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Accelerator Impact Report: RUEDI

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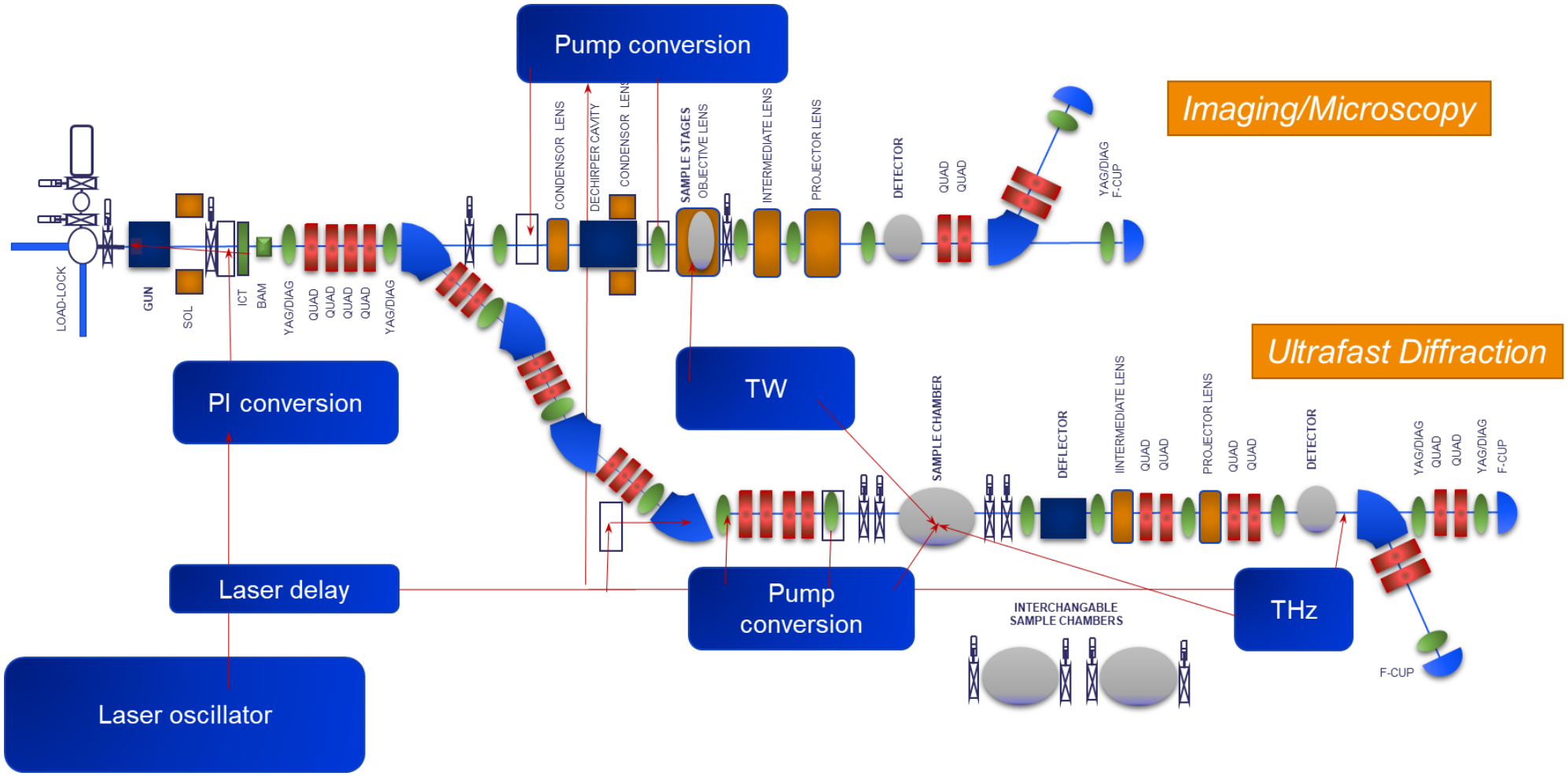
Lasers

9th IFAST LER Workshop 2024

An Introduction to RUEDI

Currently in TDR phase
Produces MeV electron energies



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RUEDI: Relativistic Ultra-fast Electron Diffraction and Imaging

Note: NC-RF and no LINACs

Goals of LCA

- Understand in each area what are the largest sources
  - What to focus on and not focus on
- Start to look at mitigation strategies
- Developing the tools to do this type of analysis for the future

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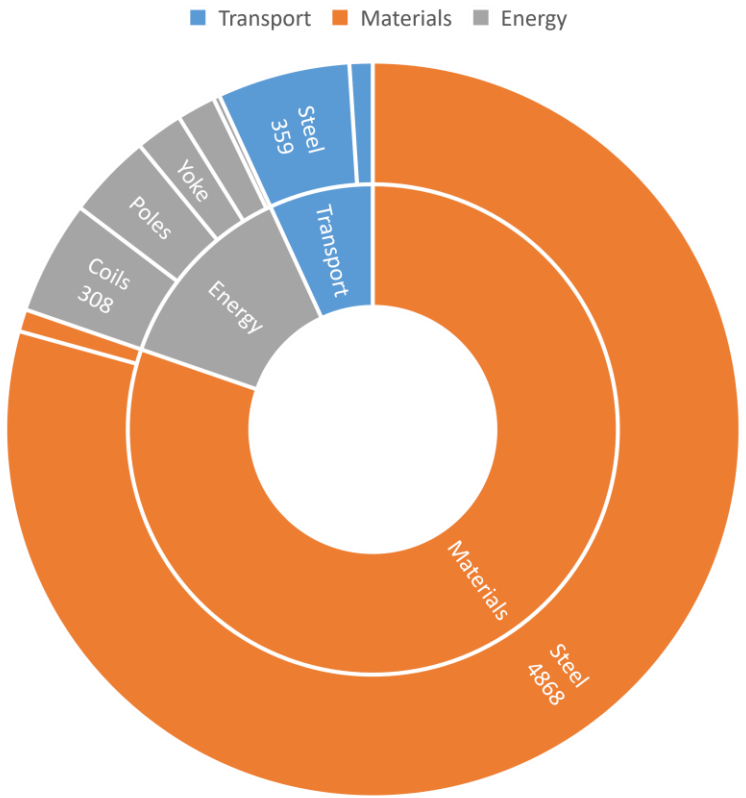
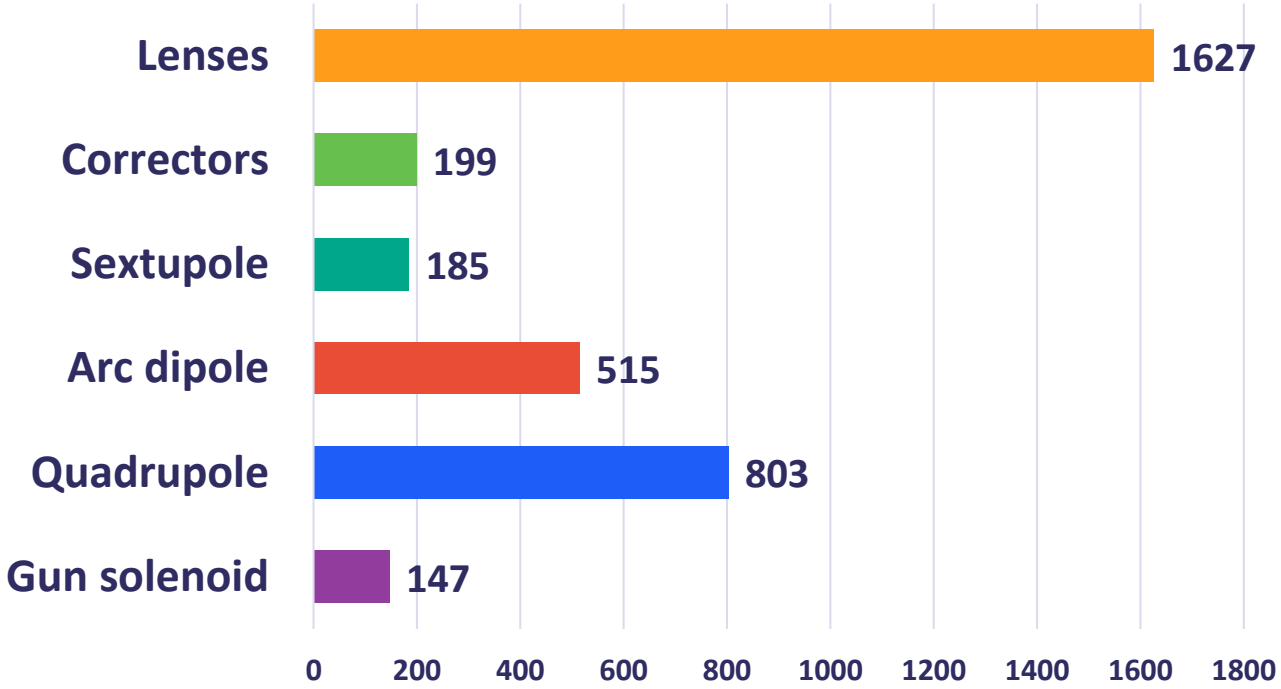
Magnets: Materials impact

RUEDI has 61 magnets: 30 quadrupoles, 6 dipoles, 4 sextupoles, 12 correctors, 8 lenses and 1 solenoid

Magnet LCA from Tesla



Total **6.2 tCO_2e** (2.9 $kgCO_2e$ / kg of finished product)



Material footprint [kgCO2e]

Total: 3.5 tonnes of CO_2e

- 30% using electric furnaces

Magnets

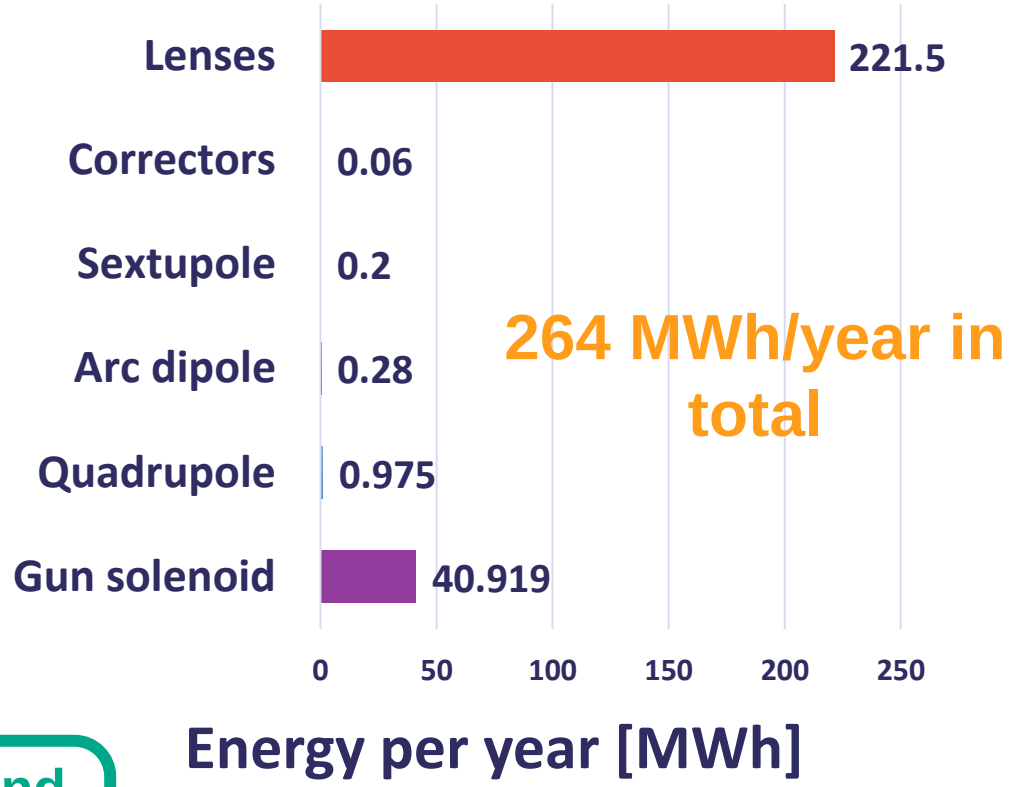
The carbon intensity of electricity in 2030 - 2040: 77.4 gCO2e/kWh

Power consumption

- Estimated from magnet design properties
- Only lenses cooled increasing power by 35%
- Carbon emissions dominated by the power consumption
- Aperture size particularly important for reducing impact, followed by current density

Total: 20 tonnes of CO_2e per year

6x manufacturing carbon footprint!



Prioritise efficiency for lenses and solenoids, as well as turning off when not in use!

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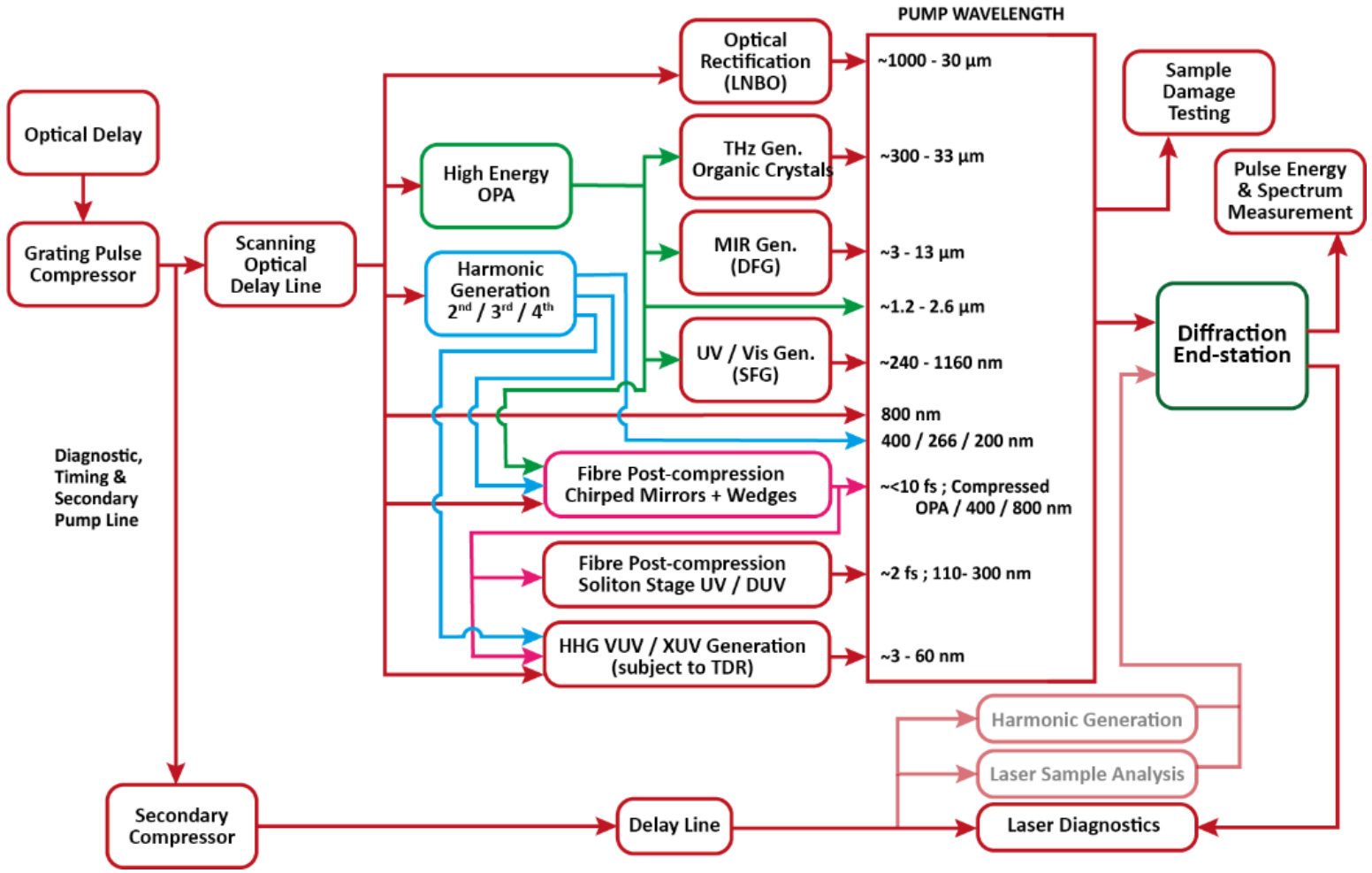
Laser and Timing system

Introduction

- Very complex, need pump/probe sources from EUV to THz (3nm to 1mm) at each end station
- A terawatt laser
- Two UV generating systems for photoinjector
- A THz source for diagnostics
- All this needs synchronised with the RF!



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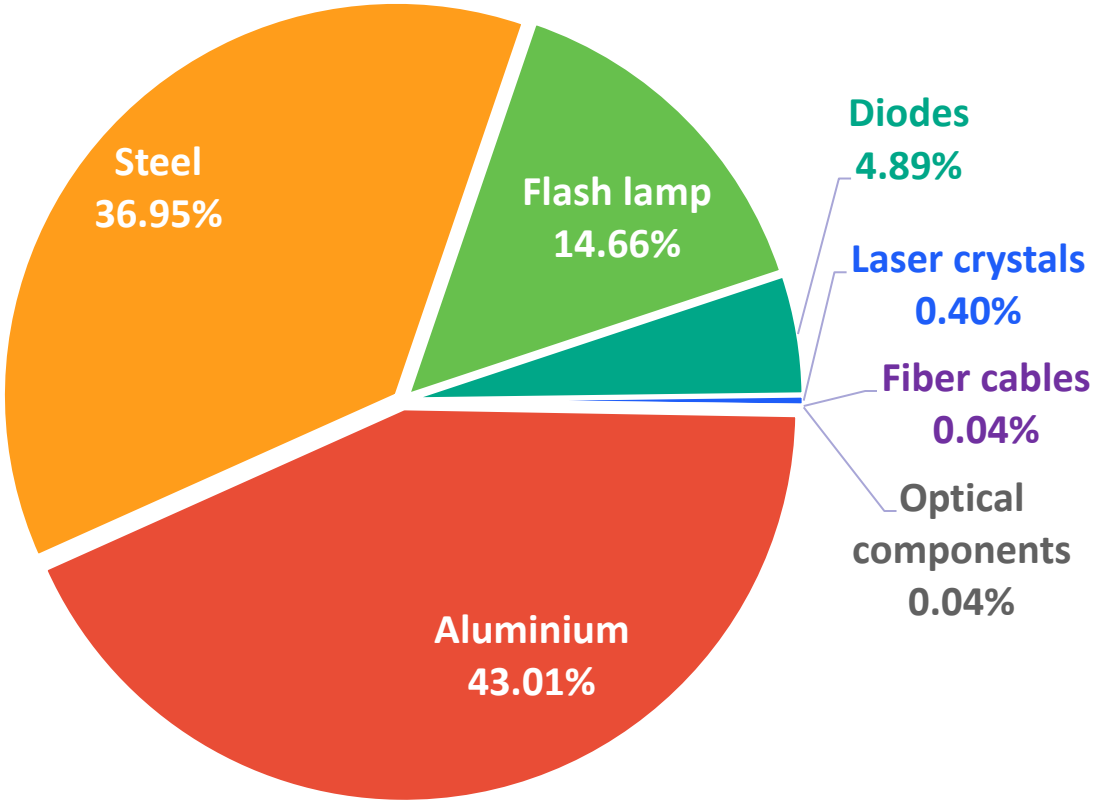
Laser and Timing system

Manufacturing

- Aluminium = housing of laser units and breadboards
- Steel = vacuum vessels and optical tables
- Assumed aluminium and steel is from China 20 CO_2e/kg
- European aluminium: 6.7 kg CO_2e/kg, Mexican steel: 1.08 kg CO_2e/kg
- Can reduce by 18 tonnes, or 44% by ensuring aluminium and steel come from ‘greener’ countries or even better… recycled sources



39 tonnes of CO_2 equivalent to:

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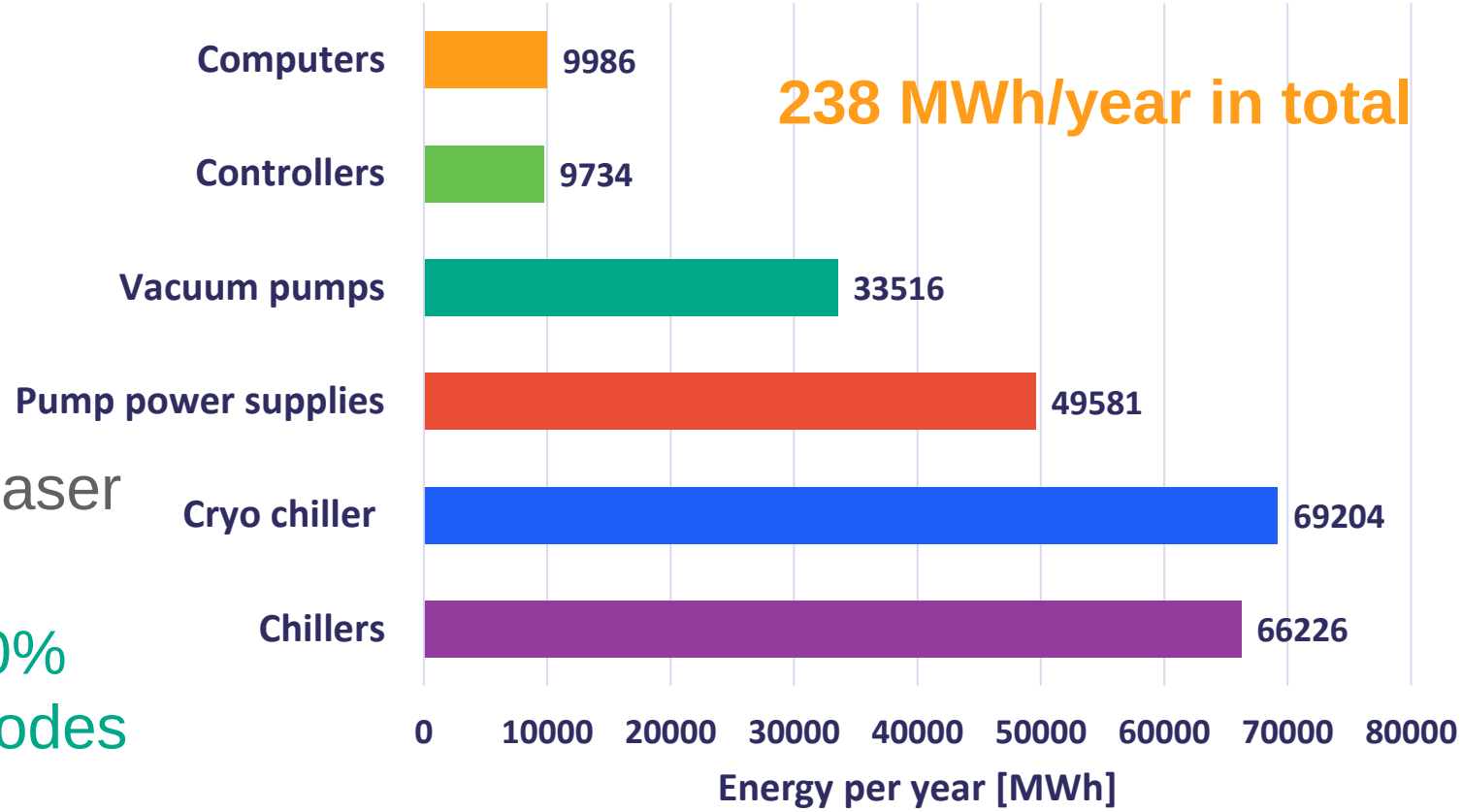
Laser and Timing System

Power consumption

- 57% from chillers
- Water cooled > air cooled
- Cryogenic cooling? 25 - 30% laser conversion efficiency boost
- Ytterbium based systems = 50% more energy available from diodes but very expensive



Total: 46 tonnes of CO_2e/year

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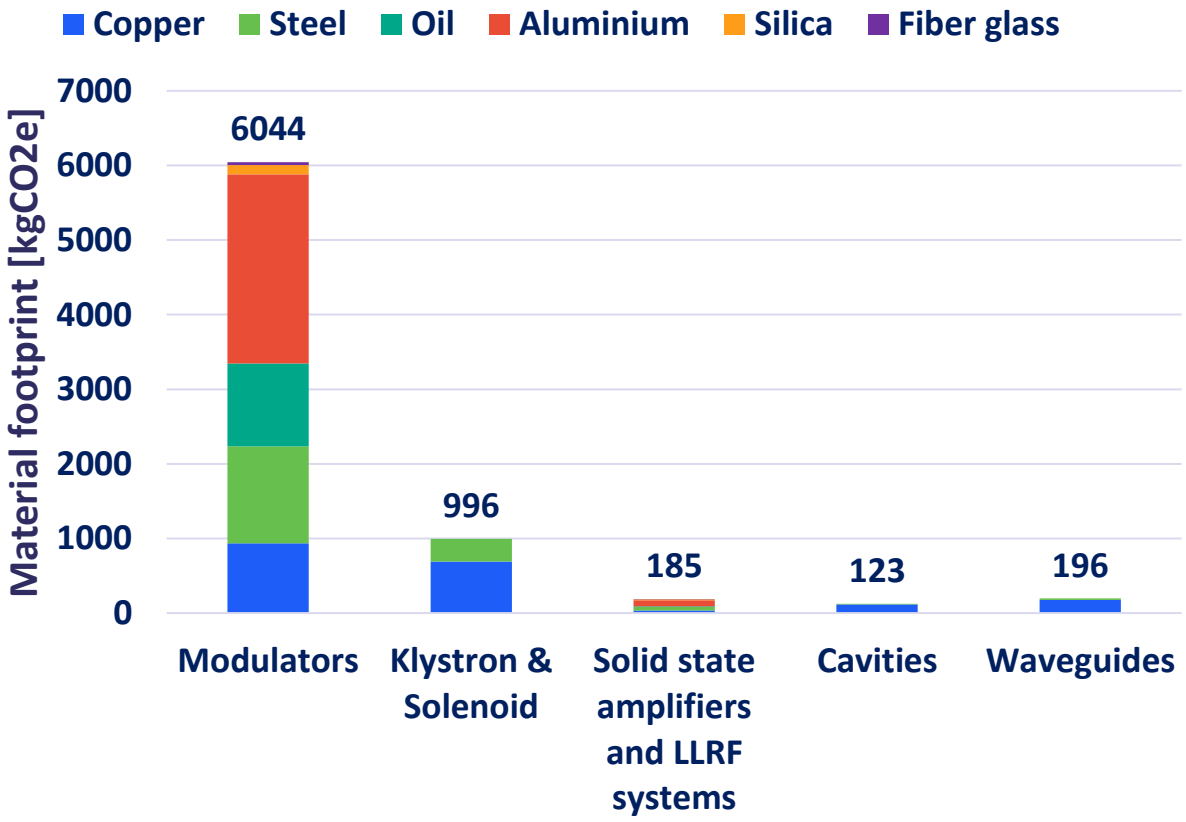
RF systems: Materials impact

- RF system:
  - 1 x RF photoinjector gun, transverse deflecting cavity
  - 2 x modulators, klystrons and solenoids
  - 3 x cavities
  - 4 x solid state amplifiers and LLRF systems
- Items such as modulator and LLRF system material breakdown estimated
- Suppliers often cannot give sources of their materials so averages have been assumed
- Single material items (cavities and waveguides) better choices could potentially be made

Total: 7.5 tonnes of CO_2e =



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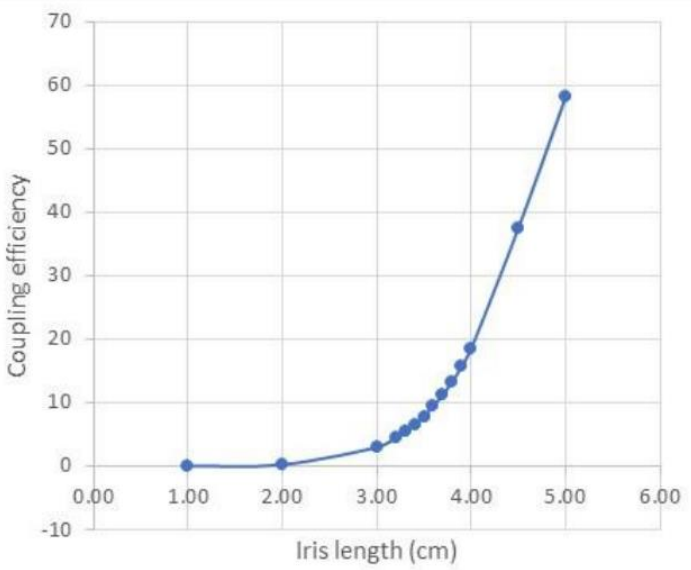
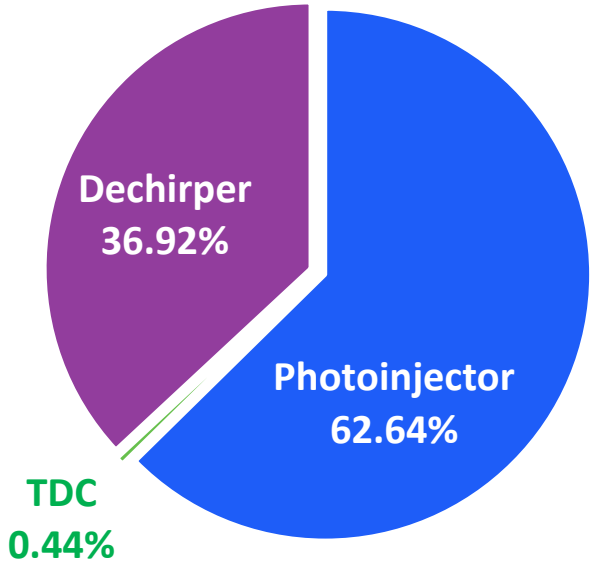
RF system

Power consumption

- Using our knowledge of losses, and the power needed for other components, the power of the modulators was estimated.
- Photoinjector efficiency = 0.003%!
- Higher current machines are more efficient
- Good cavity design can also help improve
  - Waveguide to cavity efficiency improved through iris coupling optimisation[1]
- Highly efficient RF sources talk after discussion by Igor Syratchev!





48 MWh/year or 3.5 tonnes of CO_2e/year

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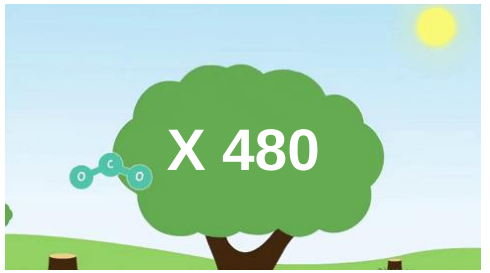
Diagnostics and controls

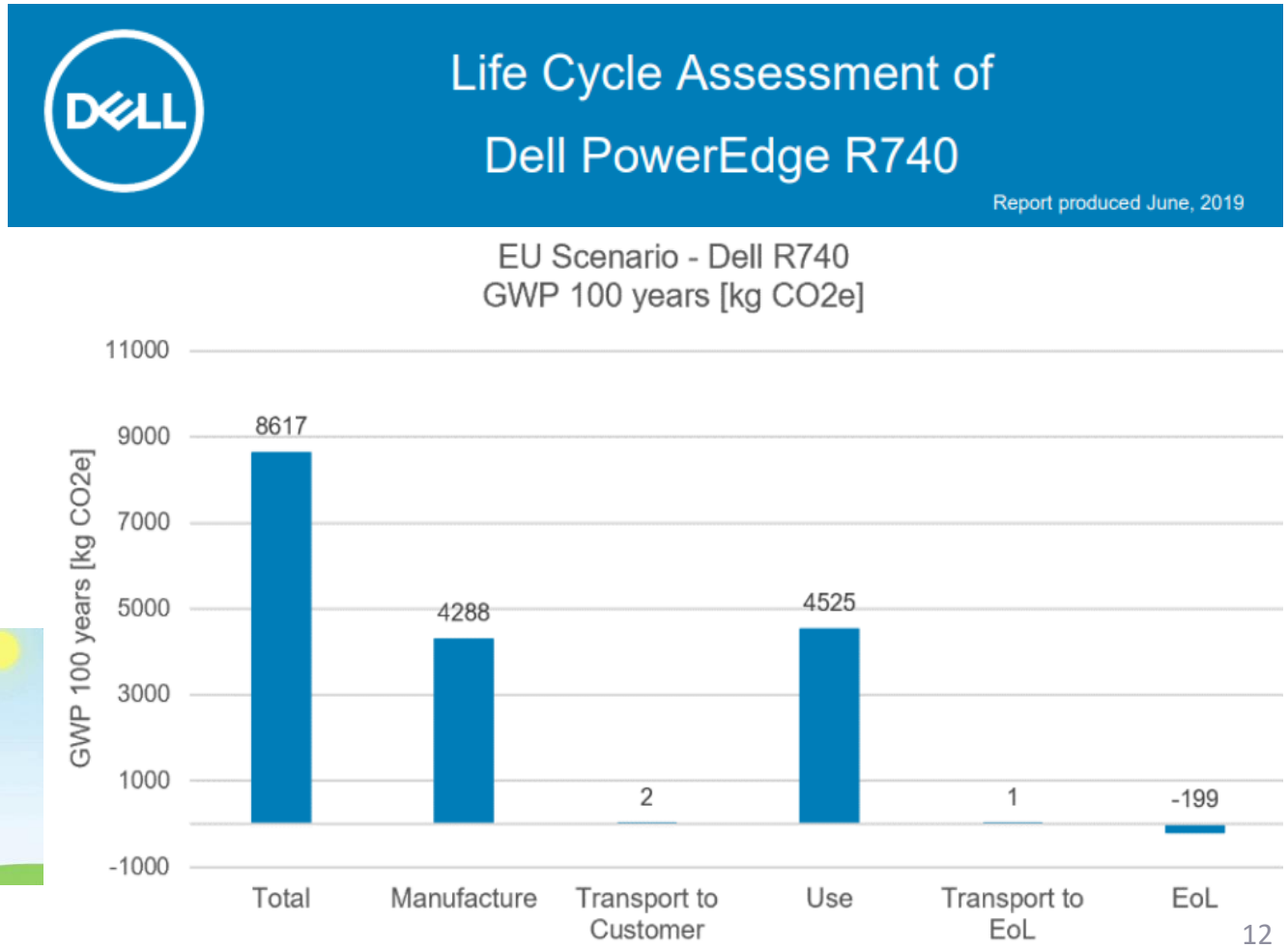
- Many companies starting to release impact reports!
- Assumed more complicated components (ie oscilloscopes, processing crates) similar impact scaled by size
- Scaled numbers based on CLARA
- Electricity far more impactful over lifetime
- Utilise low power mode and turning components outside of operation (idle mode = 1/10 energy usage)
- Code efficiently

Total energy impact: 9.6 tonnes of CO_2e/year



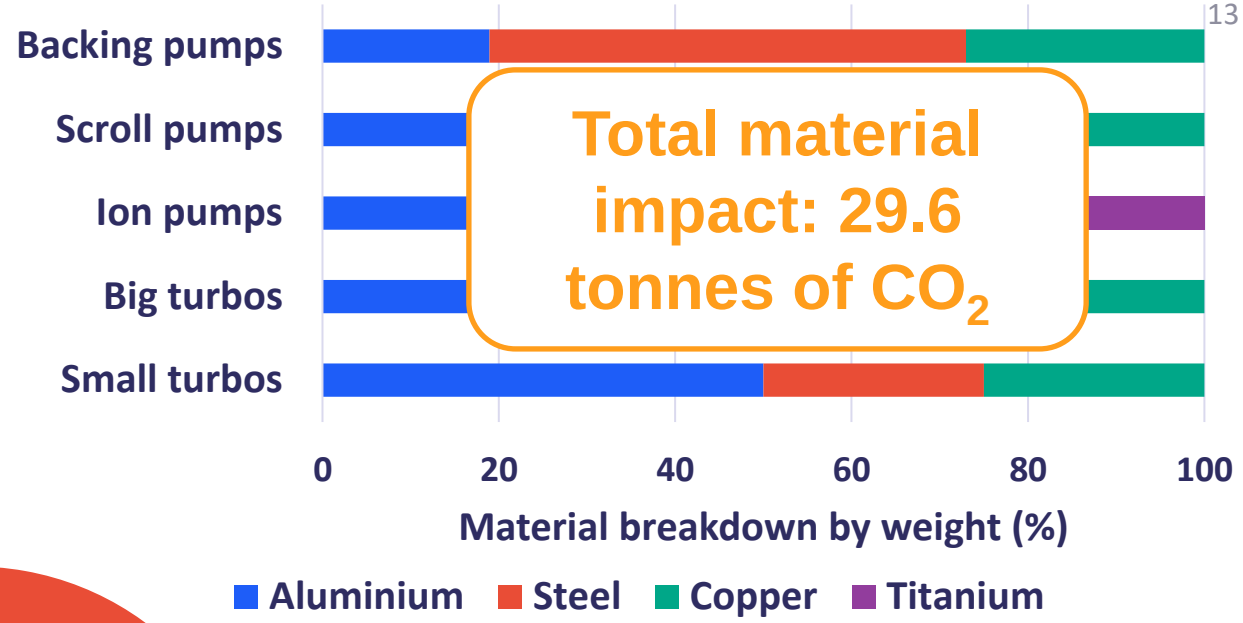
Total materials impact: 13.5 tonnes of CO_2e

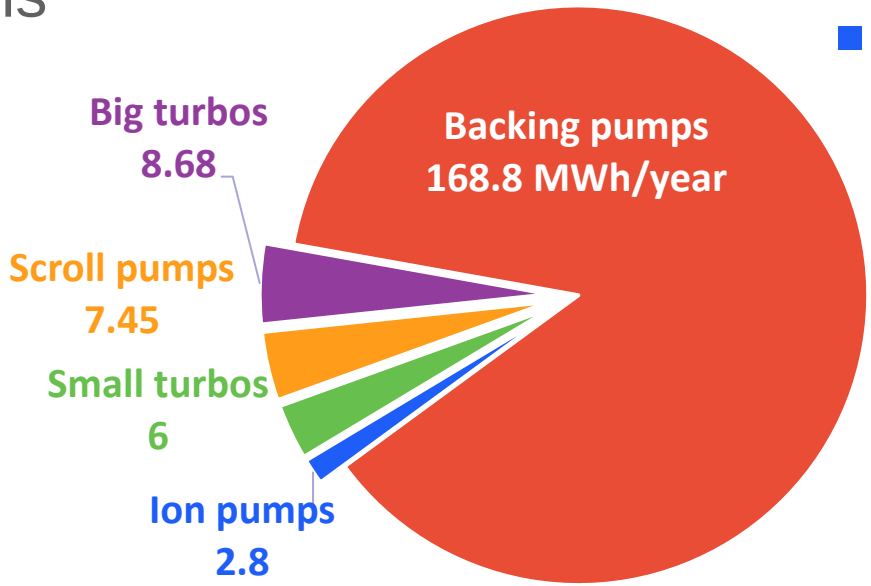
■ **Materials impact [tonnes of CO2e]**



Vacuum

- Most systems need $8x10^{-9}$, TW and IR lasers only need 10^{-7}
- One differential pumping line for gas-based laser systems
- Turn off backing pumps as soon as possible
- Consider NEG pumps and coatings





193.7 MWh/year or 15 tonnes of CO_2e/year

YAG stations, beampipes, and sample and detector stations all 100% stainless steel.

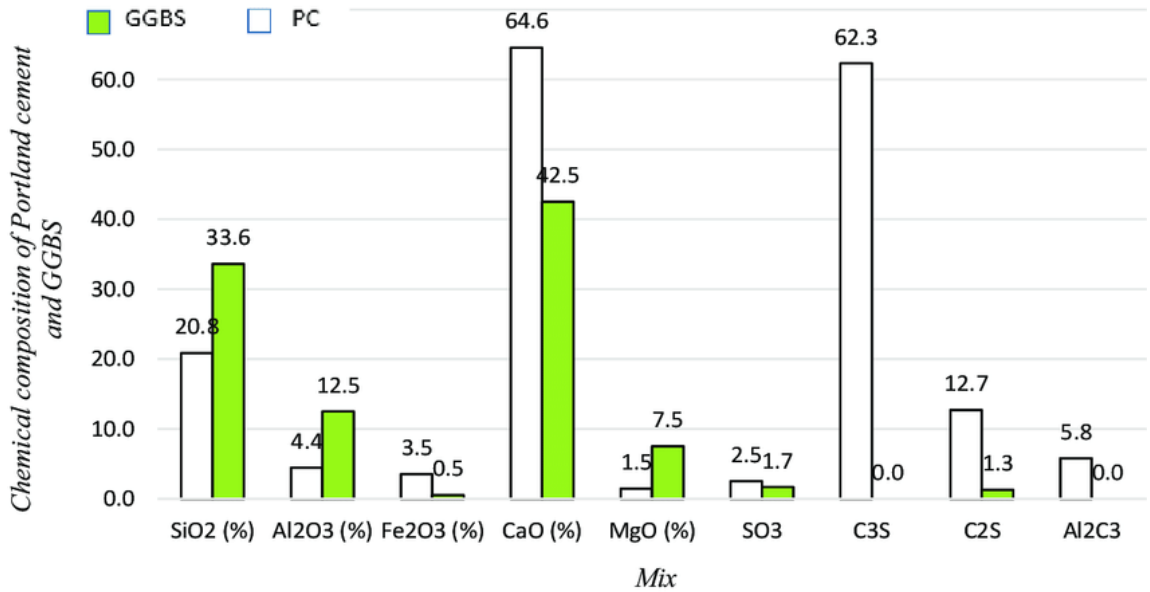
Item	Amount
Small turbos	10
Big turbos	23
Flanges	180
Beampipes	48 metres
Sample and detector chambers	6
YAG stations	18
Ion pumps	35
Scroll pumps	6
Backing pumps	15

Total: 137 tonnes of CO_2e

Shielding

Without reuse of floor slab, total: 284 tonnes of CO_2e

- 927 tonnes of concrete for 20 m by 4.5 m
- RUEDI reuses existing building, and floor slab
- Use more shielding closer to the source
- Consider different types of concretes?
  - STFC's EPAC reduced emissions by 50% using mostly GGBS instead of PC
- Concrete can last 30 years or more = REUSE!
  - Need standardised sizing and suitable persistent documentation



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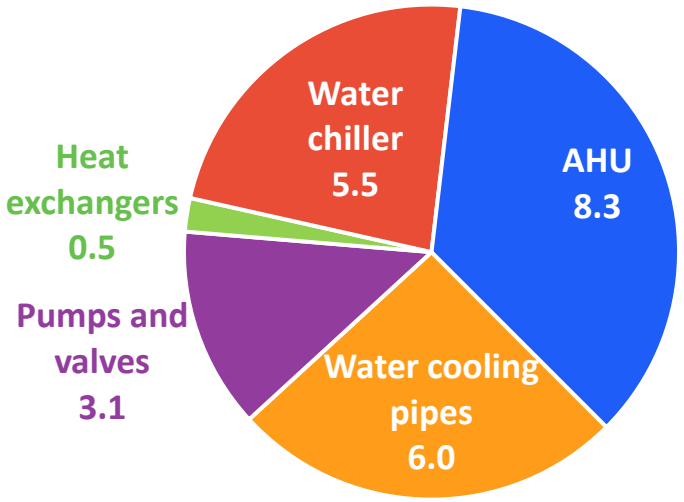
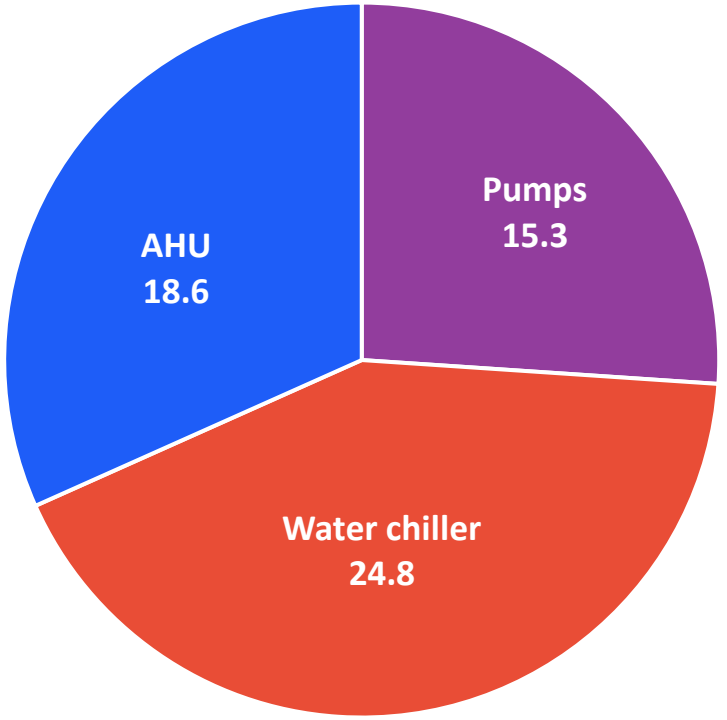
Cooling infrastructure

- Everything produces heat!
- 11 AHU needed for AC, assumed to be about 70% steel and 30% copper
- Everything else assumed stainless steel
- Variable speed drivers for AC and using motion sensitive LEDS help reduce Diamond electricity by 20%
- Using cold winter air = 75% reduction in electricity
- Ground water cooling



Material impact CO_2e



Electricity impact CO_2e/year

Total material impact: 23.4 tonnes of CO_2e

= Total electricity impact: 58.7 tonnes of CO_2e/year

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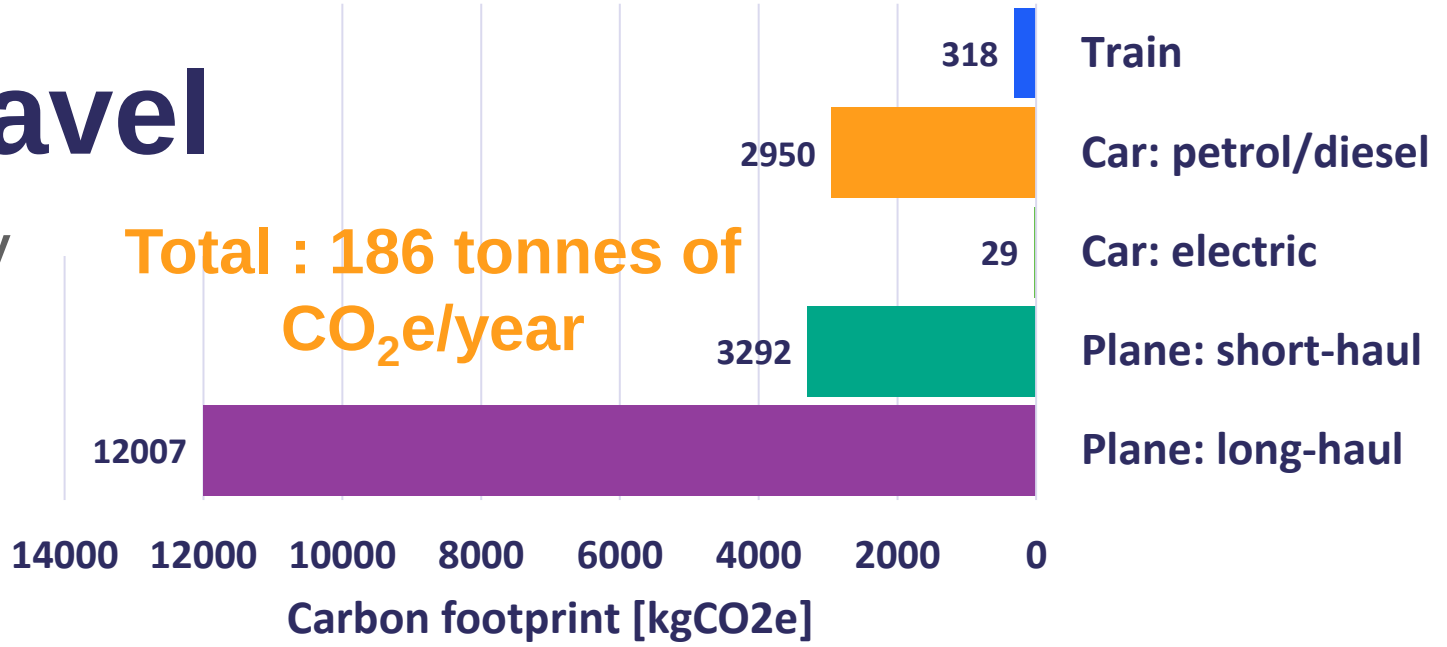
User and staff travel

- RUEDI is a national facility so mainly UK travel
- Travel is a key part of science, particularly for early careers
- Prioritise low-carbon transport despite costs
- Offer ‘sample by post’ for standardised experiments



Mode of transport	Estimated number of trips	Carbon intensity [$kgCO_2e/km$]
Train	40	0.013
Car: petrol/diesel	30	0.164
Car: electric	30	0.010
Plane: short-haul	6	0.183
Plane: long-haul	3	0.200

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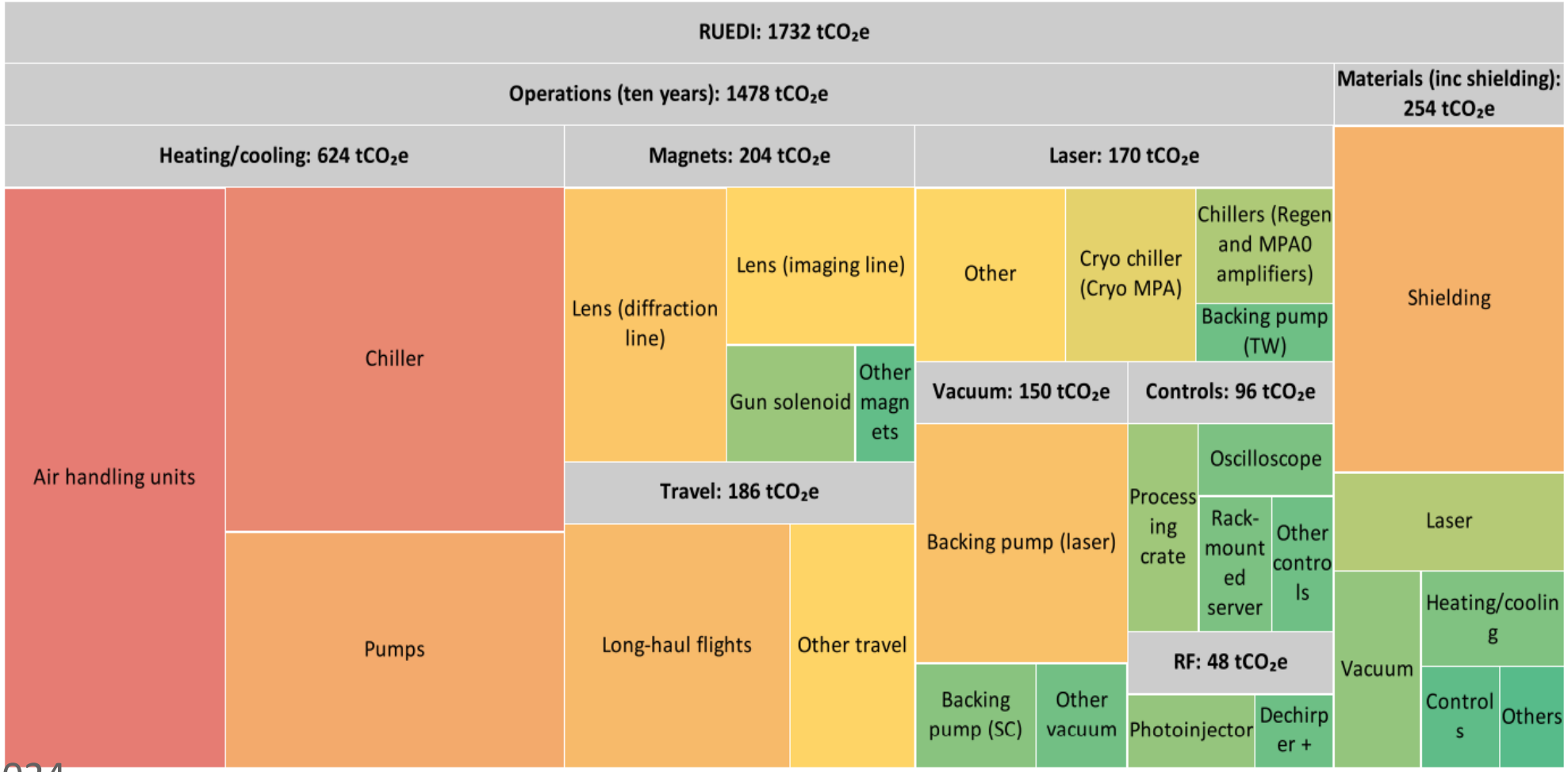
Overview

- **Over a decade operations dominate: this should be our focus**
- Particularly: magnet lenses (use quads and PM?), reusing waste heat, using variable drive for as few chillers as possible, and explore demand shifting

- Reusable shielding and investigating other concrete grade
- Submetering! Helps us make retrofit decisions



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Other STFC activities

- Haven’t mentioned all the other labs a facility like this might need to run!
  - Currently trying to encourage lab managers to conduct energy use assessments as well as doing this for our current facility
- Joint STFC/IET PAEN workshop at ESA, Harwell Campus 23rd May: keep an eye on IET website for details
- Undergoing sustainability assessment of UKXFEL
- Sustainable accelerator website – in development!

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Thank you

Any Questions?

Link to report: https://www.astec.stfc.ac.uk/Pages/Sustainable-Accelerators-Task-Force-Report-.aspx