HILT CRC

HEAVY INDUSTRY LOW-CARBON TRANSITION COOPERATIVE RESEARCH CENTRE

OVERVIEW OF GREEN IRON AND STEELMAKING RESEARCH AND TECHNOLOGY DEVELOPMENT

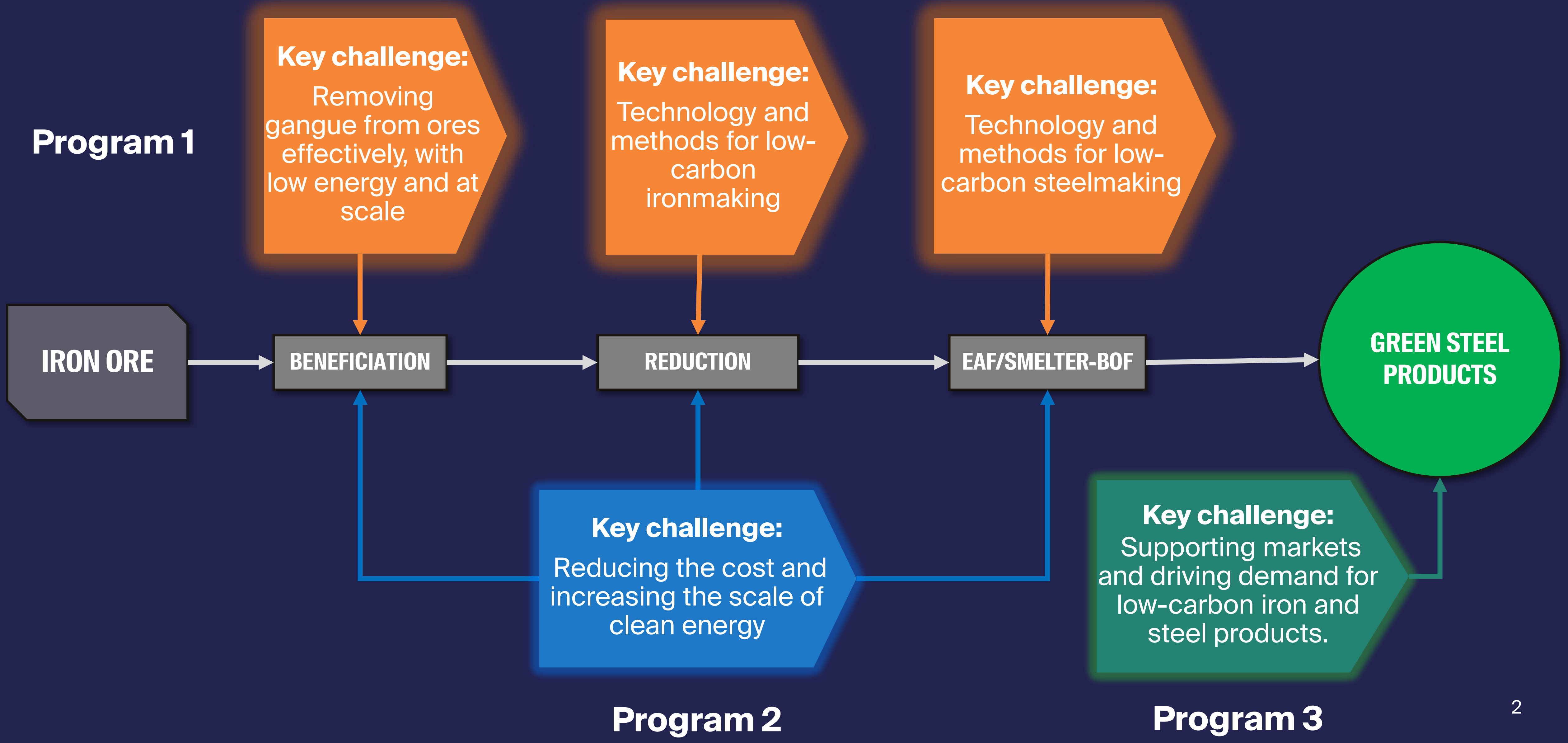
Professor Geoffrey Brooks,
Swinburne/CSIRO Joint Professor

14/10/2025

Australian Government
Department of Industry, Science and Resources

Cooperative Research Centres Program

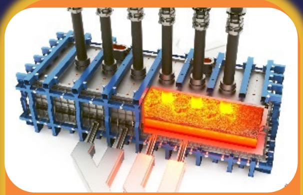
PROJECTS SUPPORTING IRON & STEEL



PROJECTS SUPPORTING IRON & STEEL

RP1.016
Thermal beneficiation

RP1.011-ARENA
Upgrading iron ore using leaching



RP1.014
De-risking electric smelting furnace

RP1.017
Biomass for green steel production

RP1.018
Green steel from magnetite

IRON ORE → BENEFICIATION → REDUCTION → EAF/SMELTER-BOF → GREEN STEEL PRODUCTS

Program 1:

RP1.010
Hydrogen and plasma iron ore reduction

RP1.012 -ARENA
Prevention of sticking in H_2DRI production

RP1.015
Hydrogen direct flash reduction

OFP 001 & 002
Metallothermic processing of Australian iron ores

PROJECTS SUPPORTING IRON & STEEL

RP2.007
Hydrogen burners for cement and iron

RP2.012
Bioenergy opportunities in heavy industry

RP2.013
Mineral carbonation for CCUS

RP2.014
Low-cost reliable green electricity supply

RP2.018
Syngas from Biomass

RP2.016
Thermophysical properties of ores

RP2.015
Hydrogen impact on materials and infrastructure

RP2.017
Thermal energy storage

IRON ORE → BENEFICIATION → REDUCTION → EAF/SMELTER-BOF → GREEN STEEL PRODUCTS

Programs 2&3

RP3.004
Green iron and steel export analysis

RP3.005
Green iron and steel market & cost factors

RP3.006
Green certification

RP3.007
Energy infrastructure investment

RP3.008
Policy roadmap

PROGRAM 1
PROCESS TECHNOLOGY PROJECTS

Producing green iron products from magnetite

Producing green iron products from hematite/goethite ores

Green alumina calcination

Green heat for alumina refining

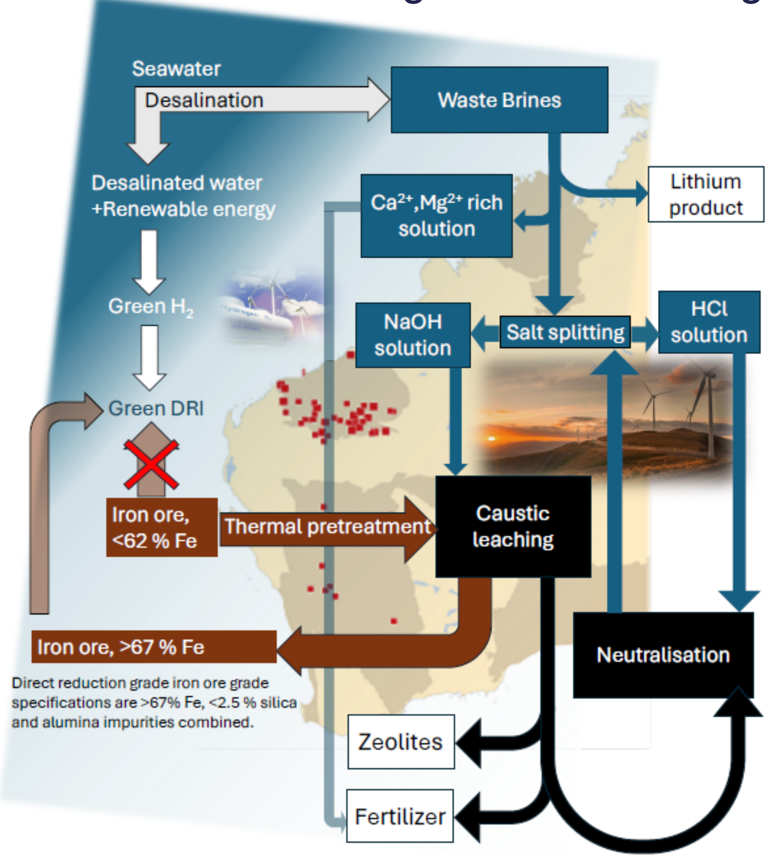
Low-carbon construction materials

Upgrading iron ore to DRI grade using leaching

RP1.011–ARENA: The upgrading of iron ore for DRI production using products from seawater reverse osmosis brines,

Jacques Eksteen and Lina Hockaday (Curtin University)

Aim: To develop and evaluate the concept design for hydrometallurgical upgrading of low-grade iron ores with reagents from seawater brines for the DRI-EAF green steelmaking route.



Areas with high concentrations of iron ore

Mineral deposits with 100+ million tonnes of iron ore

Source of map: Australian Government, Geoscience department

Reagent manufacture

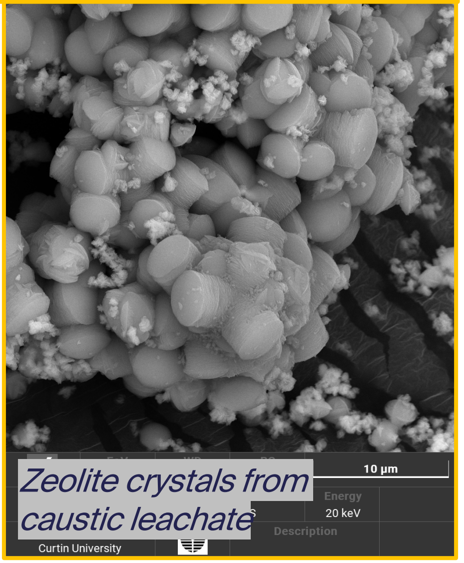
Desktop electrodialysis unit

By-product generation

Experimental setup for zeolite crystallisation process.

Process simulation

- ✓ Mass and energy balances for 3 scenarios
- ✓ Positive operating budget confirmed
- ✓ Capital costs estimated
- ✓ Financial modelling for more scenarios in progress



Zeolite crystals from caustic leachate

Key Successes:

- ✓ 4 out of 5 samples upgraded to high-grade iron ore (>65 % Fe grade, calcined) in lab experiments
- ✓ Zeolites produced with iron ore as the source of alumina and silica

Upscaling of thermal beneficiation for iron ore

RP1.016: Upscaling of novel green thermally assisted beneficiation pathways and impact of beneficiation on DRI and pellet production, Alfonso Chinnici (University of Adelaide)

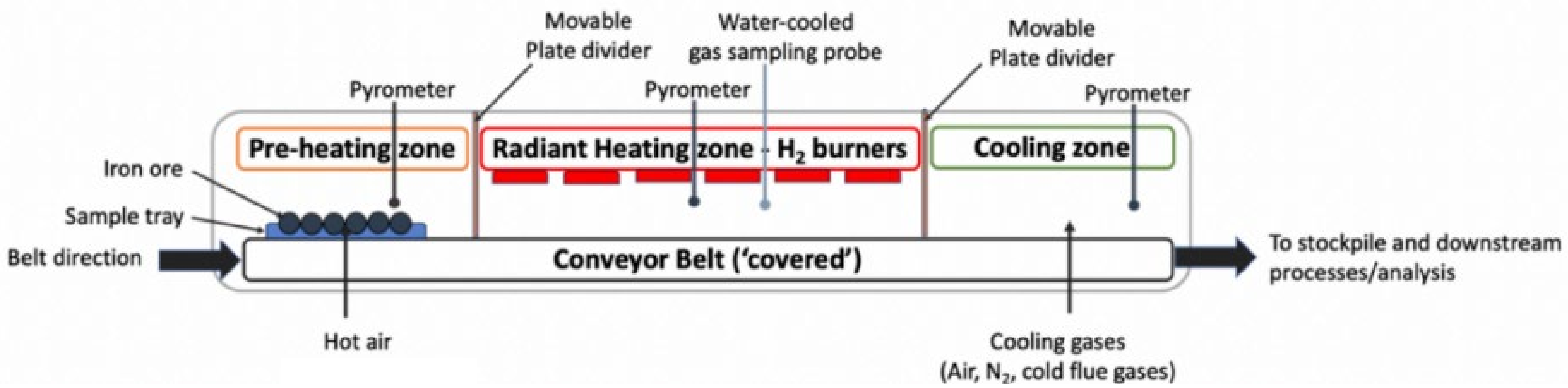
Aim: Development and demonstration at sub-pilot scale of a novel ore roasting technology.

Approach:

- Further testing of low-grade iron ores and bauxite ores under a wider range of conditions in a 10kg/hr novel thermal beneficiation reactor combined with moving bed rector
- Testing both neutral and reduction roasting

Target outcomes:

- Sub-pilot scale concept built
- Generate front-end engineering design flowsheet
- Update and refine technoeconomic models



Testing of iron ores in a flash reduction process

RP1.009: Testing of Australian iron ores in a hydrogen direct flash smelting process , Geoff Brooks (Swinburne) – completed
RP1.015: De-risking flash reduction of Australian iron ore, Shabham Sabah (Swinburne University)


Calix pilot reactor configured for ZESTY operations

Completed project: RP1.009

- Tested 7 ores tested in over 80 test runs in Calix's 50 kg/hr ZESTY pilot facility in Bacchus Marsh
- DRI produced with metallisation degrees of **70- 95%** for a wide range of Australian goethite and hematite ores resulting in a product with an iron content of **66–85%**

Aim of follow on project RP1.015:

To further de-risk scale-up of the ZESTY technology:

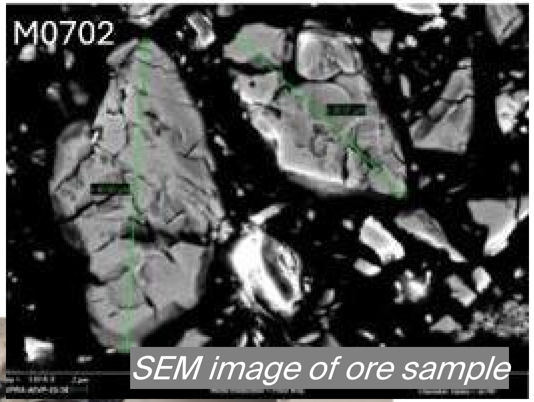
- Effects of temperature & residence time affect on fayalite
- Full kinetic study of hematite/goethite ores
- Optimisation of magnetite ores
- Study of residence time on metallisation

Approach:

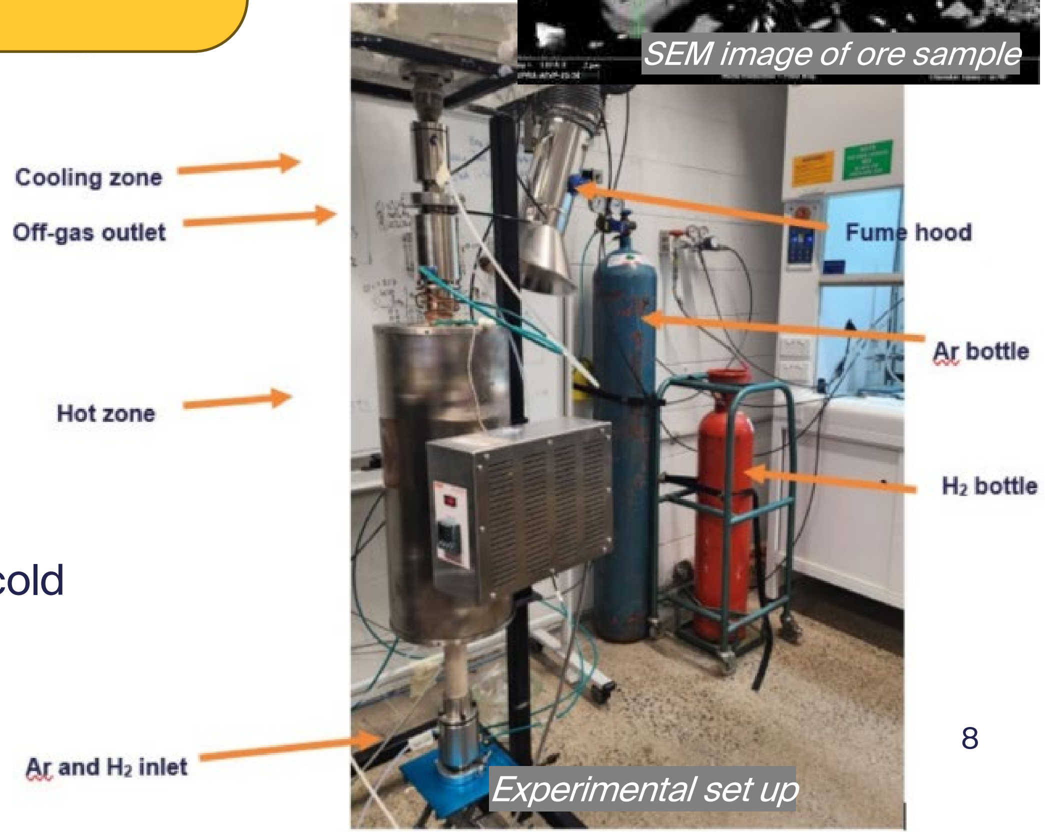
- Experimental works
- Study of residence time using lab-scale reactor in cold and hot conditions

Target outcomes:

Data for design and operation to de-risking flash reduction and scaling up of the Calix ZESTY reactor



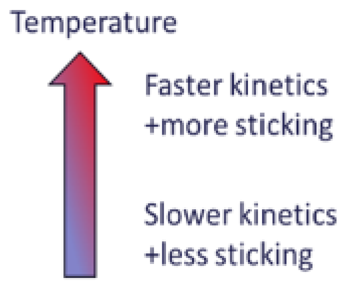
SEM image of ore sample

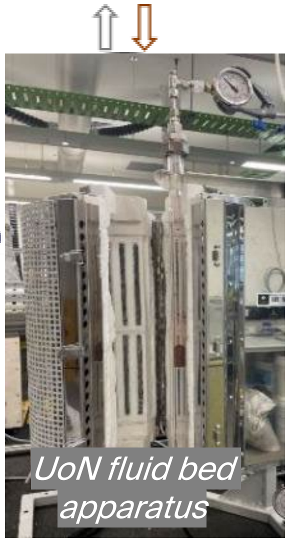


Experimental set up

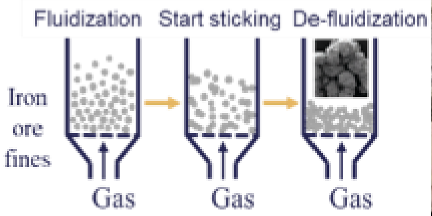
De-risking Australian ores in fluidised bed DRI

RP1.012: Prevention of sticking in H_2 fluidised bed DRI production, Tom Honeyands (University of Newcastle) – follow on from
RP1.001: Understanding & eliminating adverse materials behaviour during & after direct reduction in shaft & fluidised bed processes





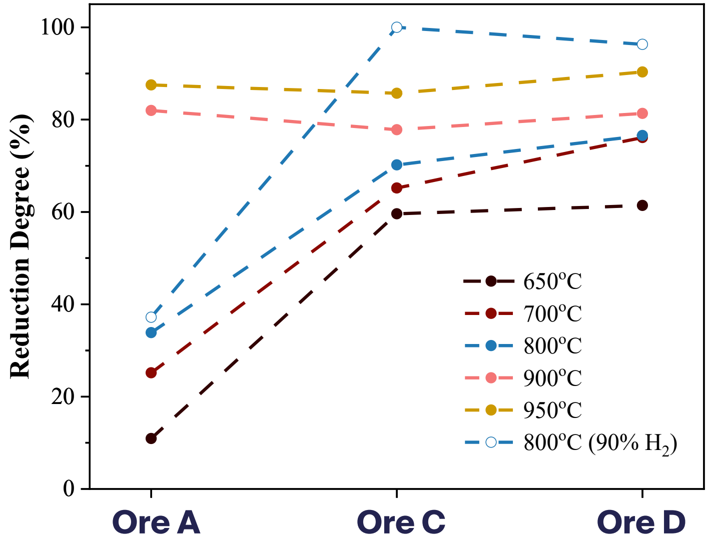
UoN fluid bed apparatus



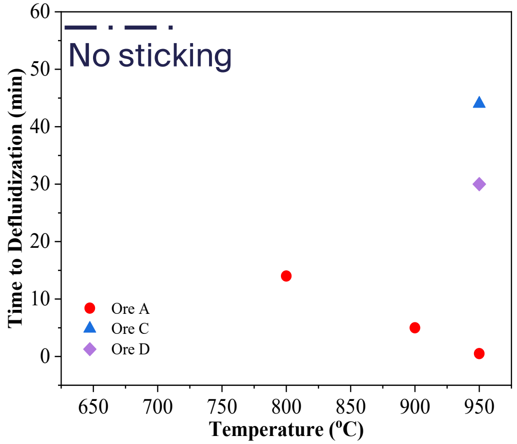
Aim: To assess the suitability of Australian ore fines in fluidised bed processes with emphasis on maximising operating temperature while preventing sticking.

Approach:

- Experimental investigation of:
  - Reduction and sticking behaviour of ores
  - Role of anti-sticking additives
  - Materials handling of DRI
  - TG analysis of single ore particle reduction
- Develop a generalised kinetics models for DRI
- Validate model using kinetic studies



Reduction degree vs temperatures



Defluidisation time vs temperatures

Key research insights:

Improved understanding the trade-off between reduction rate and sticking to de-risk production of green DRI using Australian ores:

- Hematite/goethite ores have been successfully reduced in a H_2 fluidised bed without sticking.
- Magnetite ore reduction degree has been limited by sticking, and pre-oxidation is being investigated as a countermeasure

De-risking Australian ores in fluidised bed DRI

RP1.012 ARENA Extension project: De-risking large scale Australian fine-ore hydrogen ironmaking, John Pye (ANU)

Aim: To provide fresh insights into cost-effective hydrogen-based reduction of Pilbara ores, featuring innovative reactor designs validated through experiments and modelling.

Approach:

Task 1: HILT Project RP1.012

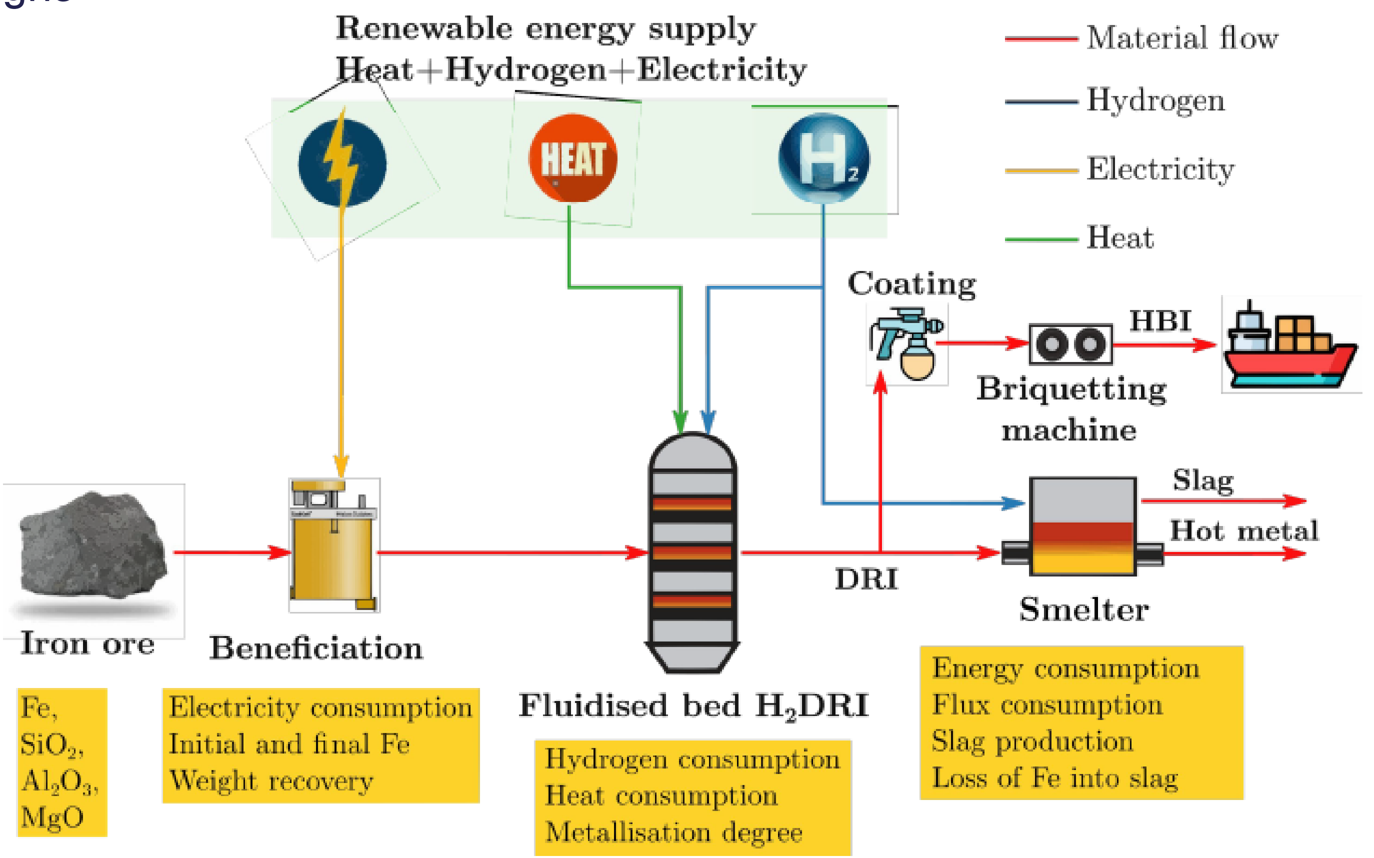
Task 2: End-to-end technoeconomic modelling

Task 3: Testing of segregated fluidised beds to enable density-controlled residence times for efficient hydrogen use

Task 4: Minimising reoxidation of high-gangue hot briquetted iron with coating materials to improve the safety of shipping

Task 5: Advancing a novel concept to replace electric melting with hydrogen burner development and melting

Task 6: Commercialisation



Key progress to date:

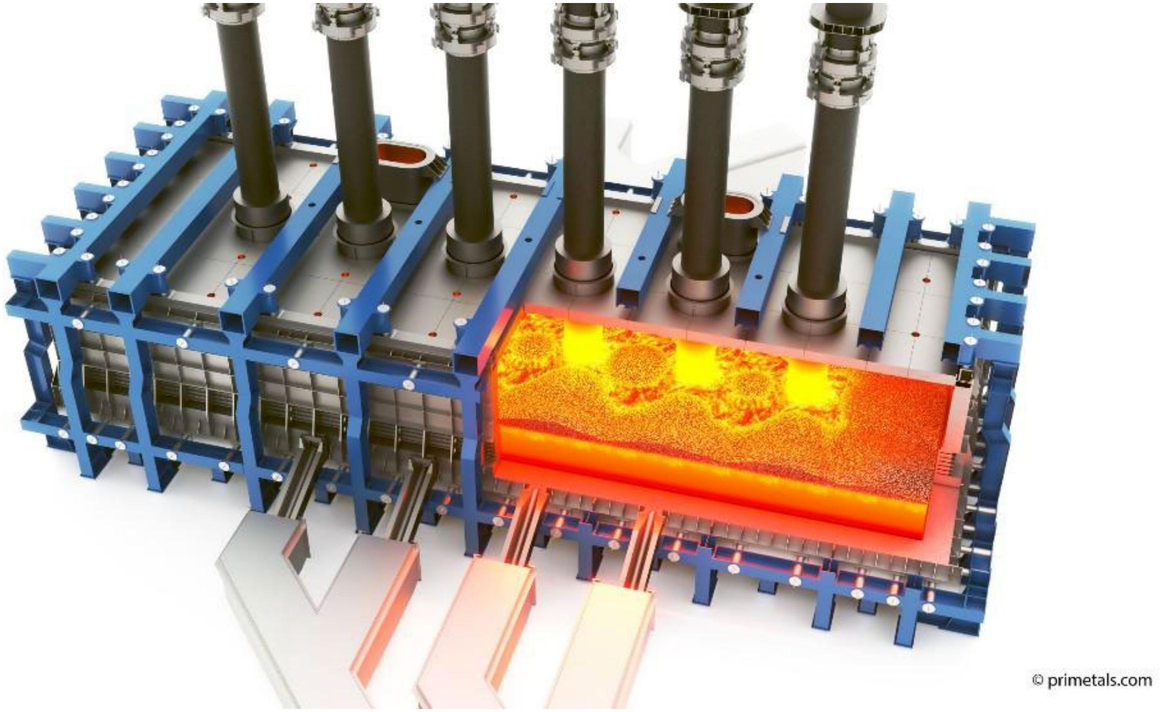
- Undertaken a wide range of cold-flow tests
- Undertaken experiments in collaboration with Victoria University of Wellington
- Technoeconomic modelling in progress

De-risking Australian iron ores for an ESF

RP1.014: De-risking of electric smelting furnace for Australian ores, Geoff Brooks (Swinburne/CSIRO)

Aims:

- How does the gangue content of the iron ore effect performance of the ESF in terms of productivity, energy usage, metal chemistry and attractiveness of the slag as cement feedstock?
- How does the form of the DRI level of carbon and operating temperature of ESF affect the productivity, energy usage, metal and slag chemistry?
- Can waste oxides and scrap be easily incorporated into the ESF process?
- What is the impact on the technoeconomics of processing Australian iron ores through the H_2 DRI-ESF route?



Approach: Mix of modelling, high-temperature experimentation, pilot plant/industrial data & technoeconomics.

Key results/insights to date:
Critical analysis of current literature on ESF has been drafted to identify the cores questions to be answered from this project.

Hydrogen and plasma iron ore reduction

RP1.010: Hybrid hydrogen direct and plasma reduction of iron ore, Alireza Rahbari (ANU)

Aim:

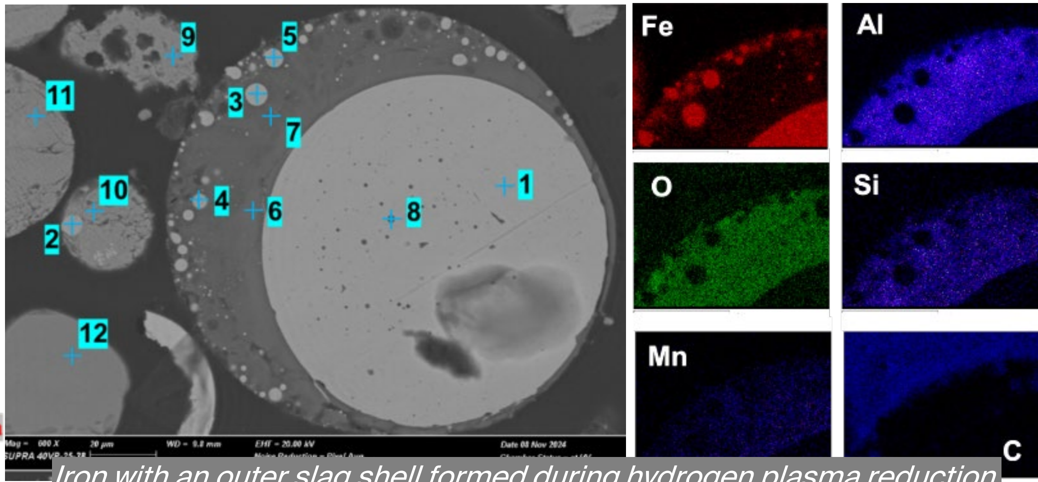
Proof-of-concept evaluation of hybrid hydrogen direct and hydrogen plasma reduction (HDR-HPR) for ironmaking using Pilbara ores.

Approach:

- Pre-reduction of ores followed by in-flight hydrogen plasma reduction experiments
- System-level technoeconomic analysis

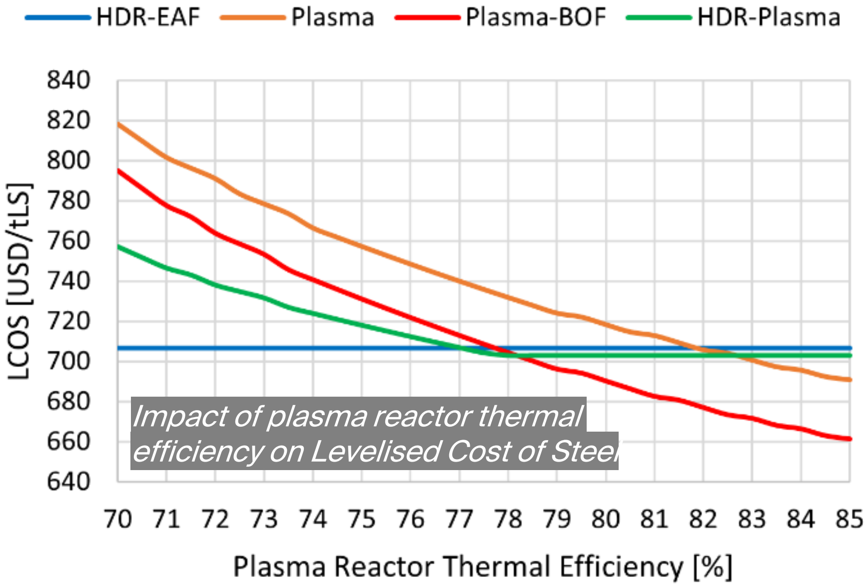
Key insights:

- Ironmaking demonstrated: product showed metallic iron cores with outer shells of slag
- Iron and wüstite concentrations increased with H_2 concentrations
- No phosphorus or sulfur found in large iron agglomerations, indicating impurity removal through high-temperature vaporisation
- HDR-HPR lowers the energy required in the plasma stage
- Plasma-BOF pathway produced the lowest LCOS in most scenarios.



Iron with an outer slag shell formed during hydrogen plasma reduction. 10% H_2-Ar plasma reduction experiment with hematite ore.

Plasma reduction apparatus.



Impact of plasma reactor thermal efficiency on Levelised Cost of Steel

Evaluating biomass for green iron & steel

RP1.017: Biomass-derived fuels/products for green steel production, Hongwei Wu (Curtin University)

Aims: To develop two novel processes that take biomass-derived fuels/products and produce improved biocoke and biocarbon/iron-ore composites:

- increased volumetric energy densification (~5x)
- higher carbon utilisation efficiency
- high mechanical strength.

Approach:

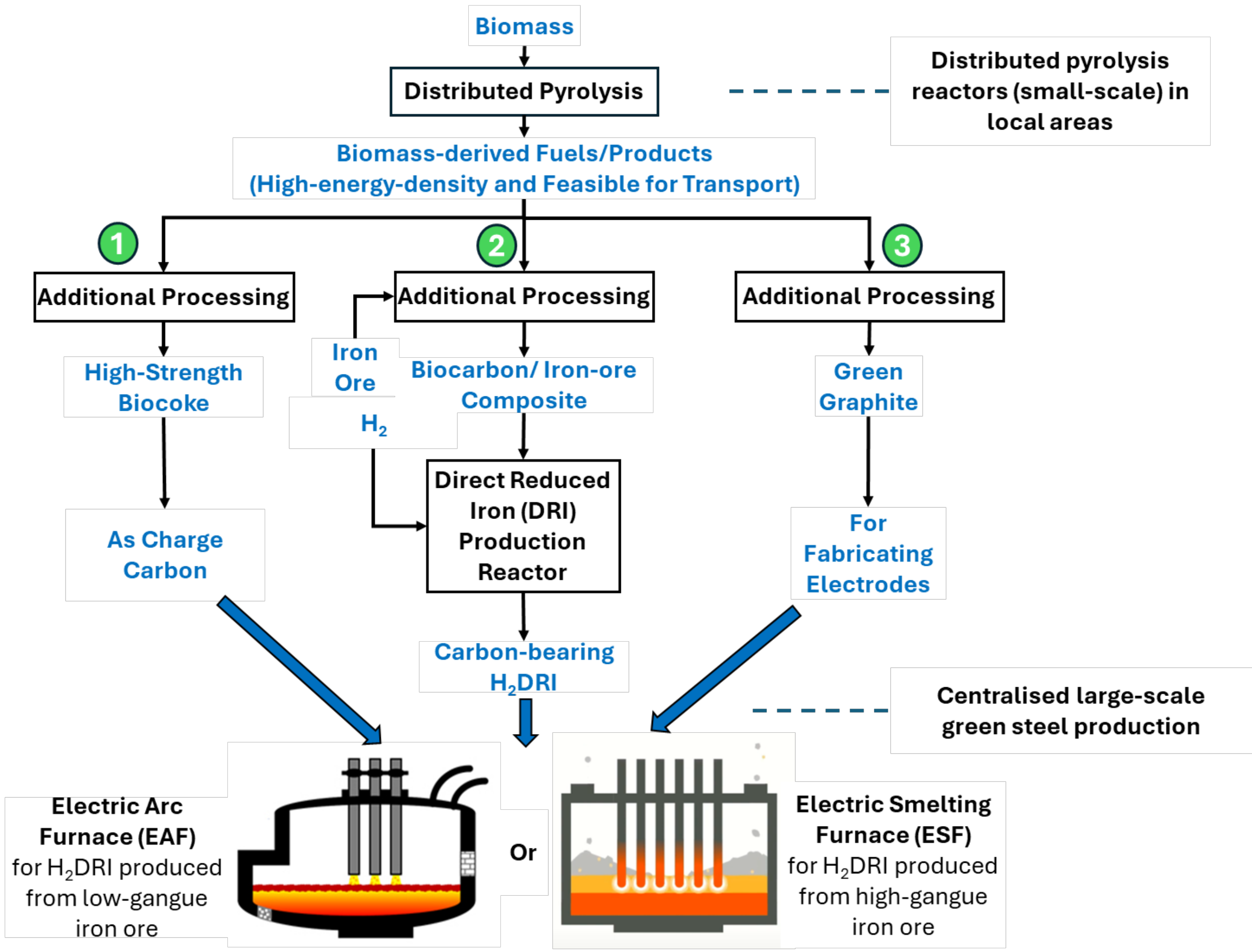
Lab-scale testing using pyrolysis-based approaches to convert biomass-derived fuels and products into:

1) High-strength biocoke
2) Biocarbon/iron-ore composite
3) Green graphite.

Focused on the biomass resources and iron ores relevant to Industry Partner(s).

Target outcomes:

- To validate, at laboratory scale, that pyrolysis can economically convert biomass into high-energy-density fuels/products, which also have small energy and carbon footprints
- Inform further technology development



PROGRAM 2
CROSS-CUTTING TECHNOLOGY PROJECTS

Integrating variable renewable energy sources into industrial processes

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Technology to accommodate use of multiple energy sources

Integrated capture and re-use of CO_2 in industrial processes

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Blending of alternative low-carbon fuels
for current industrial processes

Lowering carbon emissions through synergistic
production of industrial chemicals and fuels

Hydrogen burners for iron and cement production

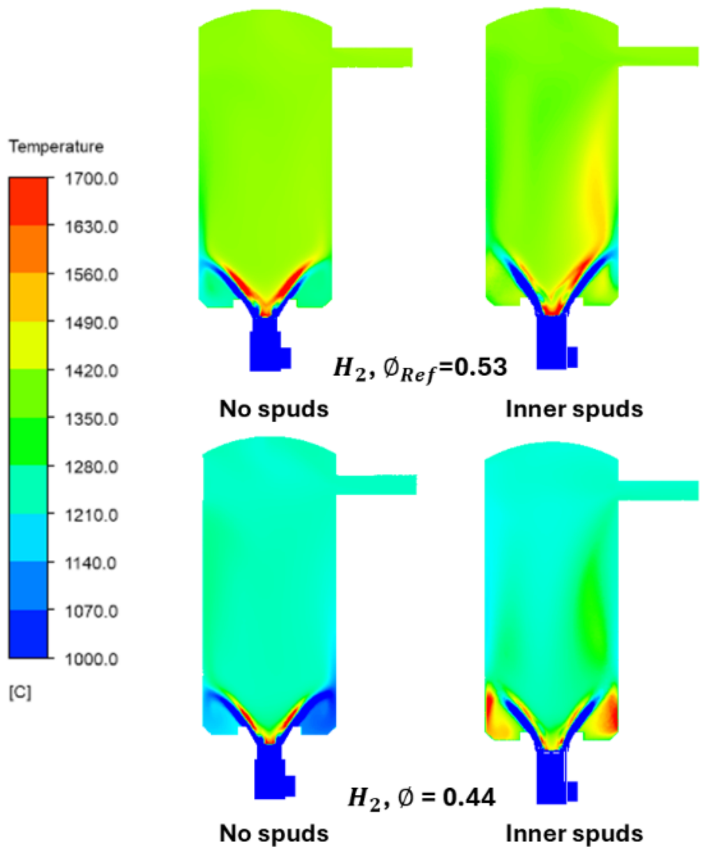
RP2.007: Feasibility combustion study to identify challenges and opportunities for hydrogen into iron and cement sectors, Alfonso Chinnici (University of Adelaide)

Case Study: Grange HGG for iron pellet production

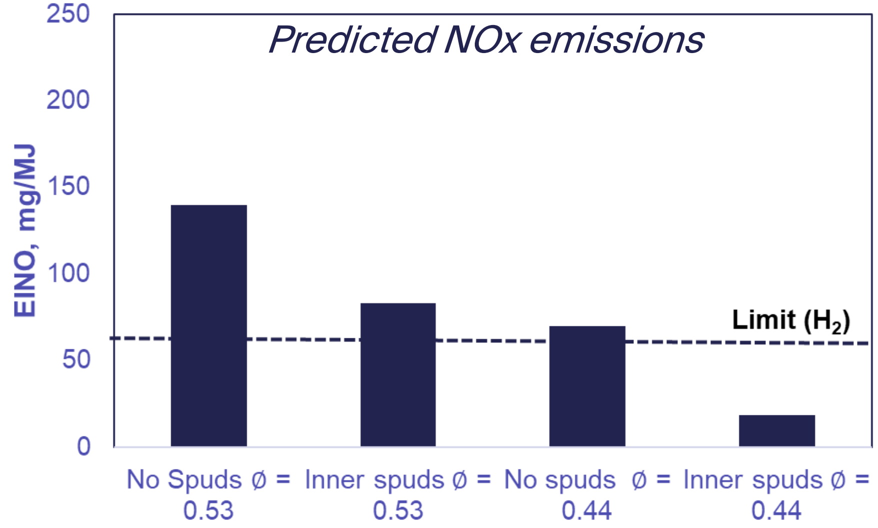
Aims:
- To predict the performances of existing burners operated with hydrogen (100% and NG blends)
- Develop novel burner designs and assess performance

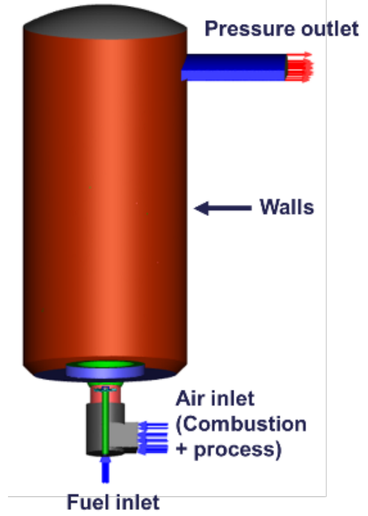
Approach:
- Joint experimental and CFD analysis of partner case studies:
  - Grange HGG (iron pellets)
  - Straight grate kiln (iron pellets)
  - Rotary kiln (cement)

Key results to date:
- Identified operational limits of current burner in Grange HGG with H_2
- Developed new ultra-low NOx burner design able to operate with 100% H_2
- Doping being investigated for radiation for 100% H_2 flames



Temperature contours





PROGRAM 3
FACILITATING TRANSFORMATION PROJECTS

Developing supporting frameworks for emerging low-carbon technologies

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Assessing barriers and policy enablers for the production and trade of low-carbon products and commodities

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Enabling facilities and infrastructure

Reorganising value chains for green iron/steel markets

RP3.004: Intermediate product exports for Australia-China green steel, Jorrit Gosens (ANU)

Aim: to assess cost-competitiveness of Australian producers in ‘intermediate product exports’ for green steel in China.

Approach: Development of a complete end-to-end model for evaluating iron supply chains from Australian mines to Chinese steel plants.

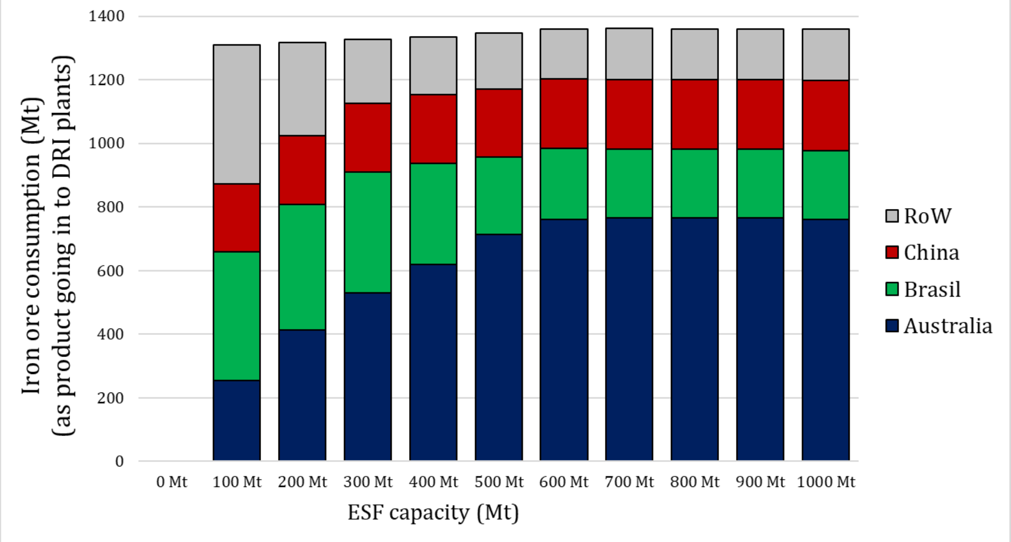
Data sources: CRU database, ANU technoeconomic models, Curtin emissions models, Industry Partner input.

Key interim results:

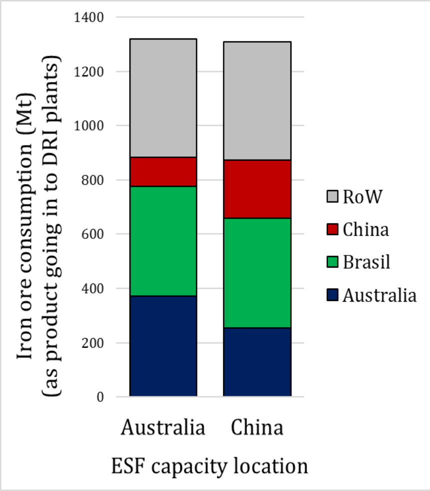
- Relative cost of hydrogen production strongly determines where (Australian) ores are processed into DRI. The location of steel production follows the location of iron production.
- Assumptions on maximum acid gangue content into an EAF strongly affect competition between ESF-BOF and EAF steel production, and drive competition between Australian and other ores.
- Higher global ESF capacity will increase demand for Australian iron ores. EAF operators are likely to prefer other ores, with less gangue. It also matters if that ESF capacity is located in Australia or in China.

Interim results:

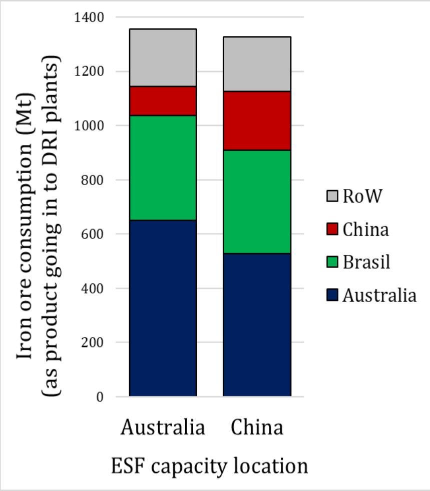
Demand for Australian iron ore in green steel value chains ramps up with global ESF capacity



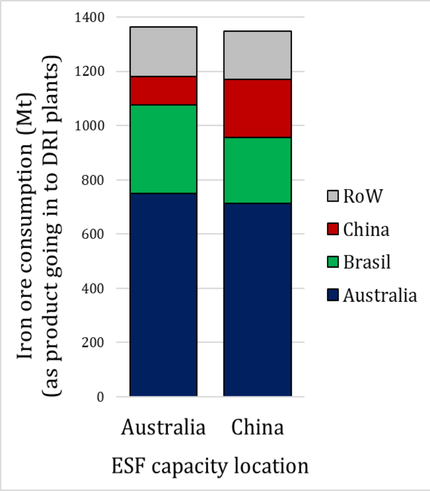
With 100 Mt ESF capacity in either Australia or China



With 300 Mt ESF capacity in either Australia or China



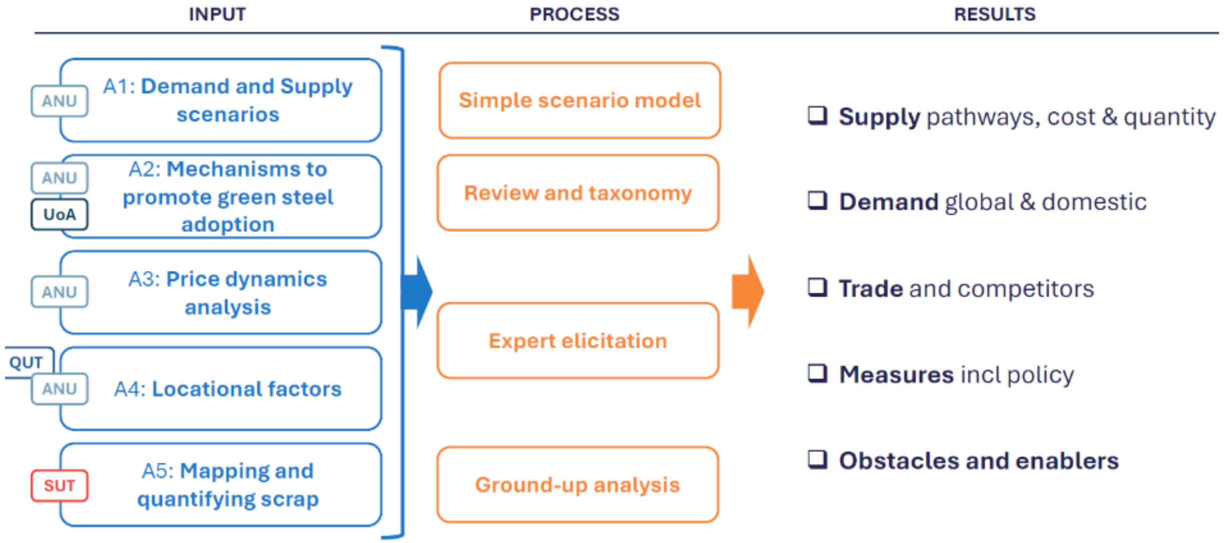
With 500 Mt ESF capacity in either Australia or China



Informing Australian green iron/steel market options

RP3.005: Analysis of market, cost and locational factors for green iron and steel in Australia, Frank Jotzo (ANU)

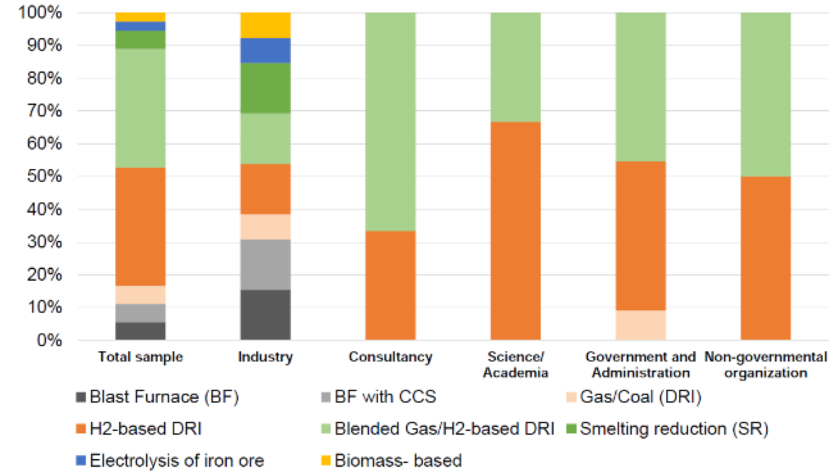
Approach:



Key preliminary insights from expert elicitation:

Major iron making process in Australia by 2050

Note nuance and diversity in industry expert expectations

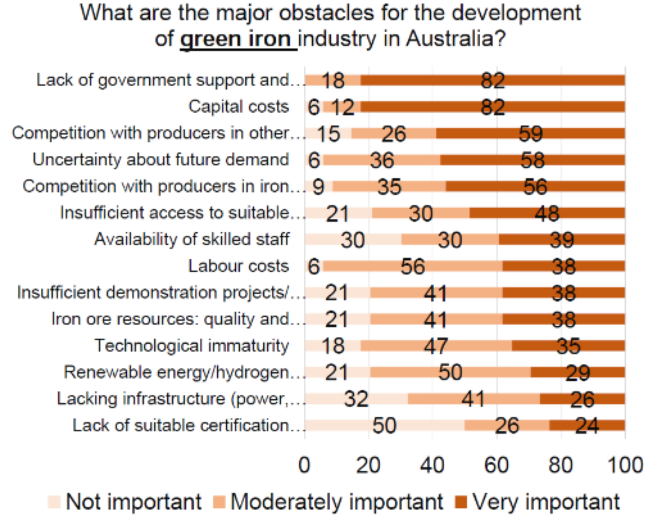


Obstacles for green iron industry in Australia

Most important:

- lack of government support
- high capital costs

Many factors important



Key insights:

- Markets for green iron expected in Japan, South Korea and China; less well defined for green steel (expert elicitation)
- Competition expected from Brazil, the Middle East, Africa and China in the green iron market, and from China, South Korea and Japan for green steel
- Sufficient carbon pricing mechanisms will be needed to drive demand, coupled with carbon border adjustments to foster import demand
- Australia generates 4Mt high-quality scrap which would support deployment of EAF, but exports of scrap would need to reduce
- Attributes and effects of a wide range of supply side and demand side policy support are assessed, e.g. reduction in investment risk and who pays

GREEN IRON AND STEEL RESEARCH SUMMARY

Green technologies from mine to products considered

Hydrogen DRI and other reducing routes studied

Technical, economic, social and policy implications

Supporting innovation and talent growth