AEMO IASR Consultation Stage 2

31 March 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.

Summary of submission

We recommendation that AEMO further develop frameworks to model industrial decarbonisation in order to better capture projections of energy demand and interactions with the electricity and gas grids. In particular, such models could inform the potential demand response of large industrial loads.

Providing more information about the models and approaches used to determine assumptions relating to projected industrial energy demand and interaction with energy grids would allow benchmarking of assumptions against independent research findings and could improve the quality of input to the IASR and the ISP planning process going forward. Currently, it appears that many of the key assumptions were developed using multi-sectoral modelling with limited visibility.

We also highlight the importance of the ISP for industrial decarbonisation. Access to low-emissions energy and enabling energy infrastructure consistently ranks as the most important barrier to industrial decarbonisation for stakeholders. This finding is based on HILT CRC analysis of partner and stakeholder perspectives on enablers and barriers to heavy industry decarbonisation collected through expert elicitations, roundtables and surveys, as detailed in the HILT submission to Stage 1 of the IASR 2025 consultation[1].

In light of this, the HILT is carrying out research to provide insights into future supply and demand for net-zero energy vectors and associated enabling infrastructure. A key focus of HILT Research Program 2

Cross-cutting Technologies is identifying optimal integration of low-carbon energy sources into heavy industrial processes and how best this future demand could be met at low cost. A key focus of HILT Research Program 3 *Facilitating Transformation* is assessment of the infrastructure requirements for sustainable and secure energy supply and strategies to unlock investment.

Flagship Research Project RP3.007 *Unlocking investment in energy infrastructure for net zero industrial hubs* is developing a suit of decarbonisation scenarios for prospective net-zero industrial hubs around Australia to estimate the energy demand and corresponding net-zero energy supply that would be required. The project aims to provide the information required to enable industry and other stakeholders to plan for the transformation of the energy system necessary for heavy industrial sectors to a net-zero carbon future. The project is in its first year and will be in a strong position to provide input into future ISP consultation processes.

AEMO is already a partner on this project, and we would welcome further collaboration to inform future ISP planning including detailed benchmarking of energy modelling and assumptions, in the following areas:

- Scenarios for the future production of green iron, steel, alumina, aluminium, and lime in Australia,
- Prospective technology pathways for decarbonisation in the iron and steel, alumina and lime industries, including transition pathways requiring the use of natural gas,
- Energy provision in the form heat, electricity, hydrogen for key industrial processes,
- Required energy infrastructure for key industrial hubs around Australia,
- Frameworks for co-investment in energy infrastructure.

Additional information on relevant projects in HILT CRC research program was provided in the HILT CRC submission to Stage 1 of the IASR 2025 consultation[1].

In addition, this submission provides feedback on the following:

- Assumptions regarding flexibility of industrial loads and impact on hydrogen production costs
- Projections for green export commodities

Benchmarking and feedback

Assumptions regarding flexibility of industrial loads and impact on hydrogen production costs

From the information provided, the IASR assumes that hydrogen supply to industrial loads is flexible over two different time scales: hourly and seasonally. More information should be provided to validate these assumptions, and the impact on the production costs of hydrogen and other green commodities should be considered. We further highlight that dynamic modelling of key heavy industrial processes is needed to inform energy demand and capture opportunities for demand response for large industrial loads, which are not yet well understood. HILT CRC research in this area could inform future AEMO planning processes.

Data in the Hydrogen Monthly Profiles sheet in the Draft Stage 2 Inputs and Assumptions Report and Workbook indicates that the 2024 multi-sectoral modelling results in seasonal variation in the supply hydrogen used to produce commodities and exports. Supply reduces as much as 30% in 2040 and 40% in 2050 during June and July. Further information on this modelling is required to assess the validity of this assumption for hydrogen exports and as an input to production of green commodities. Results from HILT research project RP2.008 *Lost production and variability* indicate that this level of seasonal variability in production would introduce significant production cost penalties, as detailed below.

Hydrogen storage and transport costs were estimated using an off-grid hydrogen cost model presented in the ACIL Allen report *Gas, liquid fuel, coal and renewable gas projections*[2]. This model assumes that the hydrogen load could be reduced by up to 50% within in each hourly timestep for all use cases. Results from HILT research project RP2.001 *Green Hydrogen Supply Modelling* indicate that firming supply of hydrogen to ensure continuous operation of a process like direct iron reduction would have significant cost implications, as detailed below.

Ongoing HILT research projects are exploring efficient operation of industrial processes powered by variable renewable energy sources: RP1.013 *Alumina Refineries' Next Generation Transition;* and RP2.017 *Advancing the viability of high temperature thermal energy storage* for alumina and iron production technologies. More information on these and other relevant projects is provided below, and further details can be provided on request.

More information

A growing body of literature is exploring the opportunities for demand response in heavy industries to improve grid stability and reduce energy costs[3], [4], [5]. The two main strategies are direct load control of suitable industrial processes and incorporating energy storage to buffer supply intermittency – including storage of hydrogen and heat. Incorporating demand response into industrial processes introduces a trade-off between lowering the cost of energy and feedstocks and imposing additional costs on production through lost productivity or increased capital costs. The profitability of high capital cost industrial plant depends on operating at or near capacity to maximise the return on investment. In addition, cycling of high temperature equipment introduces the risk of increased rates of degradation and high energy losses due to the heat input required to return it to operating temperature. At the same time, introducing electricity, heat or hydrogen storage to buffer energy supply variation introduces additional capital costs.

Optimisation of variable-rate heavy industrial processes is a relatively difficult challenge due to the interaction of large industrial demands with electricity markets, potential cycling damage and increased degradation, and non-linear process performance at off-design conditions. Generally, there is a lack of understanding of how much process flexibility exists in practice for both existing and emerging heavy industry processes and reactors. In particular, the effects of cycling on material fatigue, creep, corrosion and thermal expansion cracking are often poorly understood.

The trade-offs inherent in demand response depend on the type of process involved. Aluminium smelters are sometimes referred to as “virtual batteries” that could be used to stabilise the grid[6]. Power input to primary aluminium production (to the potlines) can be reduced by roughly 20% for 2 hours without critical operability issues and then compensated for by increasing power (to the cells) over a longer period to restore the heat balance, typically, 5% over 8 hours[7]. Green iron and steelmaking processes have the potential for demand response strategies but are less well developed[5]. In particular, hybrid energy systems incorporating variable renewable energy and hydrogen storage can firm the supply of hydrogen as a reductant feedstock. More work is needed to identify cost-optimal, scalable strategies for green iron and steel.

Summary of relevant HILT projects

Recently commenced HILT CRC research project RP1.013 *Alumina Refineries' Next Generation Transition (AlumiNEXT)* will address the needs and drivers to transition alumina refineries to next generation, net-zero production. It will de-risk technologies with strong potential to reduce emissions from current alumina refineries and advance the development of novel technologies needed to unlock a step-change in increased efficiency with low-emissions and variable energy sources.

Recently commenced HILT CRC research project P2.017 *Advancing the viability of high temperature thermal energy storage* is evaluating thermal storage technologies for buffering alumina and iron production technologies. Thermal energy storage (TES) is expected to be a critical component for low-cost decarbonisation of industry, however optimal integration for different heavy industrial processes remains a key challenge that needs to be addressed. This project will further develop TES integration scenarios though process modelling and assess the feasibility and cost with comparison to alternative options such as direct electrification or storage/combustion of hydrogen.

Ongoing HILT CRC research project RP2.008 *Lost production and variability* aims to evaluate the trade-off between installing large amounts of expensive energy storage capacity to firm renewable energy supply and varying the production rates of industrial processes at a cost of lost production and potentially increased rates of degradation to process equipment. The project team developed simplified models of energy use, productive output, and degradation of equipment for key industrial processes, alongside energy and cost modelling of renewable energy production and storage systems. Two key processes were modelled: a hydrogen-based direct reduced iron (H_2-DRI) plant for steelmaking and a clinker production process with a rotary kiln and an indirectly heated calciner. Across both industrial processes, annual-average capacity factors (yearly average production rates) in the range of 90–97% were optimal, balancing reducing capital expenditure for energy supply and minimising losses due to cycling due and lost production. This result assumed that processes could instantaneous turndown capacity to 70-90% of nominal rate. Increasing the annual-average capacity factor further was shown to increase costs due to lost productivity.

Completed HILT research projects RP2.001 *Green Hydrogen Supply Modelling* has shown that the degree of flexibility of the hydrogen load impacts the optimal configuration of off-grid hydrogen production systems and the levelised cost of hydrogen produced. The research team conducted an in-depth analysis of off-grid hydrogen costs at key locations around Australia corresponding to identified heavy industry hubs for iron, steel and alumina. The model included compression and hydrogen storage in pipelines and underground caverns, and optimised sizing of wind and solar, electrolyser, and energy (hydrogen and battery) storage capacity for different levels of hydrogen load flexibility. Figure 1 shows the calculated levelised cost of hydrogen $LCOH_2$ within each hub as a function of flexibility of the load, defined here as the supply capacity factor (CF). Assuming load flexibility of 50% reduces the overall cost of supplying hydrogen by approximately 5-9% across all hubs in 2020, 8-9% for 2030, and 10-15% for 2050, assuming low-cost storage in salt caverns. Firming hydrogen supply will cost more when relying on rock cavern or pipeline (including line packing) storage.

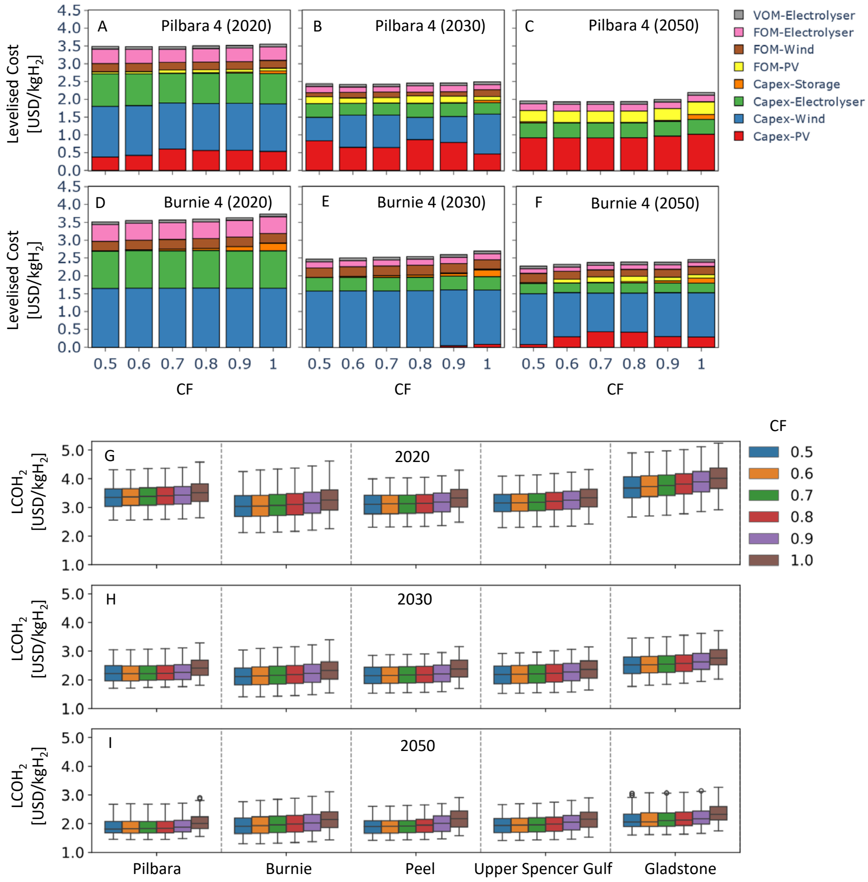

Figure 1. The calculated levelised cost of hydrogen ($LCOH_2$) within each hub as a function of supply capacity factor (CF). A-F show the breakdown of $LCOH_2$ in 2020, 2030, and 2050 in Pilbara 4 and Burnie 4. G-I show the distribution of $LCOH_2$ for all the locations within each hub for different CF, indicated by different colours defined in the legend. The box plot distributions are generated from data acquired via a Monte Carlo analysis that takes into account uncertainty in the unit price of each system component. The median value is denoted by a horizontal line within each box. The whiskers extend from the minimum to the maximum value, and the outliers are denoted by (o). The hydrogen supply plant uses lined rock cavern for hydrogen storage and a pipeline with a maximum capacity of 100 tonne to serve a hydrogen load of 5 kg/s.

Projections for green export commodities

Future demand for green commodities produced in Australia is highly uncertain and will likely depend on global climate ambition and competition from other producer countries. HILT CRC's industry led research can provide independent benchmarking for the estimates of future green commodity exports from Australia provided by the ACIL Allen report: *Gas, liquid fuel, coal and renewable gas projections*[2], as detailed below.

Green iron and steel production in Australia

HILT Research project RP3.005 *Analysis of market, cost and locational factors for green iron and steel in Australia* employed expert elicitation to gain insight into the future green iron and steel industry. Over 40 interviews were conducted with a diverse range of stakeholders, including industry, government, consultancy, NGOs, and academics, to gather perspectives on viable production pathways, anticipated costs, and projected production quantities. The expectations for green iron and steel production in Australia in 2030 and 2050 are shown in Figure 2. These values are compared with estimates from the report on *Gas, liquid fuel, coal and renewable gas projections* used as an input to determine future energy requirements for industry.

ACIL Allen estimates for green iron exports in 2030 fall within the 1st and 3rd quartiles of expert expectations for the Green Energy Exports (GEE) Scenario but are below the 1st quartile for the Progressive Change (PC), and Step Change (SC) scenarios. Estimates for green iron exports in 2050 for the GEE scenario (124.7 Mt) are significantly higher than the median expert expectation (11 Mt), falling above the 3rd quartile (98.5 Mt). Estimates for both the PC and SC scenarios once again fall below the 1st quartile.

For green steel exports, estimates from ACIL Allen for all three scenarios are within the 1st and 3rd quartiles of expert expectations in 2030. However, estimates for 2050 green steel exports (26.6 Mt) are significantly higher than the median expert expectation (3.8 Mt) and fall well above the 3rd quartile (6 Mt).

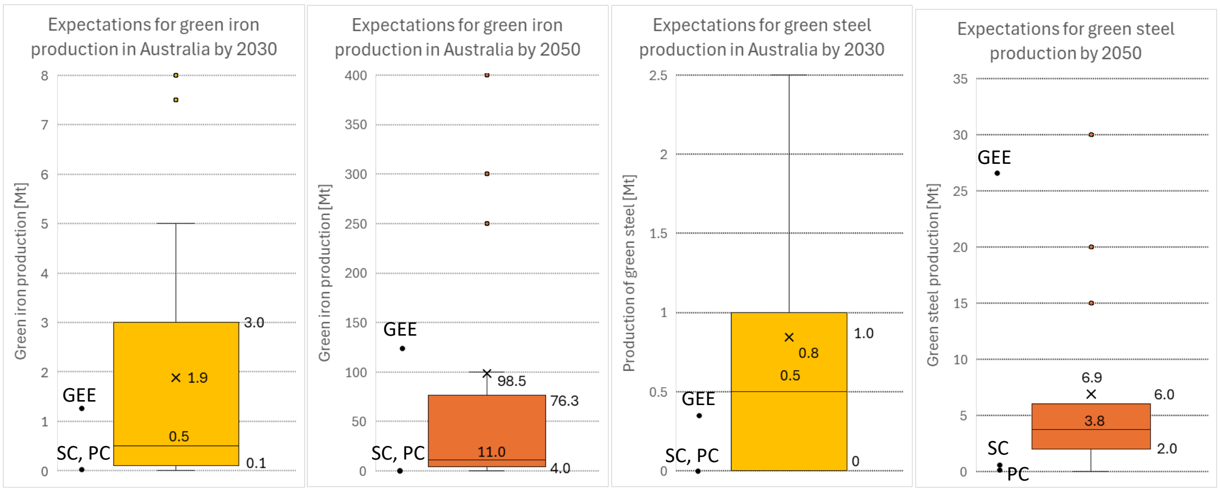

Figure 2. Expectations for green iron and steel production in Australia in 2030 and 2050. The following outliers not shown to improve data visualisation: Green iron, 1000 Mt in 2050; green steel, 6 Mt in 2030. Black dots show approximate values of estimates by ACIL Allen report for Progressive Change (PC), Step Change (SC) and Green Energy Export (GEE) scenarios.

ACIL Allen necessarily employs simplified assumptions for decarbonising iron and steel production. The opportunity for Australian industry in future net-zero steel supply chains will likely vary depending on location and ore type. Generally, there is opportunity for exports of different value-added intermediate products such as green iron pellets, green iron as hot briquetted iron (HBI), and green steel. The decarbonisation pathways for heavy industry will also be plant specific, depending on the optimal processes for the specific ore and the availability of different energy vectors. HILT CRC is continuing a range of research projects to identify prospective net-zero pathways and develop plausible scenarios for green iron and steel production in Australia, which will be able to inform future ISP planning scenarios.

Green alumina and aluminium production in Australia

The estimates provided by ACIL Allen assume no growth in alumina exports in any of the scenarios, which is in line with expectations from HILT CRC analyses. However, it is possible that the volume will decrease over time due to the degradation of available bauxite quality.

ACIL Allen necessarily employs simplified assumptions for decarbonising the Bayer and calcination processes. While electrification of the Bayer process using mechanical vapour recompression is the most efficient pathway, it is not the only option, and a combination of different steam generation and recovery technologies will likely be used. The ACIL Allen report highlights the technical and economic uncertainties as to whether hydrogen or electric calcination will prove more effective and assumes 50% of the energy will be provided by hydrogen. Identification of optimum low-carbon alumina processing pathways will be one of the key outcomes from the newly started HILT research project RP1.013 *Alumina Refineries' Next Generation Transition (AlumiNEXT™).* This analysis will inform development of realistic decarbonisation scenarios that will be able to inform future ISP planning scenarios.

References

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