Some CO_2 emissions calculations for the FCC ee

Ken Bloom, Veronique Boisvert

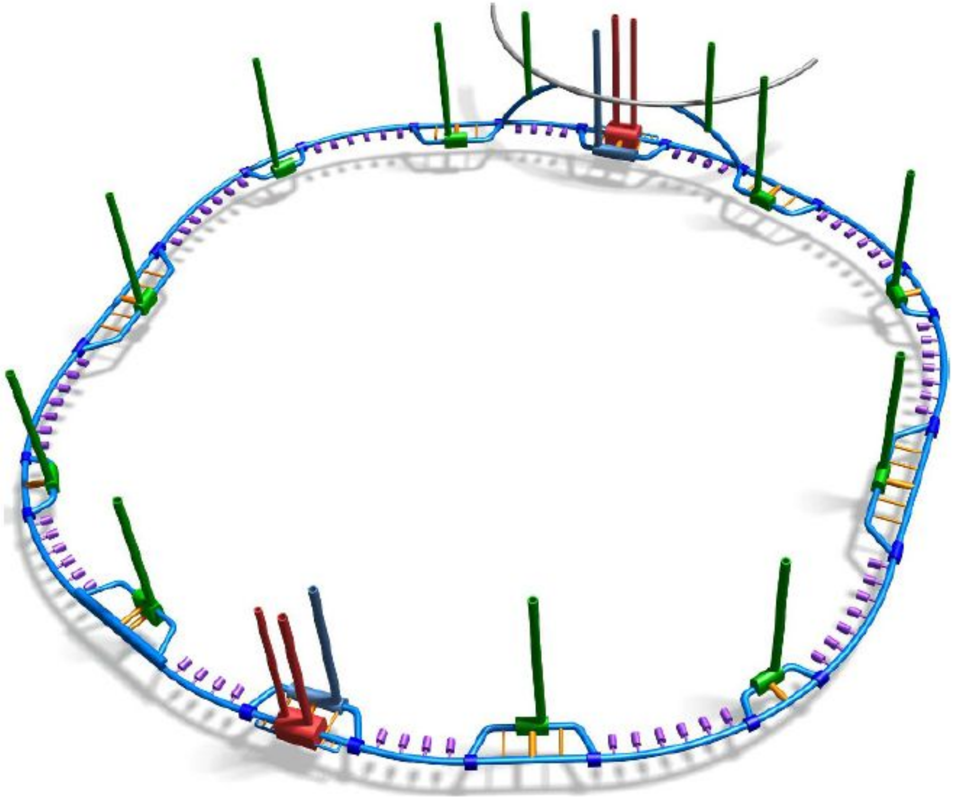
Introduction

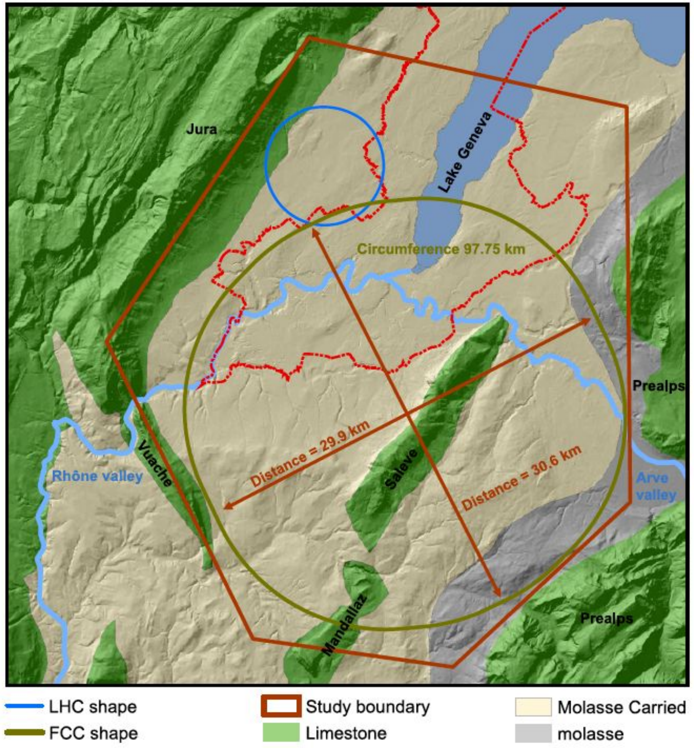
- Want to give an example of CO_2 emissions associated with large energy frontier project: chose FCC-ee (2040+)
- Using CDR

FCC ee civil engineering

- Machine tunnel: one of the longest tunnels in the world: 97.75 km in circumference
- 8 km of bypass tunnels
- 18 shafts
- 12 large caverns
- 12 new surface sites
- Excavation: 9 million cubic metres of spoil (mixture of marls and sandstone)

Some figures for FCC ee





Figures

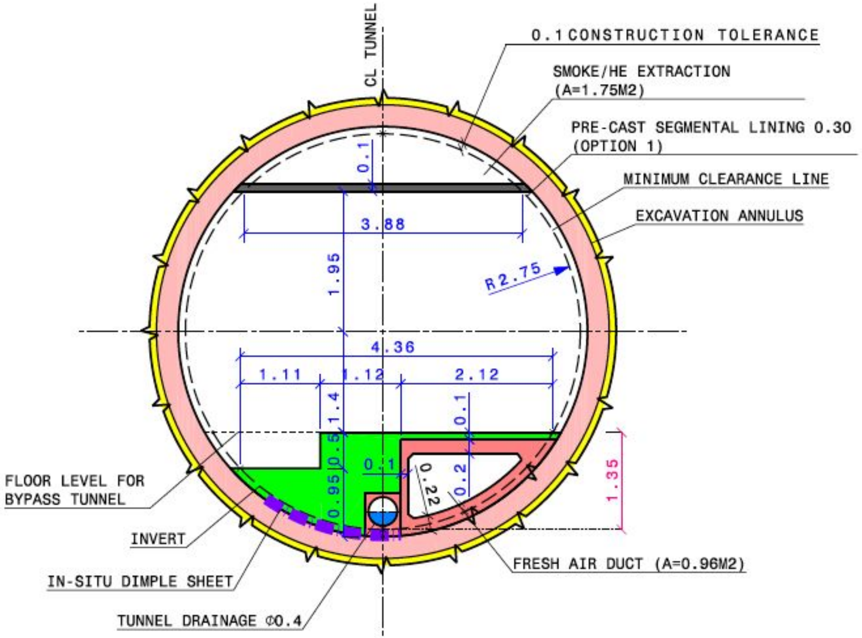


Fig. 4.4. Machine tunnel cross-section in "good" molasse.

Table 4.1. Proposed TBM excavation and lining parameters.

Parameter	TBM tunnel in "good" rock	TBM tunnel in "poor" rock	TBM tunnel in moraines
Minimum internal diameter (m)	5.5	5.5	5.5
Characteristic compressive concrete strength for pre-cast concrete, fck (MPa)	50	50	50
Pre-cast concrete thickness (m)	0.30	0.30	0.45
Reinforcement density for pre-cast concrete	Steel fibre (50%) and bars at 80 kg/m^3	Steel fibre (50%) and bars at 80 kg/m^3	150 kg/m^3
Gasketed segments	Yes	Yes	Yes
Cast in-situ concrete thickness (m)	None	0.25	0.25
Characteristic compressive concrete strength for in-situ concrete, fck (MPa)	–	40	40
Reinforcement for in-situ concrete	–	Local reinforcement cages	Local reinforcement cages
Total radial construction tolerance (m)	0.10	0.10	0.10
Excavation diameter (m)	6.3	6.8	7.1

Table 4.2. Example of the main surface structures at a typical experiment site.

Structure name	Structure type	Dimensions (W × H × L)
Shaft head/detector building	Steel-frame	25 × 25 × 100 m
Reception/office building		10 × 11 × 30 m
Gas building	Concrete	15 × 4 × 40 m
Data centre		20 × 10 × 40 m
Workshop		30 × 12 × 15 m
Cryogenic plant building	Steel-frame (noise insulated)	15 × 12 × 40 m
Ventilation building	Steel-frame	25 × 14 × 40 m
Electrical building	Steel-frame	20 × 6 × 80 m
Power converter building	Steel-frame	25 × 14 × 40 m
Access control building		10 × 4 × 10 m

Calculations: bottom up

- Can try to estimate just amount of concrete from main tunnel and get emissions from that

Minimum internal diameter (m)	5.50
Pre-cast concrete thickness (m)	0.30
Excavation diameter (m)	6.30
Cross section using excavation diameter (m^2)	31.17
Exc diam - Min interal diam (m):	0.80
Circumference of main tunnel (m)	97,750.00
Volume of concrete for main tunnel (m^3):	724,734.01
density of concrete (kg/m^3)	2,400.00
Mass of concrete (kg)	1,739,361,622.2159
1 US ton = kg	907.20
Mass of concrete in tons (US)	1,917,285.74
Fraction of cement in concrete:	0.15
Mass of cement in tons (US)	287,592.86
1 US ton = 0.907 tonne	0.907
Bill Gates: 1 ton of cement = 1 ton of CO2	
US tons of CO2 for tunnel:	287,592.86
tonnes of CO2 for tunnel:	260,846.72

Calculations: top down

- Paper looks at full CO2 emissions from building road tunnels, very comprehensive: https://www.sciencedirect.com/science/article/pii/S0886779820306581?via%3Dihub

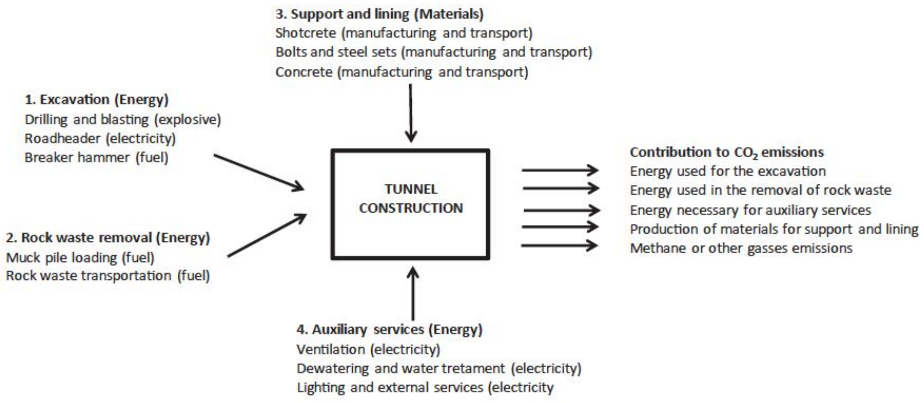


Fig. 1. Schematic overview of the system boundary.

Calculations: top down

Table 1
A schematic overview of the calculation procedure.

Task	Energy and materials consumption			Equations
Task	Fuel (liters)	Electricity (kWh)	Materials (kg)	Equations
Excavation				
Jumbo	$DC_J/833$	EC_J	–	(1), (3)
Platform	$DC_{PL}/833$	–	–	(1)
Explosive	–	–	m_{exp}	
Roadheader	–	EC_{RH}	–	(8)
Breaking hammer	DC_{HBH}	–	–	(10)
Loading and transportation				
Loader	DC_{MPC}	–	–	(11)
Truck or dumper	$DC_{TLM} + DC_T/833$	–	–	(12), (14)
Tunnel facilities				
Tunnel ventilation	–	EC_{TV}	–	(3)
Water pumping	–	EC_{WP}	–	(3)
Water treatment plant	–	EC_{TP}	–	(3)
Tunnel lighting	–	EC_{TL}	–	(3)
External services	–	EC_{ES}	–	(3)
Materials (support/lining)				
Concrete	–	–	M_c	
Steel	–	–	M_{st}	
Materials transportation	$(Cg_{MatO} + Cg_{MatI})/833$	–	–	(18), (19)
Methane emissions				
Methane emissions	–	–	$s_{met} \times M_r$	(21)

Task	CO_2 Total Emissions			Equations
Task	Fuel ($kgCO_2$)	Electricity ($kgCO_2$)	Materials ($kgCO_2$)	Equations
Excavation	$[(DC_J/833)+(DC_{PL}/833) + DC_{HBH}] \times r_D$	$(EC_J + EC_{RH}) \times r_E$	$m_{exp} \times r_{exp}$	(4) to (10)
Loading and transportation	$[DC_{MPC} + DC_{TLM}+(DC_T/833)] \times r_D$	–	–	(13) to (15)
Tunnel facilities	–	$(EC_{TV} + EC_{WP} + EC_{TP} + EC_{TL} + EC_{ES}) \times r_E$	–	(4)
Materials (support/lining)	$[(Cg_{MatO}/833)+(Cg_{MatI}/833)] \times r_D$	–	$M_c \times r_c + M_{st} \times r_{st}$	(16) to (19)
Methane emissions	–	–	$s_{met} \times M_r \times r_{met}$	(21)

Calculations: top down

- What matters is the rock mass quality (RMR) and the cross section and length

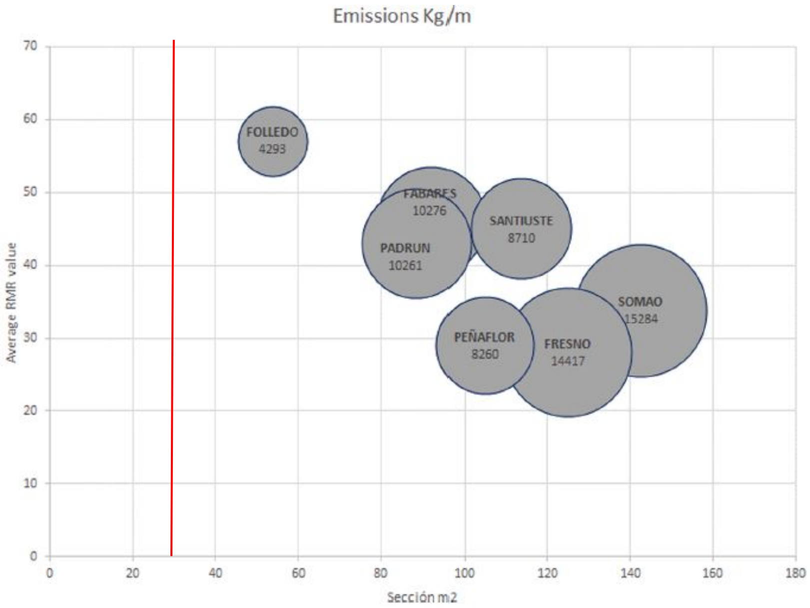


Fig. 8. Influence of the *RMR* and the tunnel section *S* in the emissions ratio.

Table 5 of tunnel paper: very favourable (cross section of 60 m^2) emissions (kgCO2/m)	5,000.00
tonnes of CO2 for tunnel using above:	488,750.00
Different kgCO2/m	10,000.00
tonnes of CO2 for tunnel using above:	977,500.00

Comparisons with other types of construction (for context)

- People have a sense of what a big building is.
- A World Business Council for Sustainable Development [report](#) on whole life cycle case studies indicates that “embodied” carbon during construction of buildings (Category A) is 500-600 $kgCO_2e/m^2$.
    - Let’s use 550 for simplicity.

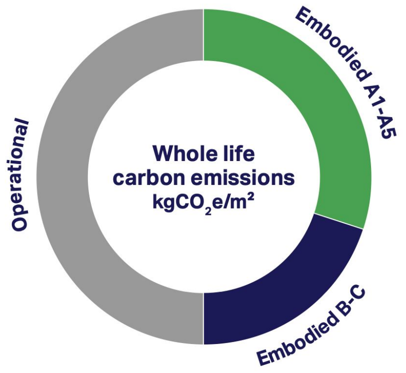


Figure 6: Building System Carbon Framework, WBCSD (2020)[11]

BUILDING LAYERS	BUILDING STAGES						BEYOND LIFE
	PRODUCTS	CONSTRUCTION	USE		END OF LIFE	EMISSIONS	BEYOND LIFE
	A1-A3	A4-A5	B1-B5	B6-B7	C	$kgCO_2/m^2$	D
Structure Foundation, load-bearing							
Skin Windows, roof, insulations							
Space plan Interior finishes							
Services Mechanical, electrical, plumbing							
Stuff *(optional)* Furniture and appliances							
Building carbon emissions							
Carbon compensation Removals and offset							

● Embodied carbon ● Operational carbon ● Partial and total sums

Comparisons with other types of construction (for context)

- NYC's 1 World Trade Center is 94 stories tall, square footage 3.5M ft^2
- Do some math: 178,838,550 $kgCO_2e$ = 197,136 tons CO_2e.
- FCC tunnel is several 1WTCs of carbon impact.
- Is that big or small?

What to write in white paper for that section?

- Very brief reminder of the layout of the FCCee (number of buildings, dimensions of tunnel, etc.)
- Present a few numbers related with the CO2 emissions of the main tunnel
- Give comparisons with other buildings/construction projects
- This is just the main tunnel, but then all the other infrastructure, including materials used for the accelerators, etc.

Recommendations

- New projects need to report on their planned emissions as part of their environmental assessment, so it becomes part of the assessment criteria
  - There might be a need for a standard way to calculate those for PP projects
- For long term projects it is important to also consider the evolving societal context
  - Eg demand on the electricity grid now not the same as in 2040, carbon pricing, etc.
- …