EU-RFCS 899248

ECT 2023

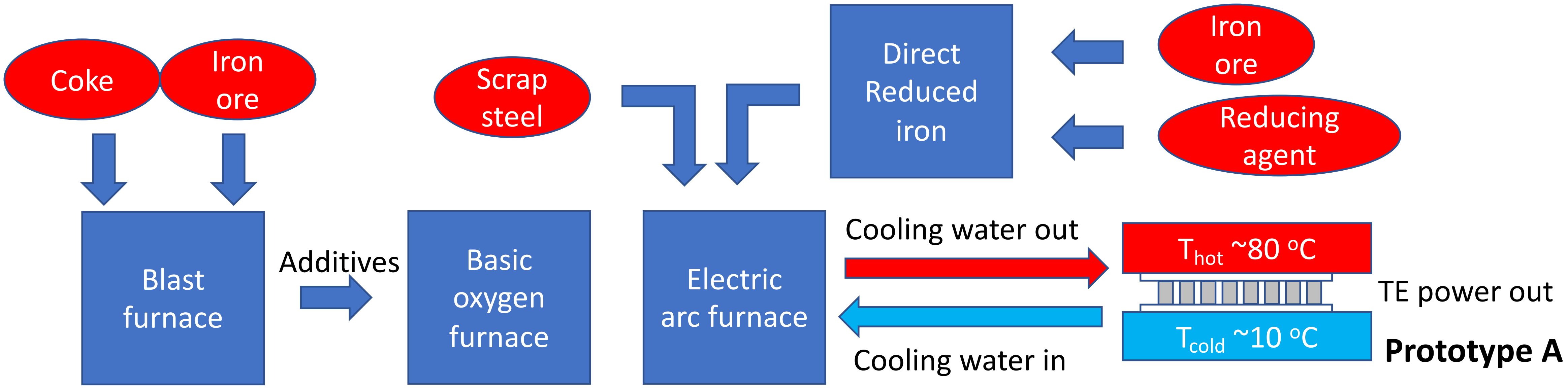
Utilising computational design tools to simulate novel thermoelectric systems for energy recovery in steel making processes

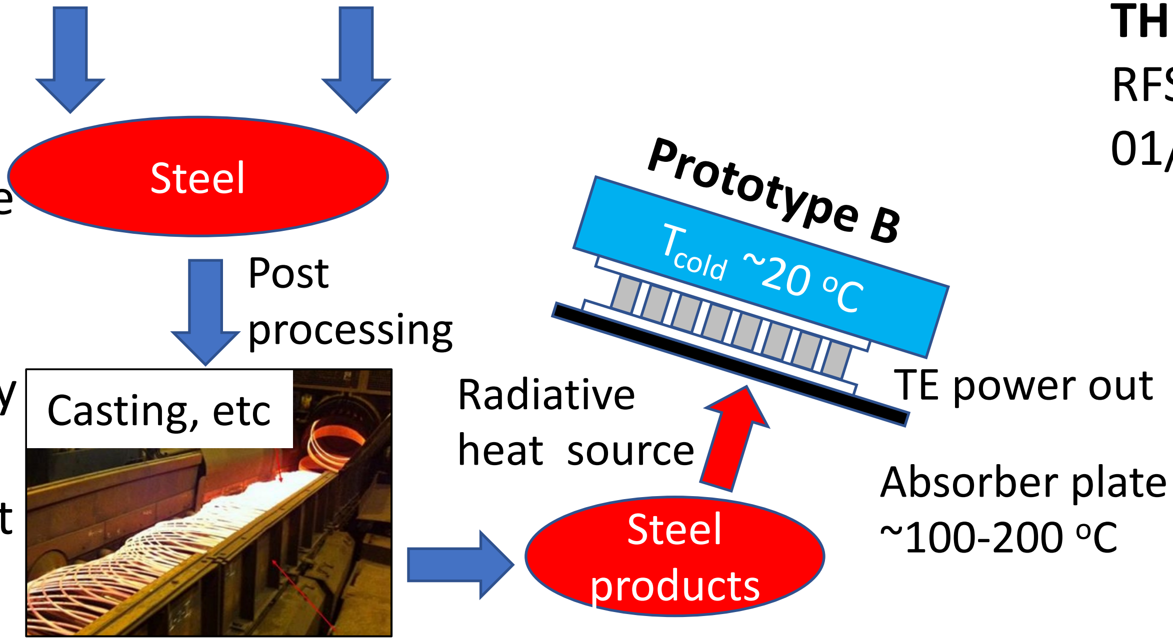
18/09/2023

M. Phillips[1], U. Chiarotti[2], V. Moroli[2], F. Mintus[3], S. Bosi[4], M. Padovan[4], S. Spagnul[4], D. Gaspardo[5], M. Chini[5], A Viotto[5], L. Bianco[5], T. Bause[6], P. Fritella[6], N. Katenbrink[7], G Min[1]

1. School of Engineering, Cardiff University UK
2. Rina Consulting – Centro Sviluppo Materiali SpA, Rome Italy,
3 VDEh-Betriebsforschungsinstitut GmbH, Germany
4 Ergolines lab s.r.l., Italy
5 Ferriere Nord S.p.A, Italy
6 ESF Elbe-Stahlwerke Feralpi GmbH, Riesa D, Germany
7 QuickOhm Kupper & Co GMBH, Germany

Steel making process and the inTEGrated project



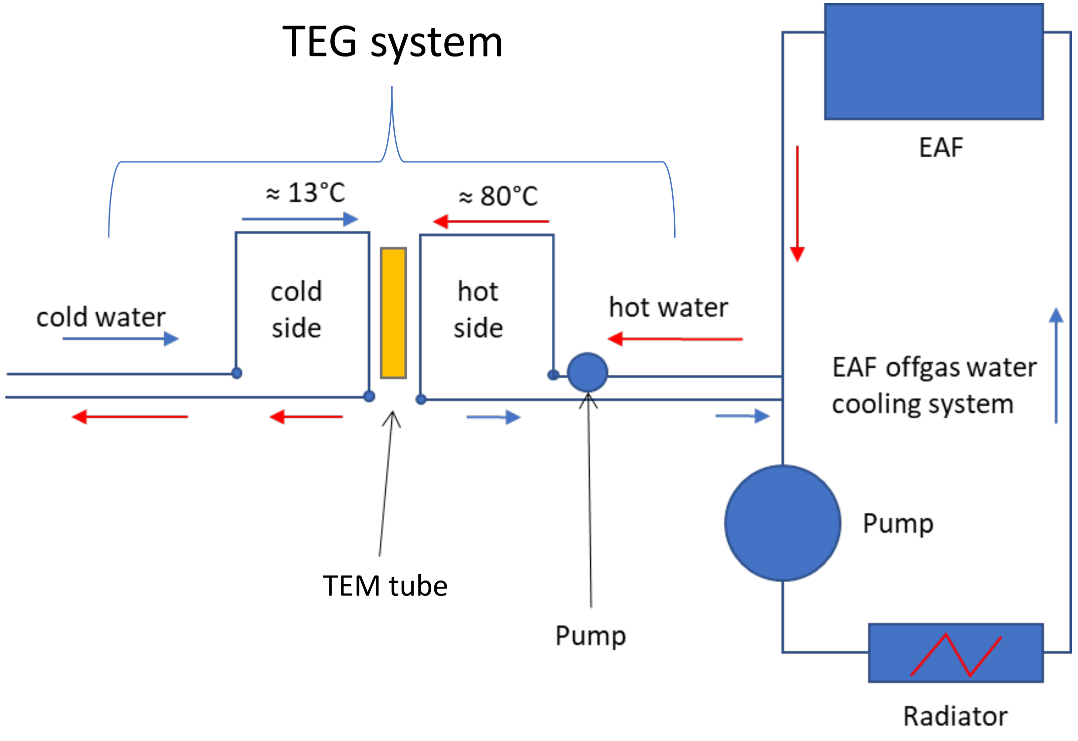


- Thermoelectric generation (TEG) part of a package of measures to improve efficiency
- Main advantage: Low interference with existing processes with good power alignment
- Main disadvantage: Low efficiency of TE modules
- What can we achieve with current TE technology?

THERELEXPRO
RFSR-CT-2013-00029
01/07/2013 – 30/06/2016

InTEGrated
RFCS-2019- 899248
July 2020-present

Prototype A design

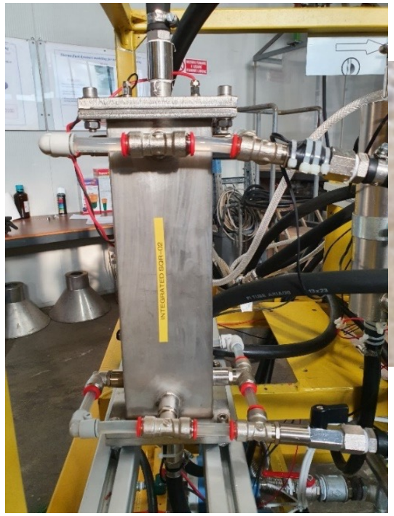


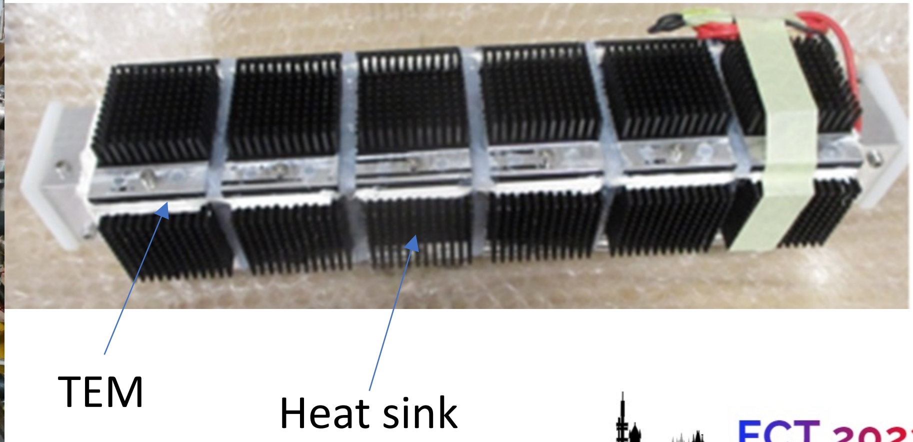
Objectives

- Extract heat from the EAF off-gas cooling system and convert to electrical energy
- Develop a TEG which is compact and modular which can fit around existing systems

Square section thermoelectric TEG

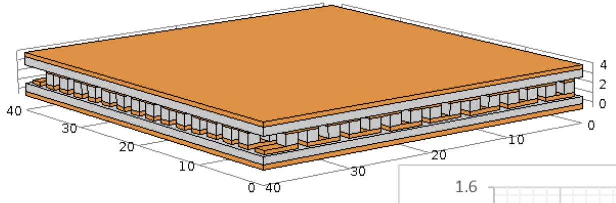
- Square section aluminum tube (40 mm wide and 300 mm long)
- 6 TEMs on each side (40 x 40 mm) → a total of 24 TEMs
- TEMs are inserted into second square tube where cold water can flow through heat sinks (black)

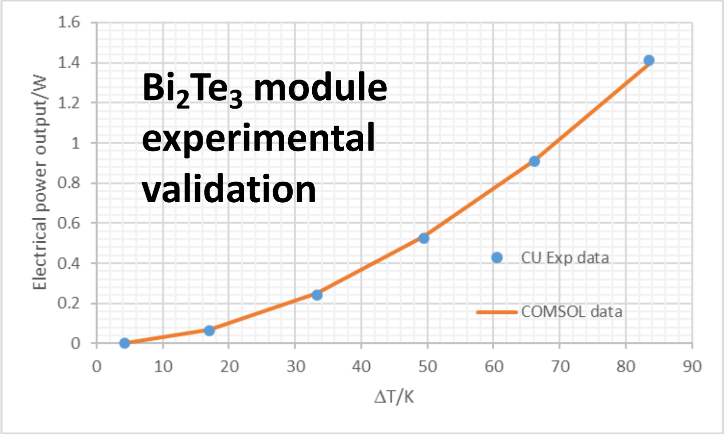




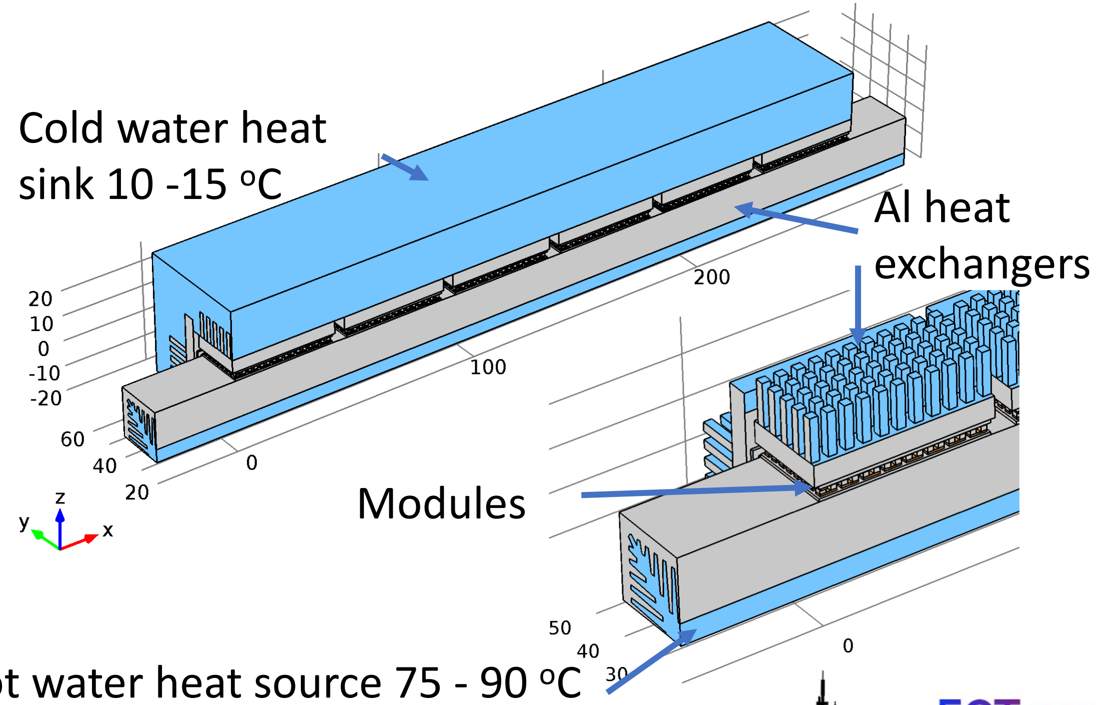
ECT 2023

System modelling and simulations





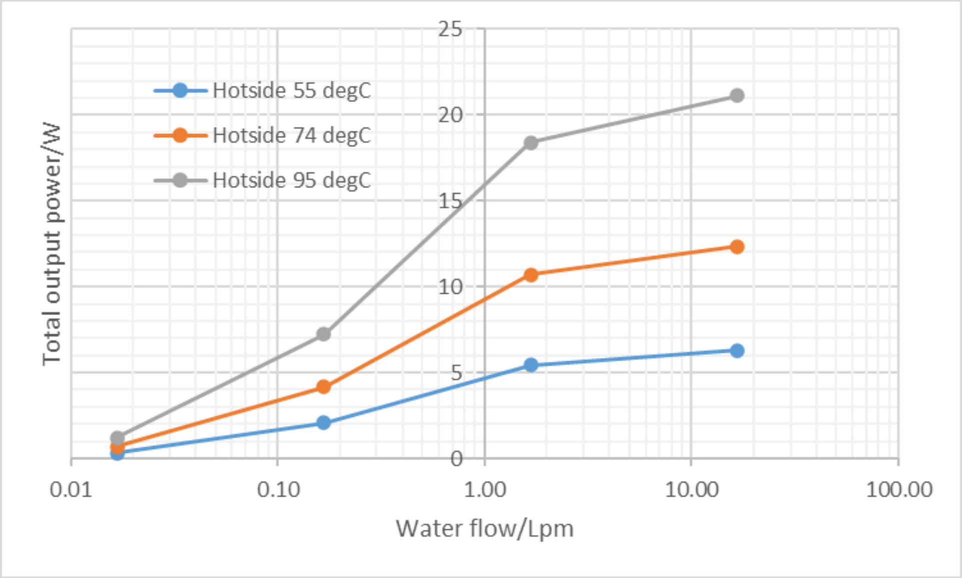
Prototype A - Square cross-sectional area COMSOL model

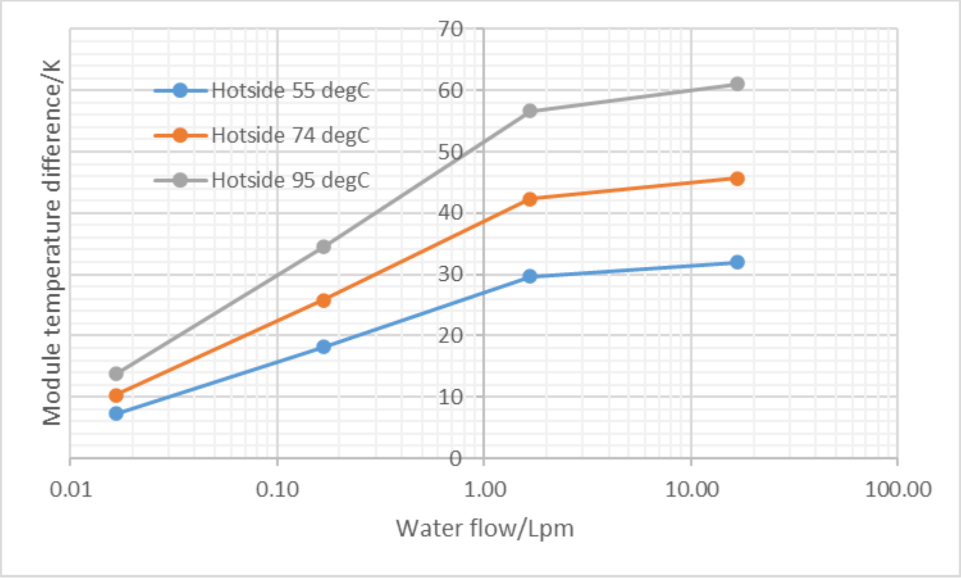


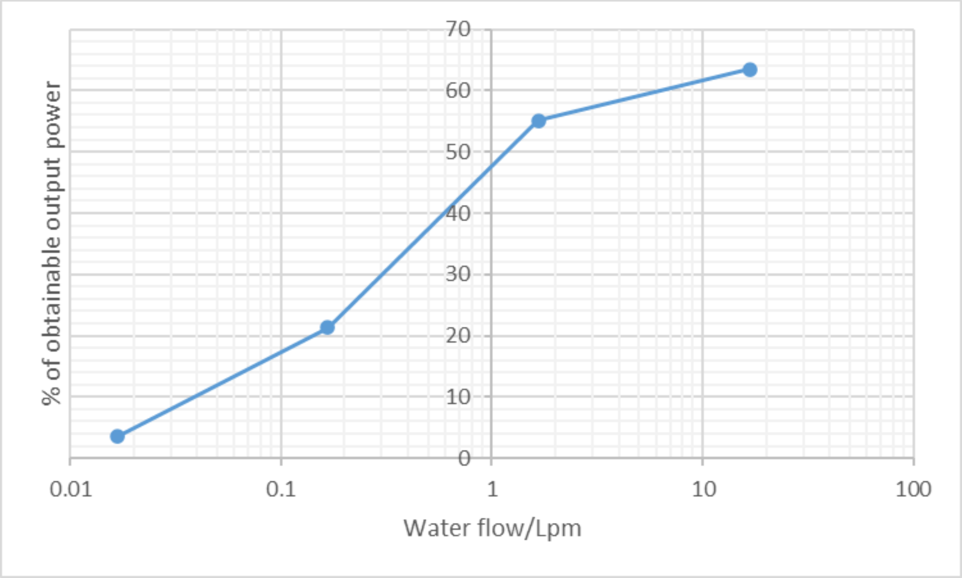
- Commercial TE modules experimentally tested to determine electrical and thermal properties
- TE Material properties k,σ and α taken from data source with similar operating range
- Thermal and electrical contact resistance parameters fitted to IV curves using COMSOL
- COMSOL output load data compared with experiment
- Module models build into TEG COMSOL model

ECT 2023

Prototype A – Simulation results

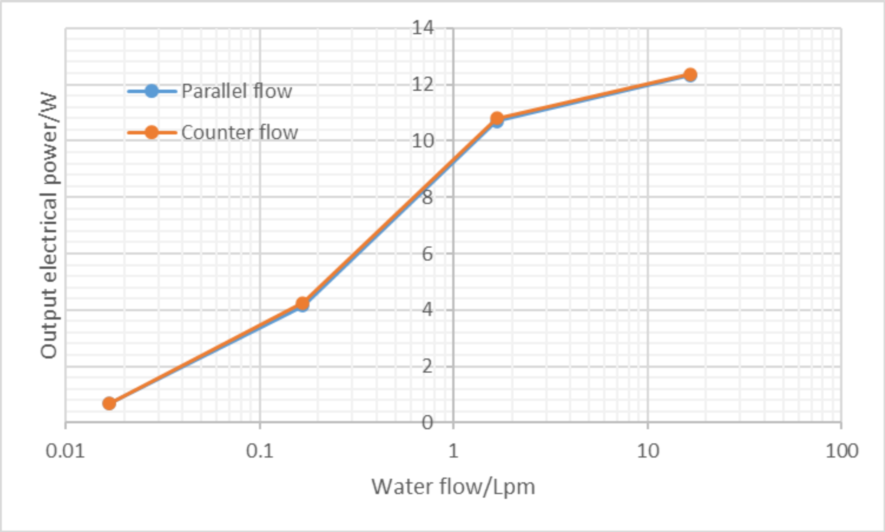


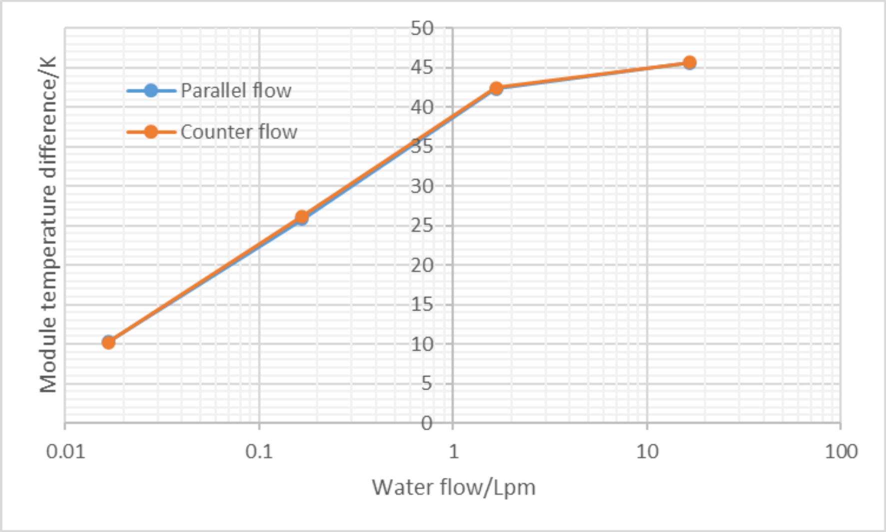


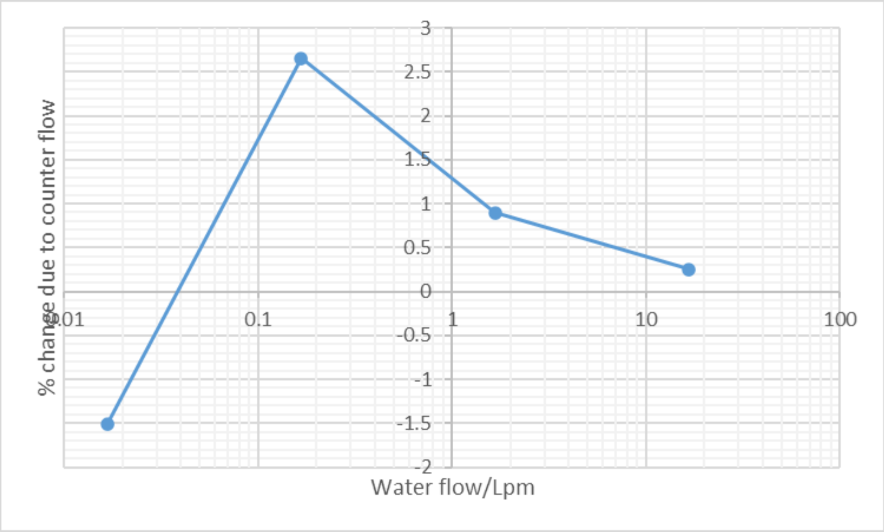


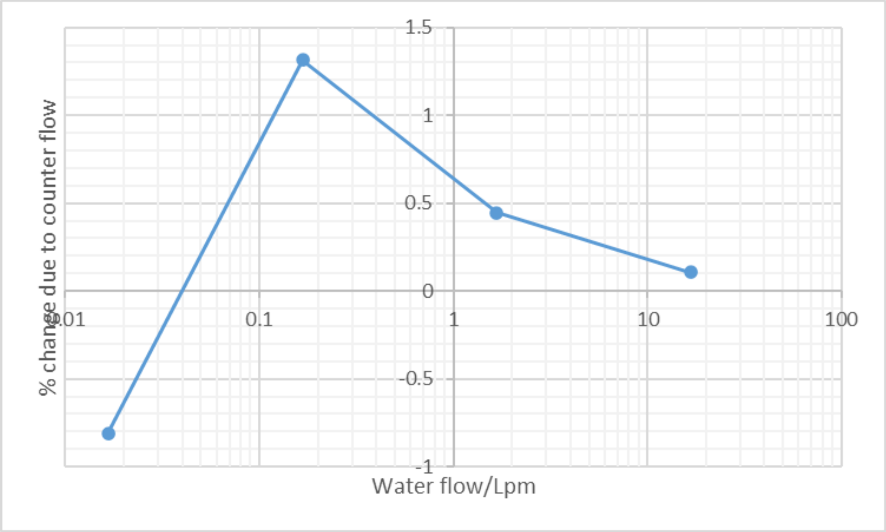
- ΔT ~ 62 K, each module should output 0.81 W giving 19.4 W for the TEG
- TEG generates ~ 12.3 W at a flow rate of 17 Lpm
- ~63 % of theoretical power obtained

Prototype A simulations with different water flow conditions

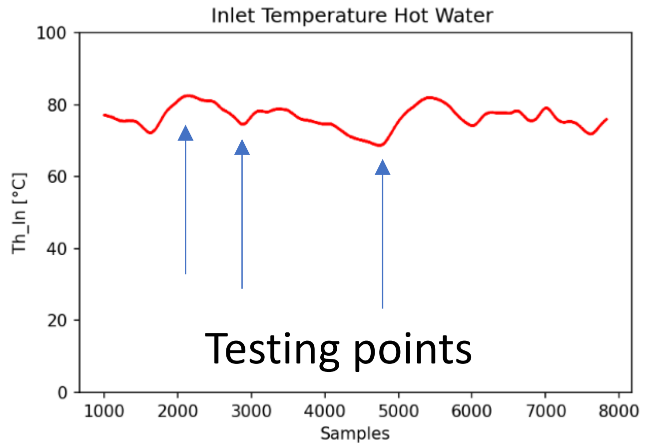




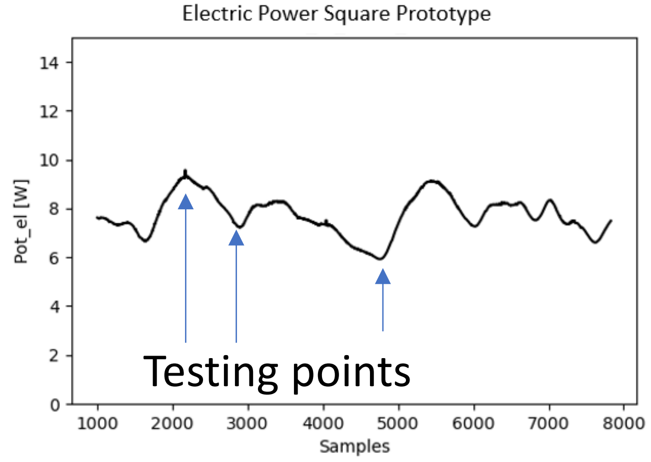




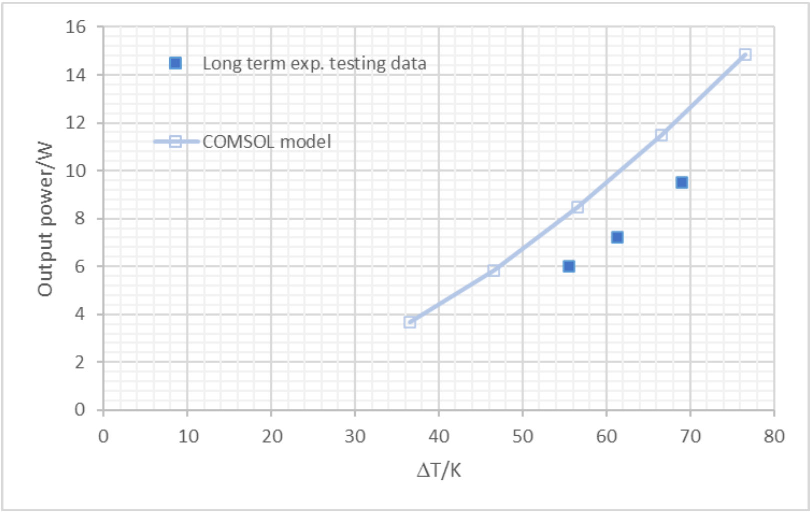
Installed Prototype A testing



Inlet temperature vs. time (1 sample/second)



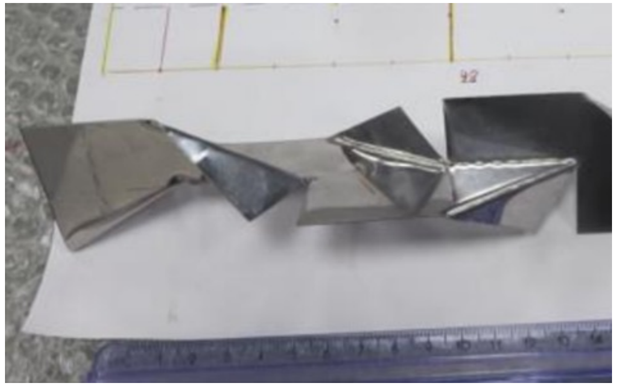
Electrical power vs. time (1 sample/second)



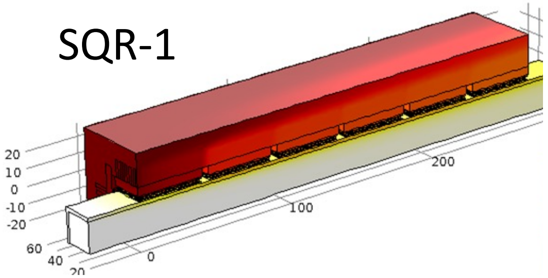
Slight difference between model and experiment

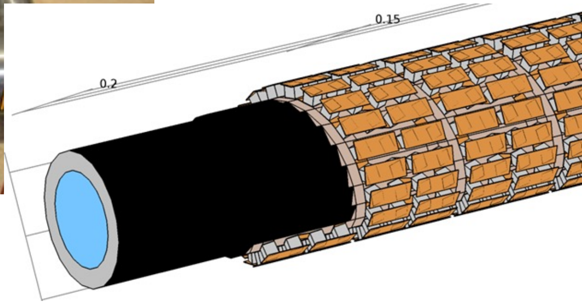
Prototype A – Installation and long-term trials of TEG tubes at Ferriere Nord steelworks

Four Prototype A designs to simulate

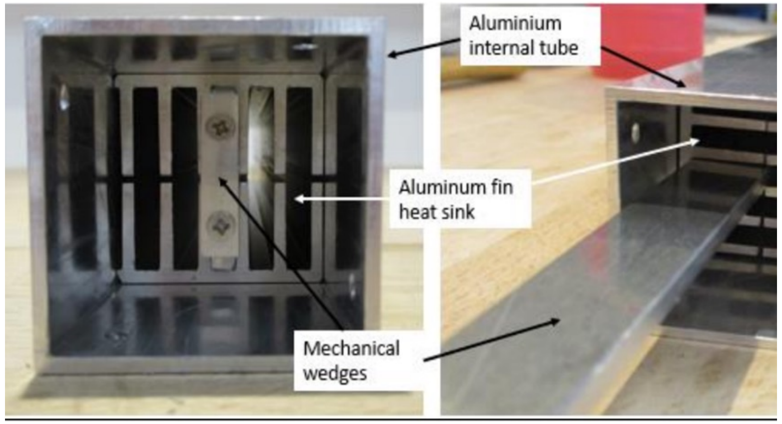


SQR-1

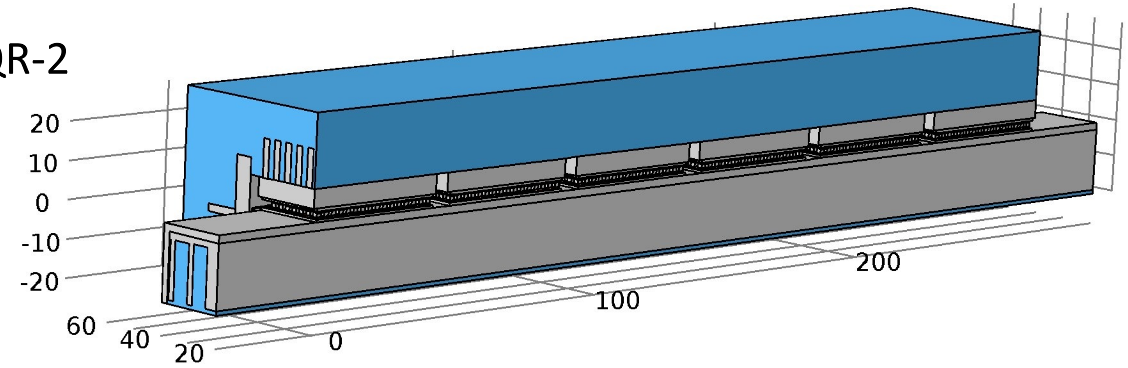




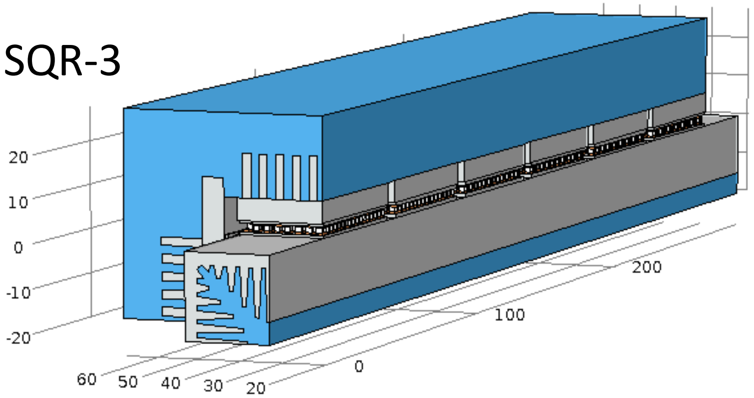
Circular design



SQR-2



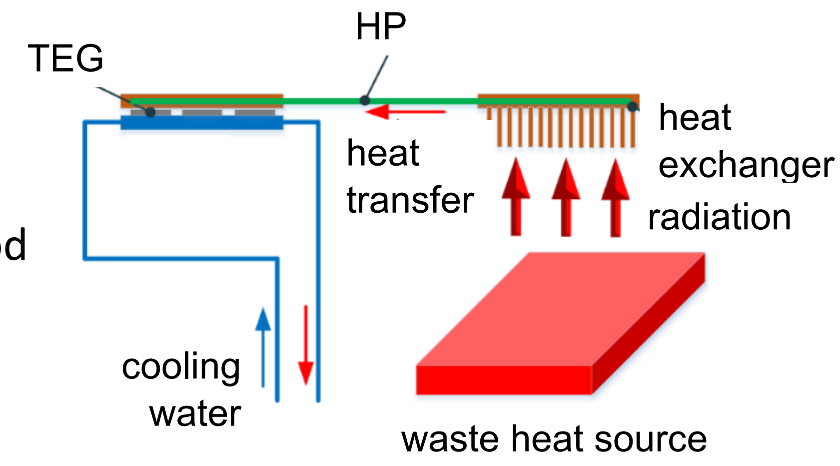
SQR-3



Prototype B design

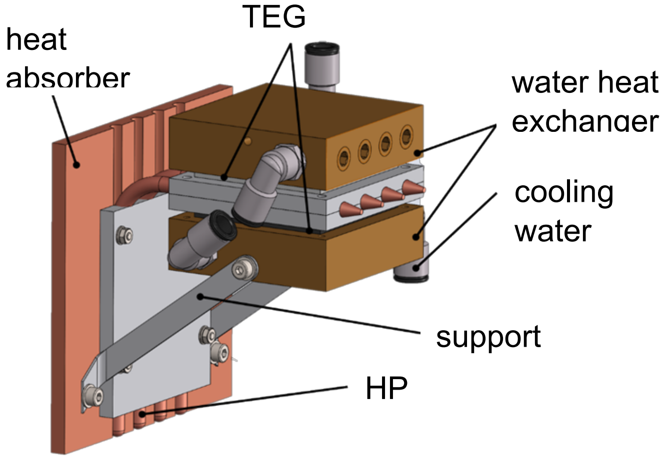
Objectives

- Capture radiative heat from cooling steel wire rod as it moves along a conveyer
- Develop systems capable of protecting TEG from over-heating due to temperature fluctuations

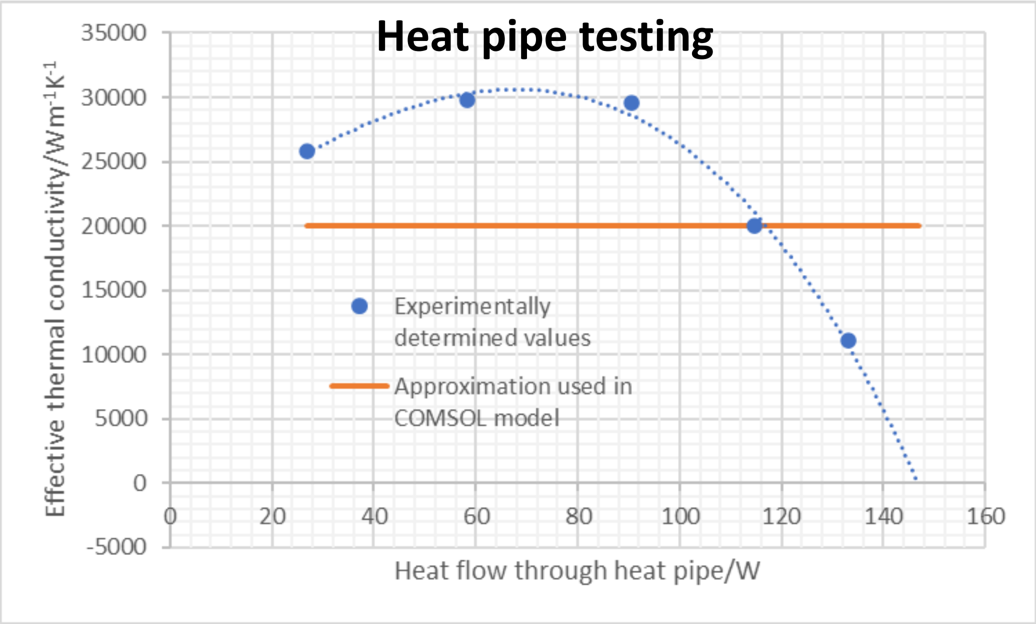


Heat pipe protected TEG

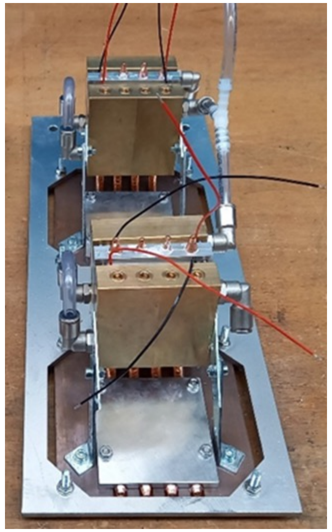
- Heat absorber made from copper plate
- Heat pipes used to place the TE modules at a distance from the absorber plate
- Two TE modules per absorber plate clamped either side of the heat pipes
- Heat pipe ‘dry-out’ at 250 ºC



System modelling and simulations

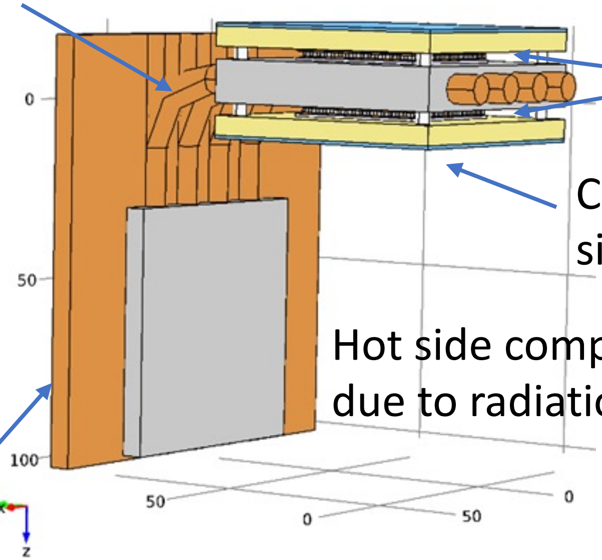


Prototype B



COMSOL model

Heat pipes



Bi_2Te_3 modules

Cold water heat-sink geometry simplified; same flow and velocity

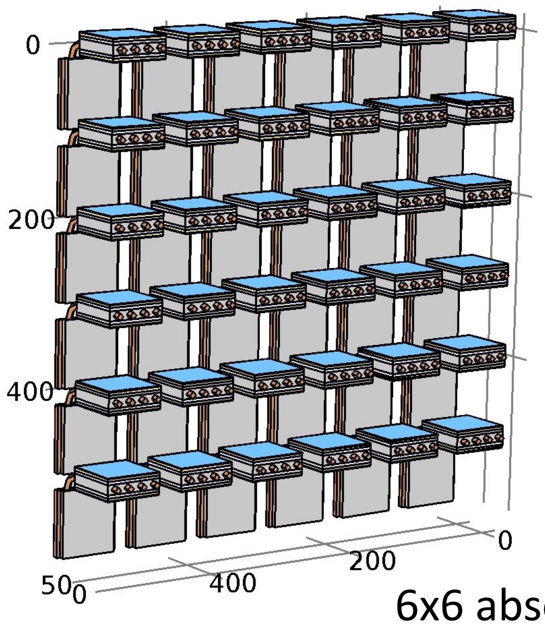
Hot side components; heat losses due to radiation and convection

Absorber plate ε=0.9 on side facing heat source
ε=0.5 on other sides

Module spec.

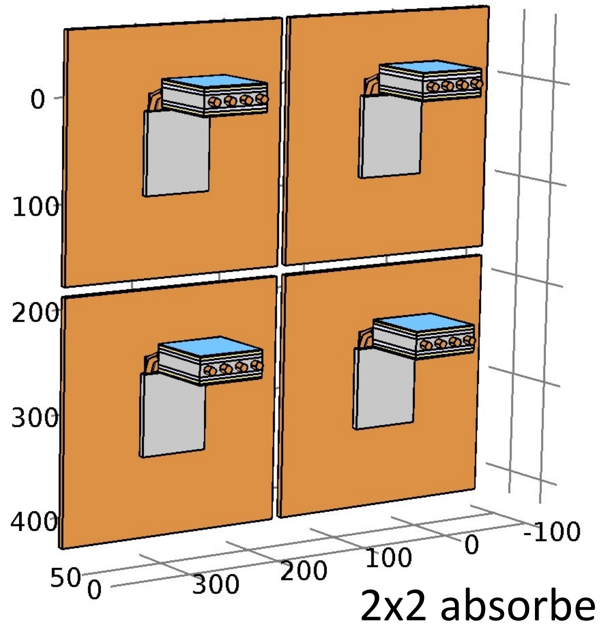
Setup	Leg length	Leg area	Total leg area	Aspect ratio A/L
High aspect ratio module	1.5mm	2.5mmx 2.5mm	3150 mm^2	2100 mm
Low aspect ratio module	1.14mm	1.4mmx 1.4mm	995.68 mm^2	873.4 mm

Prototype B design optimisation



6x6 absorbers

Total prototype area
~0.5 m x 0.5 m

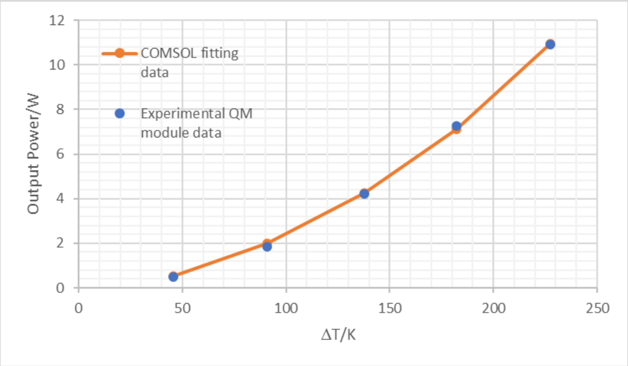


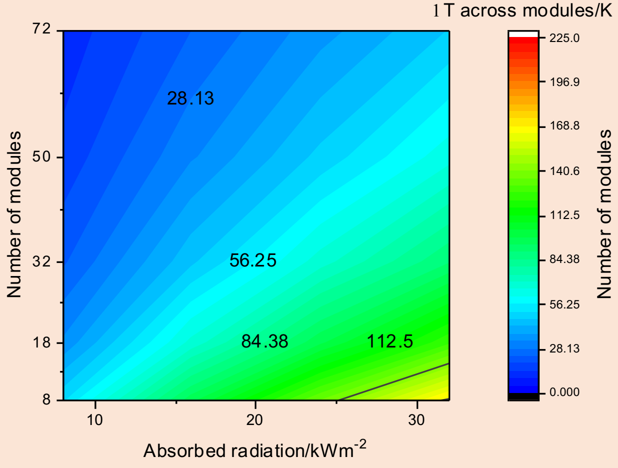
2x2 absorbers

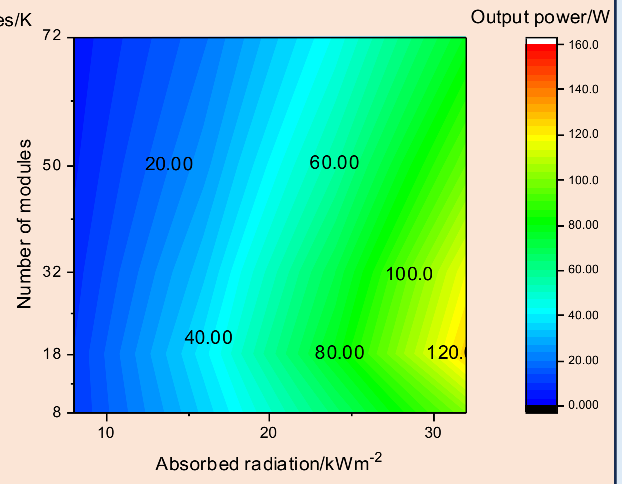
Absorber area	Area/cm^2	Absorbers in prototype	Total modules in prototype	Total absorber area of prototype
8x8 cm^2	64 cm^2	6x6	72	2304cm^2
9.6x9.6 cm^2	92 cm^2	5x5	50	2304cm^2
12x12 cm^2	144 cm^2	4x4	32	2304cm^2
16x16 cm^2	256 cm^2	3x3	18	2304cm^2
24x24 cm^2	576 cm^2	2x2	8	2304cm^2

Prototype B design optimisation

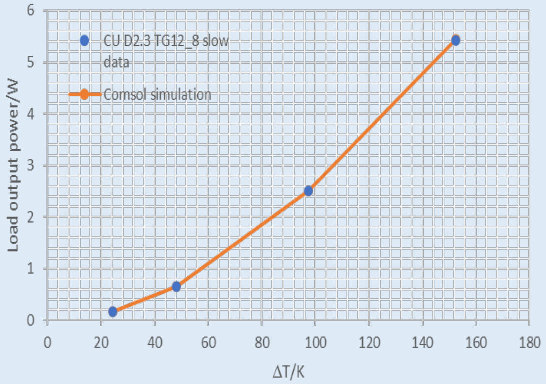
High aspect ratio (A/L) module

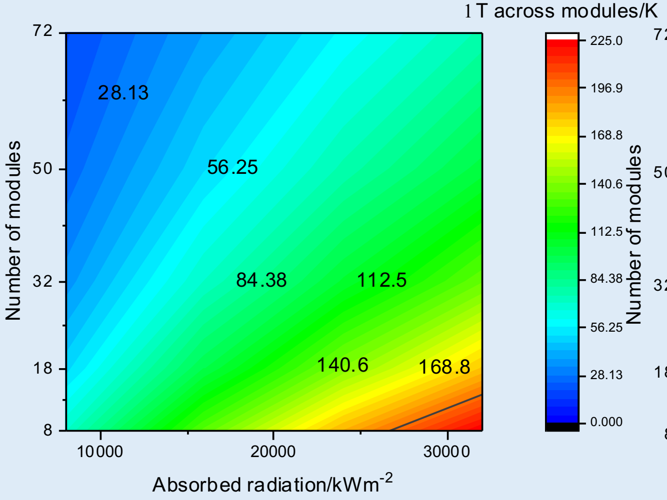


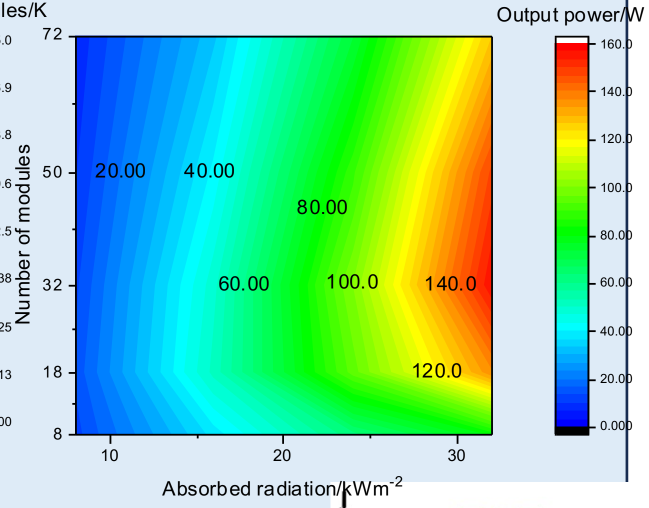




Low aspect ratio (A/L) module

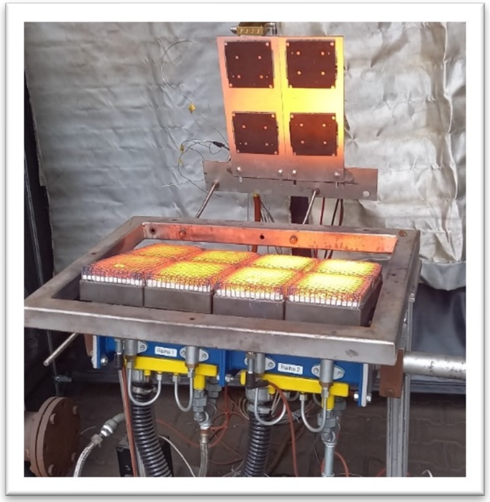




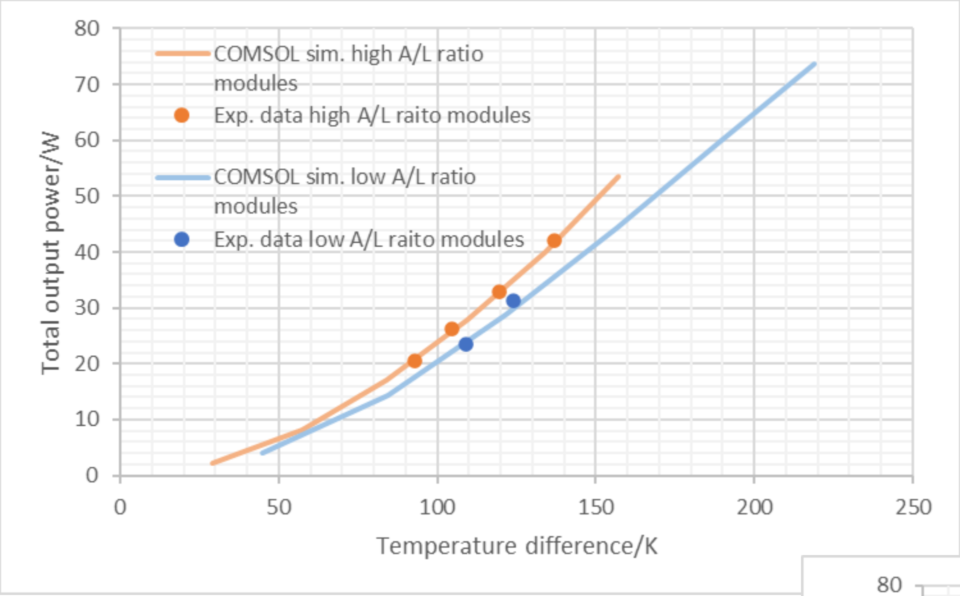


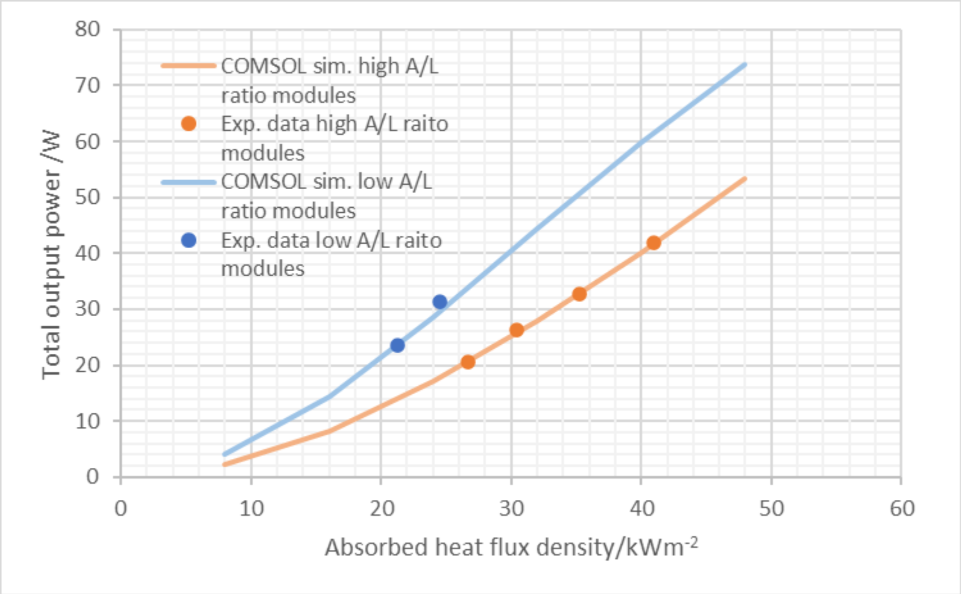
ECT 2023

System modelling and simulations



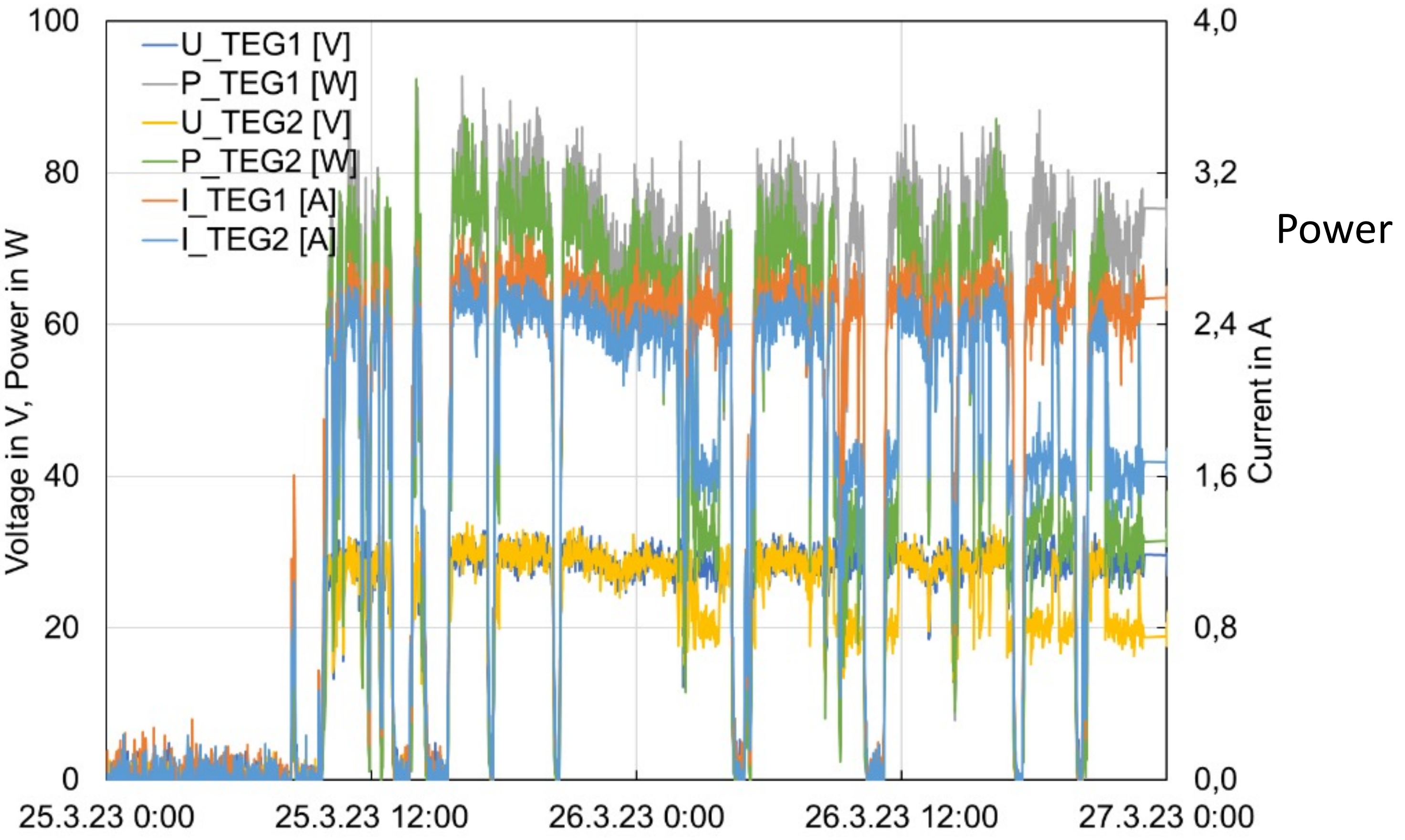
Prototype B – Lab testing of 8 module system





Installed Prototype B testing

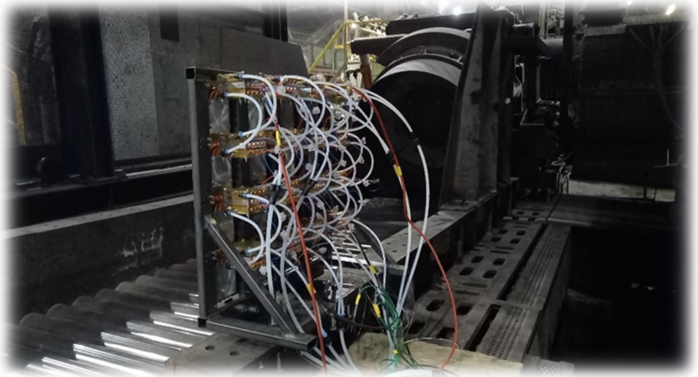
Long-term test



- System is fully operational in situ.
- The performance varies with the highly discontinuous wire production process
- Maximum measured <u>hot side temperature</u> of the TEMs: <u>200 °C</u>
- Maximum measured power production of the entire 32 module prototype: <u>160 W</u>
- Increase of cooling water temperature approx. 4 – 5 °C → heat loss by the cooling water of approx. 5 kW.
- Cold-side efficiency <u>max. 2.5 – 3.0 </u>%

Summary

- Two prototypes developed for waste heat recovery using TE modules:
    - Prototype A for waste heat recovery from cooling water
    - Prototype B for recovery of thermal radiation
- COMSOL models developed to simulate the performance of the two prototypes and used to predict performance under different operating conditions
- Prototypes tested in laboratory and installed in an industrial setting, collecting long term data samples
- Data samples input into COMSOL models to further optimise the design

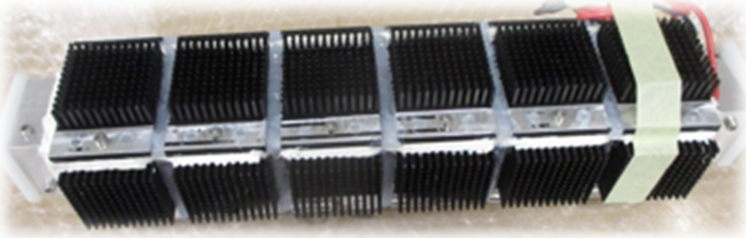


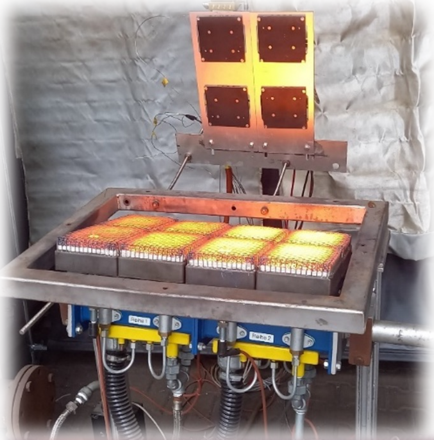
InTEGrated

EU-RFCS

European Commission

899248

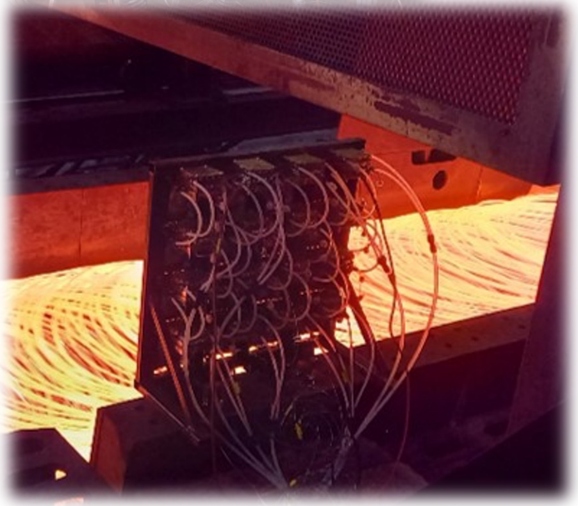




Thank you for listening

For further information please visit

www.integrated-euproject.eu



Cardiff University Prifysgol Caerdydd

PITTINI

RINA

FERALPI GROUP

BFI

QUICK-OHM Küpper & Co. GmbH

ergolines

ECT 2023