HILT CRC

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Cooperative Research Centres Program

Final Submission

GREEN METALS
A Future Made in Australia:
Unlocking Australia's Green Iron, Steel, Alumina and Aluminium Opportunity

HILT CRC CONSULTATION PAPER RESPONSE

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Department for Industry, Science and Resources

Green Metals Consultation - HILT CRC Response

About HILT CRC

The heavy industrial sector contributes significantly to the Australian economy, with an annual direct economic output of approximately $180 billion, representing around 9% of the national economy. However, the sector is also carbon intensive, with the iron/steel, alumina and cement/lime sectors alone accounting for approximately 9% of Australia total CO_2 emissions, and the global downstream processing of Australia's resources accounting for three times all of Australia's direct emissions. While some progress has been made in the decarbonisation of Australia's heavy industries, innovative technologies and transformative processing pathways are required to meet 2050 net zero emissions targets.

The Heavy Industry Low-carbon Transition Cooperative Research Centre (HILT CRC) was created as a catalyst to propel Australia's heavy industries towards a sustainable future. Through industry-led research, HILT CRC endeavours to mitigate risks and pave the way for effective decarbonisation strategies with a focus on the iron/steel, alumina and cement/lime sectors. Since commencing operations in November 2021, HILT CRC has successfully embarked on groundbreaking research in collaboration with over 50 Partners across industry, research organisations and government, and currently has 25 active research projects underway.

HILT CRC's Key Messages

HILT CRC welcomes the opportunity to respond to the Department of Industry, Science and Resources (DISR's) consultation on Green Metals: A Future Made in Australia: Unlocking Australia's Green Iron, Steel, Alumina and Aluminium Opportunity. We have provided comprehensive responses to relevant questions, with a high-level summary outlined in blue at the start of each response.

HILT's Key Messages in the Green Metals Consultation:

- Australia's Green Metals opportunity is significant from both an economic and global emissions reduction perspective. Investment in decarbonising the global processing supply chains that use Australian ores is potentially the largest impact Australia can make to emissions reduction on a global scale.
- New production technology, some of which is unique to Australian ores, requires further derisking. Coordination, knowledge sharing and collaboration between government, industry and research organisations is essential to develop the network of RD&D facilities required for the transition.
- Access to renewable / low carbon energy and energy infrastructure is a significant challenge identified by our partners, other barriers such as capital costs are described throughout our response.
- HILT has a broad research portfolio aimed at addressing these challenges, so Australia can realise our Green Metals opportunity

HILT CRC

HILT CRC has recently engaged with other Australian Federal Government departments and agencies, and submissions, in particular:

- Department of Climate Change, Environment, Energy and Water
- Department for Industry, Science and Resources – Net Zero Industrial Sector Plan
- Climate Change Authority 2024 Issues Paper: Targets, Pathways and Progress
- Net Zero Economic Agency

Copies of documents provided to these Departments can be provided upon request.

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Questions:

We want to better understand future markets for green metals.

1. *What insights do you have on green metals markets?*

   For example:

   a. *Expected current and future demand for green metals domestically and in key export destinations.*
   b. *Australia's potential production volumes of green metals.*
   c. *Which countries/markets are green metals currently being sourced from and used in?*
   d. *For exporters, what are you hearing from international partners about the transition to green metals?*
   e. *Australia's capacity to source green metals from global supply chains*
   f. *Which countries or markets will provide the greatest international competition, or demand for Australian produced green metals?*

HILT response 1:

HILT CRC has a range of projects underway addressing green metals markets, in particular in our Research Program 3 "Facilitating Transformation". Key insights from these projects relevant to this question so far are:

- The top 10 export industry competitors for Australian iron, steel and aluminium products are China, Germany, India and USA.
- China, USA, India, EU and Germany had the highest number of trade policy measures implemented to support their domestic iron/steel and alumina/aluminium industries in descending order.
- The outlook for Australian exports of green iron to China depends strongly on the relative costs of green hydrogen, and therefore renewable electricity, in Australia versus China.
- The markets with the highest potential for green steel demand are the construction, automotive, renewable energy and domestic appliances industries.
- The appetite for green steel varies significantly across Europe, North America, and Asia, driven by differing regulatory environments, market demands, and industry commitments.
- Australia's key future opportunity to supply clean processed products into international markets is likely in the form of green iron, supplied as an intermediate input to traditional steel making countries.

A better understanding of future demand of green metals is key to reducing the low-carbon transition risk for heavy industry. HILT is undertaking research to inform industry and government of global opportunities, threats and emerging best practice, including:

HILT project RP3.003: Trade and regulatory issues in Australia's heavy industry low carbon transition undertook trade import and export analysis to identify the top 10 export industry competitors for iron, steel and aluminium products. The top 4 competitors are China, Germany, India and USA. In addition, a recent CSIRO analysis has projected India, China and Western Europe have current and future renewable energy costs that are competitive with those in Australia (Graham and Havas, 2023). This project also identified trade policy measures enacted by the top 10 export industry competitors, including tariff and non-tariff barriers, export subsidies and other trade-related policies. China, USA, India, EU and Germany had the highest number of measures implemented in descending order. (Report available on request)

HILT Project RP3.004: Intermediate product exports for Australia-China green steel is developing a technoeconomic model of steel production from ore through to steel product, with the aim of identifying where and how Australian exporters may retain or achieve competitiveness in markets for iron ore, green iron, or green steel. A key aspect of the model is that it considers ore composition and effects on costs at different processing steps. Preliminary results suggest that the outlook for Australian exports of green iron to China depend strongly on the relative costs of green hydrogen, and therefore renewable electricity, in Australia versus China. Results suggest that imports of green iron from Australia are comparative vs Chinese domestic production when Australian green hydrogen costs are at or below the cost of green hydrogen in the Chinese market.

HILT project RP3.005: Analysis of market, cost and locational factors for green iron and steel in Australia will combine a variety of approaches including systematic review of literature, industrial reports and national strategies, techno-economic assessment of technologies, modelling and scenario compilation, expert elicitation, and analysis of policy and market mechanisms. Ahead of results from expert elicitation, review of literature suggests that the markets with the highest potential for green steel demand are the construction, automotive, renewable energy and domestic appliances industries. The construction industry demands the largest amount of steel, but only has low to medium pressure to decarbonise as consumers in larger cities demand greener buildings and infrastructure. Mandatory green building codes can create demand for materials with lower embodied emissions, but these are in early development and may have stronger effect on cement than steel.

Currently, approximately half of the supply agreements for green steel are within the automotive industry. This sector has shown significant interest in green steel as part of its efforts to reduce the carbon footprint of vehicle production. This is likely driven by the low additional cost to consumers for replacing conventional steel with green steel, making it a more attractive option for both manufacturers and buyers who are conscious of environmental impacts.

The appetite for green steel varies significantly across Europe, North America, and Asia, driven by differing regulatory environments, market demands, and industry commitments. Europe is leading in regulatory support, industry investment, and consumer demand for green steel. North America shows growing interest with moderate regulatory support and increasing industry and consumer demand. Asia has a varied appetite, with significant investments in Japan and South Korea, and a balancing act between growth and sustainability in China and India.

Australia's key future opportunity to supply clean processed products into international markets is likely in the form of green iron, supplied as an intermediate input to traditional steel making countries. This supply chain would make use of abundant low-cost renewable energy for the energy intensive production step of iron ore reduction, while retaining the generally highly specialized steel making production in current production locations.

References:

- Comparing and ranking the global cost of green industrial electricity, Graham and Havas, 2023. See paper.

2. How does metal recycling contribute to Australia's green metals industry in Australia?

a. What is the impact of metal recycling on reducing emissions from Australia's industrial sectors?
b. What are the opportunities to increase metal recycling in Australia? How could this be achieved?
c. What impact does the export of scrap metal have on Australia's ability to develop a green metals industry and reduce emissions from existing industry?

Preliminary findings from the HILT project RP3.005: Analysis of market, cost and locational factors for green iron and steel in Australia show that Australia exports between 1.5 – 2.2 million tonnes of steel scrap annually. Steel scrap availability is important in the realisation of green steel, particularly in a hydrogen-based direct reduction of iron ore (DRI) and steel scrap melting in an electric arc furnace (EAF). Hydrogen-based DRI-EAF is one of the most mature technological routes to date, capable of reducing CO_2 emission by 95% but relies on the availability of rich iron concentrates as feed materials. Restricting the exports of scrap from Australia would increase the scrap recovery rate and recycle rate and reduce emissions. Each 1 megaton of extra scrap in Australia for steelmaking would reduce steelmaking emissions in Australia by 5-10%.

3. What practices are used to verify and measure green metals? What are the limitations of these approaches?

There is not yet an agreed definition of "green metals" and there are many certification schemes and standards emerging internationally, leading to a complex policy landscape. HILT Project RP3.006: Certification and verification to enable a successful LCT for heavy industry, which has just started, aims to understand that landscape and make recommendations in an Australian context. The outcome of this project will be to inform the engagement of heavy industry in Australia with emerging domestic and international regulatory and market regimes based on embedded emissions accounting so that they can successfully engage, providing them with competitive advantage and supporting their successful transition to low carbon production – both financially and environmentally.

As Project RP3.006 has only just started, there are no outcomes yet. DISR is welcome to engage with HILT CRC to understand more about the project, which will:

- Assess the relevant regulatory and market initiatives both in Australia and critical markets overseas which rely on embedded/embodied emissions accounting. This includes explaining their relevance, scope, implications and timeline.
- Develop HILT partners understanding of best-practice principles and approaches to embedded emissions accounting by drawing on a combination of theory and practical examples.
- Enable HILT partners to engage in processes around the development of embedded emissions accounting regimes of relevance to their products. This includes options for as-yet unresolved questions around accounting complexity for circularity (e.g. recycled timber in steel production) and co-products.
- Identify enablers and barriers to utilisation of embedded emissions accounting for private sector initiatives, including those around net-zero and circularity.

Note: DCCEEW is a participant in this project.

4. *If you are a downstream user of metals, what factors do you consider in your decisions to purchase traditionally produced, emissions-intensive metals or green metals?*

This question is beyond HILT's remit.

5. *Are you already committed to incorporating green metals into your business plans? How do you plan to achieve those goals? If you are not planning to include green metals, what further measures could accelerate or incentivise you to do this?*

This question is beyond HILT's remit.

We are interested in better understanding the factors influencing investment decisions in Australia and globally.

6. *What is the scale of investment needed to convert existing facilities or establish new ones (including enabling infrastructure)?*

HILT Response 6:

Heavy industrial processes such as green iron production, steel making, and alumina refining are capital intensive industries with generally long lifetime assets. Hence the scale of investment needed for retrofits and/or new plants will be significant.

The low carbon transition for heavy industry will also require significant investment in enabling infrastructure, especially low-carbon, low-cost and reliable energy at scale. HILT CRC has a new project underway assessing energy infrastructure options for different demand and supply pathways to 2050.

There are many different pathways for decarbonising metal processing. The optimal solution for green iron and steel production, for example, will depend on the types and grades of ores being processed, the availability of supporting infrastructure, as well as the economics of competing globally in different parts of the supply chain. The best pathway will be different for different locations. We note that heavy industrial processes such as green iron/steel and alumina are capital intensive industries with generally long lifetime assets so the investments will be large. Due to the scale, international investments will be needed, and Australian plants will have to compete globally to be the most attractive destination for this investment.

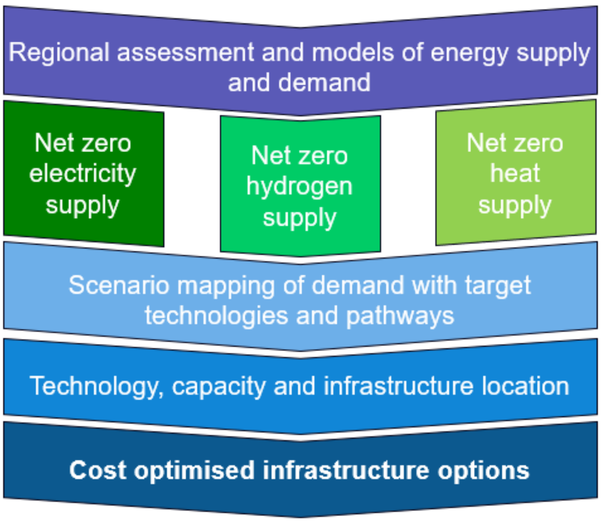
HILT CRC is beginning the process of developing scenario-based, multi stakeholder assessments, to better understand plausible responses to this question. In the meantime, HILT CRC incorporates techno-economic modelling in many of its projects, including assessing the cost of converting existing facilities to decarbonise heavy industry or building new facilities to produce low carbon products.

The low carbon transition for heavy industry will also require significant investment in enabling infrastructure, especially low-carbon, low-cost and reliable energy at scale. HILT CRC is beginning the process of developing scenario-based assessments to address this question based on multi-stakeholder assessments. While a number of previous reports of the energy inputs required to decarbonise heavy industry are relevant (e.g. AEMO Integrated System Plan, Australian Industry Energy Transitions Initiative, and Net Zero Australia Study, Venkataraman et al, *Energy Policy*, 2022 https://doi.org/10.1016/j.enpol.2022.112811), these do not attempt to address potential changes to current processes that will be needed, nor provide information on how much is likely to be needed where, and by when. HILT's preliminary work on this topic are summarised as follows:

- RP2.001: Green hydrogen supply modelling successfully created a modelling tool for estimating local costs of green hydrogen production and storage and demonstrated that a constant supply of hydrogen for industrial processes could be met with renewable energy but would require access to hydrogen storage infrastructure (final report available on request).
- Follow up project RP2.006: Hydrogen supply within HILT regional hubs is undertaking more detailed modelling for specific locations of importance to HILT industry partners, including Northern Tasmania, the Pilbara, Western Australia, and Upper Spencer Gulf, South Australia. Outputs include indicative system sizing, configuration and location (including capacity of the electrolysers, hydrogen storage and renewable energy assets), infrastructure requirements (transmission lines and hydrogen pipelines), and assessing the potential cost of delivered hydrogen (final report due August 2024).
- RP2.003 Green heat for industry concluded that Thermal Energy Storage (TES) appears to be the cheapest option for supply of green heat considering different industry locations and renewable energy inputs (final report available on request).

More details of the new project referred to above regarding future scenarios for decarbonisation are provided below. This new project, which is entitled RP3.007: Unlocking energy infrastructure investment in industrial hubs, aims to do the following:

- Develop plausible scenarios for the transition of existing processes and the establishment of new processes, needed to supply low-carbon products through the transition to net zero by 2050.
- Develop scenarios for actual demands for electricity and fuels for these investments, accounting for the type of product, feedstock and the potential impact of prospective technology pathways anticipated to be available;
- Develop cost-optimised infrastructure needed to supply these demands considering the options expected to be available, both for technologies that are commercially available and those that are expected to become available; and
- Estimate the amount of co-investment by the government that may be justified based on future economic benefits, such as employment, royalties/ revenues, social/regional benefits and co-investments.



Note: HILT CRC information on establishing new facilities for green metals is included in our response to Question 7.

7. *Is your organisation currently undertaking or planning to undertake any major green metal investments or facility refurbishments?*

    a. *When are these expected to begin, and what are the anticipated completion dates?*
    b. *When are the capital costs associated with the refurbishments expected to be recouped?*

HILT Response 7:

Capital-intensive Research Development and Demonstration (RD&D) facilities are needed to support the development and de-risking of low carbon technologies for green metals production. HILT proposes that the fastest, least cost and least risk way to develop these facilities is if they are co-ordinated nationally (and internationally) and involve industry, research and government working collaboratively, particularly on knowledge sharing.

We believe that funding is needed across all three scales of facility, from research to pilot to demonstration scale, to provide complementary information and support each other. Specific priorities for expanded research facilities and programs, as identified by HILT and its partners, are:

- Advanced beneficiation for iron ore and bauxite,
- Iron ore reduction and smelting,
- New calcination reactors for net zero mineral processing, and
- Thermal energy storage for net zero steam.

HILT is working closely with our partners to develop plans for capital-intensive Research Development and Demonstration (RD&D) facilities, which are needed to support the development and de-risking of low carbon technologies for green metals production/heavy industry decarbonisation. HILT has identified the need for the following three types of RD&D facilities:

- Research (bench to sub-pilot) scale facilities – typically owned and operated by research partners, moderate in cost and required to support technology development and de-risking projects. Order of magnitude cost: <$10M
- Trials/Pilot scale facilities – typically owned and operated by a technology company or government research laboratory and used to demonstrate the variability of an integrated process or a specific technology pathway. Order of magnitude cost: $10M - $50M
- Industrial-scale demonstration and de-risking facilities – typically owned and operated by end user/producer companies. Order of magnitude cost: >$100M

HILT proposes that the fastest, least cost and least risk way to develop these RD&D facilities is if it is co-ordinated nationally (and internationally) and involves industry, research and government working collaboratively, particularly on knowledge sharing, as illustrated in Figure 1.

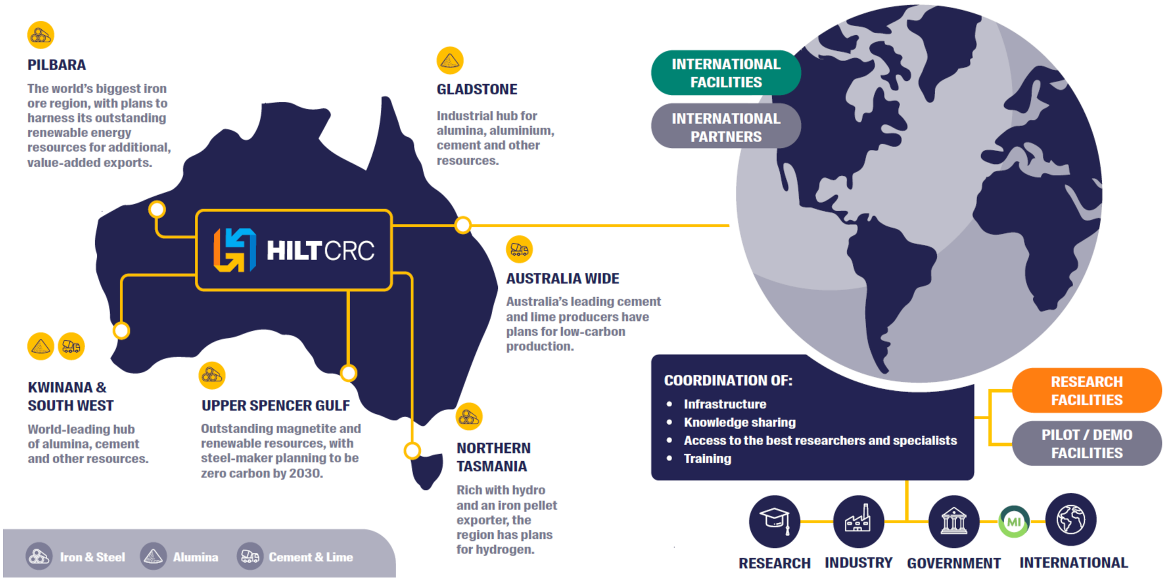


Figure 1: *HILT CRC's vision of national and international co-ordination of RD&D facilities to support decarbonisation of heavy industry.*

We believe that funding is needed across all three scales of facility. Different sized facilities provide complementary information and support each other: smaller scale facilities support large-scale deployments at commercial scale, since they are more flexible, cheaper to run and provide more data. In addition, all technology continues to evolve, so that research with smaller scale facilities is continuously needed to feed the pipeline of technology development and broaden the range of applications for new technology. Larger-scale trials/pilots and demonstrations are also needed to de-risk commercial projects and to take breakthrough ideas and low Technology Readiness Level (TRL) through the upscaling pathway.

Education and training are other important considerations: Research/lab-scale facilities are important to provide the training and building of the workforce of the future.

Such a coordinated approach is needed to bridge low TRL/small scale novel ideas and de-risk them for industrial scale application. Specific priorities for expanded research facilities and programs, as identified by HILT and its partners, are:

- Advanced beneficiation for iron ore and bauxite,
- Iron ore reduction and smelting,
- New calcination reactors for net zero mineral processing, and
- Thermal energy storage for net zero steam.

An example of a facility that is needed in the new research ecosystem is the Green Iron Technology Precinct/Common User Pilot Facility being developed by CSIRO, with the support of MRIWA, Climate-KIC and SWERIM. HILT CRC, CSIRO and MRIWA jointly organised and held an Industry Round Table on Wednesday 6th March to progress this initiative.

HILT is also working with its alumina partners to develop a coordinated plan for the development of net zero alumina processing technology.

We are interested in your views on principles for community benefit sharing and how this might apply to the green metals industry.

8. What are the benefits to the local region or community when developing a green metals project?

This question has not yet been addressed in a HILT CRC project. However, we suggest that supporting the just transition of skilled workers between sectors as the economy decarbonises will contribute to wellbeing of workers, communities and regions as the nation decarbonises, which can be assisted through:

- Development of a wholistic plan to build capacity more broadly by including producers, engineering and technology companies, construction and manufacturing companies together with the research and education sector;
- Develop the workforce of the future with the skills, knowledge and experience of developing and implementing new decarbonisation technologies and processes.

9. How are you considering these benefits in evaluating projects? Are there ways to increase opportunities for the local community or broader industry?

This question is beyond HILT's remit.

10. How can the government support industry to enable communities and workers to share in the benefits of transitioning to green metals?

This question has not yet been addressed in a HILT CRC project. However, we suggest that fostering knowledge sharing and stakeholder engagement, in particular community education and engagement regarding the significant changes and opportunities that will accompanying the transition of heavy industry its supply chains, infrastructure and jobs, will address this point.

11. Are you aware of case studies where private companies have established community benefit sharing with communities, and whether this has worked particularly well or poorly?

This question is beyond HILT's remit.

HILT CRC

We are interested to understand how quickly it is feasible to achieve different 'green milestones' as we move towards zero emissions production.

12. What are the key barriers to investing in new green metals facilities or decarbonising existing facilities?

Please indicate the level of priority for addressing each barrier.

HILT Response 12:

HILT hosted a series of Roundtables with stakeholders, including industry partners and government representatives, across Australia in 2023 to discuss non-technical barriers holding back the deployment of decarbonisation technologies. Identified issues are listed below:

- The significant amount of capital investment required
- Time, cost and risk in securing development regulatory approvals
- Access to energy and net-zero fuels (eg Hydrogen) at sufficient cost, scale and within necessary timeframes
- Enabling infrastructure such as roads, rail, water, housing
- Access to workforce with sufficient skills and experience to implement new technologies
- Green product value – need for a premium to offset the high cost of investment which, in turn, required processes for regulation and certification Policy risk and uncertainty
- Supply chain risks
- Community Engagement

In particular, it is important to note that Australian projects must compete globally to attract capital investment market share for their products. Outside of Australia, environments with significantly lower capital costs, lower regulatory risk and greater access to green energy exist, which provide additional significant barriers for projects in Australia.

HILT's roundtables identified for key priority themes for non-technical barriers to the transition:

- Enabling infrastructure
- De-risking decarbonisation investment
- Policy signals and enablers
- Trade barriers and market drivers.

Clustering analysis of discussion relating to these themes identified five topics that could address these barriers, as summarised in the matrix below.

Common Feedback Topics:	Priority Themes			
	Enabling Infrastructure	De-risking decarbonisation investment	Policy signals and enablers	Trade barriers and market drivers
Mapping cross-border impacts of existing LCT policy settings.	✓	✓✓	✓✓✓	✓✓✓
Policy scenario modelling of reaching net zero by 2050.	✓✓	✓✓✓	✓✓✓	✓✓
Harmonising LCT regulation, compliance & certification.	✓	✓✓	✓✓✓	✓✓
LCT stakeholder engagement & collaboration.	✓✓	✓	✓✓✓	✓
Coordinated LCT investment planning & knowledge sharing.	✓✓✓	✓✓✓	✓✓	✓

HILT's Program 3: Facilitating Transformation has the following flagship projects now underway to address these barriers and potential enablers:

RP 3.006: Certification and verification to enable a successful LCT for heavy industry. This project will enable Australian heavy industry to successfully engage with emerging regulatory and market regimes based on embedded emissions account, providing them with competitive advantage and supporting their successful transition to low carbon production – both financially and environmentally.

RP 3.007: Unlocking investment in energy infrastructure for net zero industrial hubs. This project will provide the information required to enable industry and other stakeholders to plan for the transformation of the energy supply system necessary for heavy industrial sectors to a net-zero carbon future.

RP 3.008: A policy roadmap for Australia's heavy industry low-carbon transition. This project will assist heavy industry partners and stakeholders to understand, manage and mitigate risks associated with the transition. It does this by deepening understanding of current and future policy developments at different government levels that directly impact heavy industry.

References:

- HiTeMP-2 Outlook Report (precursor event to HILT CRC)
- HILT Program 3 2023 Roundtables – Summary Report

13. To what extent are barriers comprised of upfront capital costs or ongoing operational costs?

As per HILT's answer to Question 12, the Program 3 roundtables held by HILT in 2023 highlighted that a significant barrier holding back the deployment of decarbonisation technologies, is access to the significant amount of capital investment required.

HILT CRC incorporates techno-economic modelling in many of its projects that considers upfront costs and ongoing operational costs to inform industry and government partners regarding technology and investment decisions – further specific information can be provided upon request.

HILT project RP1.005 Hydrogen Ironmaking: fluidised bed H_2DRI with Australian focus undertook end-to-end technoeconomic modelling of green steel production from a range of Australian ores, with emphasis on Pilbara direct-shipping ores. It was identified that variable renewable energy (VRE) infrastructure costs represent more than 50% of the final green steel price, which is primarily a result of the cost of the capital required to establish those VRE facilities.

HILT project RP3.005 Analysis of market, cost and locational factors for green iron and steel in Australia is taking a different approach, by including demand factors as well as local, operational supply factors such as labour and scrap costs and capacity, to inform an analysis of green iron and steel price dynamics.

14. *What options are there at each intermediary step to reduce emissions for metal products?*

a. What are the relevant thresholds for emissions reductions related to these intermediary steps?

b. What levels of emissions reduction might be achievable for your facility or in your industry under different levels of investment and ambition?

HILT Response 14:

The key steps HILT CRC anticipates industry will take to reduce emissions are:

1. Install 'transitional' technologies or low-carbon solutions for retrofits or brownfield installations to manage the risk of new technologies and the high capital cost of new green metals plants.
2. Trial 'Transformational' technologies or low-carbon solutions in retrofit/brownfield installations to de-risk various components of a new production process.
3. Install new green metal production facilities, with maximum emissions reduction benefit, once technology is fully de-risked and a robust business case for investment is demonstrated.

This question has not been explicitly addressed in a HILT CRC project, although costs and emissions benefits are considered in our techno-economic modelling. Nevertheless, from our discussions with industry, we anticipate that retrofitting will be a priority for some industries due to the high capital cost of heavy industrial production plants. Hence the development of 'transitional' technologies or low-carbon solutions will be an important intermediate step to reduce emissions for such retrofits or brownfield installations. Retrofit will also be used to de-risk various components of a production process, which can then be combined into new sections of a plant and eventually into new production facilities. Such investments are likely to be easier to justify if the new system offers 'transformational' low-carbon technologies, which lower cost by improved performance relative to the baseline case.

Examples of transitional pathways:

- **Iron/steel:**
  - Steel production from iron ore is dominated by the Blast Furnace-Basic Oxygen Furnace (BF-BOF) processing route. It is a highly emission intensive process, primarily due to its heavy reliance on coal and other fossil fuels in the blast furnace. According to the IEA[1], the emission intensity of the BF-BOF route is estimated to be 2.2 t CO_2/t crude steel[2]. The breakdown of emissions per processing step is as follows:

Processing step	Contribution to total emissions
Coke making	5%
Sintering	13%
Pelletisation	2%
Ironmaking in BF	70%
Steelmaking in BOF	10%

  - Steelmaking based on recycling scrap steel in electric arc furnaces (EAF) is currently the main option to significantly decarbonise the steel industry, as it releases the least CO_2 emissions, with only 0.3 t CO_2/t crude steel. China for example, is aiming to increase the share of scrap-EAF steel production to over 20% by 2030[3]. In Australia, where scrap-based steelmaking represents about 25% of the crude steel production, several new scrap-EAF steel plants are under development. However steelmaking via this process cannot supply all steel production globally, as the supply of scrap and available electricity are limited, particularly in emerging and developing economies. In addition, scrap-EAF steel is not suitable for certain applications, due to its lower quality.
  - The decarbonisation of steel production is expected to follow several major trends:
    - Optimising the BF-BOF steelmaking route, by introducing new technologies to capture, store and/or use CO_2 from process gases, substituting fossil fuels and reducing agents (e.g. coke, coal) with net-zero alternatives (e.g. green hydrogen, biomass, RDF, syngas) and improving the quality of feed materials used to feed the blast furnace (e.g. using lump, BF-grade pellets and HBI instead of sinter).
    - Transitioning steelmaking from carbon-based BF-BOF route to low-emissions DRI-based steelmaking, first using natural gas and then later green hydrogen and possibly renewable electricity, as the renewable energy infrastructure becomes more available.
  - Breakthrough net-zero steelmaking technologies, such as iron ore electrolysis or hydrogen plasma smelting reduction, may also play a role.

[1] Iron and Steel Technology Roadmap, International Energy Agency, October 2020
[2] Including direct and indirect emissions
[3] Steel Transition Strategy, Mission Possible Partnership, September 2022

- Alumina:
    - Net zero steam for the Bayer process (alumina digestion) should be able to be integrated into existing facilities. This may enable reduction in energy demands by 20-25%.
    - Whilst hydrogen fuelled calciners for alumina are likely to be retrofittable, new calciners are likely to be needed for electrification. Either way, they will need to be located on the sites current alumina plants, many of which are space-constrained.

- Cross-Cutting:
    - For those sites which use coal and have access to natural gas, the switching between these fuels offers an interim option to lower CO_2 emissions. However, this is not possible for those plants which already use natural gas or where natural gas is not readily available. Also, this approach will only go part of the way to decarbonisation.
    - To achieve net-zero emissions from high temperature heavy industrial processes using fossil fuels, the ultimate step is to transition to green hydrogen (or other sustainable hydrogen-rich gases). This will require an understanding of the technical risks associated with using increasing amounts of hydrogen in high temperature processes, and the development of novel hybrid burners that can use hydrogen as a standalone fuel or together with other low carbon energy source options (electricity from renewables, alternative fuels such as RDF)
    - Electrification of the steam-making process is now beginning internationally, with the installation of electric boilers providing potential to decarbonise steam. Both the relatively high cost and a lack of access to sufficient renewable energy will limit the extent of extent to which this can be applied. Thermal storage offers potential to lower the cost of accessing variable renewables in the next decade, although more work needs to be done to confirm the viability of this approach.
    - Carbon capture and utilisation or storage is also a potential contributor to industrial decarbonisation in the next decade, although mostly to de-risk and demonstrate it during that period. Technologies are already emerging to convert captured CO2 into low-carbon fuels such as methanol, diesel and/or aviation fuel. These are presently at pilot scale, so are potential to reach commercial scale in the next decade.
    - Biomass/RDF/alternative fuels/syngas can be integrated into existing facilities on the provision that the resources are available at sufficient scale and cost. While the barriers of access and cost will limit the extent of their contribution.

15. *What are the technologies associated with meeting green thresholds?*

HILT Response 15:

The technologies that HILT CRC has identified and evaluated as being important in helping metal production transition to net zero are listed below:

- Net zero steam and improved steam recovery for alumina production,
- Net-zero calcination technology,
- Ore beneficiation,
- Ore agglomeration,
- Direct reduction technology for iron ore,
- Electric smelting furnaces for iron- and steel-making,
- Supply and utilisation of net zero energy and fuels,
- Carbon capture, utilisation and storage,
- Ore property characterisation, and
- Monitoring and measuring.

A core focus of HILT CRC is identifying and evaluating the most prospective technology pathways for the production of green aluminium and steel, with an emphasis on the key intermediates of alumina and iron, respectively. This work has been informed by technology development roadmaps provided by our industry partners, where these are publicly available, together with our understanding of international efforts and evaluation projects led by HILT CRC researchers.

Figure 2 illustrates the individual technologies and decarbonisation pathways for each sector, as well as the linkages between them.

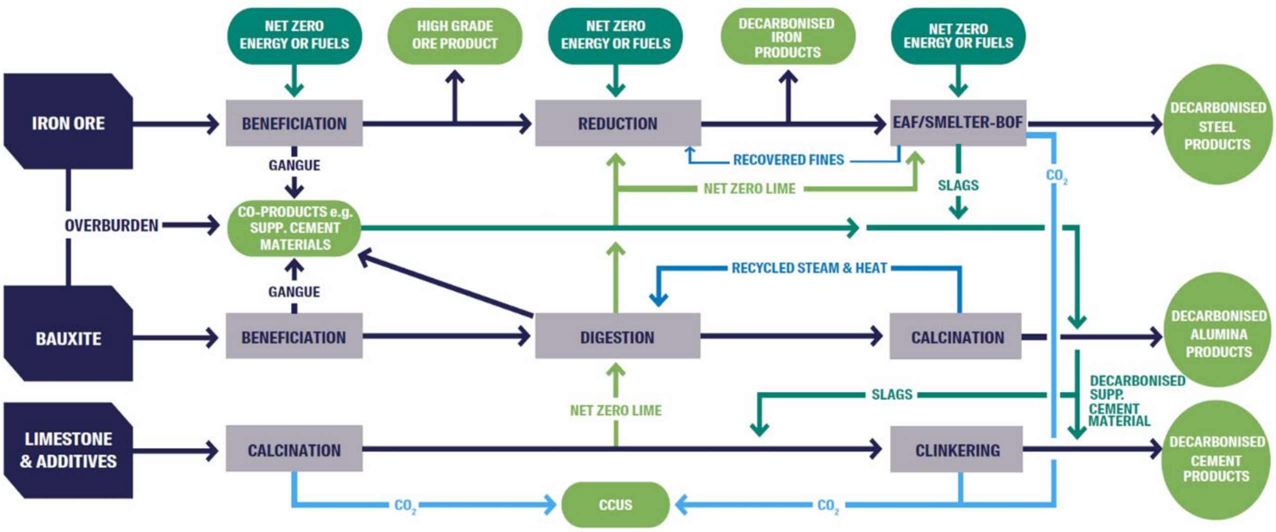


Figure 2: *HILT decarbonisation pathways and areas where technology can be deployed and have a significant impact on decarbonisation.*

HILT CRC

The technologies that HILT CRC has identified as being important in helping these sectors meet green thresholds and transition to net zero are detailed as follows:

Alumina	
Technology	Justification
Net zero steam / and improved steam recovery via: • Mechanical Vapor Recompression • Electric boilers • Heat pumps • Thermal energy storage utilising either firmed or intermittent renewable electricity	The majority of energy used in alumina processing is for steam in the Bayer (digestion and purification) process. Steam is also widely used in a range of other industries. Some specific HILT insights are: • A combination of mechanical vapor recompression, thermal vapour recompression, heat pumps, and electric boilers are expected to be needed to increase efficiency and lower the cost of decarbonising the alumina Bayer process (HILT Project RP1.002). • Thermal energy storage for high temperature air and/or steam has been assessed and identified as a technology with strong potential to contribute to decarbonisation in HILT Projects RP2.003 and RP2.009. • A key question is how to best integrate such new technologies within existing and proposed alumina production facilities. HILT is developing the analysis tools, methods, technologies and knowhow to increase steam recovery and to generate net zero make-up steam in Project RP1.013 "ALUMINext". See also: ARENA Report – Roadmap for decarbonising Australian alumina refining.
Net-zero calcination technology via: • Alternative fuels • Electrification	Calciners used for the production of various metals and intermediates, including alumina are presently fired with fossil fuels. Technology is needed, beginning with retrofit options that allows low-risk decarbonisation approaches to be implemented, followed by step-change designs. Specific HILT insights are: • HILT Project RP1.007 identified strong potential to increase the viability of alumina refining by converting calciners to operate in a steam atmosphere. This offers potential to increase the viability of recovering the steam released during the calcination process. However, a number of technology developments are needed to enable this. • Further work is underway to assess the replacement of fossils fuels with alternative fuels, such as biomass (RP2.010, RP2.012) or hydrogen (RP2.007). Opportunities to offset the relatively high cost of renewable hydrogen through utilisation of co-produced oxygen are also being considered (RP2.007). Calix's novel reactor technology has been shown to offer good potential to contribute to low-carbon alumina production. More work is needed to better understand its viability relative to other options (RP1.013)
Iron / Steel	
Ore beneficiation: • Thermal beneficiation *as per HILT projects RP1.008 and RP1.006*	New ore beneficiation technologies are important for green iron production to reduce energy and water consumption, recover additional co-products and reduce the adverse impacts of managing tailings. Some specific HILT insights on these technologies are: • HILT projects RP1.004 and RP1.005 concluded that competitive green steel production from lower-grade Pilbara hematite and goethite ores could be optimised if the ores could be upgraded to certain levels, depending on the steelmaking route. For the DRI-ESF-BOF pathway, upgrading the ores to about 62% Fe would be optimal. For the DRI-EAF pathway, more beneficiation (up to 65% Fe) would be required.

• Chemical leaching beneficiation *as per HILT project RP1.011*	• The HILT-supported beneficiation technologies, (thermal pre-treatment RP 1.008 and RP1.011 chemical leaching) both show promise to lower costs by decreasing energy and grinding costs, increasing yield and grade, together with extracting additional value from new co-products. Thermal Pre-treatment and caustic leaching showing promising results with measured increase in Fe content of up to 10%. Typical results are increasing Fe content from 60 wt% to 66 wt%, while recovering more than 90% of the iron and also lowering the Phosphorus content. This technology could be used to upgrade lower quality ores, making them more suitable for Green Steel Processes at scale. • HILT CRC project (RP1.011) recently received ARENA funding to progress the chemical leaching technology to pilot scale in the next 3 years.
Iron ore agglomeration	Production of pellets from Australian iron ores meeting the metallurgical requirements for blast furnace and shaft-based direct reduction routes is expected to play a significant role in supporting the transition to green steel. Whilst much is known about the physical and metallurgical properties of pellets prepared from magnetite concentrates, little is known about the properties of pellets made from moisture-rich Pilbara ores, and their subsequent behaviour in downstream ironmaking processes, especially shaft-based direct reduction process. Considering that shaft furnaces are the leading technology currently available at commercial scale for direct reduction, it is necessary for Australian ore producers to demonstrate that Pilbara ores can be used to produce pellets suitable for a shaft-based direct reduction process, especially when using hydrogen as reducing gas. HILT Project **RP1.001** studied the fundamentals of pellet clustering, swelling and breakage in the shaft furnace and identified possible recommendations and pathways that will serve as a guide for future experimental research projects. Another option is to investigate the potential for producing cold-bonded briquettes from Australian iron ore, suitable for blast furnace or shaft-based direct reduction processes. Cold-bonded briquettes do not need to be processed at high temperature, resulting in significant energy and emissions savings.
Direct reduction of iron ore: • Shaft furnace DRI • H_2 fluidised bed DRI • H_2 direct flash smelting	Direct reduction of iron (DRI) technology is needed to lower the cost of production and increase the range of ores which can be used in emerging green iron/steel pathways[4]. DRI production in shaft furnaces is well-suited for Australian magnetite resources and could provide a first immediate step in the decarbonisation of onshore steel production. As part of their global strategy to reach carbon neutrality by 2023 (CN30), LIBERTY (one of HILT CRC's core partners) is undertaking a transformation of their Whyalla steel plant, which will see their BF-BOF operation being replaced by a shaft-based DRI-EAF process, fed with high-grade magnetite concentrate produced from their Middleback Ranges mine. The DRI plant will use both natural gas and green hydrogen (supplied from the 250 MW South Australian Government Hydrogen Facility, expected to be operational in early 2026).

[4] See also: Western Australia's Green Steel Opportunity, Minerals Research Institute of Western Australia (MRIWA), 2023.

	To unlock the potential of Australian ores for green steel production, further research and development is required to enable DRI production from low-grade Pilbara hematite/goethite ores. Some specific HILT insights are as follows: • The techno economic analysis conducted in HILT projects RP1.004 and RP1.005 revealed that DRI production using fluidised beds could be cheaper than shaft furnaces, primarily due to the elimination of the substantial costs of pelletisation. Eliminating emissions associated with the pelletisation process would also reduce the overall carbon footprint of DRI production with fluidised beds. They would also help avoiding the issue of limited global pellet supply. • A key risk limiting the adoption of hydrogen fluidised bed DRI production is sticking of the iron ore particles in the reactor at high temperature, leading to defluidisation of the bed. HILT project RP1.012 is investigating the de-risking of the hydrogen fluidised bed reduction of Australian iron ore fines through identification of the optimum anti-sticking agent, timing of application, and maximum resulting operating temperature of the process. • Other alternative direct reduction technologies are currently being developed for iron ore fines, such as the flash reduction process, where ultrafine particles of iron ores are reduced in-flight by hydrogen, resulting in very short processing times. Calix, a key partner of HILT CRC, is currently developing the ZESTY flash direct reduction process based on their electrically heated flash calciner. • HILT CRC is supporting Calix in evaluating the potential of its ZESTY technology for processing a range of Australian iron ores to a low-carbon DRI, through project RP1.009. Initial results have shown promising metallisation in pilot-scale testing
Electric smelting furnaces for iron- and steel-making • Electric Arc Furnaces (EAF) • Electric Smelter Furnaces (ESF) • Hydrogen Plasma Smelting Furnace	Smelting of DRI/HBI in electric furnaces (EAF, ESF) is one of the most important steps to unlock green steel production for Australian ores. A techno economic assessment of various steelmaking pathways for Australian ores was conducted in HILT projects RP1.004 and RP1.005. Some of the key insights are: • High-grade DRI (i.e. with iron content > 67%, impurities < 3% and metallisation ~95%) made from magnetite concentrate can typically be processed in EAF to produce crude steel. In Australia, LIBERTY is planning to build an EAF at their Whyalla steel plant as part of their plan to achieve carbon neutrality by 2030 (CN30). In Western Australia, there is an opportunity for Greensteel WA to complement the scrap feed to their planned EAF with HBI produced at their Mid-West DRI plant. This pathway could also be very appealing for Pilbara hematite/goethite ores, providing they can be beneficiated to at least 65% Fe. However, such high levels of beneficiation may be very challenging and highly ore dependent. • Low-grade DRI produced from low-grade Pilbara ores (with an iron grade typically around 55-65%) would likely not be economically viable for EAF steelmaking, as it would significantly increase costs due to increase in slag volume and energy consumption. A techno economic assessment conducted in HILT projects RP1.004 and RP1.005 suggested that a promising route would be to first melt the DRI in an electric smelting furnace (ESF) to remove the gangue impurities as slag and produce hot metal similar to the Blast Furnace. Further processing in conventional basic oxygen furnaces (BOF) would be required to produce steel. • The ESF technology needs to be further de-risked and optimised for low-quality, low carbon DRI.

	• BHP, Rio Tinto and Bluescope's recent announcement will see them collaborate to jointly investigate the development of the country's first ironmaking electric smelting furnace (ESF) pilot plant. • A new 3-year HILT project (RP1.014), will assess the viability of this route for processing Australian iron ores, and investigate key issues associated with the Hydrogen DRI-ESF route, in particular to understand how gangue content, form of the DRI, operating temperature, and carbon content of the ESF bath affects productivity, energy usage, metal chemistry and the potential of the slag to be sold as product. This work is being conducted in collaboration with Primetals Technologies, who is developing a commercial-scale ESF for low-grade DRI smelting. In the long-term, fundamental changes to current iron and steelmaking technologies will be required to meet net zero goals and new alternative ironmaking technologies will be required. Some of these technologies are currently under development but are still at a low TRL. One of the potential options is the direct conversion of iron ore to liquid iron using a thermal hydrogen plasma. In this process, the iron ore is melted and reduced simultaneously without the need for agglomeration. HILT CRC is currently working on assessing the potential of a hybrid direct- and plasma-reduction of iron ores (project RP1.010).
Cross-cutting technologies	
Supply and utilisation of net zero energy and fuels: • Electrification • Hydrogen • Biomass/RDF • Solar thermal	The decarbonisation of heavy industries requires progressively expanded access to one or more sources of net-zero energy and fuels at sufficient scale and sufficiently low cost. (The development of technologies to utilise these alternative sources is also needed, as covered below). Some specific HILT insights are: • HILT's 2023 P3 Roundtables identified the lack of access to net-zero sources of energy as being a key barrier. This has led to the establishment of new HILT Project: RP3.007 Unlocking energy infrastructure investment in industrial hubs. • HILT has developed tools to evaluate the viability of net zero energy sources at regional level through Projects RP2.001, RP2.003 and RP2.006. • HILT is currently conducting a broader review to assess the technical feasibility of using bioenergy (including biomass, biochar and RDF) in high temperature heavy industrial processes (projects RP2.010 and RP2.012) • HILT has been working on understanding the technical risks of using increasing amounts of hydrogen in high temperature heavy industrial processes (RP2.005 and RP2.015), working closely with Grange Resources on a case study for their Port Latta pellet plant. In project RP2.007, HILT CRC is also working on furthering the technical development of novel hybrid burners that can use hydrogen as a standalone fuel or together with other low carbon energy source options. See also: ARENA Report: Renewable energy options for industrial process heat.
Carbon capture, utilisation and storage: • Carbon capture • Utilisation	CCUS is critical for hard-to-abate sectors with direct CO_2 emissions (such as cement and lime[5]). CCUS is likely to also be important for some other large industrial processes, particularly during the transition before hydrogen is available at sufficiently large scale and low cost. For example, DRI or alumina calcination using natural gas with CCUS is a potential transition pathway to hydrogen fuelled processes.

[5] It is important to note that lime will be a necessary input for both green alumina and green steel production

	The development of CO_2 re-use processes is also important to increase the economic viability of decarbonisation pathways. Some specific HILT insights are: • HILT Project RP2.002 identified mineral carbonation and Sustainable Aviation Fuels (SAF) as being particularly prospective CO_2 re-use pathway for heavy industry. • As a result, HILT has now started a 3-year project on mineral carbonation using heavy industry waste and low-grade ores (project RP2.013).
Ore property characterisation	New low-carbon processing pathways will differ considerably over current ones. Hence technology is needed to characterise the properties and behaviour of Australian ores under these conditions. Some specific HILT insights on these pathways are as follows: • HILT Project RP2.016 will provide insights on new measurement methods and models to understand the behaviour of Australian ores and optimise the performance of existing and new reactors designs.
Monitoring and measuring	New technology is needed to develop improved engineering design tools and also to monitor and control new, low-carbon reactors and processes. A key aspect of this would be tools and approaches to accommodate intermittently available green energy due to the relatively high cost of providing firmed electricity at the required scale. Such tools will also be critical for process safety and process optimisation.

References:

- Port Kembla Steelworks Identification of Prioritised Options
- Effect of gangue on CO_2 emission for different decarbonisation pathways
  S Sabah, M Shahabuddin, A Rahbari, G Brooks, J Pye, MA Rhamdhani, Ironmaking & Steelmaking 51 (4), 356-36

- Process modelling for the production of hydrogen-based direct reduced iron in shaft furnaces using different ore grades
  M Shahabuddin, A Rahbari, S Sabah, G Brooks, J Pye, MA Rhamdhani, Ironmaking & Steelmaking, 03019233241254666

16. Are these technologies being developed or commercialised?

a. If yes, when do you expect these to be ready for commercial scale deployment?
b. If not, why not?

The technologies described in HILT's answer to Question 15 are at various stages of development and commercialisation, as described below:

Alumina	
Technology	**Technology status and timeline for commercial scale deployment**
Net zero steam / and improved steam recovery via: • Mechanical Vapor Recompression • Electric boilers • Heat pumps • Thermal energy storage utilising either firmed or intermittent renewable electricity	It is technically possible to begin to deploy emerging technologies suited to producing net-zero steam and improving steam recovery in the Bayer process this decade. However, the cost of steam production via these routes is likely to be greater than the current approaches and these new technologies will also require access to renewable electricity at sufficient scale and cost to be viable. Furthermore, the rapid evolution of both emerging technologies and of understanding of the options with which they could be potentially integrated means that it is risky to proceed too quickly, since this risks investing in plant that is not the most competitive in the long term, adversely impacting on viability over the longer term. Various net-zero steam production technologies are already commercially available, such as electric boilers and solar thermal heat, both of which can be deployed with or without thermal storage. However, these are typically not well established in the industry at this scale, so still bring some risk, and also require access to sufficient land and/or access to sufficient renewable electricity at sufficiently attractive cost. Their full integration into plants this decade will be limited by these constraints, which vary from site-to-site variations. Increased recovery of steam is technically viable now through the use of commercially ready technology such as mechanical vapour recompression. However, the extent to which this can be applied, also varies from site to site with issues such as temperature requirements of the plant, access to land and to power. Hence full decarbonisation of the steam cycle will take decades. See also: • Pathways to Low-carbon Alumina Production: HILT Webinar • ARENA Report: Roadmap for decarbonising Australian alumina refining
Net-zero calcination technology via: • Alternative fuels • Electrification	Current research activities provide experimental, small-scale pilot testing and modelling of different technological approaches to calcination, balancing the targeted carbon reductions with a need to maintain alumina quality at Smelter Grade Alumina (SGA) specifications. A key target of an approved HILT CRC project is to develop the specification of a demonstration plant for the identified preferred technology, either electrical, alternative low carbon fuel or a hybrid, that will proceed to construction with industrial partner support in a subsequent project commencing in 2027. In addition, HILT CRC partner Calix has a pilot plant in Victoria that has already undertaken alumina calcination tests using electric heating and has the capability to also conduct tests using hydrogen combustion (and potentially other alternative fuels) and HILT CRC partner Rio Tinto is undertaking tests of hydrogen combustion in a conventional alumina calciner in Queensland with ARENA support.

Iron / Steel	
The vital importance of Pilbara hematite and magnetite ores both to Australia's economy and to the global iron/steel supply chains, highlights the importance of taking a parallel approach of expanding the investment in research and technology development to develop and de-risk the technologies needed to produce 'green' iron products, whilst also lowering the cost of supplying and integrating the infrastructure for energy, fuels and CO2 management. The HILT CRC is undertaking work on both of these aspects for this reason.	
Ore beneficiation: • Thermal beneficiation *as per HILT projects RP1.008 and RP1.0011* • Chemical leaching beneficiation *as per HILT project RP1.011*	While beneficiation is already employed commercially for magnetite ores, and for some hematite/goethite ores, its high cost and water consumption limits its applicability. It is therefore highly desirable to develop new beneficiation technologies with lower demands for energy and water. HILT projects RP1.008 and RP1.011 have identified strong potential for two such technologies, one thermally pretreats the ore and other for leaching using brines derived from desalination. The thermal pre-treatment can be used to de-hydroxylate goethite ores to increase both its yield from magnetic separation and its specific surface area, while the leaching offers potential to remove alumina silicates and, in some cases, phosphor, whilst also offering potential for co-products. Preliminary techno-economic analyses of both technologies are promising.
Iron ore agglomeration	Magnetite ore is usually more suitable and preferable for producing high-grade concentrate and pellets used in DRI production or blast furnaces. There are currently two magnetite pellet plant in Australia: Grange Resources in Tasmania and SIMEC/LIBERTY in South Australia. While it is technically possible to produce pellets from Pilbara hematite-goethite ores using technology commercially available, the economic viability of this processing route faces significant cost and productivity challenges. There are several research programs looking at demonstrating the production of commercial-grade pellets from Pilbara ores (e.g. CSIRO, University of Wellington). BHP announced last year that they successfully collaborated with customers in China to demonstrate that their Pilbara products could be blended with a variety of ores to produce pellets with metallurgical quality similar to commercial pellets. In addition, they also produced pilot scale quantities of pellets made from 100% Pilbara ores that meet metallurgical quality requirements for BF and DRI use. Iron ore producer Vale is at the forefront of the development of cold-bonded iron ore agglomerates. At the end of 2023, they opened the world's first iron ore briquette plant in Brazil, with second plant to be commissioned in 2024, bringing the production capacity to 6 Mtpa. Vale announced that cold-bonded briquette, produced from high-grade hematite ore, was suitable for both blast furnace and direct reduction processes. Mineral Resources, Australia's fifth-largest iron ore mining company, recently invested in a new cold agglomeration technology being developed by UK-based company Binding Solutions Limited (BSL). It will provide technical, engineering, project management and procurement support to BSL for the proposed demonstration plant, which is expected to be able to produce 350,000-400,000 tonnes per year of cold-bonded iron ore pellets by 2026. Western Australia is being considered as a potential location for the demonstration plant.

Direct reduction of iron ore: • Shaft furnace DRI • H_2 fluidised bed DRI • H_2 direct flash smelting	The pellet-based DRI route using shaft furnaces is already in use commercially internationally and represents about 5% of the global steel production. The best-known technologies are MIDREX and HYL/Energiron with MIDREX accounting for almost 60% of the global DRI production in 2022. Both technologies currently use a reducing gas mixture made up of H_2 and CO, most often produced from the reforming of natural gas. Although both technologies can be converted to use of 100% green hydrogen as the reducing gas, it has not yet been demonstrated at commercial scale. The HYBRIT project in Sweden (based on Energiron technology) has been operating with 100% green hydrogen at pilot scale (1 tonne per hour) since 2020 and is expecting to start a demonstration plant capable of producing 1.2 Mt of crude steel per year in 2026. Still in Sweden, H2 Green Steel is also planning on starting hydrogen-based DRI production at commercial scale in 2025. Both projects will be based on DRI-EAF steelmaking, using high grade Swedish magnetite pellets. In Australia, several projects have been announced based on the same processing route: • LIBERTY is expecting to start a 1.8 Mtpa DR plant by 2025 to process locally mined magnetite using natural gas, before transitioning to green hydrogen when the 250 MW South Australian Government Hydrogen Facility becomes operational in early 2026). • Green Steel WA announced plans a commercial-scale DR plant using the Energiron technology at the beginning of 2028. Once again, the plant is expected to begin operations on natural gas and transition to green hydrogen as supplies become available • South Korean Steelmaker POSCO is looking into the feasibility of a green iron facility in Port Hedland consisting of a 3.5 Mtpa magnetite pellet plant and a 2 Mtpa HBI plant. The plant would be using the Midrex Flex technology, which can operate at increasing levels of hydrogen inputs up to 100%, when hydrogen becomes available. This technology is likely the only viable ironmaking technology that could be plausibly deployed this decade for iron pellets or steel produced from magnetite ores (MRIWA, 2023). However, it is important to note that the production of 'green' iron via this route also requires the establishment of the new low-carbon energy-related infrastructure to supply hydrogen (and/or natural gas) and also mitigate CO_2 via CCUS technology at sufficiently attractive cost and scale. Direct reduction processes designed to process iron ore fines could potentially be more suitable for Pilbara hematite/goethite ores, especially in combination with an ESF. Several technologies (HyREX, CIRCORED and HYFOR) are currently being developed based on the fluidised-bed process, using 100% hydrogen (produced from natural gas reforming) as the reducing gas. Until now, CIRCORED is the only 100% hydrogen-based process that has proven functionality and performance in an industrial scale demonstration plant in Trinidad, where over 300,000 tons of HBI were produced over several months of operation. The plant was stopped reportedly due to changes in ownership, political issues and natural gas scarcity. Recent renewed interest in hydrogen-based DRI has led to a relaunching of the technology by Metso.

	POSCO is currently operating a pilot-scale HyREX facility with a production capacity of 24 tonnes of molten iron per day and plans to begin construction in early 2025 of a full-scale demonstration plant with a production capacity of 300 ktpa, with completion scheduled by 2027. The HYFOR technology, being developed by Primetals Technologies, has successfully tested Australian iron ores with Fe content at or below 65% at pilot-scale. Primetals is now planning to combine their HYFOR direct reduction and new electric smelter technologies in a new industrial-scale prototype plant with a continuous capacity of three to five tons of green hot metal per hour. Fortescue is a key partner of this project. The alternative ZESTY hydrogen flash reduction process developed by Australian technology developer Calix is currently being demonstrated at pilot-scale using various iron ores to produce H-DRI at an equivalent throughput rate of 2,000 tonnes per year (250 kg/h). Calix has undertaken a Front-End Engineering Design (FEED) study for a 30,000tpa commercial demonstration plan in Australia, with a final investment decision expected in 2024. See also: • Technoeconomic data and analysis on decarbonising Australia's steel sector, Final Report from HILT Projects RP1.004 and RP1.005 (available upon request) • Decarbonisation of Australian Steel Production: Where is it heading? HILT Webinar • Minerals Research Institute of Western Australia (MRIWA), 2023, Western Australia's Green Steel Opportunity.
Electric smelting furnaces for iron- and steel-making • Electric Arc Furnaces (EAF) • Electric Smelter Furnaces (ESF) • Hydrogen Plasma Smelting Furnace	As previously mentioned, EAF is an established technology, already commercially available for steel production using high-quality DRI/HBI. LIBERTY is planning to replace the existing Coke Ovens and Blast Furnace by 2025. The EAF will initially be fed by domestic steel scrap and other Fe-bearing materials. In Western Australia, Green Steel WA expects to start construction of its EAF in late 2024, with early operations beginning in 2026. Both projects have selected Italian equipment supplier Danieli for the EAF supply. Electric smelting furnaces (ESF) are commonly used to produce ferro-alloys and other nonferrous metals, however, it has rarely been used for iron production, with only three commercial plants in operation globally (Bluescope Zealand Steel, Steel Dynamics Incorporated in the USA and Highveld Robusteel in South Africa). Even though most of the major steelmakers (including Tata Steel Europe, Thyssenkrupp, voestalpine, POSCO, Baowu) are actively working on ESF projects for their operations, it is expected that the metallurgy, engineering and operational requirements for its application to Pilbara-type ores have not been sufficiently characterised. In Australia, BHP and Hatch are looking at developing a pilot-scale ESF to test and optimise ironmaking using Pilbara iron ores, in collaboration with Rio Tinto and Bluescope. If approved, the pilot facility could be commissioned as early as 2027. The Hydrogen Plasma Smelting Reduction technology for green steel production is still under development at laboratory and batch pilot scale and is not expected to reach TRL 7 before at least 2025.

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Cross-cutting technologies	
Supply of net zero energy and fuels: • Electrification • Hydrogen • Biomass/RDF • Solar thermal	Despite the emergence of some technologies to partially integrate net zero energy sources (renewable electricity, biomass/refuse-derived energy resources, hydrogen, and solar thermal energy) into industrial processes, one limitation to their wide-scale deployment is access to them at sufficient scale and competitive prices. Further investment in research, development and demonstration is therefore needed to develop the understanding and know-how to lower their cost. The increased penetration of refuse-derived fuels is one important component of decarbonisation that is already commercially available for partial substitution of fossil fuels. However, for the utilisation of this resource to reach its potential also requires further development. For example, the gasification of such sources to increase their heating value is a viable emerging platform that has potential to be demonstrated and deployed this decade and can provide an important component of low-carbon energy sources for other large industrial sources. See also: • ARENA Report: Renewable energy options for industrial process heat.
Carbon capture, utilisation and storage: • Carbon capture • Utilisation	CCUS from industrial processes is also a realistic target for first deployments in the next decade. CCUS is likely to be important for processes such as for DRI production, particularly because it is likely that the first commercial DRI plants would be fed with natural gas, until such time as hydrogen becomes available at sufficient scale and competitive costs. However, a number of barriers need to be overcome to allow the introduction of CCUS from industrial processes including increasing the cost of production, the need for a suitable downstream sink, and social acceptance. Prospective re-use processes include methanol to aviation fuels by reacting captured CO2 with hydrogen, and mineral carbonation. The first demonstration of such processes is plausible this decade, although further roll out will take longer.

We are interested in understanding what external constraints may be limiting the production of green metals, including capital investment, technological barriers and access to renewables and hydrogen.

17. What factors would enable the acceleration of metals decarbonisation? For producers, what levels of production would be feasible over time?

HILT Response 17:

The factors that HILT has identified that will accelerate green metals production and heavy industry decarbonisation and enable Australia to be at the forefront of a growing global industry with net-zero emissions at scale and within a rapidly evolving environment include

- Investment in a green metals innovation ecosystem, specifically
  - Funding to establish a Green Metals Network to co-ordinate research and demonstration facilities, programs and develop international linkages.
  - Enhancing knowledge sharing processes and agreements attached to government funding.
  - Supporting universities and vocational education training provides to develop new courses and programs needed for new skills and industries.
- Provide enabling policy and regulation, including addressing trade barriers and market drivers
- Investment in enabling infrastructure: bringing down the cost and increasing the supply of renewable and decarbonised sources of energy, fuels and CCUS;
- De-risking decarbonisation investment: de-risking the bespoke decarbonisation of the core metals processing technologies

As per HILT's response to Question 7 we believe that investment in Research Development and Demonstration (RD&D) facilities to establish an eco-system of innovation, understanding and capacity building will accelerate green metals production and heavy industry decarbonisation. The bespoke nature of both the ore resources and the sector, together with the rapidly changing technology landscape, implies that focussing on a few isolated factors or single demonstrations is a high-risk strategy. It will be much more effective to invest in the establishment of a highly skilled sector that supports collaborations between industry, research, government and community, which builds a comprehensive understanding of how to be at the forefront of a growing industry to process bespoke ores with net-zero emissions at scale within a rapidly evolving environment.

Building an effective innovation eco-system requires investment in long-term partnerships between industry and research will be critical to address technical barriers. HILT CRC Partners at the 2023 HILT CRC Annual Conference voted for co-ordination and collaboration amongst stakeholders as the number one need from industry need, in terms of infrastructure and commercialisation, to de-risk their low carbon transition.

HILT CRC is already taking a leadership role to support the decarbonisation of heavy industry by seeking to co-ordinate the research and development needed by its Partners. However, these activities are constrained by its current budget. Our vision is to expand HILT's activities to co-ordinate RD&D facilities and projects nationally and develop international linkages.

Specific suggestions are:

Funding to establish a Green Metals Network to co-ordinate knowledge sharing, facilities and international linkages. For Australia to truly capitalise on the green metals opportunity afforded by the net zero transition will require more substantial investment, coordinated nationally, in order to establish a globally leading research and development ecosystem. A more comprehensive approach to investing in the research eco-system will accelerate the rate at which new technologies are adapted to the bespoke conditions in Australia, drive understanding of how to lower cost and increase performance in the new processing pathways, and position Australia at the forefront of the supply of value-added materials for the net-zero economy.

HILT is willing and able to coordinate such a Network, building on its extensive list of existing partners to also include those beyond its current partners. Additional resources would be needed to undertake this role.

Foster knowledge sharing: The more information is shared and co-ordinated across Australia, the more rapidly industry, government and researchers will be able to learn, innovate and de-risk deployment of new emerging technologies and approaches. However, this should also have strategic global links.

While it is well known that the sharing of knowledge, information and know-how can accelerate technology development and uptake, such sharing is inhibited by the need to protect intellectual property and confidential information. Hence support is needed to foster knowledge sharing suited for the heavy industrial sector, which may include both formal structures and agreements, informal arrangements and opportunities to build trusting relationships. HILT is investing in all of the above.

Importantly mechanisms to foster collaboration and knowledge sharing should not be confined to Australian companies. Heavy industry is truly global in terms of technology, markets and impact. Furthermore, some Australian companies may find it easier to partner with international companies than local ones for various reasons. Hence collaboration and knowledge sharing should also have strategic global links.

Specific suggestions are

- Enhance knowledge sharing processes and agreements attached to government funding.
- Support universities and vocational education training provides to develop new courses and programs needed for new skills and industries.

Provide Enabling Policy and Regulation:

The development of enabling policy and regulatory framework is essential to support the development and deployment of decarbonisation technologies. As per HILT's response to Question 12, we have identified key focus areas to reduce barriers and facilitate heavy industry's transformation: trade policy to balance international competitiveness, industry policy to de-risk decarbonisation investment, regulation and certification to supports markets for decarbonised products and finally investment in enabling infrastructure development.

Specific suggestions arising from the HILT Program 3 roundtables are:

- **Co-ordinated trade and industry policy** to assist Australian industry in attracting capital investment, in accessing technology and remaining internationally competitive with their products:
  - HILT investigated regulatory and policy needs in RP3.003 Review of trade regulatory implications,
  - HILT is establishing a new project: RP3.008 A policy roadmap for Australia's heavy industry low-carbon transition.
- **Green product certification and regulation:**
  - Production certification was identified as a priority in HILT's 2023 P3 Roundtables, leading to the new project: RP3.006 Certification and verification to enable a successful LCT for heavy industry
- **Consistent, co-ordinated and streamlined regulations and approval processes** across state and federal governments.

Investment in enabling infrastructure:

The provision of enabling infrastructure is crucial to support a successful green metals industry in Australia including energy infrastructure, roads, rail, water and housing. As industries are likely to dominate the demand for energy and labour in regional Australia, focusing the deployment of shared enabling infrastructure in regional industrial hubs is an efficient option. Investments and development of this infrastructure needs to be staged, in alignment with the progressive transition of the sector.

Specific suggestions arising from the HILT Program 3 roundtables are:

- Development of framework to assess infrastructure requirements for heavy industry, including regional development opportunities
- Facilitation and coordination of common infrastructure in industrial hubs
- Development of frameworks for industry-gov collaboration on shared infrastructure, considering models for co-investment/ownership
- Clarity on requirements for social license to enable build out of required infrastructure
- Acceleration of clean energy development by consistent, co-ordinated and streamlined regulations and approval processes across state and federal governments.

De-risk decarbonisation investment:

Australian green metal projects will need to attract private finance from global capital markets. However, Australia is very high-cost country and incentives will likely be needed to make investment globally attractive.

Specific suggestions arising from the HILT Program 3 roundtables are:

- Reduce financing risk and cost of capital via the use of public partnerships and public ownership.
- Providing financial support for projects attract investment (grants, production tax credits)
- Understand investment risk profiles for deploying and developing clean technologies required for decarbonisation

18. What are the best examples of a 'green premium' being established for low emissions products? What actions could improve demand for these products?

HILT project RP3.005 Analysis of market, cost and locational factors for green iron and steel in Australia will consider green premiums through several of its aims:

1. Bottom-up model to understand how the market size and supply balance green iron/steel demand in context of decarbonisation over time?
2. How policy and other factors drive demand for green steel products?

Preliminary findings indicate that higher production costs of green steel, including green iron production located in Australia, could be covered in principle through one or more of four channels: government support (subsidies) for production; government mandates for the use of 'green' products; voluntary uptake by industries in response to consumer demand; and carbon pricing that provides a market premium for green products while 'grey' product needs to cover carbon costs.

The subsidy approach currently prevails in some countries especially in Europe, however it is inherently focussed on domestic production and thus unlikely to support the emergence of an Australian export industry. Product mandates may emerge as a source of demand in future (eg building standards). Voluntary demand is gradually emerging in selected applications (eg automotive). Carbon pricing stands to be the key driver of green iron/steel uptake. For example, the EU emissions trading scheme results in a significant carbon cost for conventional steel production in Europe, and once the EU Carbon Border Adjustment comes into force, the EU ETS carbon price will effectively be extended to imports. This will result in a cost advantage to 'green' product, including green iron from Australia. Similar policy trajectories could in principle be on the cards in other countries including East Asia.

This project is still in progress, so recommendations on examples or actions are not available yet, however DISR are encouraged to contact Project Leader Frank Jotzo, from the Australian National University.

19. What are the key production volumes, cost profiles and price assumptions that would support minimum commercial viability for green metals production?

This question is beyond HILT's remit.

20. How would adopting renewable energy and green hydrogen impact on your current costs and the commercial viability of your operations, if you were able to implement them right now?

a. How does this compare to interim or transition fuels?

HILT Response 20:

Understanding the costs and requirements for the provision of clean, firmed, reliable energy has been identified as a critical factor by HILT's partners, and a focus of HILT research projects. Key findings are:

- RP1.004/1.005: Renewable energy costs, as a fraction of green steel are estimated to be around 50%+. Hence the cost of green steel will be highly sensitive to the cost of the energy supply (particularly hydrogen) and storage technologies
- RP1.002/1.007: Demonstrated that converting Alumina refineries to utilise either electricity or hydrogen at current prices and efficiencies is likely to add approximately 50% to the cost per tonne of product alumina. That would translate to 15% addition to the cost per tonne of aluminium. Research indicates power demand reduction of between 20-25% may be realisable by adopting steam recycling and other energy efficiency innovations
- RP3.004 Intermediate product exports for Australia-China green steel: the outlook for Australian exports of green iron to China depend strongly on the relative costs of green hydrogen, and therefore renewable electricity, in Australia versus China.
- RP2.003 Green Heat for Industry: thermal energy storage is likely to be the most economic energy storage technology, cheaper than batteries and pumped-hydro for constant heat provision powered by renewable energy.
- RP2.001/RP2.006 Hydrogen Supply Modelling: renewably powered energy systems function with capacity factors of >90%, defined here as the fraction of the time that the system is able to supply a fixed amount of hydrogen to a continuous industrial process. The size and configuration of the system is strongly location dependent and the transport and storage of hydrogen was found to be more cost effective than the transport and storage of electricity.
- HILT's new flagship project RP3.007 Unlocking energy infrastructure investment in industrial hubs will integrate the techno-economic results from previous projects focussed on hydrogen, electricity and heat to provide recommendations for 'no regrets' pathways to invest in enabling energy infrastructure.

When asked during a survey at the 2023 HILT Conference: What do you think are the key enablers HILT should prioritise to support Heavy Industries' decarbonisation transition", the top answer from HILT's partners was "Affordable clean energy." As such, understanding the costs and requirements for the provision of clean, firmed, reliable energy has been a focus of HILT research projects, as outlined below.

RP1.004/1.005: Renewable energy costs, as a fraction of the Levelised Cost of green steel are estimated to be around 50%+. Hence the cost of green steel will be highly sensitive to the cost of the energy supply (particularly hydrogen) and storage technologies.

RP 1.002 / 1.007: Demonstrated that converting Alumina refineries to utilise either electricity or hydrogen at current prices and efficiencies is likely to add approximately 50% to the cost per tonne of product alumina. That would translate to 15% addition to the cost per tonne of aluminium. HILT CRC research activities in new project RP1.013 are aligned with increasing the process efficiencies with optimised incorporation of low cost variable renewables to minimise the costs of firming of the energy inputs. That is likely to require the implementation of technologies such as thermal storages and heat recycling in the near future to meet industry targets in carbon reduction, and then new technologies using electricity and alternative low carbon fuels for the hard to abate areas of the plants that are likely to be implemented further into the future. This research indicates power demand reduction of between 20-25% may be realisable.

RP3.004 Intermediate product exports for Australia-China green steel: Preliminary results suggest that the outlook for Australian exports of green iron to China depend strongly on the relative costs of green hydrogen, and therefore renewable electricity, in Australia versus China. Results suggest that imports of green iron from Australia are comparative vs Chinese domestic production when Australian green hydrogen costs are at or below the cost of green hydrogen in the Chinese market.

RP2.003 Green Heat for Industry undertook a techno-economic analysis to compare different technologies and system configurations to provide a constant supply of high-temperature heat to a large-scale industrial demand scenario (500 MWth) for seven locations in Australian industrial regions. It found that thermal energy storage is likely to be the most economic energy storage technology, cheaper than batteries and pumped-hydro for constant heat provision powered by renewable energy.

RP2.014 Low-cost reliable green electricity supply for low-carbon heavy industry (in progress) is developing an integrated approach to combine multiple energy balancing methods, including: (i) geographic dispersion of renewable energy resources; (ii) integrated low-cost solar and brownfield hydro storage; (iii) hydrogen or biogas-fuelled gas turbines; and (iv) demand response.

RP2.001: Green Hydrogen Supply Modelling for Industry estimated the levelized cost of supplying a constant amount of green hydrogen to a large, continuous industrial process using a system powered by variable renewable electricity. The system capacity and configuration was shown to depend on its location and indicative costings were provided. Critically, these results demonstrated that it is possible to supply a constant amount of hydrogen to a continuous industrial process using renewable electricity. These results were based on GenCost 2020 and can be provided upon request. Project RP2.006 currently underway is using updated these results using GenCost 2023 data and expanding them, considering optimal locations of system components and including the costs for transmission and hydrogen pipelines. Preliminary results show that the transport and storage of hydrogen is more cost effective than the transport and storage of electricity.

Follow up project RP2.006: Hydrogen Supply within HILT Regional Hubs is undertaking more detailed modelling for specific locations of importance to HILT industry partners, including in Burnie, TAS, the Pilbara, WA, and Upper Spencer Gulf, SA. Outputs include indicative system sizing, configuration and siting for the renewable assets (including capacity of the electrolysers, hydrogen storage and renewable energy generators), infrastructure requirements (transmission lines and hydrogen pipelines), and assessing the potential cost of delivered hydrogen. (final report due August 2024)

Flagship project RP3.007: Unlocking energy infrastructure investment in industrial hubs, will link the techno-economic results from the projects described above to assess the requirements for enabling infrastructure. It will evaluate plausible projections for the energy demands for each hub accounting for the staged implementation of technology and new products of interest. It will link industry needs to customised supplies of the different energy types using a common framework. Results will be used to identify and evaluate investment options for enhancing energy infrastructure within the regional hubs in the short-term and long-term.

21. What are your estimates of the cost-gap differences between producing green metals and traditional metals, across your planned decarbonisation pathway (per tonne)?

a. How do you expect this to change over the next 20 years? Please include what data or assumptions you have factored into your calculations.

b. How do the cost gaps differ if you are able to use recycled metals as inputs?

HILT Response 21:

HILT Projects RP1.004 and RP1.005 undertook end-to-end techno-economic analysis of green iron making in Australia using hydrogen direct reduced ironmaking. Key outcomes of this project are:

- At the assumed H_2 cost of 3.5 USD/kg green steel is estimated to cost ~45-60% more than conventional BF-BOF steel. Significantly more work is needed on the cost of all components, however.
- Low grade ores have potential to produce competitively priced green steel.
- Renewable energy costs, as a fraction of LCOS are around 50%+. Hence the cost of green steel will be highly sensitive to the cost of the energy supply (particularly hydrogen) and storage technologies.

HILT Projects RP 1.002 / 1.007: Demonstrated that converting Alumina refineries to utilise either electricity or hydrogen at current prices and efficiencies is likely to add approximately 50% to the cost per tonne of product alumina.

HILT Project RP3.004 Intermediate product exports for Australia-China green steel, currently in progress, is aiming to assess the cost-competitiveness of Australian producers in 'intermediate product exports' for green iron and steel in China.

Cost gaps between green iron/steel and traditional pathways has been assessed in completed HILT Projects RP1.004 Impact of hydrogen DRI on melting in an electric furnace and RP1.005 Hydrogen ironmaking: fluidised bed H2DRI with Australian focus. This pair of projects was aimed at achieving an understanding of the end-to-end techno-economics of hydrogen direct reduced ironmaking in the Australian context, with an emphasis on understanding the impacts of Australian ore grades on the overall process design, ore beneficiation, and specifically incorporating a comparison the two important downstream steelmaking options, namely, the electric arc furnace (EAF) and smelter plus basic oxygen furnace (smelter-BOF) combination.

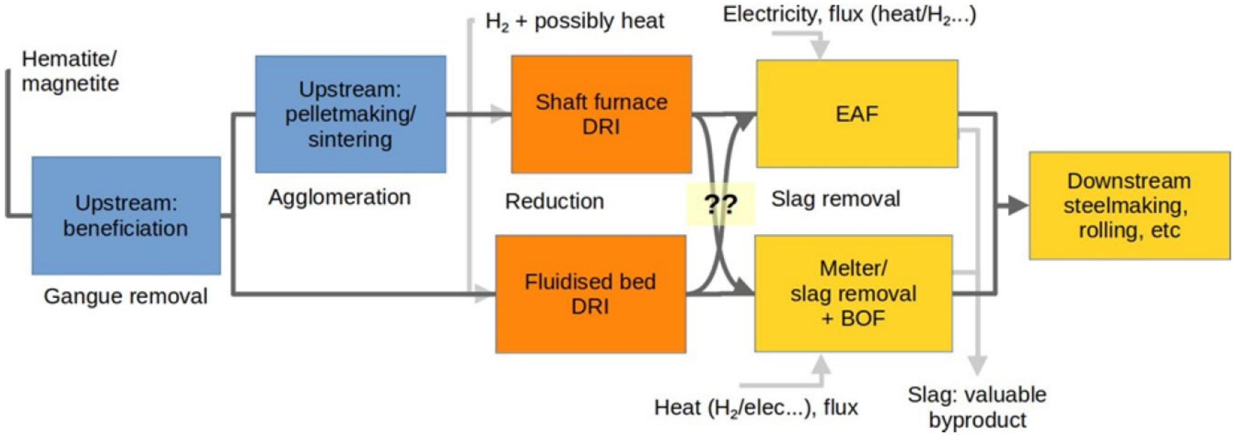

Figure 3: *Hydrogen steelmaking with Australian ores: alternative process options: (i) FBH2DRI-EAF, (ii) FBH2DRI-smelter-BOF, (iii) SFH2DRI-EAF, and (iv) SFH2DRI-smelter-BOF.*

Further details can be found in the project reports which can be provided on request.

RP 1.002 / 1.007: Demonstrated that converting Alumina refineries to utilise either electricity or hydrogen at current prices and efficiencies is likely to add approximately 50% to the cost per tonne of product alumina. That would translate to 15% addition to the cost per tonne of aluminium. HILT CRC research activities in new project RP1.013 are aligned with increasing the process efficiencies with optimised incorporation of low cost variable renewables to minimise the costs of firming of the energy inputs. This research indicates power demand reduction of between 20-25% may be realisable. Further details can be found in the project reports which can be provided on request

HILT Project RP3.004 Intermediate product exports for Australia-China green steel, aims to assess the cost-competitiveness of Australian producers in 'intermediate product exports' for green iron and steel in China. This project is in currently in progress with results expected by the end of the year. Further information can be supplied upon request.

We are interested in understanding how existing policies are shaping decarbonisation strategies and investment decisions.

22. To what extent has government support influenced investment thinking in Australia in respect to projects targeting decarbonisation?

a. What impact will the government's industry investment measures, such as the National Reconstruction Fund and Future Made in Australia Innovation Fund, have on your transition?
b. What impact will the government's recently announced renewable hydrogen measures have on your transition?
c. What impact do the government's policies to incentivise renewable electricity generation, storage and transmission have on your transition?

HILT Response 22:

HILT's Partners have stated that government support is a significant influence in their investment thinking in Australia in respect to projects targeting decarbonisation. Specific suggestions arising from HILT Program 3 roundtables for Government to support investment in decarbonisation projects are:

- Support enabling infrastructure, particularly energy (but also including roads, rail, water and housing):
- De-risk decarbonisation investment by providing financial support for projects:
- Put in place enabling policies and regulations to assist Australian industry in attracting capital investment, in accessing technology and remaining internationally competitive with their products:
- Foster knowledge sharing and stakeholder engagement:
- Develop the workforce of the future with the skills, knowledge and experience of implement new decarbonisation technologies and processes.

As per Question 12, HILT conducted a series of Roundtables HILT in 2023 across Australia focussed on our Program 3: Facilitating Transformation. HILT's Partners stated in these roundtables and at the HILT 2023 Conference that government support significantly influences their investment thinking in respect to projects targeting decarbonisation. Private finance is also needed to accelerate the adoption decarbonisation technologies beyond what government can do on its own, particularly in heavy industry, which is very capital intensive. Significant capital markets are available globally to support decarbonisation activities but to attract them to Australia, the investments need to be globally attractive.

Actions that HILT suggest government can take to increase capital investment in Australian heavy industry projects are:

- Support enabling infrastructure, particularly energy (but also including roads, rail, water and housing):
    - Provide guaranteed access to low cost, low carbon energy (electricity and hydrogen) at scale and at time required, and
    - Accelerate clean energy development by consistent, co-ordinated and streamlined regulations and approval processes across state and federal governments.
- De-risk decarbonisation investment by providing financial support for projects:
    - Australia is very high-cost country, so to attract technology and investment to Australia, it will need incentives.
- Put in place enabling policies and regulations to assist Australian industry in attracting capital investment, in accessing technology and remaining internationally competitive with their products:
    - Co-ordinated trade and product certification policy and regulation to assist industry with getting a firm price for new green products,
        - HILT is establishing a new project: RP3.008 'A policy roadmap for Australia's heavy industry low-carbon transition'.
    - Trade and market policy to support international competitiveness of Australian green products.
        - HILT investigated regulatory and policy needs in RP3.003: Review of trade regulatory implications, which identified key international competitors and reviewed their trade regulations. In particular, it identified the aluminium sector as being heavily affected by government interventions including subsidies, import tariffs and regulatory measures.
    - Green product certification and regulation:
        - Production certification was identified as a priority in HILT's 2023 P3 Roundtables, leading to the new project: RP3.006 Certification and verification to enable a successful LCT for heavy industry.
    - Use Government purchasing agreements / procurement contracts to create demand for green products, and
    - Consistent, co-ordinated and streamlined regulations and approval processes across state and federal government so they do not overlap, clash and/or cause regulatory burden.
    - Ensuring policies such as Safeguard and CBAM support local industry, particularly in sectors where Australia already has a competitive advantage by engaging with local industry to ensure that 'top-down' policy objectives are aligned with 'bottoms up' pathways of what is achievable.
    - Long-term (non-partisan) policy commitment and support, commensurate with timescales of heavy industry infrastructure.

- Foster knowledge sharing and stakeholder engagement:
    - Community education and engagement regarding the significant changes and opportunities that will accompanying the transition of heavy industry its supply chains, infrastructure and jobs.
    - Strategic international partnerships with key countries, where there are complementary strengths to enable win-win (e.g. Germany-Australia).
- Develop the workforce of the future with the skills, knowledge and experience of implement new decarbonisation technologies and processes.

We are seeking views on the types and design of supply side options that should be considered.

23. What approach and features do you consider to be most effective?

For example:

a. Which incentive would lead to the biggest increase in private investment in green metals production across production, investment, and innovation-linked incentives?
b. What are the merits of receiving incentives through the tax system relative to grant-based funding?
c. Would a 'contracts for difference' scheme or other program designs be preferred?
d. What length and timing of support is required for long-term viability?
e. Are there any additional features or design principles that would enhance the efficacy of support to produce green metals?

Analysis of the implications of different supply side policies and incentives have not been explicitly carried out in HILT CRC projects. However, based on our Program 3 projects and 2023 roundtables, HILT suggests that supply side support will need to be supported by actions to attract capital investment in Australian heavy industry projects as described in response to Q22.

24. *Are there parts of the value-chain that require particular support (for example, energy inputs, green alumina or iron inputs, or green aluminium or steel production)?*

a. Should support be prioritised towards certain parts of the value chain in the first instance?

HILT Response 24:

HILT's Program 3 Roundtables clearly identified parts of the value chain thar require support to increase investment in Australian green metals projects, including:

- Support enabling infrastructure, particularly energy (but also including roads, rail, water and housing),
- De-risk decarbonisation investment by providing financial support for projects, and
- Enabling policies and regulations: particularly co-ordinated trade and market policy to support international competitiveness of Australian green products.

As per our answers to Question 12, 22 and 23, HILT's Program 3 Roundtables clearly identified parts of the value chain that require support to increase investment in Australian green metals projects, including:

- Support enabling infrastructure, particularly energy (but also including roads, rail, water and housing):
    - Provide guaranteed access to low cost, low carbon energy (electricity and hydrogen) at scale and at time required, and
    - Accelerate clean energy development by consistent, co-ordinated and streamlined regulations and approval processes across state and federal governments.
- Co-ordinated trade and product certification policy and regulation to assist industry with getting a firm price for new green products,
- Trade and market policy to support international competitiveness of Australian green products.
- Ensuring policies such as Safeguard and CBAM support local industry, particularly in sectors where Australia already has a competitive advantage by engaging with local industry to ensure that 'top-down' policy objectives are aligned with 'bottoms up' pathways of what is achievable.

25. Where support is provided across a value chain, such as intermediate metal outputs, what design features are necessary to ensure support is effective for producers with different levels of vertical integration?

This question is beyond HILT's remit.

26. What eligibility thresholds would be appropriate to access production incentives?

For example:

a. A minimum amount of green production output (for example, tonne of metal).
b. Emissions intensity reductions per unit of production (for example, tonne CO2 emitted per tonne of metal).
c. Eligible business size (for example, minimum facility production capacity).

This question is beyond HILT's remit.

27. Should incentive levels be varied for different thresholds?

For example, different incentive levels for different emissions intensity reductions per unit of production.

This question is beyond HILT's remit.

28. Should there be time limits for accessing production support? If so, what should the duration be and when should it commence, cease, or phase down?

This question is beyond HILT's remit.

29. What would be an appropriate level of incentive to support the development of competitive production for green alumina, aluminium, steel and iron?

This question is beyond HILT's remit.

30. How could eligibility criteria be most appropriately linked to the delivery of strong community benefits?

This question is beyond HILT's remit.

We are seeking views on demand side options that could be considered.

31. What demand side options would best drive confidence for green metals producers? Should the government consider regulation, procurement rules for government purchasing, voluntary targets or other demand options?

This question has not yet been addressed in a HILT CRC project but is of interest for future projects. We suggest that government should put in place enabling policies and regulations such as:

- Co-ordinated trade and product certification policy and regulation to assist industry with getting a firm price for new green products, (under study in RP3.006: Certification and verification to enable a successful LCT for heavy industry)
- Trade and market policy to support international competitiveness of Australian green products. (under study in RP3.008: A policy roadmap for Australia's heavy industry low-carbon transition)
- Use Government purchasing agreements / procurement contracts to create demand for green products, and
- Long-term (non-partisan) policy commitment and support, commensurate with timescales of heavy industry infrastructure.

32. How could the introduction of new demand measures affect competition?

This question is beyond HILT's remit.

We are interested in any other ideas you have.

33. Are there any other issues or opportunities that can be addressed to unlock an Australia green metals industry?

For example, any workforce and supply-chain constraints, better investment facilitation, sequencing issues, scrap recycling or circular economy opportunities.

Role of Australia in decarbonising the region: Australia is a globally significant provider of resource commodities and therefore has significant potential to impact global carbon emissions through downstream processing. For example, investment in decarbonising global iron and steel supply chains that use Australian ores is potentially the largest impact Australia can make to emissions reduction on a global scale. However, this will be challenging to achieve if Australia cannot navigate a pathway to allow it to accommodate the onshoring of emissions during the transition period. That is: the establishment of an industry that supplies new, higher value low-carbon products such as Direct Reduced Iron (DRI) or Hot Briquetted Iron (HBI) for the global green steel industry will on-shore emissions presently generated internationally. Note that this may give rise to a local (Scope 1) increase in emissions during the transition period to 2050, whilst contributing to a larger decrease in Scope 3 emissions, leading to a significant reduction in overall emissions globally.

The Australian Context: The predominant processing challenge that is uniquely Australian for green iron/steel is accommodation of the particular composition and mineralogy of the impurities in our hematite/goethite ores within the range of emerging green steel technology platforms. There is a need for a 'breakthrough' in these pathways. An equally important challenge is how to supply the hydrogen and associated clean energy at sufficient scale and cost for Australia to be globally competitive. This is a challenge that is common both with hematite and magnetite processing as well as other metals such as alumina. While the outstanding quality of Australian resources is well known, we also have a higher cost of capital and less supporting infrastructure than many international competitors. Furthermore, while magnetite can be processed to high grade iron with commercially available beneficiation technologies, as is needed for green iron/steel, such processing is expensive. There are significant opportunities to lower the cost, and water consumption, of beneficiation of magnetite ores with emerging technology.

The development of these technologies brings a uniquely Australian challenge, because each ore is different. Such technologies have strong potential to increase the competitiveness of the processing of Australian magnetite ores to green steel, by increasing their competitiveness against other types and sources of ore. Similarly, other technical challenges such as the supply and integration of Australia's superior renewable energy resources, alternative fuels, carbon capture and utilisation and non-technical challenges, such as policy, regulation, community engagement and workforce development all have unique, local aspects to them.

HILT has a broad research portfolio aimed at addressing these challenges, so Australia can realise our Green Metals opportunity.

HILT CRC

References

HILT documents listed below can be provided upon request. Links are provided for publicly available and external (non-HILT) reports.

HILT:

- HILT Overview presentation
- Accelerating the transition to net-zero for heavy industry, Gus Nathan, HILT 2023 Conference presentation.
- HILT Program 3 2023 Roundtables – Summary Report.
- Combined Final Report - RP1.004: Impact of Hydrogen DRI on Melting in an Electric Furnace and RP1.005: Hydrogen Ironmaking: Fluidised Bed H2DRI With Australian Focus
- Winning the race to decarbonise the iron ore and steel industries: Geoff Brooks, HILT 2023 Conference presentation.
- Decarbonisation of Australian Steel Production: Where is it heading? Geoff Brooks, HILT Webinar
- Pathways to Low-carbon Alumina Production: HILT Webinar and PowerPoint.
- Effect of gangue on CO_2 emission for different decarbonisation pathways, S Sabah, M Shahabuddin, A Rahbari, G Brooks, J Pye, MA Rhamdhani, Ironmaking & Steelmaking 51 (4), 356-36
- Process modelling for the production of hydrogen-based direct reduced iron in shaft furnaces using different ore grades, M Shahabuddin, A Rahbari, S Sabah

External:

- Comparing and ranking the global cost of green industrial electricity
- ARENA Report: Renewable energy options for industrial process heat.
- Minerals Research Institute of Western Australia (MRIWA), 2023, Western Australia's Green Steel Opportunity, MRIWA Project M10471
- ARENA Report: Roadmap for decarbonising Australian alumina refining.
- Net Zero Industries Whitepaper: 'Currency of Trust'.
- HiTeMP-2 Outlook Report
- Port Kembla Steelworks Identification of Prioritised Options
- Australia Faces Growing Green Iron Competition from Overseas