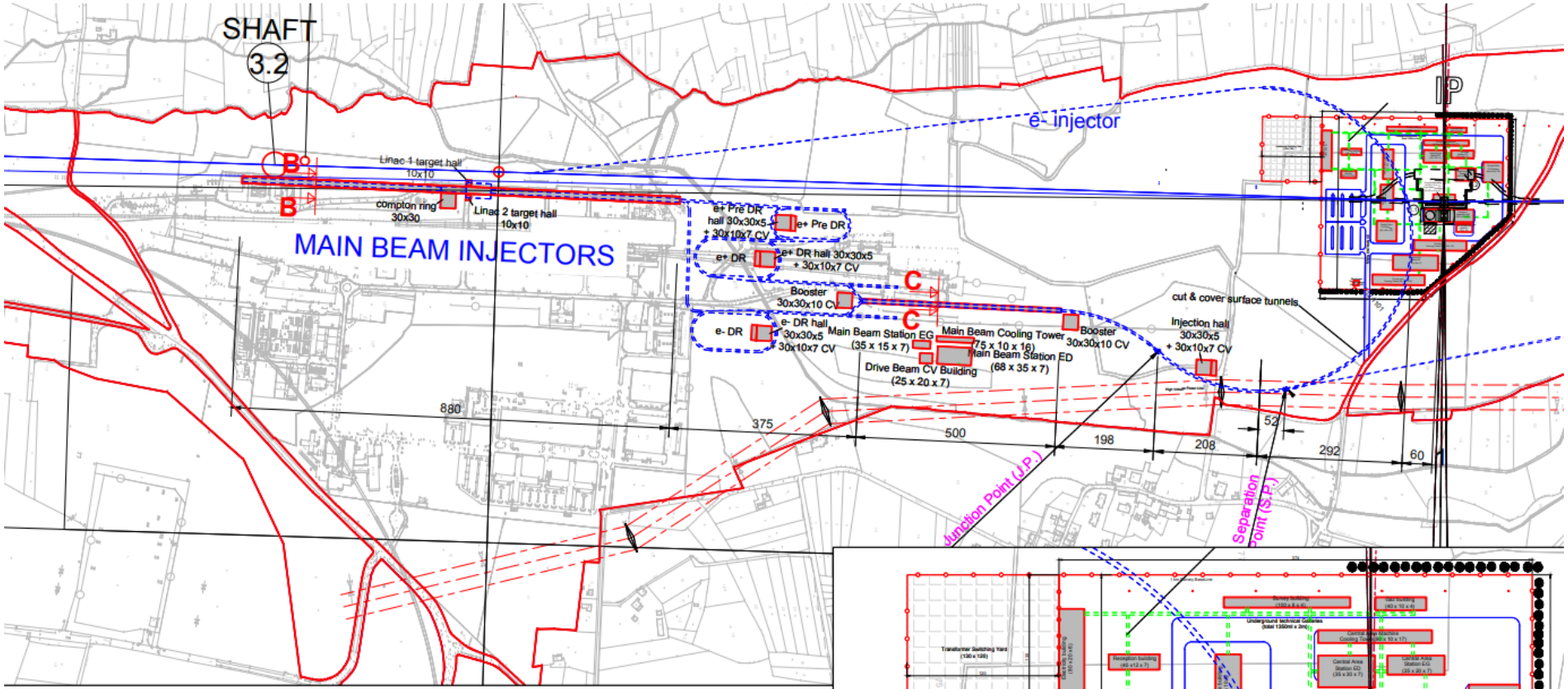
GROUP : GS-SE
CIVIL ENGINEERING
SUPERVISOR : J.OSBORNE
DESIGNER : P.SERAFINO

SCALE : 1/7500(A3_FORMAT)
DATE : 16-MAY-2024

CLIC.CE-1.1799.0005

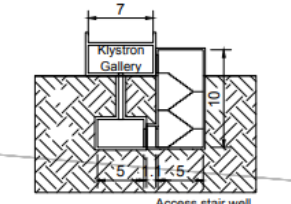
SIZE 3
INDICE M

ARUP

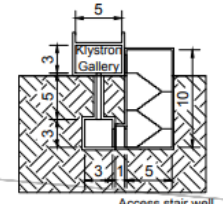


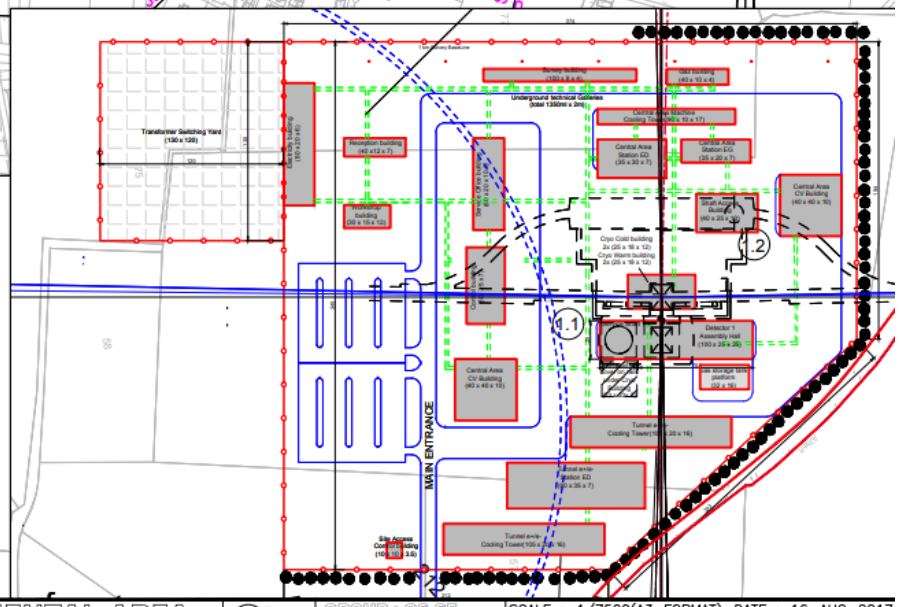
380 Gev Klystron Main Beam Injector Cross Sections

Section B-B



Section C-C





CLIC - 380 Gev KLYSTRON MAIN BEAM INJECTORS AND EXPERIMENTAL AREA
SURFACE BUILDINGS LAYOUT

CERN
GROUP : GS-SE
CIVIL ENGINEERING
SUPERVISOR : J.OSBORNE
DESIGNER : P.SERAFINO

SCALE : 1/7500(A3_FORMAT) DATE : 16-AUG-2017

	SIZE	INDICE
CLIC.CE-1.1799.0007	3	-

KLYSTRON & DRIVE BEAM

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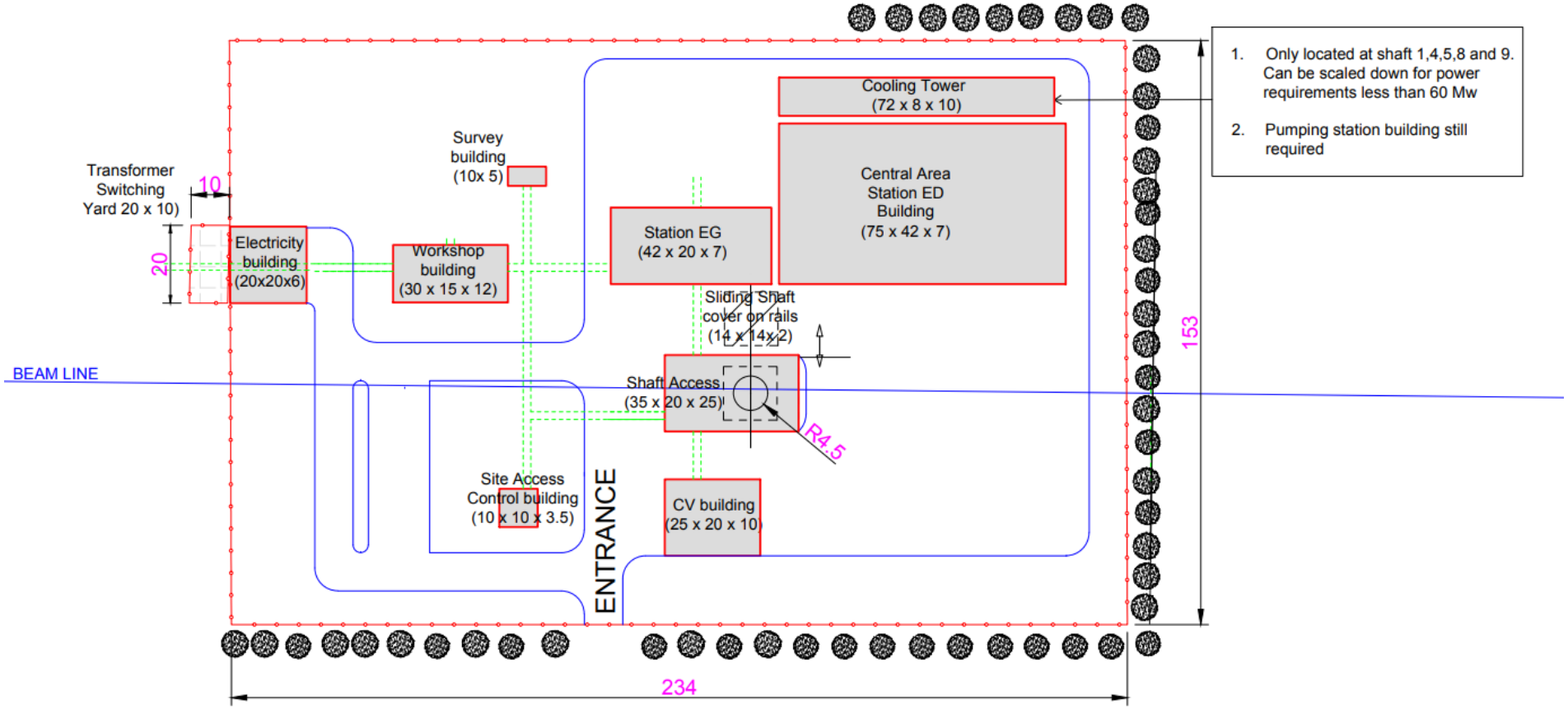

CLIC- SHAFT AREA
SURFACE BUILDINGS LAYOUT

CERN
GROUP : GS-SE
CIVIL ENGINEERING
SUPERVISOR : J.OSBORNE
DESIGNER : P.SERAFINO

SCALE : 1/10000(A3_FORMAT) DATE : 31_OCT_2018

CLIC.CE-1.1799.0006 | SIZE 3 | INDIC B

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CLIC Drive Beam 380GeV Data hierarchy

System	Sub-system	Components	Underground / Surface	Sub-components
CLIC 380GeV Drive Beam				
	Injectors Complex			
		Drive beam injectors complex		
			Underground	
				Linac
				DL1
				DL2
				CR1
				CR1
				Transfer lines
				TT to Junction point
				Access stair well every 200m for Linac
				Connecting structure between Linac and stairwell
			Surface	
				Linac surface buildings
				CR1 halls
				CR2 halls
				CV buildings
				RF power distribution
				Drive beam CV building
				Drive beam Station EG
				Drive beam cooling tower
				Drive beam station ED
				CR1 CV building
				CR2 CV building
		Main beam injectors complex		
			Underground	
				Preliminary e- beam LINAC
				Access stair well every 200m for main beam linac
				Connecting structure between main beam linac and stairwell
				Polarised e- source
				Positron target
				Transfer lines
				e+ pre DR
				e+ / e- DR
				SpinRotator+BC1+TD
				Booster LINAC
				Access stair well every 200m Booster linac
				Connecting structure between Booster linac and stairwell
				TT to Junction point
			Surface	
				Preliminary e- beam LINAC surface buildings
				Compton ring surface buildings
				Linac1+2 surface buildings
				e+ pre DR surface buildings
				e+ DR surface buildings
				e- DR surface buildings
				Booster LINAC surface buildings
				CV buildings main linac tunnel
				Drive beam CV building
				Drive beam station EG
				Drive beam station ED
				Drive beam cooling tower
				CV buildings booster tunnel
				CV buildings booster tunnel

System	Sub-system	Components	Underground / Surface	Sub-components
		Common transfer tunnel J.P. to S.P.		
			Underground	
				Transfer tunnel J.P to S.P
			Surface	
				Injector hall
				CV buildings
		Final transfer tunnels (from separation point)		
			Underground	
				e- TT
				e- TT
				e+ TT
		Experimental area surface buildings layout		
			Surface	
				Site access control building
				Transform line CV building
				Control building
				Service office building
				Detector 1 Assembly hall
				Gas storage tank platform
				CV
				Cryo cold building
				Cryo warm building
				Central IP station EG
				Central IP station ED
				Central Area CV building
				Central IP Cooling tower
				Reception building
				Workshop building
				Survey building
				Gas building
				Electricity building
	Shafts			
		Surface buildings		
			Surface	
				Electricity building
				Workshop building
				Survey building
				Station EG
				Cooling Tower
				Central Area Station ED building
				Shaft access
				Site access control building
				CV building

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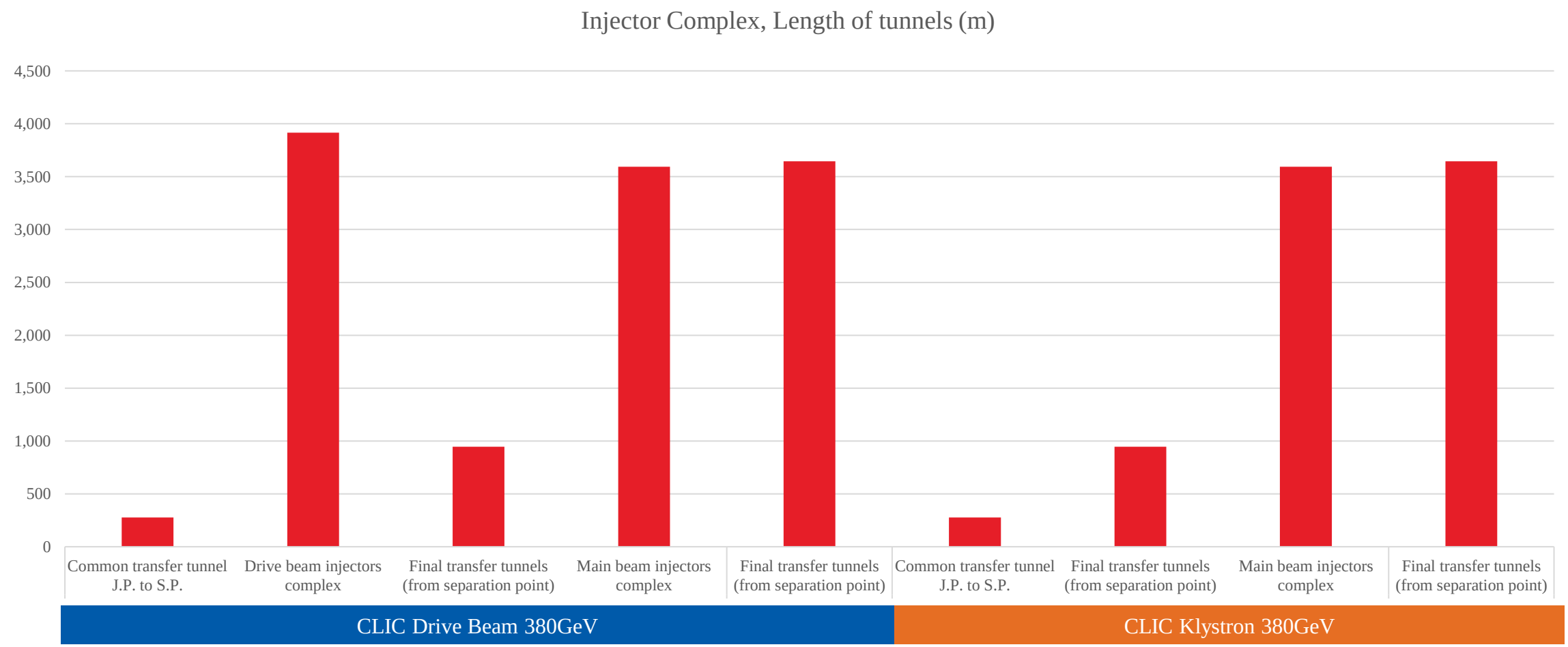
CLIC Klystron 380GeV Data hierarchy

System	Sub-system	Components	Underground / Surface	Sub-components
CLIC 380GeV Klystron				
	Injectors Complex			
		Main beam injectors complex		
			Underground	
				Preliminary e- beam LINAC
				Access stair well every 200m for main beam tunnel
				Connecting structure between main beam tunnel and stairwell
				Polarised e- source
				Positron target
				Transfer lines
				e+ pre DR
				e+ / e- DR
				SpinRotator+BC1+TD
				Booster LINAC
				Access stair well every 200m Booster linac
				Connecting structure between Booster linac and stairwell
				TT to Junction point
			Surface	
				Preliminary e- beam LINAC surface buildings
				Compoton ring surface buildings
				Linac1+2 surface buildings
				e+ pre DR surface buildings
				e- DR surface buildings
				Booster LINAC surface buildings
				CV buildings
				Booster CV buildings
				Main beam station EG
				Drive beam CV building
				Main beam cooling tower
				Main beam station ED
		Common transfer tunnel J.P. to S.P.		
			Underground	
				Transfer tunnel J.P to S.P
			Surface	
				Injector hall
				CV buildings
		Final transfer tunnels (from separation point)		
			Underground	
				e- TT
				e- TT
				e+ TT

System	Sub-system	Components	Underground / Surface	Sub-components
		Experimental area surface buildings layout		
			Surface	
				Site access control building
				Tunnel e+/e- cooling tower
				Tunnel e+/e- station ED
				Central area CV building
				Control building
				Service office building
				Detector 1 Assembly hall
				Gas storage tank platform
				Cryo cold building
				Cryo warm building
				Central Area station EG
				Central Area station ED
				Central Area CV building
				Central Area machine IP Cooling tower
				Reception building
				Workshop building
				Survey building
				Gas building
				Electricity building
	Shafts			
		Surface buildings		
			Surface	
				Electricity building
				Workshop building
				Survey building
				Station EG
				Cooling Tower
				Central Area Station ED building
				Shaft access
				Site access control building
				CV building

Length of tunnels (m)



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Injector complex - Underground

Inputs

A1-A3

Select a material type for each material.

Material	Name	Unit	Comment
Shotcrete	Concrete 20MPa | CEMI (Portland cement) | Global	m3	
Insitu concrete	Concrete 30MPa | CEMI (Portland cement) | Global	m3	
Precast concrete	Concrete 50MPa | CEMI (Portland cement) | Global	m3	
Steel rebar	Reinforcing steel | 80% recycled | Global	kg	
Steel fibre	Reinforcing steel | 80% recycled | Global	kg	

A4

Select a transport distance for each material.

			Comment
Shotcrete	50	km	Locally manufactured
Insitu concrete	50	km	Locally manufactured
Precast concrete	50	km	Locally manufactured
Steel rebar	1500	km	European manufactured
Steel fibre	1500	km	European manufactured

Select a transport mode for each material.

Shotcrete	Road transport, freight lorry | Global
Insitu concrete	Road transport, freight lorry | Global
Precast concrete	Road transport, freight lorry | Global
Steel rebar	Road transport, freight lorry | Global
Steel fibre	Road transport, freight lorry | Global

A5w

Comment: IStructE carbon guidance

Equation: $ECF_{A5w} = WF \times (ECF_{A1\text{-}A3} + ECF_{A4} + ECF_{C2} + ECF_{C34})$

Select a waste factor for each material.

Shotcrete	0.05
Insitu concrete	0.05
Precast concrete	0.05
Steel rebar	0
Steel fibre	0

Select transport distance away from site (C2)

			Comment
Shotcrete	30	km	Assumed
Insitu concrete	30	km	Assumed
Precast concrete	30	km	Assumed
Steel rebar	30	km	Assumed
Steel fibre	30	km	Assumed
Earthworks	20	km	Assumed

Waste processing and disposal embodied carbon factor (C3 C4)

Waste factor	0.013	kgCO2e/kg	IStructE carbon guidance

A5a

Comments

Diaphragm walls, excavate, base slab, inverted U unit, backfill

Cut and cover tunnel

Electricity	22.4	kWh/m3 excavation
Diesel	104.3	kWh/m3 excavation

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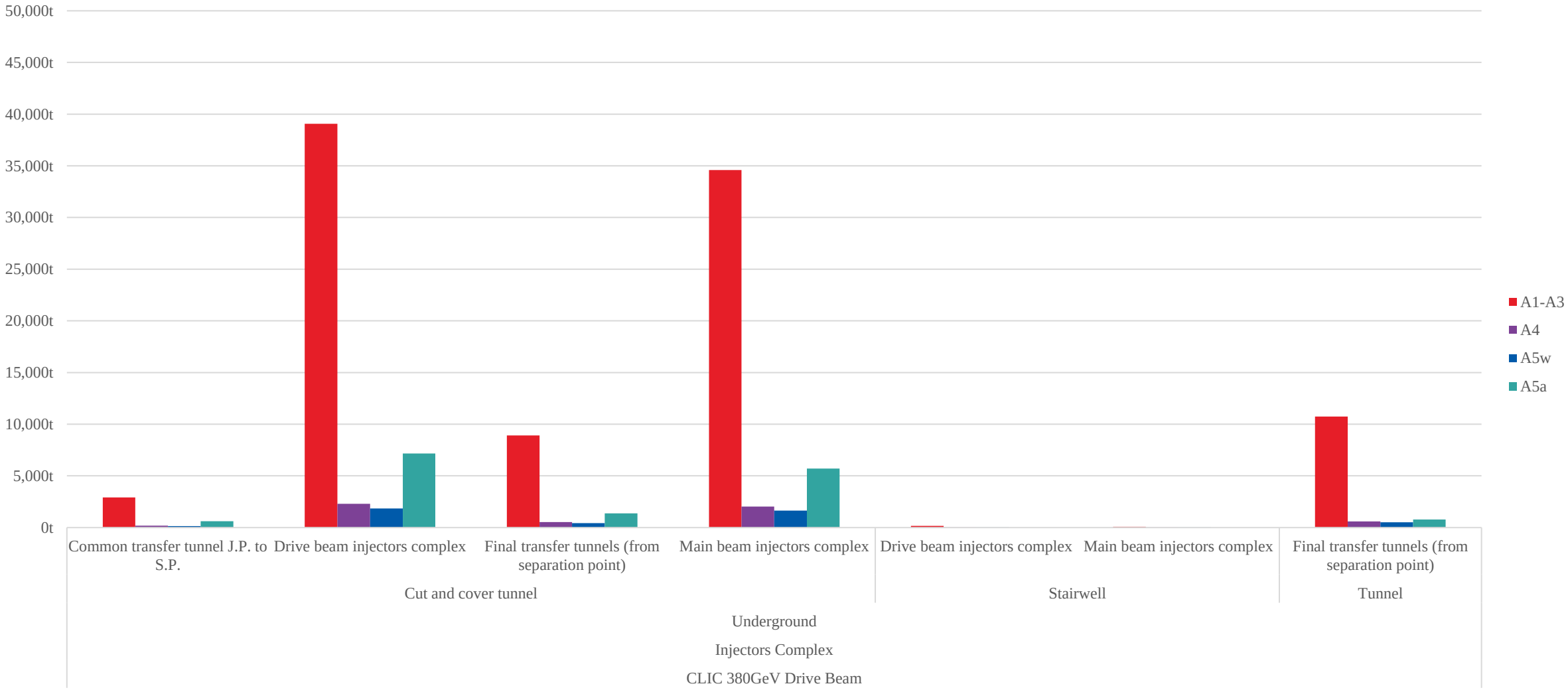
CLIC Drive Beam 380GeV

GWP (tCO_2e)



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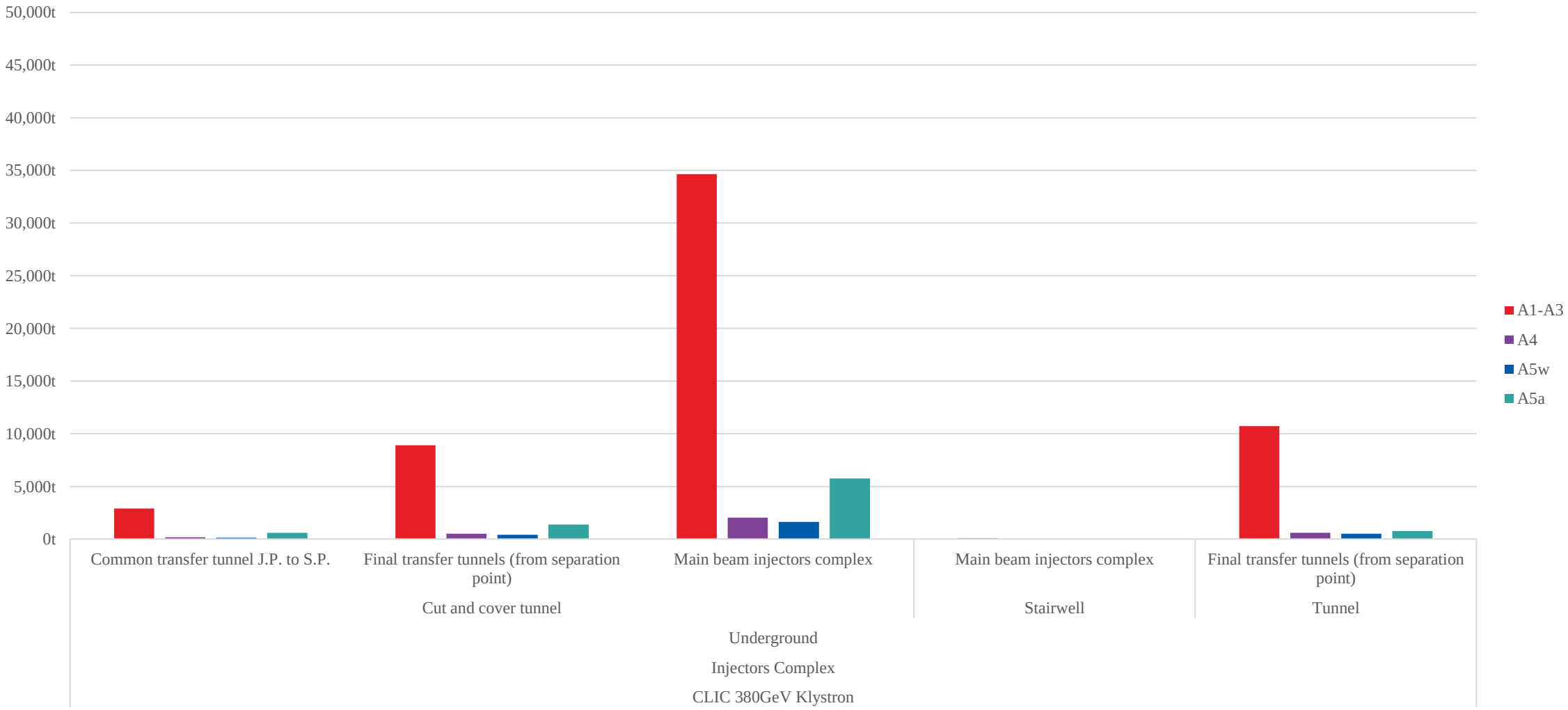
CLIC Klystron 380GeV

GWP (tCO_2e)



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Tunnel service systems

Inputs

A1-A3

Comment

Select a material type for each material.

Material	Name	Unit
Steel pipe	Steel sheet | RER	kg
PVC pipe	PVC | RER	kg
Steel sheet	Steel sheet | RER	kg
Aluminium	Aluminium, sheet | Europe	kg
Cable	Cable | unspecified | GLO	kg

Select a material density

Steel pipe	7800	kg/m3
PVC pipe	1400	kg/m3
Steel sheet	7800	kg/m3
Aluminium	2700	kg/m3

A4

Comment

Select a transport distance for each material.

Steel pipe	1500	km	European manufactured
PVC pipe	1500	km	European manufactured
Steel sheet	1500	km	European manufactured
Aluminium	1500	km	European manufactured

Select a transport mode for each material.

Steel pipe	Road transport, freight lorry | Global
PVC pipe	Road transport, freight lorry | Global
Steel sheet	Road transport, freight lorry | Global
Aluminium	Road transport, freight lorry | Global

A5w

Comment

Assume negligible as all services are manufactured to specification before transported to site.

A5a

Comments

Assume installation is manual labour with minimal plant required therefore assume negligible impact.

Ref: Technical Prescriptions on Ventilation Installations - Unless otherwise approved by CERN, the contractor shall install all the instruments and accessories following the installation instructions and guidelines provided by the instrument manufacturer.

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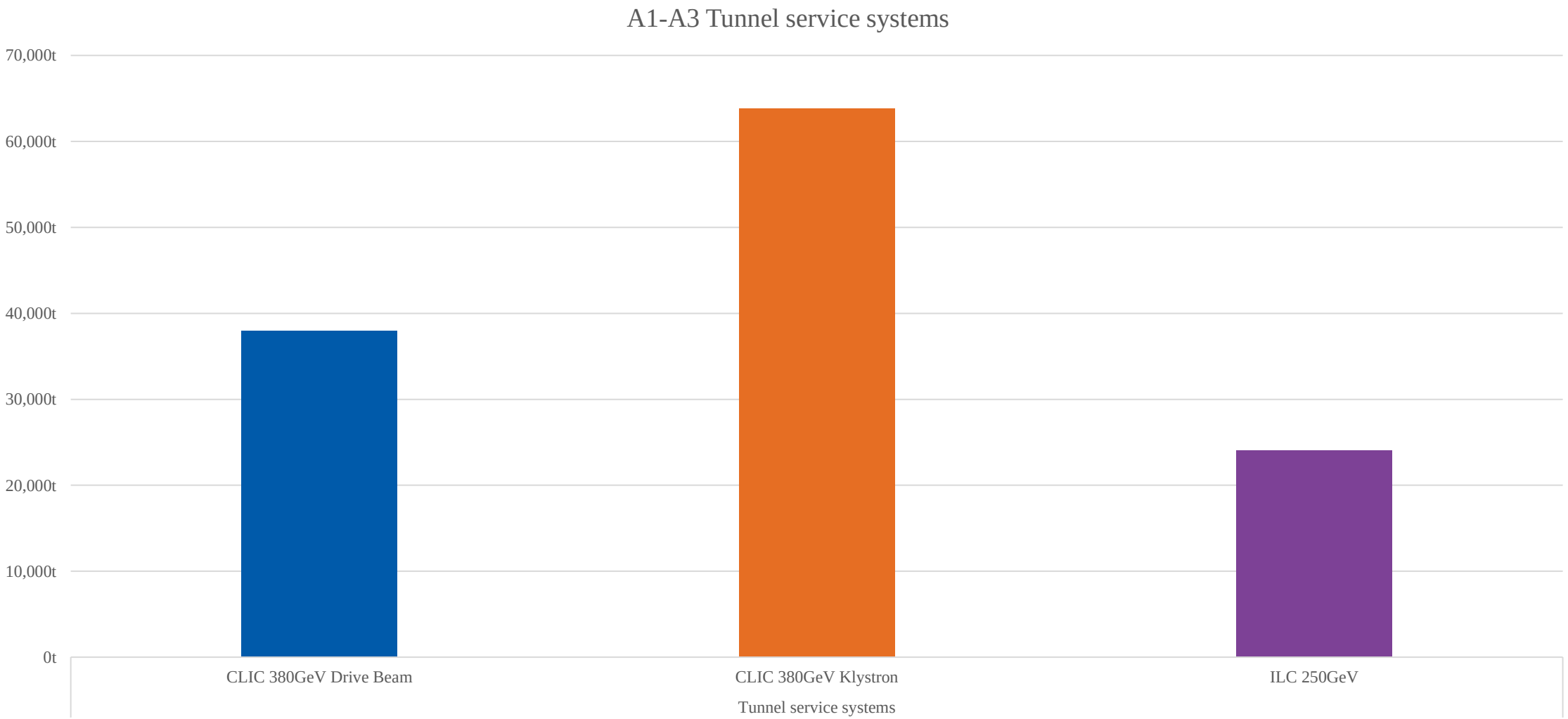
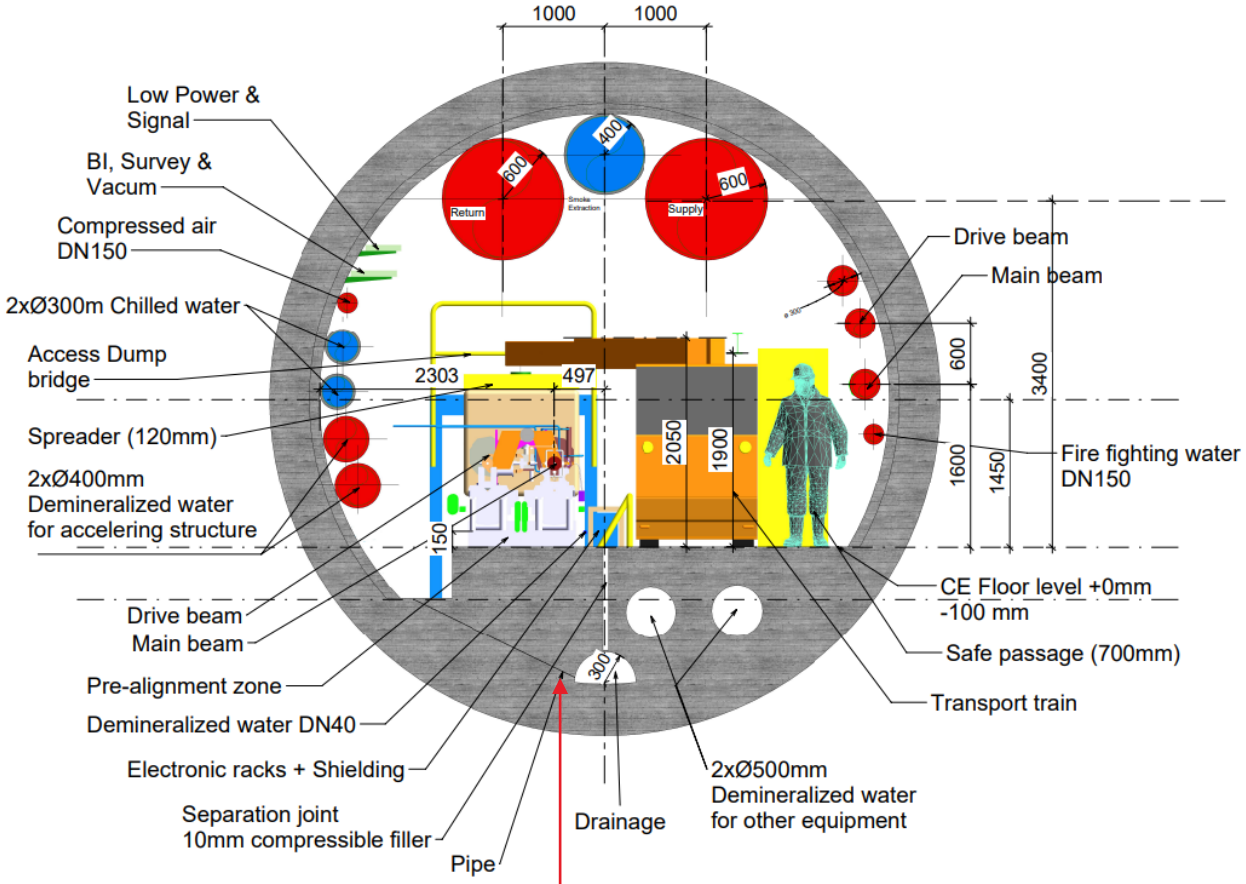
Tunnel service systems comparison

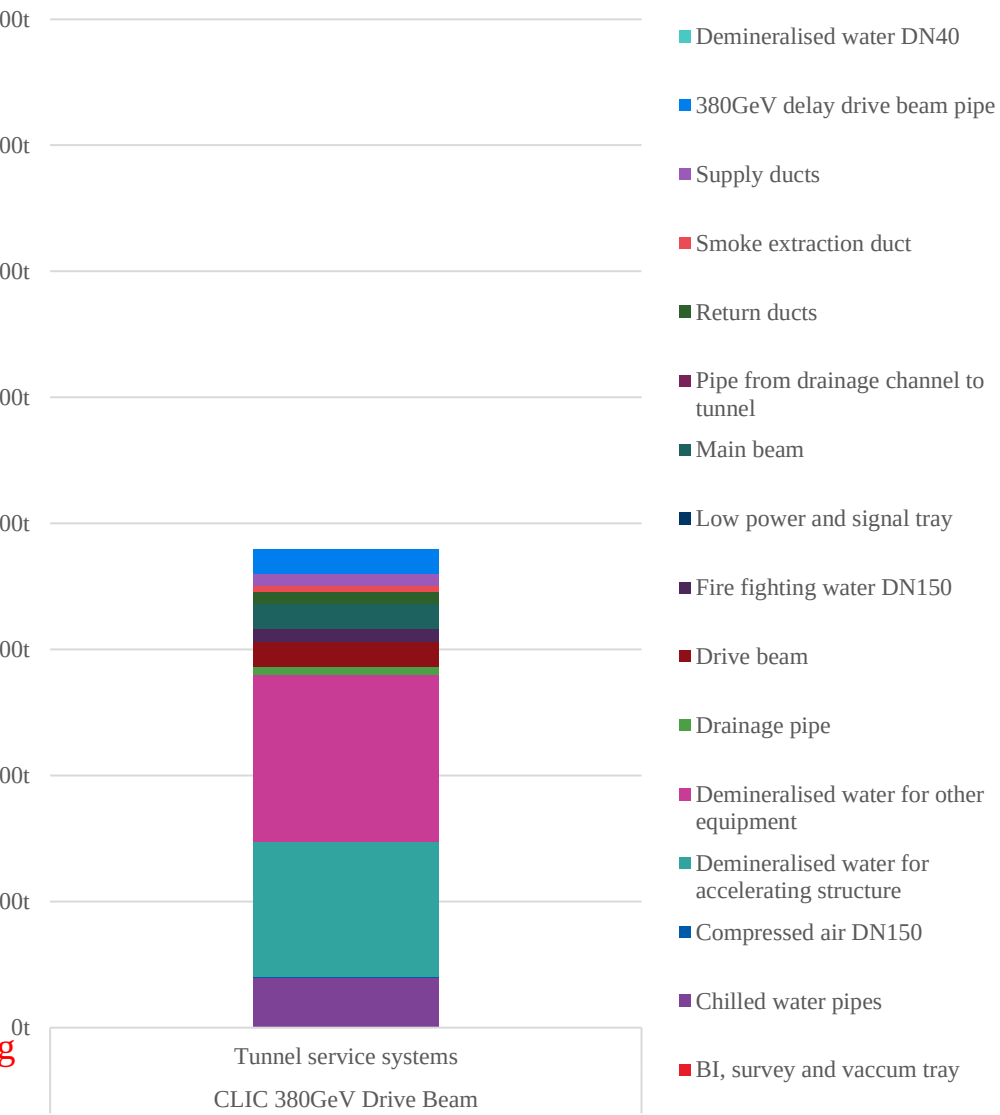
GWP (tCO_2e)



CLIC Drive Beam 380GeV

GWP (tCO_2e)





Ref: CLICCE-117000007

Comments:
50mm dia. Pipe from tunnel to drainage channel at 40m spacing
Access dump bridge and spreader to be excluded
Cable tray is continuous – to be updated

CLIC Klystron 380GeV

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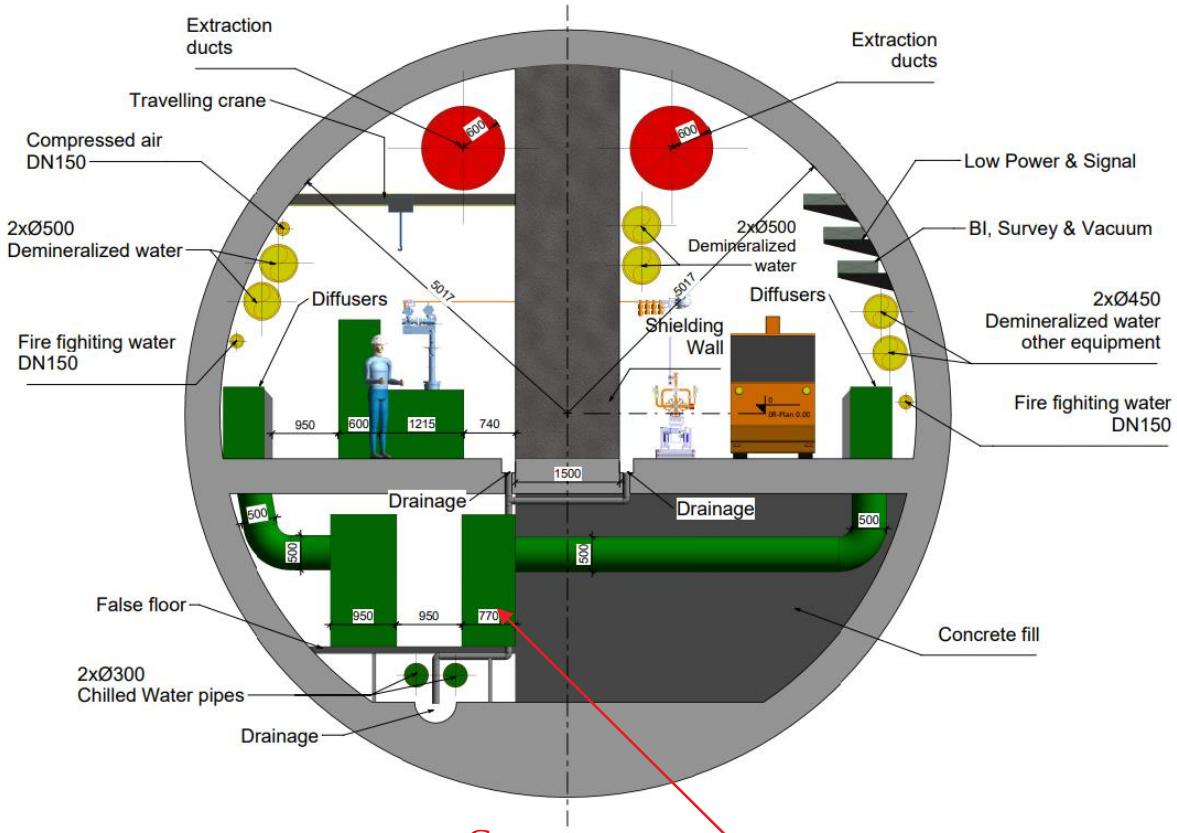
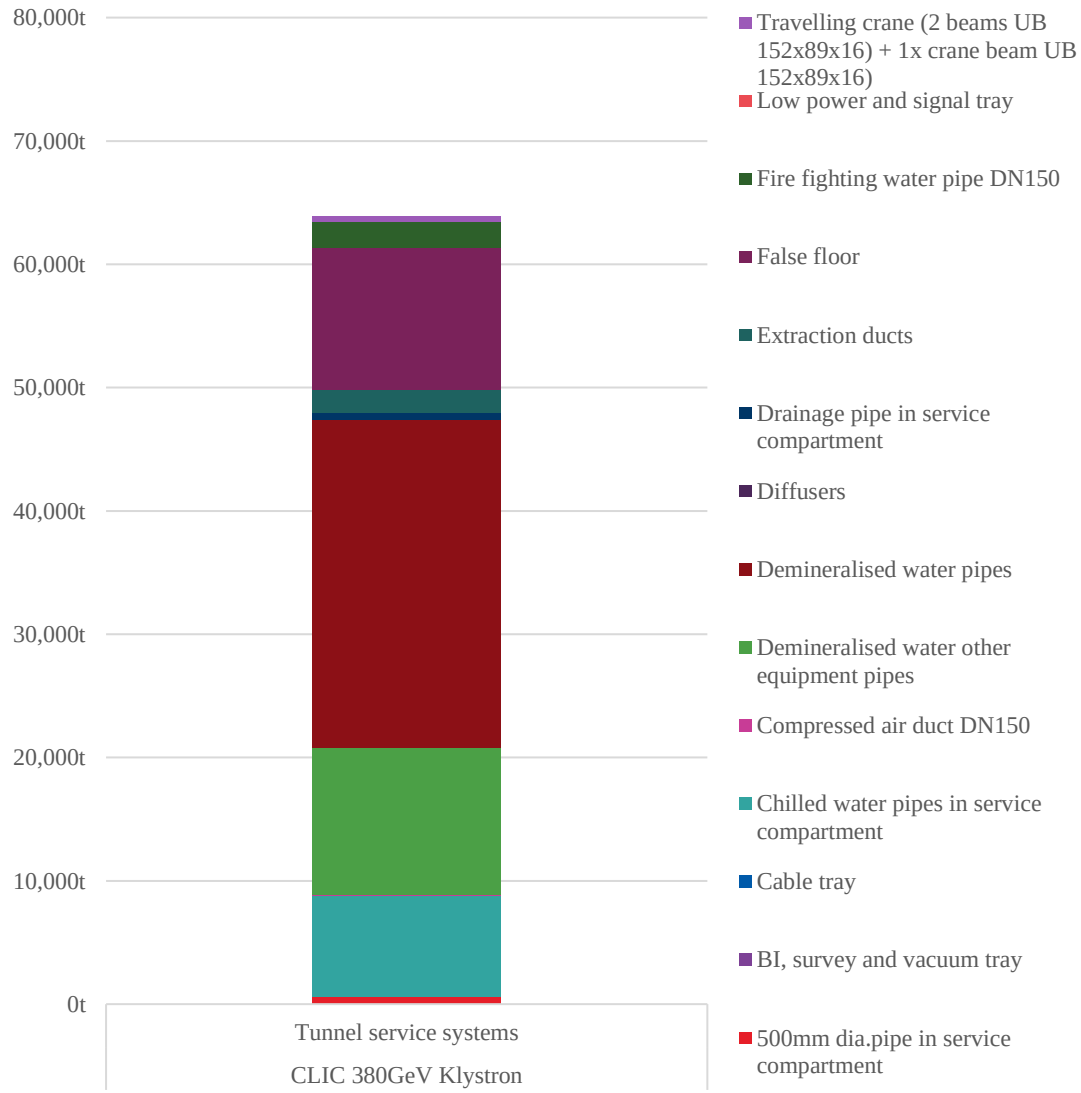
GWP (tCO_2e)



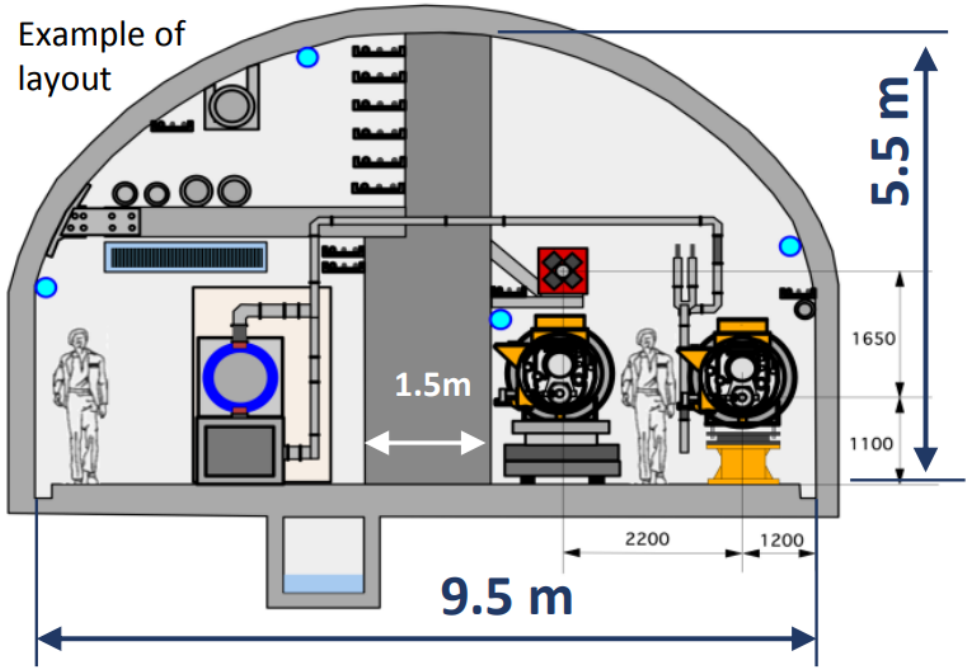


Ref: CLICCE-117100102

Comments:
Spacing of diffusers assumed every 87m Ref: Cooling and Ventilation Studies for the CLIC pg 25. Steel unit will be assumed for diffuser.
Assume steel unit is square for calculation
Cable tray is continuous

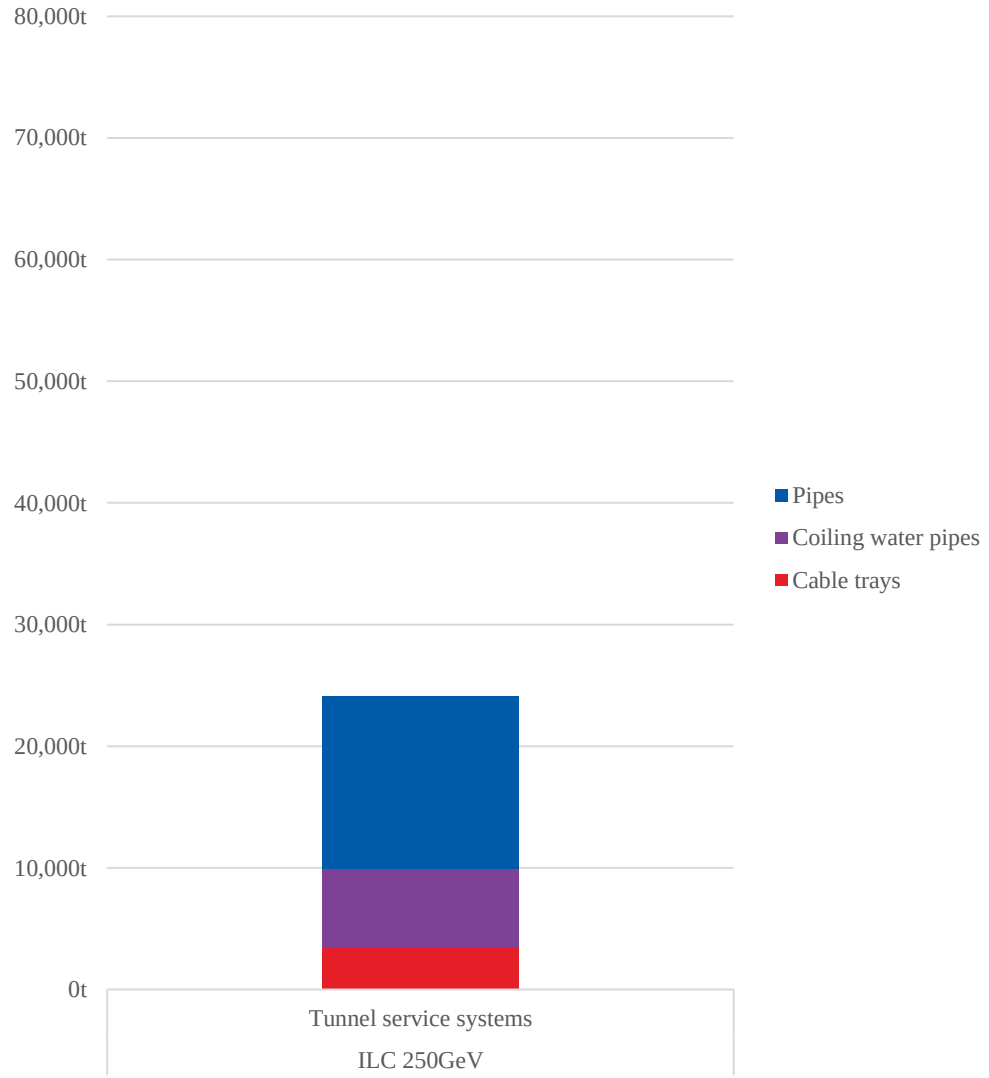
ILC 250GeV

GWP (tCO_2e)



- **66 kV distribution cables**
- **Colling water pipes**
- Fan Coil Units
- Low power and signal cables
- **RF klystrons and modulators**
- **Electric Power Stations**

Comments:
Exclude cables (check Steffen tunnel service system data)
No fan coil units for ILC
Exclude ventilation
Cable tray continuous



Ref: ILC Civil Engineering Overview pdf

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Surface buildings

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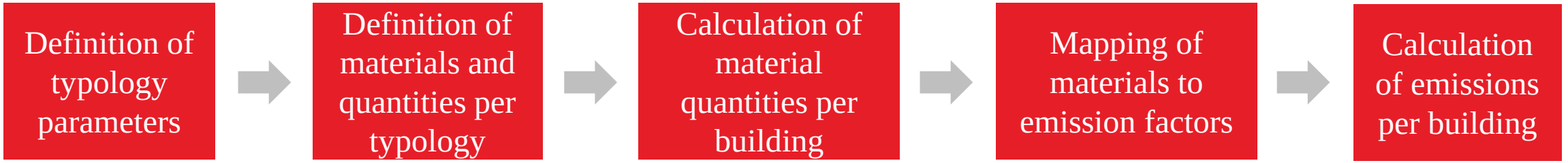
Building typologies

8 building typologies: 3 concrete warehouse typologies, 3 steel warehouse typologies, 2 steel office typologies

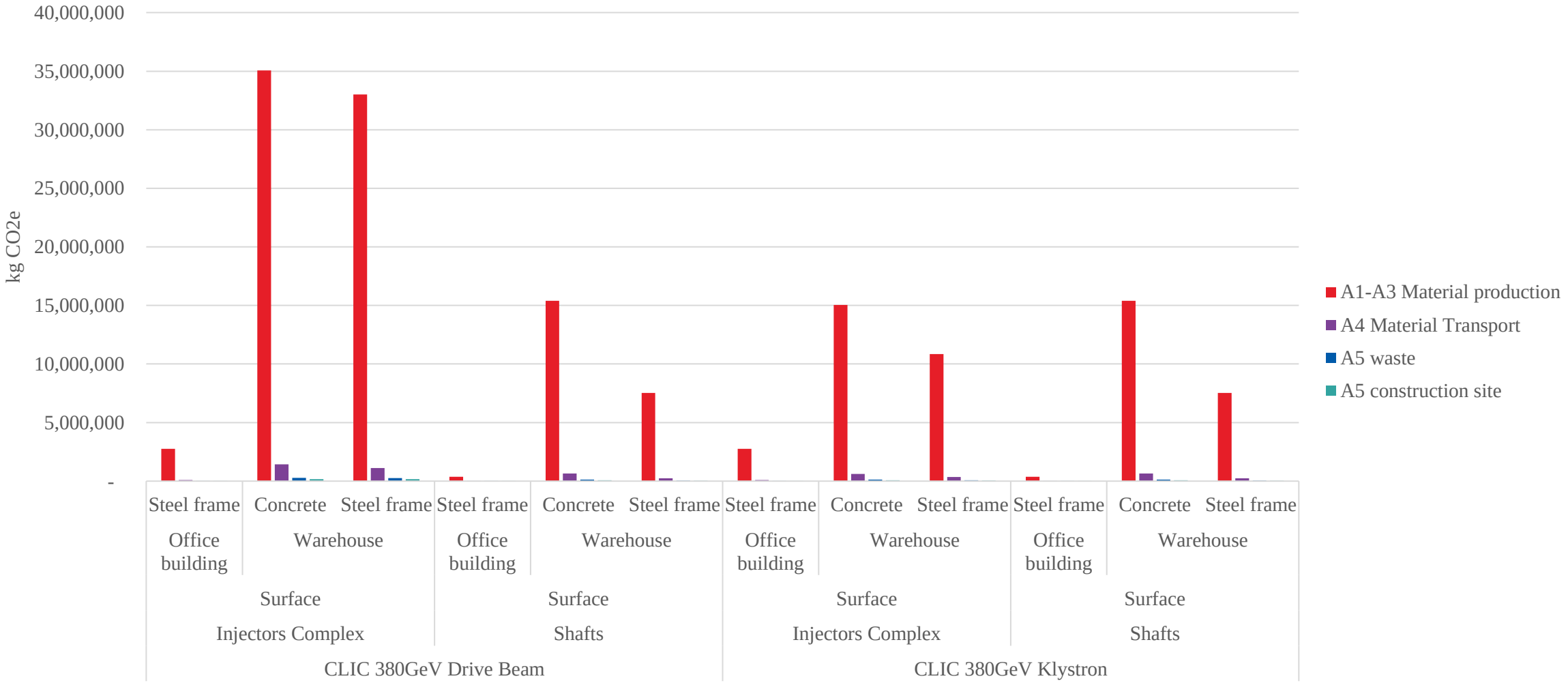
archetype_ID	Building Structure	Building Typology	Age	Morphology	GFA, m²	Floors, #	Facade, m²	Height, m	Columns, m	Heated?
SW_nsq	Steel frame	Warehouse	New	squat	1000	1	680	6.3	176	no
SW_nst	Steel frame	Warehouse	New	stocky	1000	2	1100	13	353	yes
SW_nsl	Steel frame	Warehouse	New	slender	800	1	2880	25	578	yes
CW_nsq	Concrete	Warehouse	New	squat	1000	1	680	6.3	202	no
CW_nst	Concrete	Warehouse	New	stocky	1800	2	1350	13	403	no
CW_nsl	Concrete	Warehouse	New	slender	800	1	1040	10	245	no
SO_nst	Steel frame	Office building	New	stocky	2500	2	875	7	216	yes
SO_nsl	Steel frame	Office building	New	slender	100	1	120	3.5	32	yes



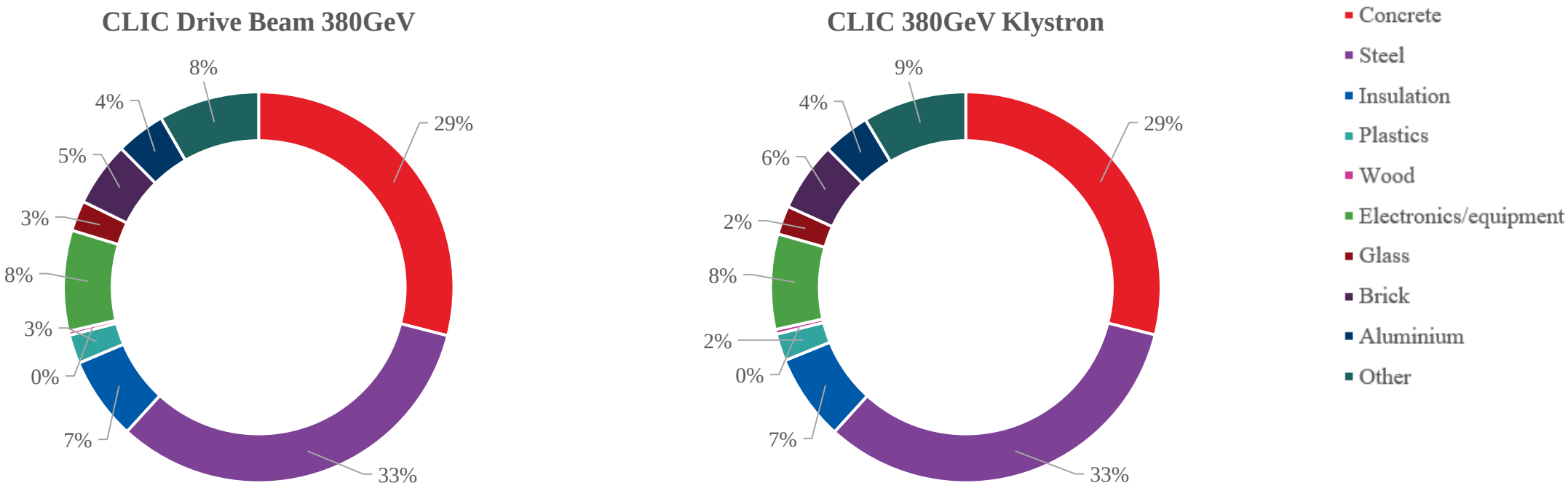
Materials and material mapping

	A1-A3 Material production	A4 Transport	A5 Waste at construction site		
Material	**Mapping material**	**Distance (km)**	**Waste factor**	**Mapping waste**
Concrete, low-strength	Concrete 20MPa | CEMI (Portland cement) | GLO	60	4%	Inert waste | CH
Steel rebar	Reinforcing steel | 80% recycled | GLO	370	4.85%	Scrap steel | CH
Concrete, normal-strength	Concrete 30MPa | CEMII/A-S (6-20% blast furnace slag)| Global	60	4%	Inert waste | CH
Structural steel	Reinforcing steel | 60% recycled content | RER	370	3%	Scrap steel | CH
Insulation, EPS	EPS | RER	430	4%	Waste polystyrene | CH
Plastic membrane	Fleece | PE | RER	430	10%	Waste plastic | mixture | CH
Mortar	Mortar | Light | CH	110	13%	Inert waste | CH
Door, wood	Door | Wood | RER	350	0%	-
Paint	Alkyd paint | Water-based | RER	470	10%	Waste paint | CH
Gypsum board	Gypsum plasterboard | CH	60	12.50%	Waste gypsumboard | GLO
Insulation, glass wool	Glass wool insulation | CH	60	8%	Waste mineral wool | CH
Sandwich panel	Sandwich panel | 200 mm | RER	430	15%	Waste sandwich panel | CH
Door, steel	Door | Steel | RER	350	0%	-
Window, triple glazed and wood-alu frame	Window | wood-metal frame, triple glazed | RER	380	0%	-
Steel sheet	Steel sheet | RER	370	3.30%	Scrap steel | CH
Ceramic tile	Ceramic tile | CH	320	10%	Inert waste | CH
Vinyl flooring	PVC | RER	430	10%	Waste plastic | mixture | CH
Cable	Cable | unspecified | GLO	320	1%	Used cable | GLO
Air handling unit	Air handling unit | 720 m^3/h | RER	320	1%	Used blower and heat exchange unit central | 600-1200 m3/h | CH
Duct, steel	Steel duct | DN 125 mm | RER	370	6%	Scrap steel | CH
Pipe, PE	Polyethylene pipe | DN 75 mm | RER	370	6%	Waste plastic | mixture | CH
Elevator	Elevator, hydraulic | GLO	320	0%	-
Steel, unalloyed	Steel, unalloyed | RER	320	1%	Scrap steel | CH
Wood, lath	Wood lath | softwood | CH	220	17.90%	Waste wood | CH
Polyamide	Polyamide | RER	430	10%	Waste plastic | mixture | CH
Clay brick	Clay brick | RER	60	5%	Waste brick | CH
Concrete block	Autoclaved aerated concrete block | CH	60	7.50%	Inert waste | CH
Concrete tile	Concrete tile | CH	60	0%	Inert waste | CH

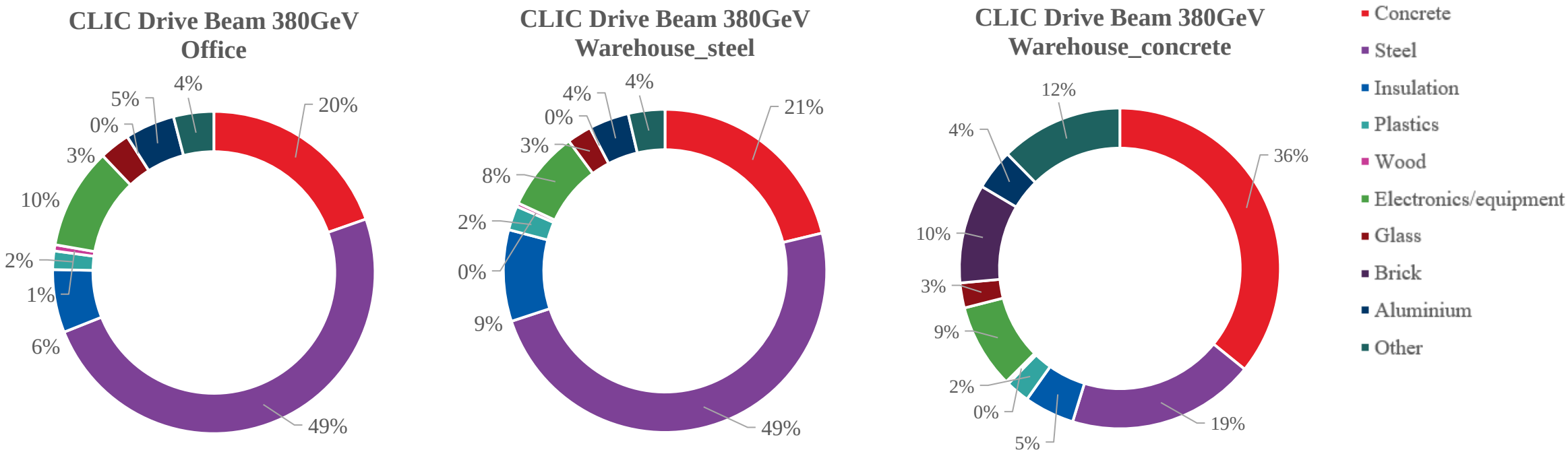
Surface buildings carbon per typology



Surface buildings carbon per material (A1-A3)



Surface buildings carbon per material (A1-A3)



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Results summary

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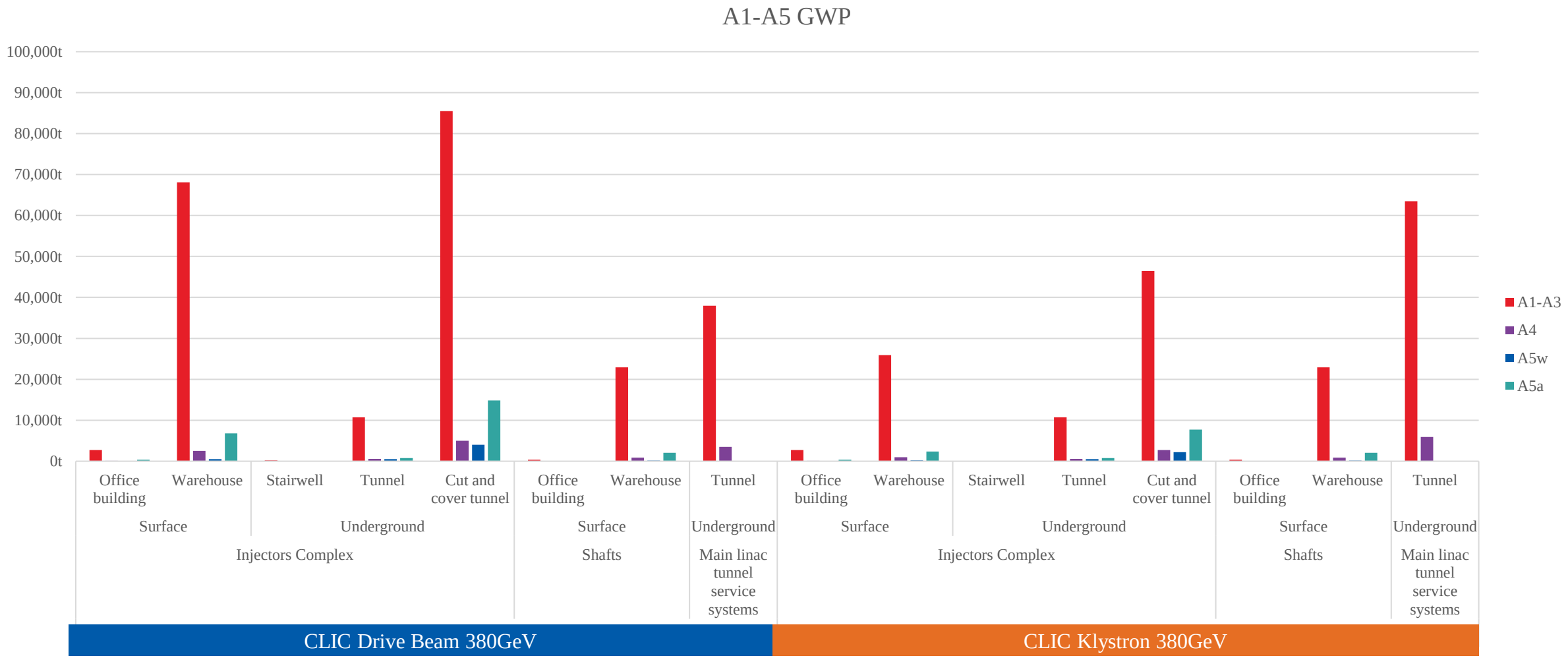
CLIC DB & CLIC KL summary

A1-A5 GWP (tCO_2e)



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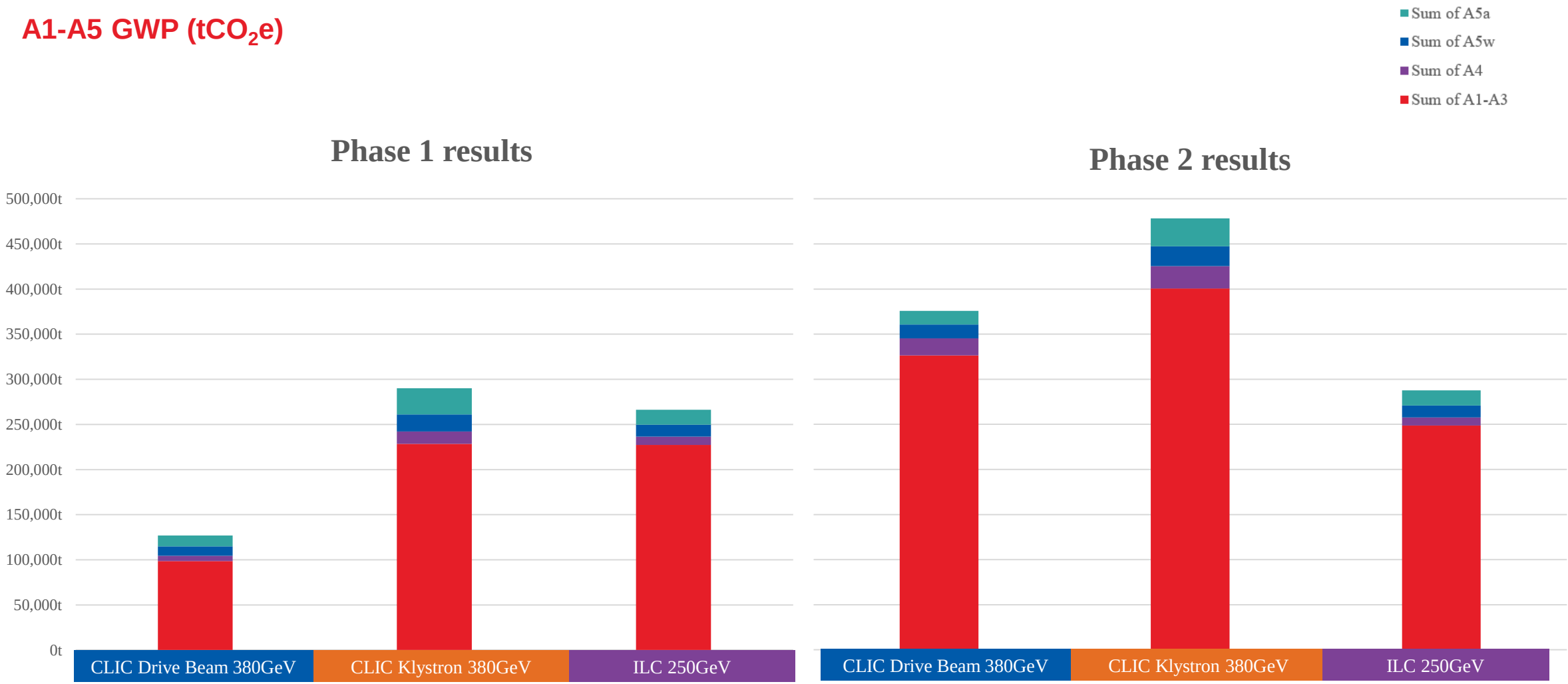
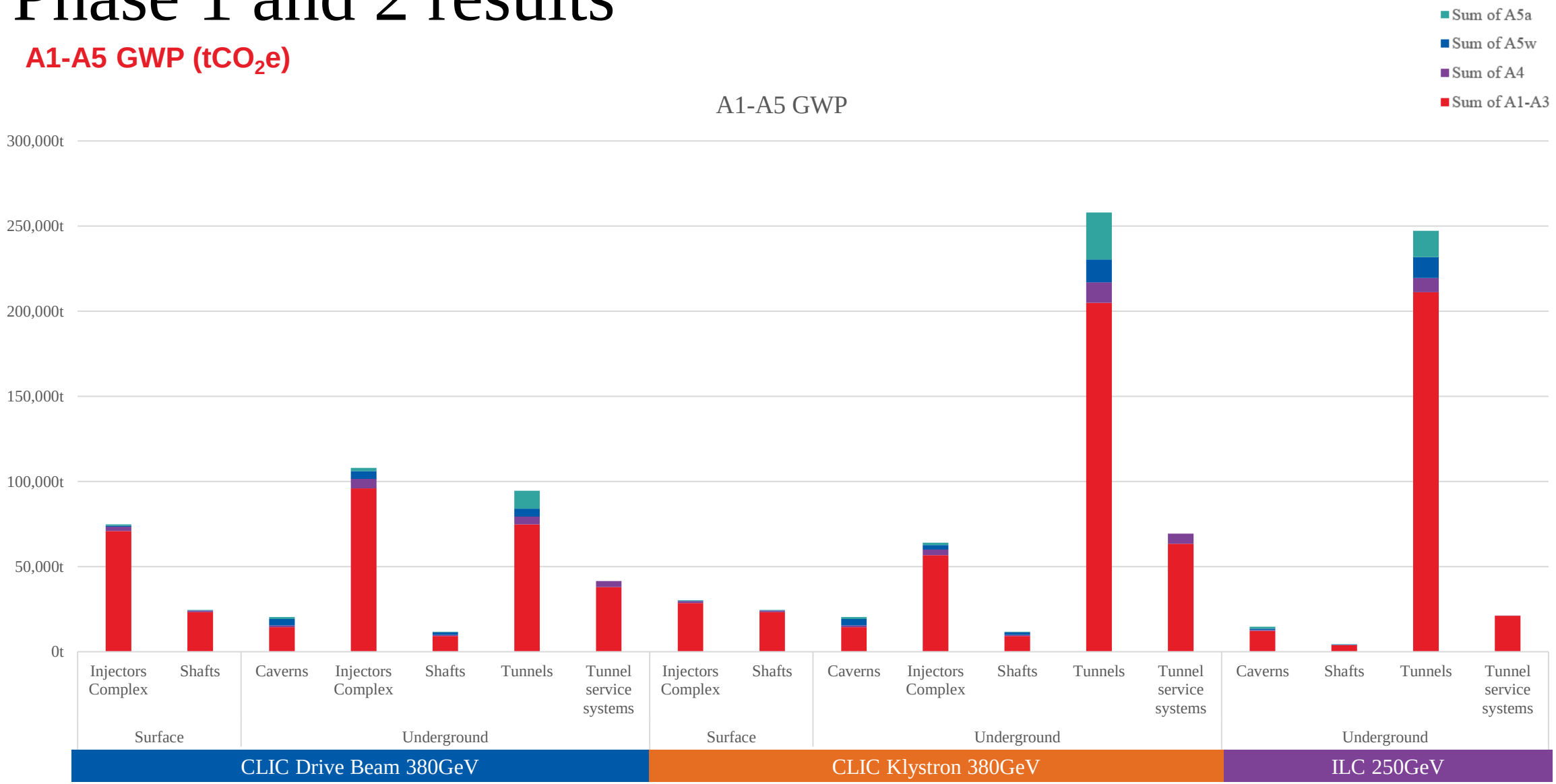
Phase 1 and 2 results

A1-A5 GWP (tCO_2e)



Phase 1 and 2 results

A1-A5 GWP (tCO_2e)



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Machine componentry

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Material modelling

Example: CLIC 380GeV Klystron

A1-A3 Material production

Components	Material	Mapped material	Processing step	Origin	Note from CERN
Main linac modules klystron	Steel	Steel, stainless, type 304 | Europe	Average metal working, stainless steel	Europe	high quality steel 304/316 L
Main linac modules klystron	Copper OFC	Copper, high grade | Global	Average metal working, copper	Europe	
Main linac modules klystron	Aluminium	Aluminium, wrought alloy | Global	Average metal working, aluminium	Europe	
Main linac modules klystron	Titanium	Titanium | Global	Average metal working, metals	Europe	
Main linac modules klystron	Mild steel	Steel, unalloyed | Europe	Average metal working, steel	Europe	Supports
Main beam magnets	Steel	Steel, unalloyed | Europe	Average metal working, steel	Europe	Magnet steel
Main beam magnets	Copper	Copper | Global	Average metal working, copper	Europe	
Main beam magnets	Mild steel	Steel, unalloyed | Europe	Average metal working, steel	Europe	Supports
Modulators/klystrons/waveguides	Steel	Steel, stainless, type 304 | Europe	Average metal working, stainless steel	Europe	high quality steel 304/316 L
Modulators/klystrons/waveguides	Copper	Copper | Global	Average metal working, copper	Europe	only 500 t are OFC copper
Modulators/klystrons/waveguides	Copper OFC	Copper, high grade | Global	Average metal working, copper	Europe	
Modulators/klystrons/waveguides	Mineral Oil	Lubricating oil | Global		Europe	transformer oil for isolation
CV infrastructure klystron	Steel	Steel, unalloyed | Europe	Sheet rolling, steel	Europe	water pipes and venitlation ducts
CV infrastructure klystron	Copper	Copper | Global	Wire drawing, copper	Europe	magnet cables
CV infrastructure klystron	Mild steel	Steel, unalloyed | Europe	Sheet rolling, steel	Europe	cable trays, sheet metal

Material modelling

A3 Waste at production site

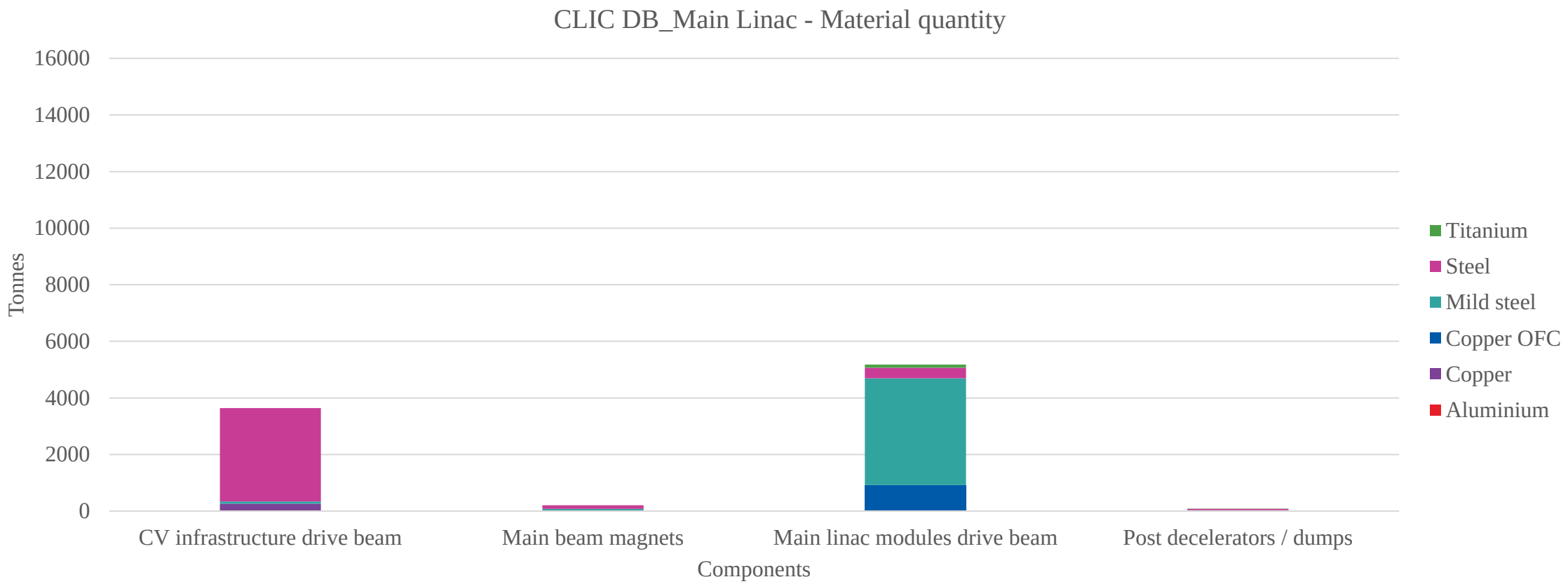
Material	Treatment	Location
Mild steel, stainless steel	Average market for steel waste	Switzerland
Copper, Copper OFC	Average market for copper waste	Switzerland
Aluminium	Average market for aluminium waste	Switzerland
Titanium	Average market for steel waste	Switzerland
Mineral oil	Waste mineral oil	Switzerland

A4 Transport

Average distance 750 km (CERN input: 500-1000 km), truck, empty return.

Assumed EURO 6 truck, 16-32 metric ton

Material analysis, CLIC Drive Beam 380GeV



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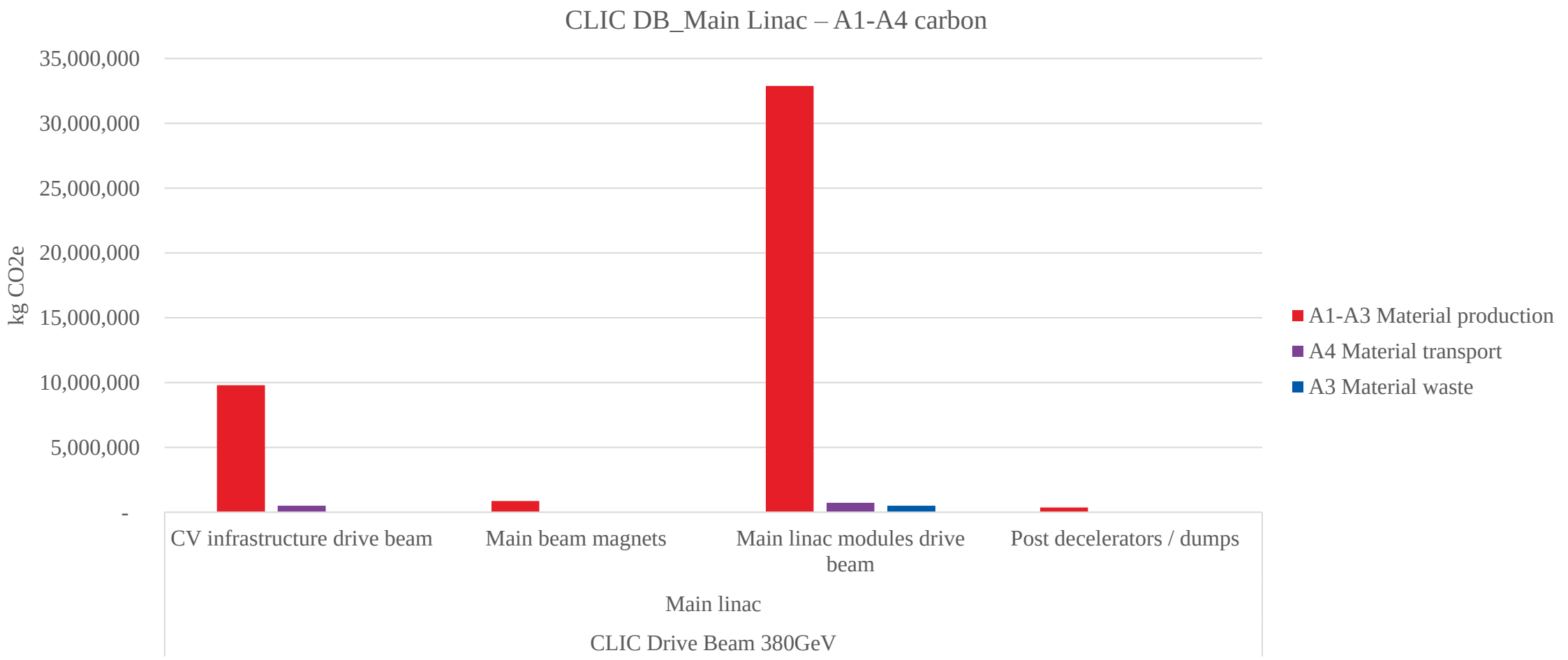
Carbon results, CLIC Drive Beam 380GeV

PRELIMINARY RESULTS



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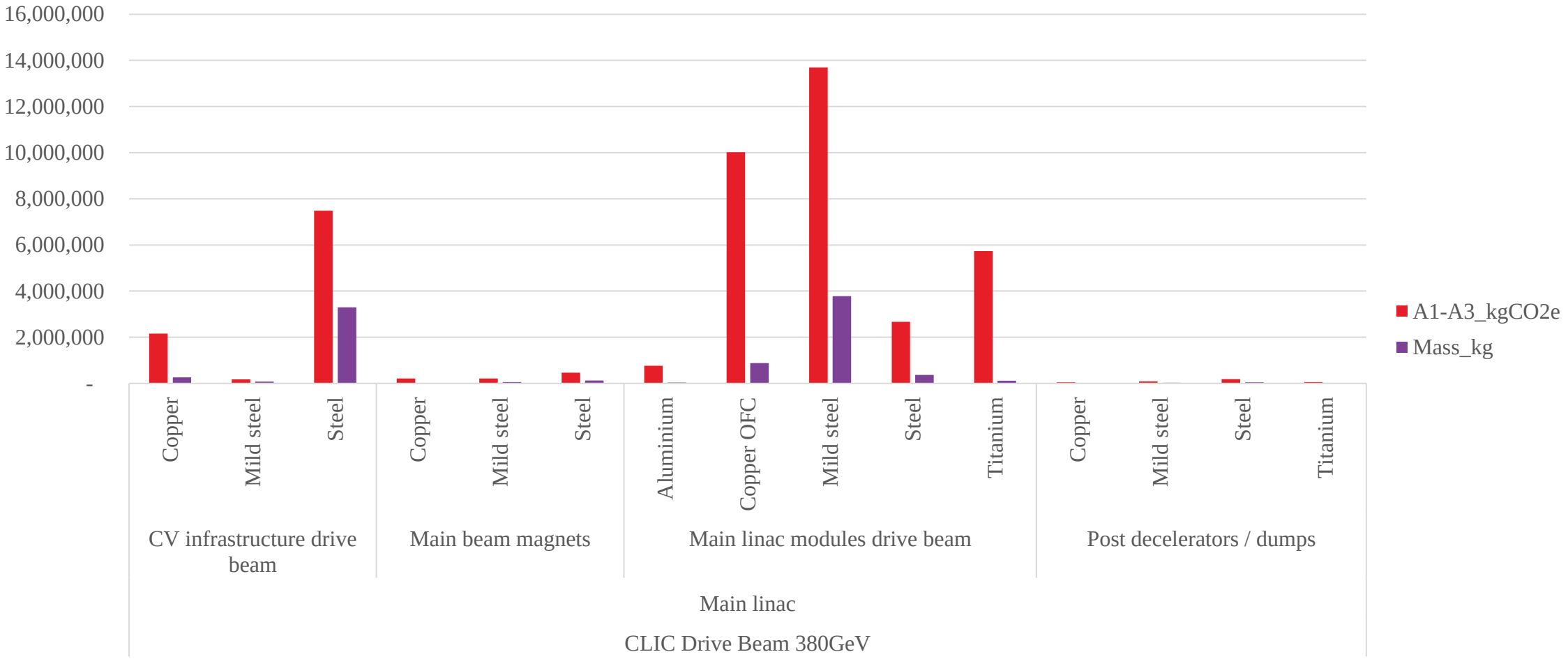
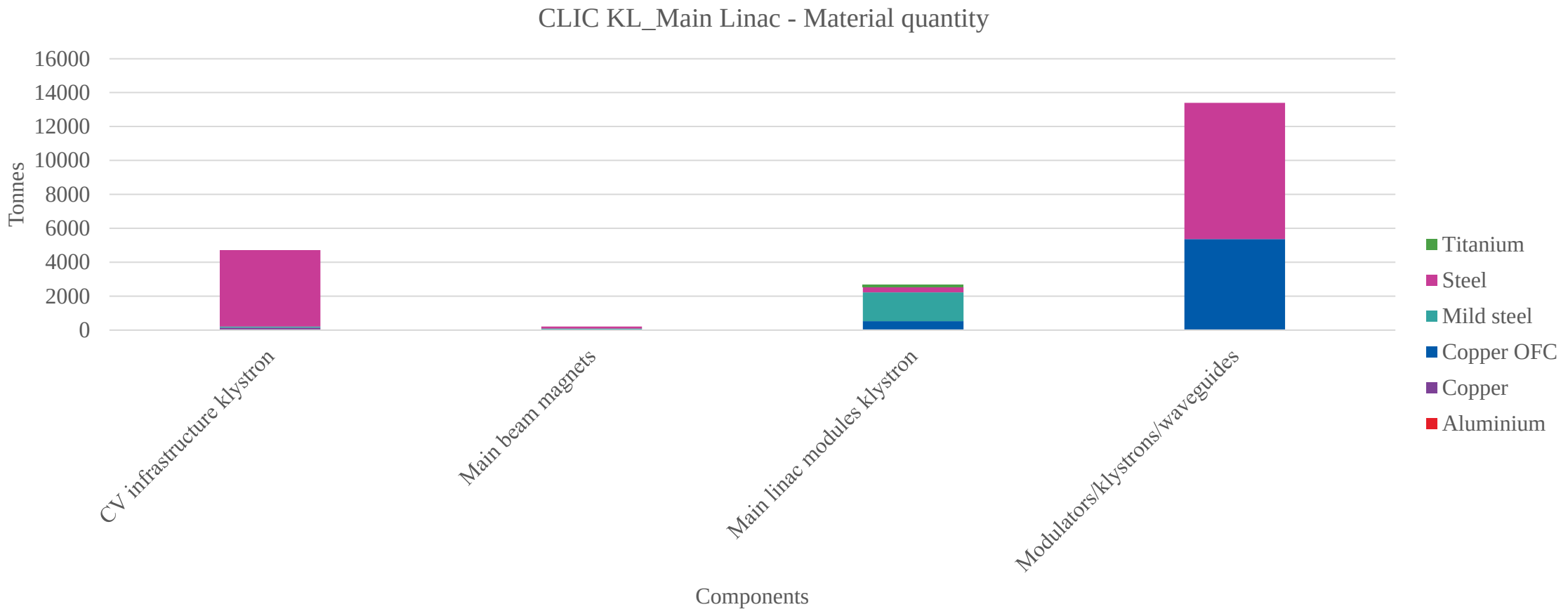
Carbon results, CLIC Drive Beam 380GeV

PRELIMINARY RESULTS



Material analysis, CLIC Klystron 380GeV



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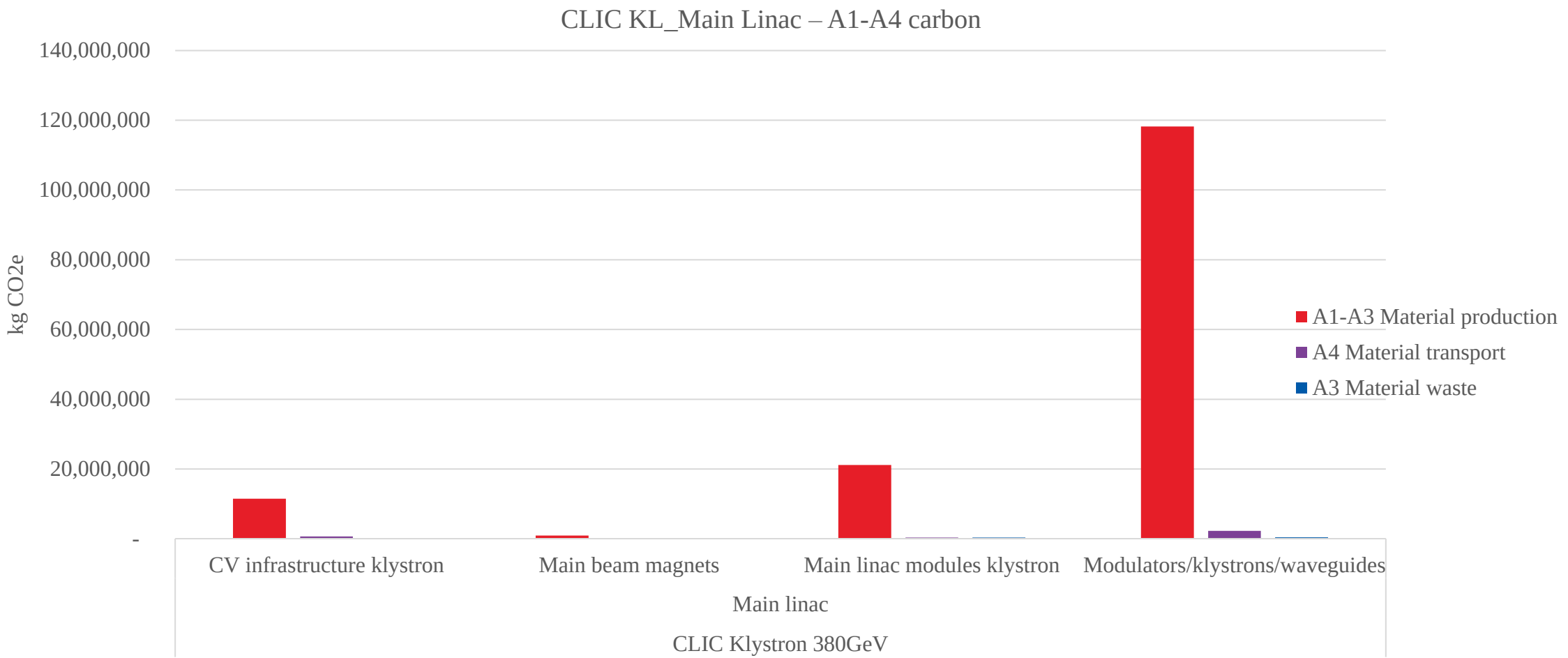
Carbon results, CLIC Klystron 380GeV

PRELIMINARY RESULTS



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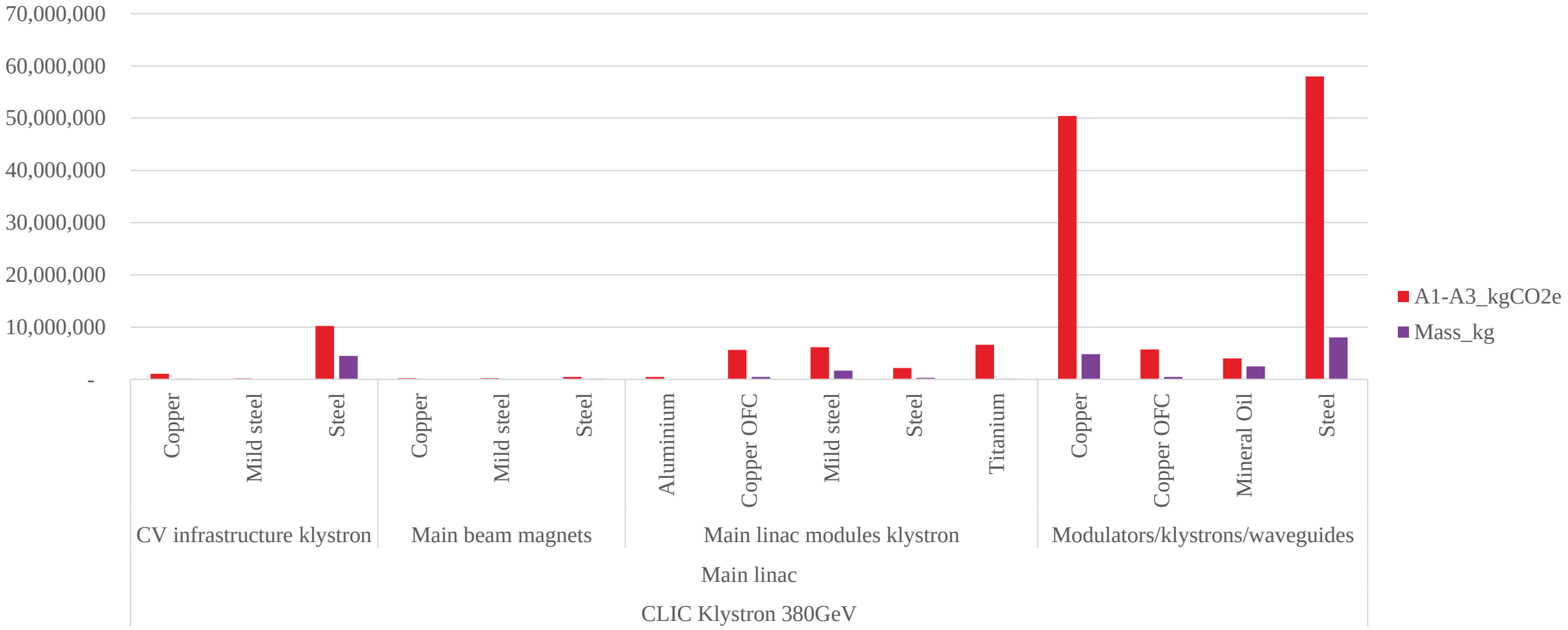
Carbon results, CLIC Klystron 380GeV

PRELIMINARY RESULTS



Niobium modelling

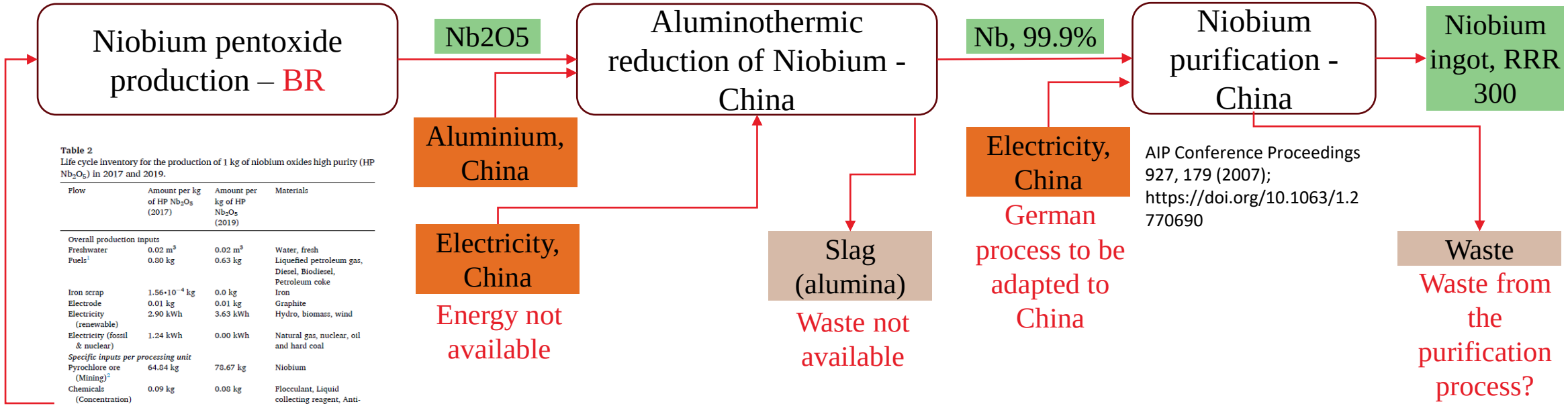


Table 2
Life cycle inventory for the production of 1 kg of niobium oxides high purity (HP Nb_2O_5) in 2017 and 2019.

Flow	Amount per kg of HP Nb_2O_5 (2017)	Amount per kg of HP Nb_2O_5 (2019)	Materials
Overall production inputs			
Freshwater	0.02 m^3	0.02 m^3	Water, fresh
Fuels[1]	0.80 kg	0.63 kg	Liquefied petroleum gas, Diesel, Biodiesel, Petroleum coke
Iron scrap	$1.56 \cdot 10^{-4}$ kg	0.0 kg	Iron
Electrode	0.01 kg	0.01 kg	Graphite
Electricity (renewable)	2.90 kWh	3.63 kWh	Hydro, biomass, wind
Electricity (fossil & nuclear)	1.24 kWh	0.00 kWh	Natural gas, nuclear, oil and hard coal
Specific inputs per processing unit			
Pyrochlore ore (Mining)[2]	64.84 kg	78.67 kg	Niobium
Chemicals (Concentration)	0.09 kg	0.08 kg	Flocculant, Liquid collecting reagent, Anti-foaming agent, Wetting reagent, Hydrochloric acid, Fluosilicic acid, Hydrated lime
Chemicals (Refining)	0.01 kg	0.03 kg	Activated bentonite
Charcoal (Refining)[3]	0.09 kg	0.15 kg	Charcoal residues
Chemicals (Nb oxide processing)	2.25 kg	1.35 kg	Potassium hydroxide, Sodium hydroxide, Sulfuric acid
Outputs			
High purity niobium oxide (Nb oxide processing)	1.00 kg	1.00 kg	Reference product
Aqueous waste flows (Wastewater treatment)	0.02 m^3	0.03 m^3	Wastewater
Atmospheric emissions (overall production)	2.70 kg	2.37 kg	Carbon dioxide, Particulates, Sulfur dioxide, Lead

Journal of Cleaner Production 348 (2022) 131327

New source:
Rangel Alves and dos Reis Coutinho, Life cycle assessment of niobium: A mining and production case study in Brazil, Minerals Engineering Volume 132, 1 March 2019, Pages 275-283

Questions/open points

- For Modulators/klystrons/waveguides of CLIC Klystron, a note in the data collection says that “only 500 t out of 5358 t are OFC copper”, the remaining amount is assumed to be standard copper. Is it correct?
- Metal materials from the database have a default recycled content, shall we assume that this applies to the machine components when material purity is not specified?

- Given the contribution to results, refine model of Copper OFC (current ecoinvent process selected: “electrorefining of copper anodes to produce high grade copper cathodes”).
- Titanium waste treatment: missing in ecoinvent
- Review material mapping assumptions
- Review Niobium assumptions and inputs/outputs quantities

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Next steps

- Clarifications on tunnel service systems
- Update of carbon factors with newer SimaPro and ecoinvent database version
- Finalise summary slide deck of construction LCA results
- Continue with machine componentry LCA

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