

AEMO IASR Consultation Stage 1

11 February 2025

About HILT CRC

The Heavy Industry Low-carbon Transition Cooperative Research Centre (HILT CRC) was established in November 2021 to support the decarbonisation of Australian heavy industry in the iron/steel, alumina, and cement/lime sectors. Since commencing operations, HILT CRC has co-developed a groundbreaking research program in collaboration with over 60 partners from industry (including heavy industry, end users, technology providers, and consultants), government, academia, and non-governmental organisations. HILT's ongoing mission is to pave the way for a prosperous, net-zero Australian heavy industry sector by delivering rigorous, industry-led research to develop and derisk new technologies and address non-technological barriers to heavy industry decarbonisation. An important aspect of HILT CRC activities is providing high-quality, evidence-based information for decision-makers (see website for links to [submissions to consultations](#)).

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: the iron/steel, alumina and cement/lime sectors alone account for approximately 9% of total domestic emissions within Australia; while emissions released during downstream processing of these resources in other countries (corresponding to Australia's indirect scope 3 emissions) are three times larger than Australia's total (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 our 2050 net zero emissions targets while maintaining the international competitiveness of these industries.

Scope of submission

This submission is based on a synthesis of HILT CRC research and learnings from stakeholder engagement, with supporting evidence provided wherever possible. It focuses on providing context and information to address the following consultation questions from AEMOs Inputs Assumptions and Scenarios Report (IASR) Stage 1 Draft:

- Are the scenarios, and the scenario collection, suitable for use in AEMO's planning publications including the 2026 ISP? Does the scenario collection support the exploration of a diverse range of possible futures that could occur over the planning horizon?
- Which of the two described scenario variants for the Green Energy scenario is the more appropriate variant for application as the scenario in AEMO's 2025 IASR scenario collection (depending on the planning analysis, AEMO may apply the alternate variant in sensitivity analysis)?
- Are the scenarios parameters, and parameter values, clear and suitably aligned with their respective narratives?
- What uncertainties are valuable to explore with sensitivity analysis?
- Is there any information on non-network technologies or proponents regarding opportunities for competitive non-network investment?
- Given that non-network investments generally involve commercial arrangements with plant with multiple revenue streams, how should AEMO estimate their cost transparently?

The submission also highlights HILT CRC research that may be able to inform Stage 2 of the IASR.

Green Energy Scenario

The following synthesis of findings from the HILT CRC research program and broader literature may provide insights into the broader context of industry decarbonisation and which of the two variants of the Green Energy scenario is most suitable.

Insight 1: Domestic demand for hydrogen to service export-focused industries could be comparable to demand for direct exports of hydrogen and derivatives (i.e. ammonia and methanol).

There is a growing consensus in academic and grey literature that hydrogen and derivatives will most likely be produced close to the point of use due to cost of transport and storage[1][2][3]. Recent analyses have suggested that only roughly one third of hydrogen demand will be met by international trade, and that only roughly one fifth will be transported long distances[4].

Australia is generally thought to be a potential hydrogen exporter, particularly to the Asia Pacific region where it has geopolitical advantage[5]. Recent projections from the Hydrogen Council estimates that Australia will export 4.4 Mtpa of hydrogen or equivalent derivatives (likely ammonia) in 2035, mainly to Japan and Korea [1]. Similar export volumes of roughly of 3.5 Mtpa by 2035 were forecast in the updated Australian National Hydrogen Strategy based on CSIRO modelling[2].

At the same time, the potential for low-cost renewable energy and hydrogen production in Australia will enable opportunities for decarbonisation of existing heavy industry, as well as production of new, value-added net-zero commodities. One of the most prospective new net-zero industries is onshore processing of Australian iron ores (see section below on [Australia's opportunity in green metals supply chains](#) for details).

The opportunity will vary depending on location and ore type (see section below on [Pathways and timelines for heavy industry decarbonisation](#) for details). While Australia already has commercial activity at all points in the aluminium supply chain as an exporter of bauxite, alumina, and aluminium metal, leveraging the potential for low-cost renewable energy could lead to more onshore processing, and therefore significant increases in energy requirements (as electricity and net-zero fuels and feedstocks). Conversely, Australia only contributes significantly to the very beginning of the iron and steel supply chain, exporting most of its resources as minimally processed ores. Preliminary results from ongoing HILT CRC research suggest Australian green iron could be supplied as an intermediate input to traditional steel making in trade partner countries, representing a new, energy intensive industry in Australia.

For comparison with projected export volumes, the Australian Industry Energy Transitions Initiative modelled the hydrogen demand for net-zero steel and iron making in Australia and showed that this industry alone would require 1.9 Mtpa of hydrogen by 2040[6]. Estimates based on CSIRO modelling of hydrogen demand over time predict a smaller portion of total hydrogen demand, roughly one third, would be from domestic use of hydrogen for decarbonisation and the production of other export products [2].

In summary, it is likely that it will be more economic to use renewable energy generated in Australia onshore (as electricity or renewable fuels/feedstocks) to produce value-added commodities for export. This suggests that a significant fraction of the renewable energy demand (as electricity or renewable fuels/feedstocks) for export-focused industries could be used domestically, rather than exported directly as hydrogen (and derivatives).

Insight 2: The same global and domestic settings that would favour high demand for net-zero embedded emission commodities (i.e. alumina/aluminium, iron/steel), will also favour demand for exports of green hydrogen or derivatives (i.e. ammonia, methanol).

2.1 Global demand drivers for net zero commodities

High levels of global climate change ambition, backed by implementation of effective policy and public co-investment, will be required to drive international demand for net-zero emission, value-added commodities. Without a global price on carbon, net-zero commodities cannot compete on cost alone and additional policies will be needed to drive demand and support a green premium in global markets. In a scenario with strong global demand for net-zero commodities, hydrogen and derivatives will also be required by industries across the world as feedstock and fuels for production processes that cannot be easily electrified, to decarbonise industry and produce net-zero commodities.

2.2 Access to low-cost, low-emissions energy and hydrogen

In a scenario with strong global demand for net-zero commodities, HILT CRC research indicates that the competitiveness of Australian value-added commodities will likely strongly depend on relative costs of net-zero energy competitor countries (see section below on [Critical role of the cost of renewable electricity and low-emission hydrogen for decarbonisation of heavy industry](#) for evidence). While the costs of different decarbonisation technologies and pathways are still evolving, HILT CRC research has shown that the cost of renewable energy and hydrogen will likely make up a significant fraction of the levelised cost of low-carbon metals and minerals (roughly 50% for green steel and alumina). In addition, preliminary results from an economic supply model developed within HILT's research program show that the outlook for Australian exports of green iron to China depends strongly on the relative costs of green hydrogen in Australia versus China. This is further supported by stakeholder feedback that access to low-cost, low-emissions energy and hydrogen is one of the most important enablers for heavy industry decarbonisation in Australia (see section below on [Enablers and barriers to heavy industry decarbonisation](#) for evidence).

This suggests that scenarios with high demand for competitive Australian net-zero, value-added commodities will have to assume competitively priced hydrogen is available locally, implying high demand for direct export of Australian hydrogen and derivatives.

Further information: HILT CRC is developing a suite of decarbonisation scenarios which will provide realistic, industry informed pathways for heavy industry transition to net-zero, accounting for region-specific differences in ore availability and type, energy resources, and suitable processing pathway.

These decarbonisation scenarios will be based on HILT's extensive expertise and research and developed in conjunction with HILT CRC industry partners and a wide range of stakeholders, including other industry actors, energy and technology providers, and government planning departments. They will provide a range of estimates for potential Australian exports of net-zero alumina, iron, and steel and the required energy inputs (renewable electricity, hydrogen, bioenergy, gas with CCUS) from now to 2050. More information on preliminary results and timelines for this initiative can be provided on request.

Off-grid supply of renewable energy and net-zero fuels for regional and remote heavy industry

This section provides insight into potential non-network options for net-zero energy supply for large industrial loads. Decarbonisation of heavy industry could require a very large increase in primary electricity demand, particularly if industry looks to expand into new, net-zero, value-added commodities. As part of their decarbonisation plans, plants will evaluate to what extent their net-zero energy needs can be met by electrification (as heat, electricity, and net zero fuels and feedstock), and whether this electricity can be supplied from the grid, from third parties, or from their own dedicated off-grid renewable energy systems.

Insight: HILT CRC research has shown that off-grid variable renewable energy systems can provide a firm supply of heat, electricity, and hydrogen for continuous industrial processes.

HILT CRC has developed a range of energy system modelling tools to evaluate the viability of low-emissions energy sources at regional level for the provision of electricity, heat and hydrogen for continuous industrial processes (see section below on [Off-grid renewable energy supply for heavy industry](#) for evidence). This research is providing information on optimal off-grid system configurations (such as optimal capacities of wind, solar, electrolysers), lowest cost energy storage (in the form of hydrogen, heat, batteries and pumped hydro) for the provision of different energy sources such as hydrogen or heat, as well as trade-offs between optimal siting of renewable capacity and the need to transport electricity or hydrogen long distances. More information can be provided on request.

Further information: Ongoing research is combining tools and learnings from across the HILT CRC research program to further scope potential industry energy demand, identify a range of options for cost-optimal and location-specific provision of energy needs from low-emission sources, and provide information on required energy infrastructure.

Timing and options for heavy industry fuel switching

Decarbonisation of heavy industries will depend on there being a compelling business case for the very large investments needed to transform industrial processes and move away from fossil-based fuels and feedstocks. Each company/project will make investment decisions based on their individual circumstances and perceived risks and commerciality. HILT CRC research may provide useful context in understanding the timing and potential options for heavy industry fuel switching.

Insight: Fuel switching for heavy industry will depend on bespoke decarbonisation plans that account for the unique circumstances of individual plants.

Each plant will have been custom designed to process specific ores with properties that vary with geography, using location-dependent combinations of energy sources and supporting infrastructure. Plant-specific decarbonisation pathways will depend on the type and age of existing plant, as well as the unique combination of potential net-zero energy sources and CO₂ sinks available, spanning wind and solar resources, through to natural gas.

Reaching net-zero by 2050 for heavy industry will require transformation of processes throughout the supply chain. Many of the required technologies are at various stages of development and have not yet reached commercial maturity and/or require access to large-scale supplies of net-zero energy sources and/or CO₂ sinks at economically competitive rates. Furthermore, heavy industrial processes require plants/refineries/assets that generally have long lifetimes, meaning that industry decarbonisation plans

are multi-decadal, with timing determined by capital renewal cycles as well as ongoing technology development.

While each plant will make different decisions as to which combination of technology options are most suitable for near-term, it is likely that they will initially aim for partial decarbonisation using '*transitional*' technologies, before identifying which technology pathway will be most effective for long-term '*transformational*' change to net-zero operation. Critically, *transformational technologies* will need to be developed and derisked in parallel to deployment of *transitional technologies*, requiring ongoing investment from before 2030. Each technology pathway will have different implications for fuel-switching and energy efficiency in heavy industry (see section below on [Pathways and timelines for heavy industry decarbonisation](#) for more info).

Further information: HILT CRC is undertaking comparative technoeconomic analysis of the various potential transformational technologies under development which, together with the decarbonisation scenarios mentioned above, will provide realistic, industry informed estimates of full switching for heavy industry, accounting for region specific differences in energy resources, ore type and processing pathway.

Supporting Information

Pathways and timelines for heavy industry decarbonisation

HILT CRC has developed an industry-informed vision of the technology pathways to progressively decarbonise steel and alumina manufacturing, considering both transitional and transformational technologies. In general, plants will seek to decarbonise progressively, with likely actions described below:

1. **Adapt '*transitional*' technologies** via retrofits or brownfield installations, to partially decarbonise processes. Examples of transitional technologies can include the use of natural gas in place of coal as a feedstock and/or fuel; the partial or full replacement of fossil-fuel based electricity, fuels and feedstock with low or net-zero emissions electricity, hydrogen, biofuels and/or biomass in processes; and the deployment of carbon capture, use, and/or storage (CCUS).

The majority of these transitional technologies come with the risk of increased production cost due to increases in the cost of energy and/or reduction in performance, the significance of which typically increases with the extent of decarbonisation. Even where some of these technologies may be commercially available for other processes or applications (i.e. CCS or renewable electricity), they typically require additional integration and/or adaptation for specific processes.

2. **Trial '*transformational*' technologies** or low-carbon solutions in retrofit/brownfield installations to de-risk various components of a new production process which will be introduced at a time in the future. Such technologies have not yet reached commercial maturity and are at various stages of development, from the laboratory to pilot or small demonstration scale.

Transformational technologies offer opportunity as well as risk. Re-designing part of a process to integrate a net-zero energy source, even within a brown-field site, offers the potential to increase process efficiency, and in turn, to offset the higher cost of net-zero energy. Nevertheless, significant risk is introduced due to uncertainty in which transformational technologies will be most cost-competitive, when different options will be commercially ready, and their likely performance in the plant in question.

3. **Demonstrate first-of-a-kind decarbonised production facilities in commercial operation**, to confirm viable, low emissions performance.

Despite the requirement for plant-specific decarbonisation solutions, sectors have a common interest in de-risking new technologies and evaluating different pathways, presenting opportunities for collaboration and cost-sharing. HILT CRC undertakes industry led-research focused on developing key decarbonisation technologies, the integration of net-zero energy into heavy industry processes (including CCUS, bioenergy, hydrogen and renewable electricity) and address non-technological barriers and enablers to heavy industry decarbonisation.

Of particular interest to the ISP, HILT CRC is undertaking research to develop a range of **plausible decarbonisation scenarios, which will the most prospective potential decarbonisation technologies and pathways for iron and steel, alumina and cement industries**, accounting for their various stages of development and commercial readiness. These scenarios will include high, medium, and low levels of ambition, defined by information and projections from different sources such as

- Research outputs from the HILT CRC program
- Engagement and feedback from HILT CRC industry partners
- Publicly available industry decarbonisation plans
- Net-zero modelling by researchers and consultants in publicly available reports
- Stated ambitions of state and federal governments
- Feedback from stakeholder group, including other relevant industry actors, energy and technology providers, consultants, HILTs national and international research network, and relevant government departments.

HILT CRC is also progressively establishing a **comparative analysis of the various potential transformational technologies under development**, using a common set of costing assumptions to provide guidance on the relative commerciality of these alternative potential pathways accounting for region specific differences in energy resources, ore type and processing pathway. More information on these initiatives can be provided on request.

Iron and Steel

Figure 1 illustrates HILT CRC's industry-informed vision of the technology pathways to progressively decarbonise steel manufacturing, with indicative timings. Currently, primary 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.

Secondary 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 CO₂ emissions. In Australia, where scrap-based steelmaking represents about 25% of the crude steel production, several new scrap-EAF steel plants are under development. However, secondary steelmaking cannot fully replace primary steel production globally, as the supply of scrap and available electricity are limited, particularly in emerging and developing economies. In addition, the secondary steel is not suitable for certain applications, due to its lower quality.

Beneficiation of ores is already employed commercially for magnetite ores, and for some hematite/goethite ores to upgrade them to the required quality for further processing, however its high cost and water consumption limits its applicability. 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.

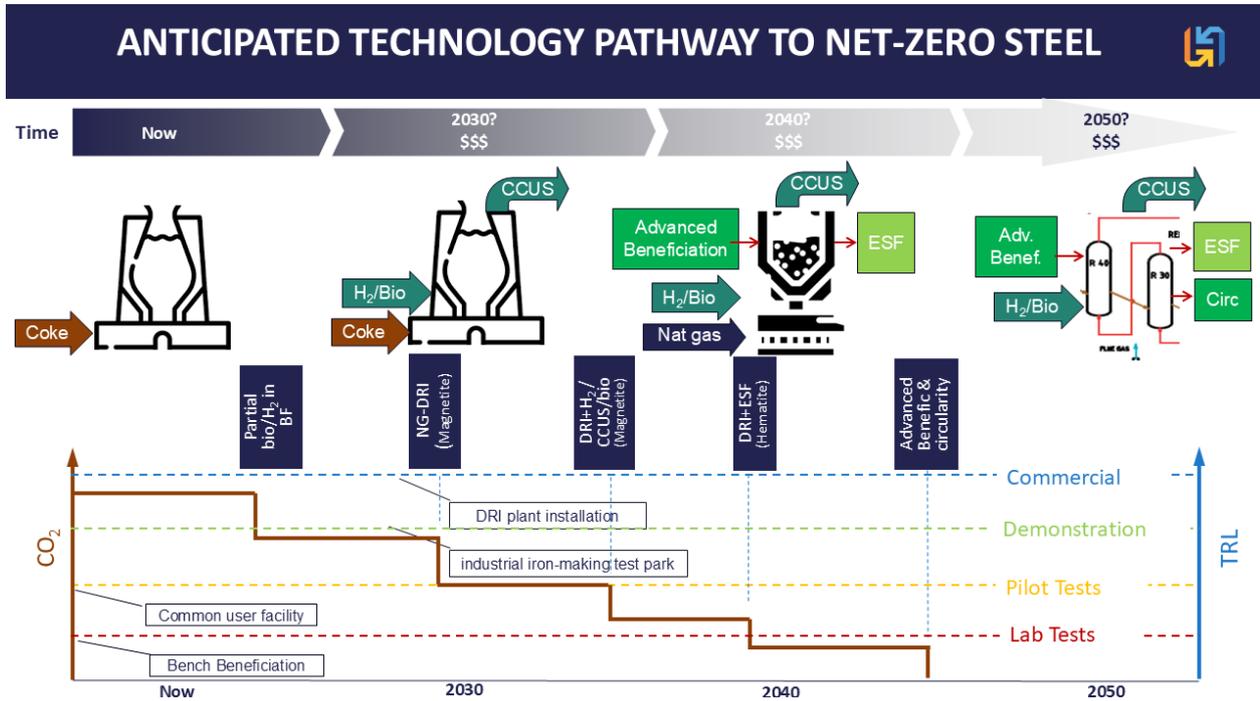


Figure 1: HILT CRC's vision of the technology pathways to decarbonise steel making.

The decarbonisation of primary steel production is expected to follow several major trends:

- Optimising the BF-BOF primary steelmaking route, by introducing new technologies to capture, store and/or use CO₂ 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 primary 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 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.

Alumina

Figure 2 illustrates HILT CRC's industry-informed vision of the technology pathways to progressively decarbonise alumina manufacturing, with indicative timings.

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. Net zero steam and improved steam recovery 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%. Various technologies are possible including

- Mechanical vapor recompression
- Electric boilers
- Heat pumps
- Thermal energy storage

Calciners are used for the production of various metals and intermediates, including alumina, and are presently fired with fossil fuels. Transitional technologies will employ retrofit options like hydrogen fuelled calciners. Transformational approaches, like electrification of calciners, will require new technology to be deployed. These will likely be located on the site of current alumina plants, many of which are space-constrained.

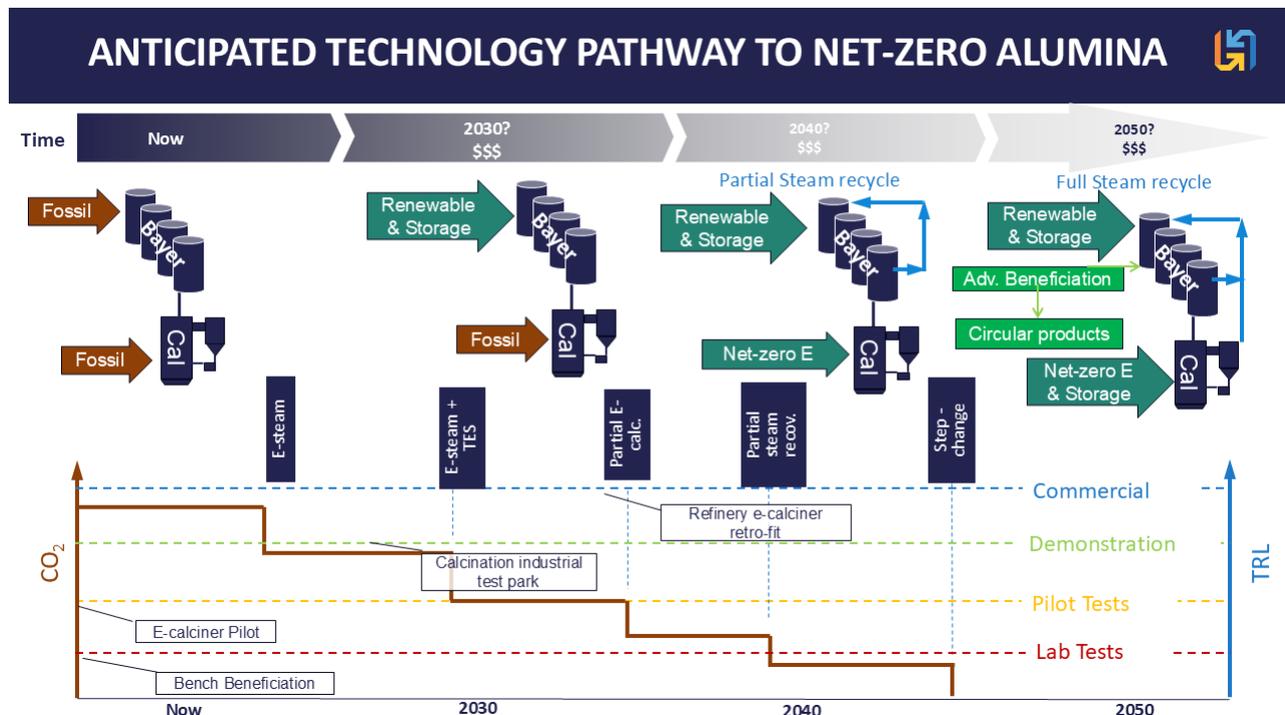


Figure 2: HILT CRC's vision of the technology pathways to decarbonise alumina making.

Australia's opportunity in green metal supply chains

Currently, Australia has significant economic activity all along the aluminium supply chain, exporting bauxite, processing the ore to alumina for export, and producing and exporting aluminium itself. As the global market for green commodities grows, and there could be opportunities to onshore more of the processing, leveraging Australia's competitive low-cost renewable energy.

Australia only contributes significantly to the very start of the iron and steel supply chain, exporting the majority of its resources as minimally processed iron ores. As discussed above, the opportunity for Australian industry in future net-zero steel will vary depending on mine location and ore type. Generally, there is opportunity for exports of value-added intermediate products such as green iron pellets, green iron as hot briquetted iron (HBI), and green steel, produced by on shore processing of Australian ores. Conversely, failure to upgrade ores so that they are suitable for low-carbon processing techniques could result in reduced demand as global climate goals become more ambitious and the steel industry moves to decarbonise in response.

HILT CRC research project RP3.005 *Analysis of market, cost and locational factors for green iron and steel in Australia* conducted an expert elicitation of 42 experts to better understand the expectations for green iron and steel in Australia. Preliminary results suggest that Australia's key future opportunity to supply net-zero, value-added products into international markets is likely in the form of green iron, supplied as an intermediate input to traditional steel making in trade partner countries. Processing iron

ore to iron is the most emission intensive step in making steel and is currently carried out offshore, meaning that Australia could play a role in significantly reducing the emissions from steel processing, particularly as Australia is the largest iron ore producer. However, development of net-zero iron production in Australia would lead to very large increases in the energy required by the iron and steel sector in Australia (see Figure 3.06 and 3.07 in ref [6]) for example). Additionally, it could potentially increase domestic (scope 1) emissions, especially during the transition phase when natural gas may be used as a feedstock and fuel (see Figure 4.4 in ref [7] for example). Project RP3.005 is due to be finalised in Q1 2025 and more information can be provided on request.

Ongoing HILT CRC research project RP3.004 *Intermediate product exports for Australia-China green steel* is evaluating relative commerciality of Australia green iron and steel commodities (including upgraded ores, hot briquetted iron, and steel) in a future decarbonised supply chain where Australia competes with other global exporters of ore to supply the Chinese market. The project has developed an economic supply model incorporating different Australian ore types and potential (ore dependent) processing pathways. The model allows the interrogation of where the different processing steps along the decarbonised supply chain may occur (i.e beneficiation and agglomeration of ores, processing of green iron, green steelmaking): either in China, Australia or another competitor country. The project is due to be finalised in Q1 2025 and more information can be provided on request.

Critical role of the cost of renewable electricity and low-emission hydrogen for decarbonisation of heavy industry

While the costs of different decarbonisation technologies and pathways are still evolving, HILT CRC analysis indicates that the cost of renewable energy and hydrogen will make up a significant fraction of the cost of heavy industry decarbonisation.

HILT CRC research projects RP 1.004/1.005 undertook an end-to-end technoeconomic analysis of green steel making in the Australian context, with an emphasis on understanding the impacts of Australian ore grades on the overall process design. Specifically, the project compared pathways incorporating different ore upgrading processes (beneficiation), low emissions iron making (direct iron reduction via a shaft furnace or a fluidised bed) and steelmaking options (the electric arc furnace or smelter plus basic oxygen furnace). From preliminary estimates of technology costs, the project concluded that the cost of hydrogen made up roughly half of the levelised cost of green steel (assuming hydrogen costs of 3.5 USD/kg), and that green steel was 45-60% more expensive than conventional steel making.

HILT CRC research projects 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. 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.

Ongoing HILT CRC research project RP3.004 *Intermediate product exports for Australia-China green steel* is evaluating potential opportunities for Australia green iron and steel commodities (including upgraded ores, hot briquetted iron, and steel) in a future decarbonised supply chain between Australia and China. The project has developed an economic supply model incorporating different Australian ore types and potential (ore dependent) processing pathways. Preliminary results show that the outlook for Australian exports of green iron to China depends strongly on the relative costs of green hydrogen in Australia versus China.

Enablers and barriers to heavy industry decarbonisation

Importance of access to low-emissions energy and enabling infrastructure

HILT CRC has analysed partner and stakeholder perspectives on enablers and barriers to heavy industry decarbonisation collected through expert elicitations, roundtables and surveys, as detailed below, as well as ongoing engagement with partners in HILT CRC research projects. Access to low-emissions energy (electricity and fuels such as hydrogen), and specifically that low emissions hydrogen is not yet economically viable, has consistently emerged as one of the most important concerns.

HILT CRC research project RP3.005 *Analysis of market, cost and locational factors for green iron and steel in Australia* conducted an expert elicitation of 42 experts to better understand the expectations for green iron and steel in Australia. Preliminary results have identified “availability and cost of renewable energy” and “proximity to renewable energy and hydrogen” supply as the most important local factors to enable green iron and steel. In addition, “renewable energy and hydrogen availability” was ranked as either a moderately (50%) or very (20%) important obstacle for a green iron industry by the majority of respondents.

HILT CRC conducted a survey of partners at the HILT CRC conference in October 2024 to rank the most important topics for discussion on technology and policy developments to facilitate transformation and a green metals industry. Participants ranked “Hydrogen supply and integration” as a priority, second only to “Accelerating low-cost, reliable electricity at scale”.

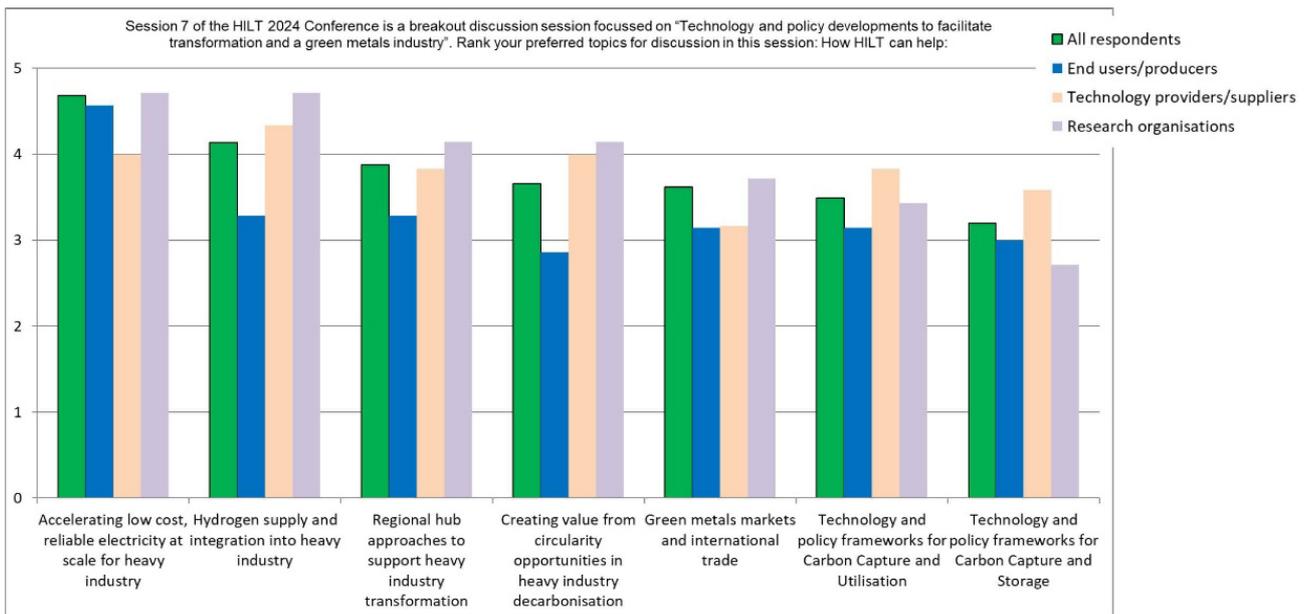


Figure 3: Results from HILT CRC Conference, October 2024 in response to the question: Rank the most important topics on technology and policy developments to facilitate transformation and a green metals industry for discussion.

HILT CRC hosted a series of roundtables with stakeholders, including industry partners and government representatives, across Australia in 2023 on “Facilitating Transformation” to discuss non-technological barriers holding back the deployment of decarbonisation technologies. One of the key themes that was identified was the need for “enabling infrastructure”, which included supply of low-cost and low-emissions electricity and hydrogen.

Other insights on policy barriers and enablers

Outcomes from HILT CRC stakeholder engagement described above may provide insights into likely trajectories for industry decarbonisation. Information is also provided on targeted HILT CRC research underway to address these barriers and potential enablers.

When considering polling results from all Roundtables the top four ranked themes were:

- Enabling infrastructure
 - *Access to low cost, low emissions energy and hydrogen on required timescale*
 - *Coordination and investment in energy infrastructure and*
 - *Non-energy infrastructure such as roads, rail, water, housing*
- De-risking decarbonisation investment
 - *Ensuring regulations and approval processes are efficient, consistent and co-ordinated and across state and federal government*
- Policy signals and enablers
 - *Co-ordinated trade and industry policy to assist Australian industry in attracting capital investment, in accessing technology, and remaining internationally competitive with their products*
 - *Long-term (non-partisan) policy commitment and support, commensurate with timescales of heavy industry decarbonisation pathways*
- Trade barriers and market drivers
 - *Developing internationally recognised and interoperable net-zero product certification and verification.*
 - *Driving demand for green commodities domestically and through engagement with existing and potential international*

Text in italics provides more detail and is based on further analysis by HILT CRC program leadership, with feedback from partners. 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:

HILT CRC Research Project RP3.006 *Certification and verification to enable a successful LCT for heavy industry* aims to enable Australian heavy industry to be able to successfully engage with emerging certification and verification schemes relying on embedded emissions accounting. In doing so, it will

help ensure that Australian industries remain competitive while aligning with the future trajectory of global climate policies.

HILT CRC Research Project RP3.007 *Unlocking investment in energy infrastructure for net zero industrial hubs* will develop a suit of decarbonisation scenarios for prospective net-zero industrial hubs around Australia and estimate the energy demand and corresponding net-zero energy supply that would be require. The project aims to 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.

HILT CRC research project RP3.008: *A Policy Roadmap for Australia's Heavy Industry Low-carbon Transition* aims to enhance the understanding of the relevant climate and green industrial policy landscape among heavy industry decision-makers, thus instilling a higher degree of confidence in their investments in the transition.

Off-grid renewable energy supply for heavy industry

Providing energy to continuous heavy industry processes from off-grid variable renewable energy sources such as wind and solar is a key challenge. HILT CRC has developed a range of energy system modelling tools to evaluate the viability of low-emissions energy sources at regional level for the provision of electricity, heat and hydrogen for continuous industrial processes.

HILT CRC research project RP2.003 *Green Heat for Industry* undertook a techno-economic analysis to compare different technologies and energy system configurations to provide a constant supply of high-temperature heat for large-scale industrial process (500 MWth), considering different industry locations and renewable energy inputs. 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.

Ongoing HILT CRC research project RP2.008 *Lost production and variability* aims to evaluate the various trade-offs between installing large amounts of expensive energy storage capacity to firm VRE power supplies and varying the production rate of the industrial process at a cost of lost production and potentially increased rates of degradation to process equipment.

Ongoing HILT CRC research project RP2.014 *Low-cost reliable green electricity supply for low-carbon heavy industry* is developing an integrated approach to combine multiple energy balancing methods, including geographic dispersion of renewable energy resources, integrated low-cost solar and brownfield hydro storage, hydrogen or biogas-fuelled gas turbines, and demand response.

HILT CRC is currently conducting a broader review to assess the technical feasibility of using bioenergy (including biomass, biochar and Refuse-Derived Fuels) in high temperature heavy industrial processes (projects RP2.010 and RP2.012). Preliminary findings indicate available biomass resources that can be economically transported to users are unlikely to be sufficient to meet all the energy requirements of heavy industry. However, there are niche opportunities where bioenergy might offset or replace other sources of energy in hard to abate processes (e.g. alumina calcination), as a long-term solution or in the transition, particularly if bioenergy can be used to directly displace fossil fuels as a retrofit option (e.g. using bio-derived synthesis gas to replace natural gas in existing high-temperature combustion processes). Future work will explore the technical feasibility of some potential applications at pilot scale.

HILT CRC research project RP2.001 *Green Hydrogen Supply Modelling* demonstrated that it is possible to supply a constant amount of hydrogen to a continuous industrial process using renewable electricity with relatively low cost increases for more stringent requirements for load matching by relying on

hydrogen storage. Follow on project RP2.006 *Hydrogen supply within HILT regional hubs – H2 cost and synergistic opportunities* identified location-specific optimal combination and capacity of off-grid solar, wind, battery storage, and hydrogen storage plant to provide a firm (continuous) supply of renewable hydrogen to an industrial process at lowest cost. Constraints due to geography and land availability were included in the analysis and additional expenditure due to construction in remote regions were accounted for by using locational costs factors developed for the construction industry [8]. The project revealed that transporting hydrogen was more economical than transporting electricity, and that there were significant variations in the levelised cost of a firm supply of hydrogen across different regional hubs (see Figure 4 (a)). These variations were primarily driven by the quality of the local renewable energy resource, the availability of suitable geographical storage sites for low-cost hydrogen storage (in salt caverns or lined caverns), which determined the optimal system configuration and capacity (see Figure 4 (b)), but also locational cost factors. The project used GenCost predictions of capital costs to estimate how production costs could change in the future (Figure 4 (c)).

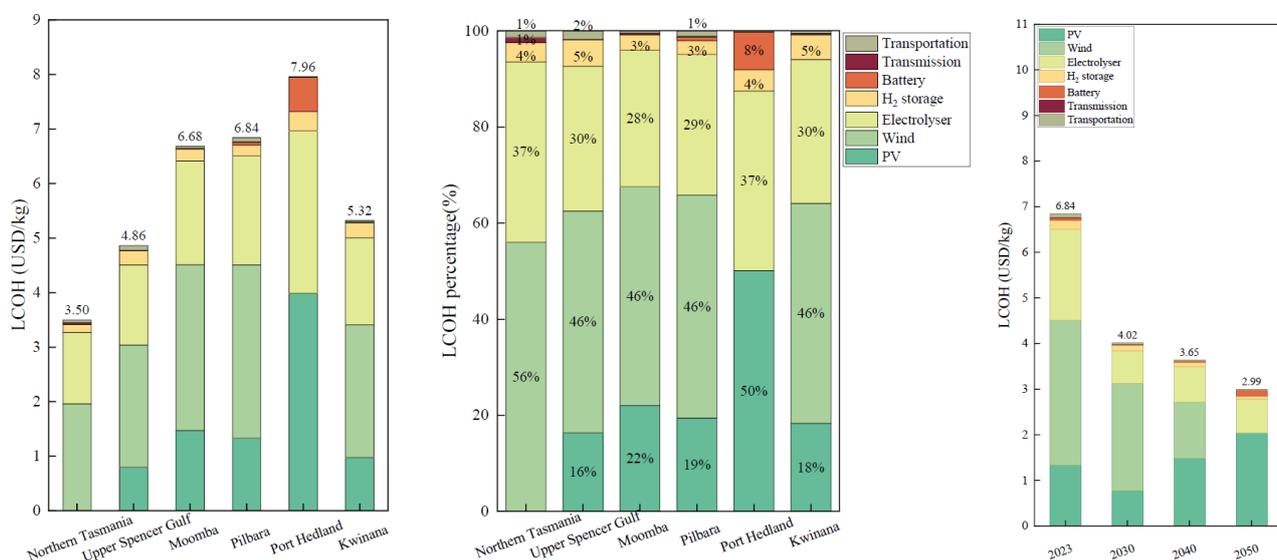


Figure 4: Levelised cost of hydrogen (LCOH) estimates for all locations, showing contributions from different system components as (a) total costs, and (b) percentage breakdown. (c) Estimates for hydrogen systems built in future years in the Pilbara, showing contributions from different system components.

HILT CRC is continuing research to further inform the location-specific energy demand (electricity, heat, and hydrogen) and supply infrastructure required for heavy industry to transition to net-zero in Australia. Flagship HILT CRC project *PR3.007 Unlocking investment in energy infrastructure for net zero industrial hubs* kicked off in August 2024 and will greatly improve our understanding of the public investment in energy capacity and infrastructure required to achieve net zero by 2050 under a series of scenarios that major stakeholders, including the industry, considers to be plausible. This will be achieved by:

1. Developing plausible, realistic and industry informed scenarios both for the transition of existing processes and the establishment of new processes needed to reach net zero emissions by 2050 for major industrial hubs in Australia.
2. Combining existing energy system modelling tools and HILT CRC research on decarbonisation technologies to estimate energy demand including electricity, heat, fuels and feedstock for these processes.

3. Identifying options for energy system configurations to meet these demands at lowest cost, within geographical constraints.
4. Identifying required energy infrastructure and estimating the potential government co-investment that may be required and justified based on future economic benefits, such as employment, royalties/revenues, social/regional benefits and private co-investments.

The project will be using PLEXOS software for part of this project and AEMO is a partner in this project.

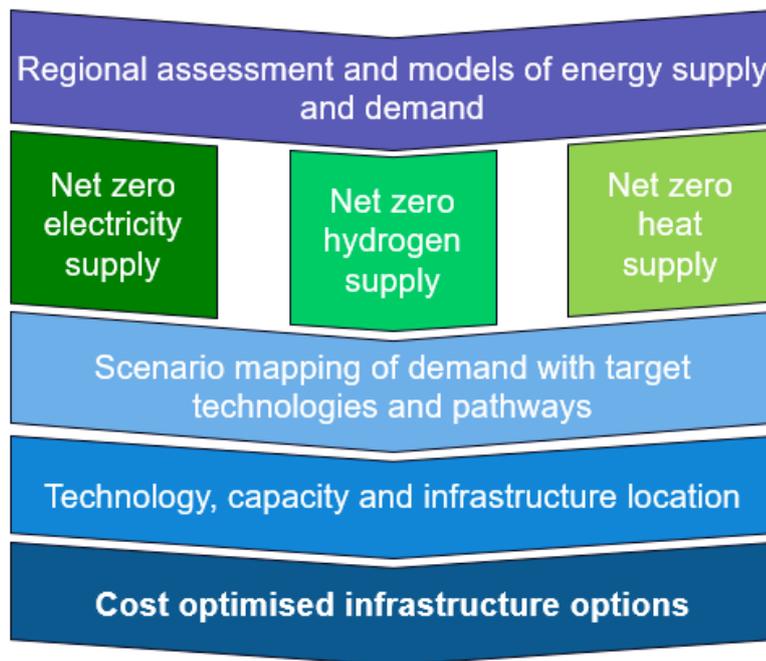


Figure 5: Schematic of RP3.006 project aims and outcomes.

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