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CALIX – ZERO EMISSIONS STEEL TECHNOLOGY (ZESTY)

FEED STUDY REPORT AND FINAL REPORT

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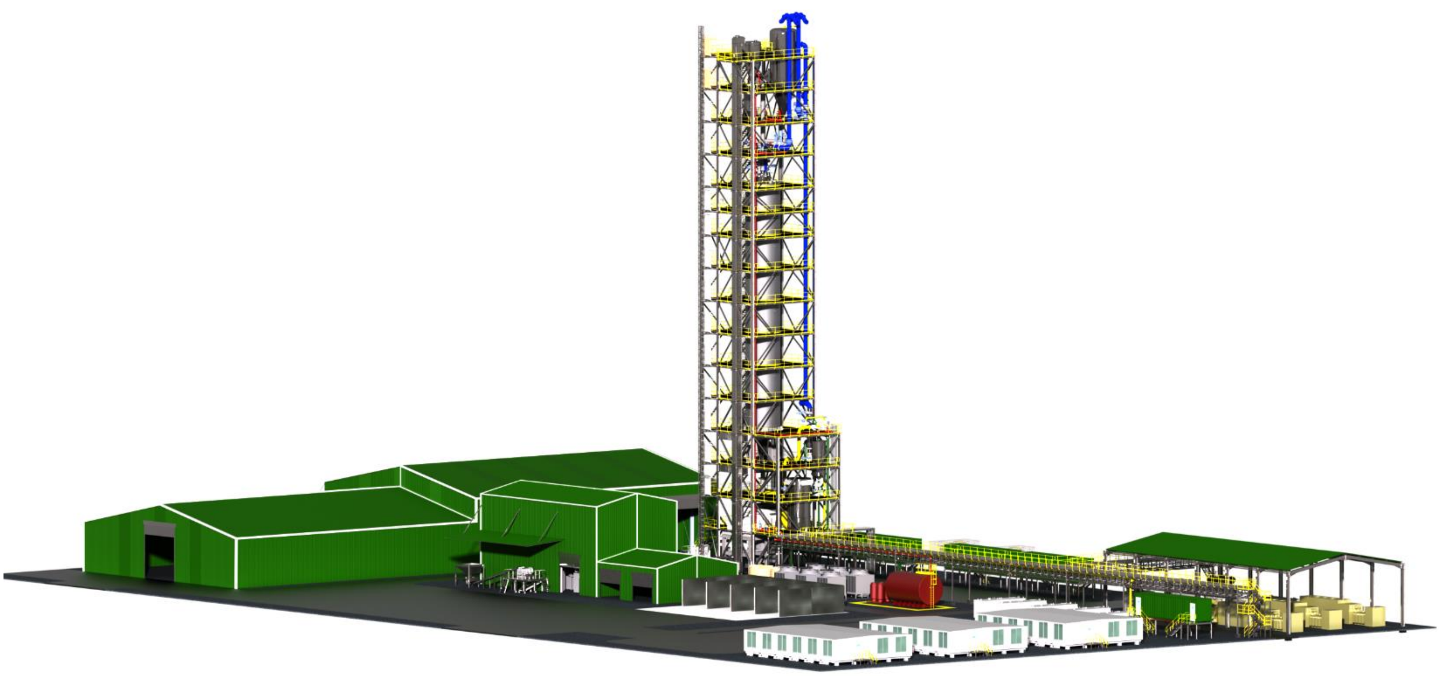
30/4/2024



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DEFINITIONS

ARENA	-	Australian Renewable Energy Agency
AS	-	Australian Standard
ASME	-	The American Society of Mechanical Engineers
ASTM	-	Australian Society for Testing and Materials
BatMn	-	One of Calix's Electric Calciners
BF	-	Blast Furnace
BoD	-	Basis of Design
BOF	-	Basic Oxygen Furnace
BoM	-	Bill of Materials
Calciner	-	The process vessel inside which the targeted reaction(s) occur.
CAPEX	-	Capital Expenditure
CFC	-	Calix Flash Calciner
CGA	-	Compressed Gas Association
COD	-	Chemical Oxygen Demand
DCS	-	Distributed Control System
DM	-	Demineralised (Water)
DRI	-	Direct Reduced Iron
EAF	-	Electric Arc Furnace
EIS	-	Environmental Impact Statement
EPCM	-	Engineering, Procurement, and Construction Management
EPL	-	Environmental Protection Licence
ESD	-	Emergency Shutdown
FAT	-	Factory Acceptance Tested
FEED	-	Front-End Engineering Design
FEL	-	Front End Loader
FID	-	Final Investment Decision
FOAK	-	First of a Kind
GA	-	General Arrangement
Gt	-	gigatonne
HA	-	Hydrogen Attack
HAZOP	-	Hazard and Operability Review
HBI	-	Hot Briquetted Iron
H-DRI	-	Direct Hydrogen-Reduced Iron
HE	-	Hydrogen Embrittlement
HMI	-	Human-Machine Interface
I/O	-	Input/Output
IEA	-	International Energy Agency
IFC	-	International Fire Code
ISA	-	International Society of Automation
IEC	-	International Electrotechnical Commission
IECEx	-	International Electrotechnical Commission System for Certification to Standards Relating to Equipment for Use in Explosive Atmospheres
ktpa	-	kilotonnes per annum

LCODRI	-	Levelised Cost of Direct Reduced Iron
LCOH	-	Levelised Cost of Hydrogen
LEILAC	-	Low Emissions Intensity Lime and Cement
LIW	-	Loss in Weight
MCC	-	Motor Control Centre
MEL	-	Mechanical Equipment List
MOC	-	Management of Changes
MOU	-	Memorandum of Understanding
NEPM	-	National Environment Protection Measures
NFPA	-	National Fire Protection Association
NZS	-	New Zealand Standard
OPEX	-	Operational Expenditure
OSHA	-	Occupational Safety and Health Administration
PCS	-	Plant Control System
PDC	-	Process Design Criteria
PEP	-	Project Execution Plan
PFD	-	Process Flow Diagram
P&ID	-	Piping & Instrumentation Diagram
PLC	-	Programmable Logic Controller
ppm	-	parts per million
Pre-FEED	-	Preliminary Front-End Engineering Design
PSA	-	Pressure Swing Adsorption
PSV	-	Pressure Safety Valve
QA	-	Quality Assurance
REIP	-	Renewable Energy Industrial Precinct
RO	-	Reverse Osmosis
SCADA	-	Supervisory Control and Data Acquisition
SCR	-	Silicon Controlled Rectifier
SEPP	-	State Environment Protection Policy
SDA	-	State Development Area
SoW	-	Scope of Works
TCP	-	Transmission Control Protocol
TEM	-	Techno-Economic Modelling
tph	-	tonnes per hour
TPH	-	Total Petroleum Hydrocarbons
ZESTY	-	Zero Emissions Steel Technology

DISCLAIMER

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1 EXECUTIVE SUMMARY

Calix has undertaken a Front-End Engineering Design (FEED) study for a 30,000tpa equivalent hydrogen-based direct reduced iron (DRI) demonstration plant based on its Zero Emissions Steel Technology (ZESTY) with support from the Australian Renewable Energy Agency (ARENA).

The FEED study serves to define the scope of work and preliminary design for the ZESTY system to enable the project to proceed on a risked and costed basis, through development of capital and operating cost estimates (+/-25%). The cost estimates, combined with the FEED study's technical outcomes, shall form the foundation for a Final Investment Decision (FID) for the project.

This document serves to summarise the work completed as part of the FEED study, including:

- General plant considerations including site layout, environmental considerations, permitting considerations and safety
- Process design including different operating regimes, venting, emergency response, startup, and shutdown
- Sizing of major equipment including the reactor and furnace using performance data from the pilot plant test work
- High level construction methodologies, mass estimates of equipment and steel work in order to plan and cost construction
- Technoeconomic modelling to assess the relative cost of the hydrogen and DRI based on predictions of real-world electricity grid pricings.

The central outcomes of the FEED study are the following values:

- A levelised cost of hot briquetted iron (HBI) of $632-$802 AUD/Tonne Fe ($411-$522 USD), based on a levelised cost of Hydrogen of $5.5 - $6.2 AUD per kg, which is close to the range of existing conventional HBI processing costs. ZESTY is therefore a potential economic proposition to produce HBI before the cost of carbon is taken into account, even at small scale. This number assumes an average iron ore production cost of $49 AUD but excludes transport cost and margin applied by the producers.

2 PROJECT BACKGROUND

The iron and steelmaking process involves the processing of iron ore into steel. Ironmaking is the first stage, which involves reducing iron ore into molten iron in a Blast Furnace (BF). The conventional ironmaking process uses coal as a reducing agent to produce molten iron. The steelmaking process also requires large amounts of energy, either in the form of coking coal or electricity, to melt the iron and convert to steel.

Conventional iron and steelmaking processes generate substantial CO_2 emissions, contributing approximately 7-9% of global CO_2 emissions. The ironmaking process is particularly carbon intensive responsible for 64% (or 2.3 gigatonnes (Gt) of CO_2 emissions annually) of iron and steel making derived $CO_{2,}$ emissions with steelmaking responsible for remaining 36% (or 1.3 Gt CO_2 emissions annually).

Efforts to reduce CO_2 emissions from the iron and steelmaking process include:

(i) Efficiency improvements for existing iron and steelmaking e.g. top gas recovery (TGR) and steel scrap recycling.

(ii) Carbon capture, utilisation, and storage (CCUS) which involves capturing and concentrating the CO_2 produced from iron and steel making, compression of the concentrated CO_2 stream for re-use or storage . There are several technologies at various stages of development for capturing CO_2 from iron and steel including post-combustion CO_2 capture processes using MEA amine-based chemical absorbents ; pre-combustion CO_2 capture such as the DISPLACE technology (high temperature sorption-DISPLACEment process for CO_2 recovery) piloted by Swerim AB and TNO as part of the EU Horizon C4U project and HIsarna a smelting direct reduction process being developed by Tata steel which uses O2 in place of air to produce a flue gas containing > 90% CO_2.

(iii) Electrification and the application of renewable electricity to power iron and steel making processes such as the electric arc furnace (EAF) for making steel.

(iv) The substitution of biomass for fossil-based fuels and reductants such as Rio Tinto's BioIron™ process.

(v) Direct hydrogen reduction, which involves the substitution of carbon-based fuels such as methane and syngas with green or blue hydrogen reductants. Examples of direct hydrogen reduction iron making technologies include MIDREX-H_2, HYL, HYBRIT and HYFOR.

The complete substitution of CH_4 with hydrogen in a current DRI iron making process (e.g. MIDREX and HYL) is challenging because the reaction of H_2 with iron oxide is endothermic. Additional heating is required to maintain the process temperature and product metallisation rates. This can be achieved through the partial substitution of the CH_4 with H_2 up to around 30% - the exothermic reaction between CO (generated from CH_4 reforming) and iron oxide can be used to balance the endothermic reaction between H_2 and iron ore to the detriment of a higher CO_2 footprint. Alternatively, pre-heating the H_2 through partial combustion of the H_2 or the use of another low-carbon energy source (e.g. electricity or biomass) can be applied to maintain process temperature.

Retrofitting existing blast furnaces to allow partial H_2 substitution is also challenging, a certain level of coke is required (>50% of the current coke feed) to maintain the physical structure near the hearth region to distribute gases in the shaft and also ensures that phases are molten in the region below the tuyeres . There are also other substantial issues including material compatibility issues such as H_2 embrittlement, high temperature corrosion, increased process complexity and lower thermal efficiency/higher running costs associated with the higher energy requirements.

The utilisation of lower grade ores presents further challenges to shaft furnace based DRI technologies such as Midrex, HYL and Hybrit that rely on pellet and sinter grade where a high crush strength is required to limit fracturing, fines generation and maintain the target productivity.

Calix is an Australian company developing and commercialising low carbon technologies to facilitate industrial decarbonisation of several mineral processing sectors including magnesite, lithium, lime, and cement processing. ZESTY (Zero Emission Steel Technology) is a H_2-direct reduction iron-making process based on Calix's proprietary Calix Flash Calcination (CFC) technology processing of low-grade iron ore fines and ultra-fines for decarbonised iron and steel production.

With support from ARENA, Calix is scaling its technology from pilot scale to a plant that can demonstrate commercial scale production.

2.1 The Calix Technology

The core Calix Flash Calcination (CFC) platform technology is an in-directly heated, lean-phase calcination technology designed for the flash heating of mineral fines and ultra-fines. In its simplest form, the CFC technology consists of a central process tube which is heated indirectly via an external furnace (Figure 2-1). Calix has proven the technology with natural gas and electric heating options . A finely ground mineral (particle size depending on mineral properties and application) is introduced at the top of the process tube, as the mineral falls through the reactor under gravity the particles are rapidly heated predominantly through radiative heat transfer from the walls. Flash heating can be applied to invoke: (i) the thermal decomposition of minerals containing trapped or chemically bound volatile components such as carbonates and hydroxides; (ii) phase transformations and/or; (iii) facilitate thermochemical gas-solid reactions between the mineral input and an additional reactive gas such as reduction of iron oxide by H_2 as is the case for ZESTY. Depending on the application, process gases (including gaseous reaction products) exit the plant via a de-dusting step to remove entrained powder at the top or base of the plant for counter-flow and co-flow operation respectively. Calix is scaling the technology through a multi-tube module approach.

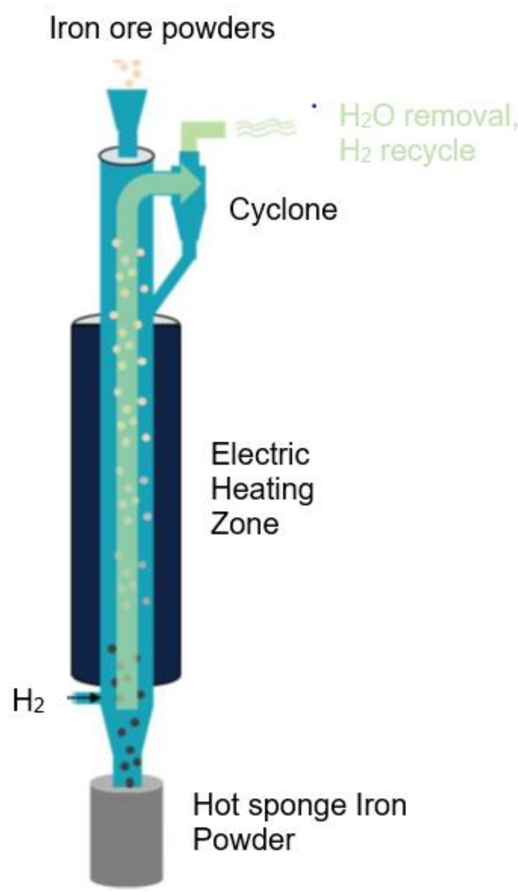

Figure 2-1 Calix Core Technology

Calix's "ZESTY" (Zero Emissions Steel Technology) process is an extension of Calix's core CFC technology in which iron ore fines iron ore feed (typically < 500 µm) is introduced at the top of the reactor and H_2 at the base in a counter-flow arrangement. The iron ore is rapidly heated and reduced to a direct reduced iron (DRI) product. The DRI product may be subsequently processed to a Hot Briquetted Iron (HBI) or melted in melting unit to separate gangue from iron for export to steelmakers and/or integration into downstream steelmaking processes (Figure 2-2).

The key benefits of the ZESTY technology that will be demonstrated through the proposed demonstration plant include:

- Compatibility with low grade hematite/goethite ores, consistent with the forecasted decline in quality of Australian iron ore
- Capability of processing fines and ultra-fine ore feedstocks thereby eliminating the need for energy and carbon intensive agglomeration, namely pelletisation or sintering
- Electrical heating and its compatibility with intermittent operation means the process can be heated using renewable energy sources.
- Indirect electric heating means that hydrogen is consumed as the reductant only (not as the fuel). Calix's ZESTY process is targeting the theoretical minimum hydrogen use (54 kg/t H-DRI for a hematite ore) with a recycle loop to return the unreacted H_2 back to the process.

Calix's LEILAC® (Low Emissions Intensity Lime and Cement) technology can be used to supply zero-emissions lime – used in steelmaking as a fluxing and slag forming agent to remove impurities.

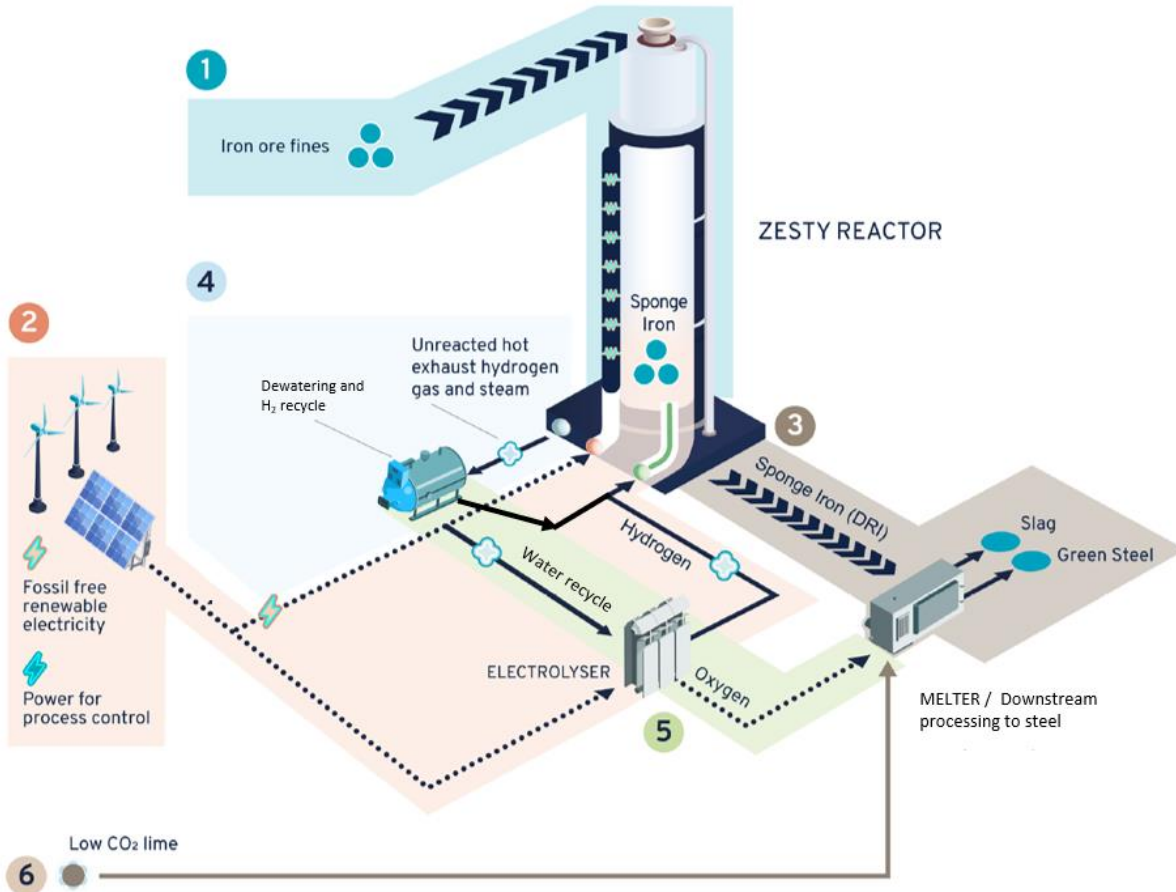

Figure 2-2 Calix ZESTY Iron Technology

Calix's LEILAC® (Low Emissions Intensity Lime and Cement) technology can be used to supply zero-emissions lime – used in steelmaking as a fluxing and slag forming agent to remove impurities.

3 PROJECT OVERVIEW

3.1 Project Scope

The ZESTY demonstration plant project is structured with clear engineering and development stage-gates and milestones to allow key stakeholders to review the scope, progress, risk profile, budget forecasts, technical acumen and business case ensuring the project proceeds with the endorsement and support of Australian iron ore and steel producers for a demonstration plant.

The FEED stage of the project involved the completion of engineering design of a 30ktpa equivalent (4tph DRI production rate) ZESTY demonstration plant to allow CAPEX and OPEX cost plans to a +/-25% confidence level – required to inform the project Final Investment Decision (FID).

Five potential sites were identified (with one preferred option), commercial agreements are currently under negotiation. As such the demonstration plant will be of generic design that can be installed across all identified potential sites, capable of receiving unprocessed ore from multiple suppliers and producing HBI (hot briquetted iron) and DRI fines as a product. Whilst Calix's preference is to receive hydrogen over the fence, two scenarios have been considered to reduce the risk associated with the sourcing of hydrogen:

Scenario 1 (preferred) – Hydrogen supplied over the fence

The scope of the project under Scenario 1 includes:

- Calix ZESTY reactor
- Cooling system and associated water treatment
- Step down transformers
- Switchroom and control centres
- Drying, crushing, and milling of raw iron ore
- Hot Briquetting Iron plant
- Compressed air and nitrogen generation
- Nitrogen compression and storage
- Hydrogen compression and storage for buffering
- Material receiving and handling
- Product storage and dispatch
- Site office including QA laboratory facilities
- Standard civil works

A second scenario without external supply of hydrogen has also been considered for comparison:

Scenario 2 (contingency) – electrolyser included in project scope

- Electrolyser stack and associated pipe work
- Power supply for the electrolyser
- Additional Water treatment for the electrolyser supply

- Additional civil works, pipe bridges and pipe runs to accommodate hydrogen pipeline

The following site specific considerations have not been costed within the project scope at this time:

- Power transmission lines
- Electrical Substations
- Incoming roads and other infrastructure outside site battery
- Major civil works including clearing and significant leveling of land
- Downstream processing of HBI or DRI into steel
- Green lime production

3.2 Timelines and Progress

The development of the ZESTY process technology can be separated into 4 phases:

- **Phase 1:** Lab study (*complete*)
- **Phase 2:** Pilot plant (*complete*)
- **Phase 3:** Pre-FEED & FEED study ZESTY ARENA Project (*complete*)
- **Phase 4:** FID for Demonstration Plant (targeted 2024)

3.3 Basis of Design

3.3.1 Basis of Design Report

The fundamental requirements and objectives that govern the design and implementation of the ZESTY demonstration plant are detailed in the ZESTY Basis of Design (BoD) document, *ZESTY pre-FEED/Basis of Design (BoD) report*[1].

The Basis of Design report established initial sizing and operating conditions required to further develop the process flow and equipment design.

3.3.2 Pilot Plant Test Report

The pilot plant test work has been completed at Calix's Bacchus Marsh R&D facility allowing the learnings to feed into the sizing of the plant and further the understanding of where ZESTY can be used for green steel production. The detailed findings of the report are summarised in the *ZESTY Pilot Plant Study Report*[2].

The pilot plant test results showed good metallisation rates across a range of process conditions. Trends indicate that the process can be suited to a range of process conditions but with the limiting factor likely to be material recovery, particularly at higher gas flows and finer PSDs. The information from the pilot plant resulted in the following outcomes:

- Selection of mill circuit design to target the preferred PSD range.
- Trade-off of various operating conditions including temperatures and flow rates to understand the effect of the CAPEX and OPEX on the techno-economics.
- A suitable understanding of the performance of various ores from a range of providers.
- Initial estimates of the emissions reduction and techno-economics achievable with the proposed demonstration plant.

3.3.3 Design Intent

The design intent of the demonstration plant is to facilitate and de-risk the scale up of the ZESTY process to a size that is relevant to industry and allow demonstration of the technology at the minimum industrially relevant scale (i.e. full-scale single tube design). A final plant location is subject to commercial arrangements. To provide a cost that will be within ±25% confidence, conservative assumptions have been made when developing the design. Some of the conservative assumptions that were applied include:

- Location will be subject to high temperatures using Pilbara, WA as baseline
- Location will be subject to cyclone conditions using Pilbara, WA as baseline

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[1] https://arena.gov.au/knowledge-bank/calix-zesty-tech-zero-emissions-iron-and-steel-pre-feed-report-demo/

[2] https://arena.gov.au/knowledge-bank/calix-zesty-tech-zero-emissions-iron-and-steel-ks5-pilot-plant-study-report/

- Plant will be subject to intermittent operation due to external causes
- Feedstock is energy intensive ore (high goethite content, low Fe content)

These assumptions hold true and are largely conservative when applied to the preferred site with some additional work required to firm up assumptions.

The plant has been designed to test and operate with a broad range of ores and input conditions to allow demonstration of the ZESTY technology as an industry wide solution. Several of the plant's major components have been overdesigned to facilitate flexible operation and a wide operating window in terms of ore types and process conditions.

The following considerations were applied when undertaking the demonstration plant FEED study:

- Safety – a cautious approach to hydrogen safety has been prioritised ahead of cost due to the First of a Kind (FOAK) nature of the plant
- Flexibility of feed source – the plant will have the ability to receive, store, and process a wide range of ore types.
- Flexibility of feed processing – the milling and drying circuit will be arranged to allow for a wide range of input materials and compositions
- Flexibility of process conditions – the system will be designed to operate at a range of gas flow rates, gas compositions, temperatures, heating profiles, particle sizes etc to determine the ideal operating conditions for differing ore types
- Design for highest cost site location
- Robustness and simplicity of design – simpler solutions for operation and maintenance have been prioritised ahead of high energy efficiency.
- Flexibility in operations – storage systems (both gas and powder), as well as multiple diversion points, have been included to allow for operational flexibility and intermittent operation.

4 FEED STUDY OUTPUT SUMMARY

4.1 Description

The FEED study was completed for a generic site to inform FID. A preferred site has been identified and further refinement of the FEED will be undertaken to finalise details specific to the selected site. The FEED study is comprised of the following details:

- Basis of design and design intent
- Overview of the potential locations –and the preferred location
- Environment health and safety considerations including
    - Air emissions
    - Water emissions
    - Hazardous area zoning
    - Noise
- Learnings from the pilot plant operations
- Process functional description of the main elements of the plant
- Feed material specification
- Design review and preliminary HAZOP
- Final reactor sizing
- Overview of the various engineering discipline work completed including:
    - Process
    - Piping
    - Mechanical
    - Civil
    - Structural
    - Electrical
- Site layouts
- Permitting and licencing requirements
- High level construction methodology
- Cost development of CAPEX and OPEX
- Techno-economics and deployment strategy
- Detailed risk assessment
- Key decision criteria for FID

4.2 Deliverables

The following table lists the main document deliverables that were produced as part of the FEED study.

Table 4-1 Deliverable List

	Document Number	Document Name
A.1	P-V30902-0001-RA	Process Flow Diagram
A.2	P-V30902-0009-RA	Energy & Mass Balance
A.3	P-V30902-0010-RA	Piping & Instrumentation Diagram
A.2	J-V30902-0001-R0	Instrument Index
A.5	H-V30902-0001-R0	ZESTY HAZOP Design Review (Action Summary List)
A.6	P-V30902-0007-RA	Process Design Criteria
B.1	M-V30902-0001-RA	Mechanical Equipment List
-	-	3D CAD plant model
C.1	M-V30902-0005-R0	Concrete slab footings
C.2	M-V30902-0010-R0	Site layout 1
C.3	M-V30902-0011-R0	Site layout 2
C.4	M-V30902-0012-R0	Site layout 3
C.5	M-V30902-0013-R0	Site layout 4
D.1	E-V30902-0001-R0	Scope of Works: Electrical Engineering – ZESTY Demonstration Plant
D.2	E-V30902-0002-RA	Electrical load list
D.3	BRSQ-22186-E-4021_A	Single Line Diagram: Furnace Zones 1 – 15
D.4	BRSQ-22186-E-4022_A	Single Line Diagram: Furnace Zones 16 – 30
D.5	BRSQ-22186-E-4023_A	Single Line Diagram: Motor Control Centre
E.1	R-V30902-0001-RB	Risk Register

5 TECHNOECONOMIC FEASIBILITY SKETCH

A techno-economic assessment of the ZESTY demonstration plant project was undertaken to evaluate the viability of the process. The methodology employed assesses various economic factors, with a specific focus on determining the levelised cost for various scenarios and providing a breakdown of critical parameters. A parallel analysis has been conducted for the levelised cost of Direct Reduced Iron (LCO-DRI).

Inputs into the techno-economic model include:

- Capital breakdown of the project
- Forecast electrical spot pricing for each site (where available)
- Scheduled and unscheduled breakdowns
- Electrolyser efficiency curves based on load
- Operational costs including servicing of specific equipment, operations staff and other overheads

Figure 5-1 and Figure 5-2 provide a snapshot of the techno-economic modelling (TEM) outputs for a range of electricity prices, assuming hydrogen generation is included in the project scope.

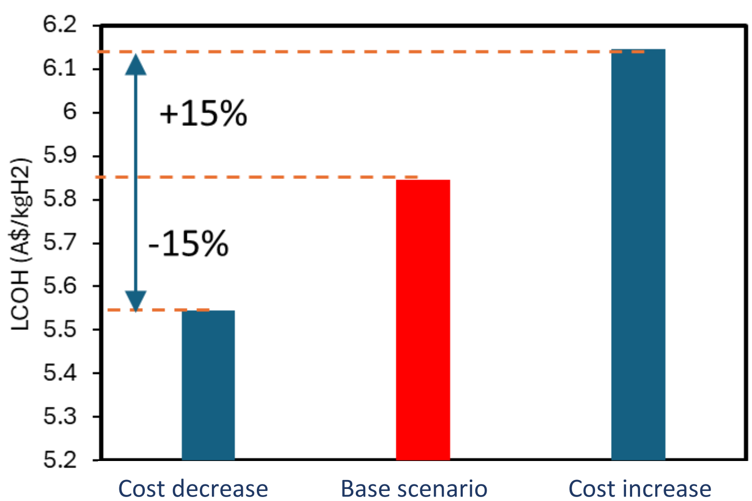

Figure 5-1 Impact of the electricity pricing on Levelised cost of Hydrogen

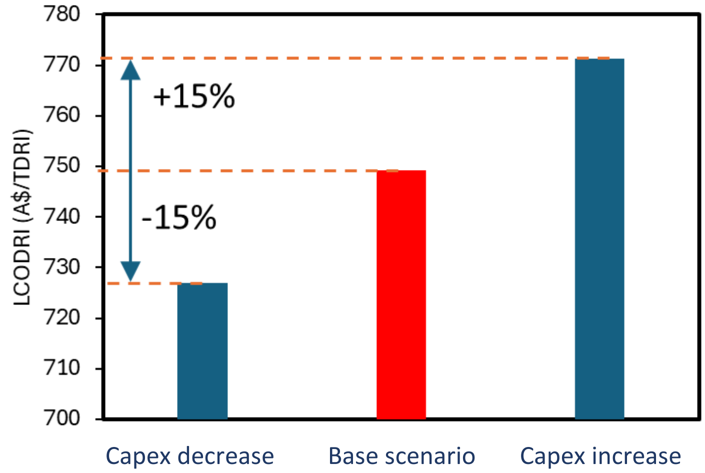

Figure 5-2 Impact of the electricity pricing on Levelised cost of DRI

The overall range of levelised cost of HBI sits between $632-$802 AUD/Tonne Fe ($411-$522 USD) taking the highest and lowest set of assumptions.

At a high level, the LCO-HBI sits at a level that is competitive with zero-carbon or carbon-adjusted iron products ($762-1295 AUD, $500-850 USD) and could potentially achieve costs near existing, non-hydrogen based DRI and HBI production ($617-900 AUD, $405-590 USD).

The major cost components of the production costs, accounting for two-thirds of the total cost are:

- Energy cost electrolyser - 21%
- Capital of ZESTY plant – 18%
- Capital of electrolyser – 14%
- Energy cost of ZESTY plant – 6%

Electrolyser CAPEX and electricity costs are the key factors influencing the effective hydrogen price of $5.5 - $6.2 per kg H_2. Cost of electricity is based on forecast spot market pricing for each of the different sites where available, with an average cost of $36-48 AUD/MWh plus transmission and connection costs.

For ZESTY technology to become even more economical for steel producers, the fundamental path is the reduction in hydrogen costs from current prices to the target of approximately $3 AUD (~$2USD) per kg.

In addition, Calix sees the following aspects as areas to further reduce the levelised cost of DRI:

- Reduction in CAPEX with economies of scale beyond the demonstration plant
- Upgrading of ore to higher grade within the process
- Increase in efficiency through utilisation of waste heat
- Reduction in electricity pricing by targeting low cost and renewable generation
- Reduction in shipping costs and carbon emissions through the onshore conversion of iron ore (H_2 reduction and briquetting/smelting) to a HBI or ingot respectively
- Sale or utilisation of Oxygen gas to downstream steel making processes

Further details of the techno-economics will be described in a separate public whitepaper that will be published at a later date.

6 FEED STUDY - HIGH LEVEL SUMMARY

This section provides a high-level summary of key outcomes of the FEED report. The detailed engineering is confidential and has been submitted to ARENA. The key outcomes include:

- High level layout of site
- High level process flow
- High level reactor layout
- Hydrogen source
- Sponge iron handling
- General integration including permitting and licensing considerations
- High level CAPEX
- High level OPEX

6.1 Analysis of the Size of the Demonstration Plant Required to Validate the ZESTY Technology

The ZESTY demonstration plant is sized to produce the equivalent of 30ktpa of hot briquetted iron or DRI fines and represents a key milestone on the ZESTY technology roadmap towards an industry wide solution for decarbonisation of iron and steel. The demonstration facility was sized based on the following considerations:

- The scale of the plant is consistent with other scale-ups of hydrogen-based DRI plants that are under development and will be built in the coming years.
- The demonstration plant will represent the full-scale implementation of a single reactor tube that forms the basis of Calix's modular scale-up approach
- The demonstration plant hydrogen requirements are in-line with current hydrogen generation projects coming online in appropriate time frames
- Capable of producing sufficient quantities of HBI or DRI to support product qualification and assess the compatibility of ZESTY HBI and DRI fines into downstream steelmaking processes
- Demonstrate the safe production and handling of DRI and HBI products

6.2 High Level Site Layout

The site layout was arranged in a compact manner to allow for easier plant integration to a wide array of potential locations.

The site layout includes the following features which are required for a standalone greenfield site:

- Main ZESTY tower
- Electrolyser and adjoining pipe bridge
- Undercover storage for incoming material, processed HBI and DRI fines
- Raw material storage bunkers
- Nitrogen generation and storage
- Hydrogen generation and storage (location of storage to be confirmed based on minimum separation distances)
- Containerised Reverse-Osmosis (RO) water treatment systems
- Containerised Power supply switch rooms
- Water tanks
- Cooling towers
- Site offices and labs
- Car parking
- Truck, Front-end loader, and forklift manoeuvring areas

Final site layout may be altered for the following reasons dependent on actual location:

- Locations of adjoining power supplies
- Location of adjoining hydrogen or water connections
- Location of adjoining roads
- Geotechnical data for location of main tower
- Irregular site footprint or terrain
- Coordination with other facilities on site (if brownfield or adjacent to existing facilities)

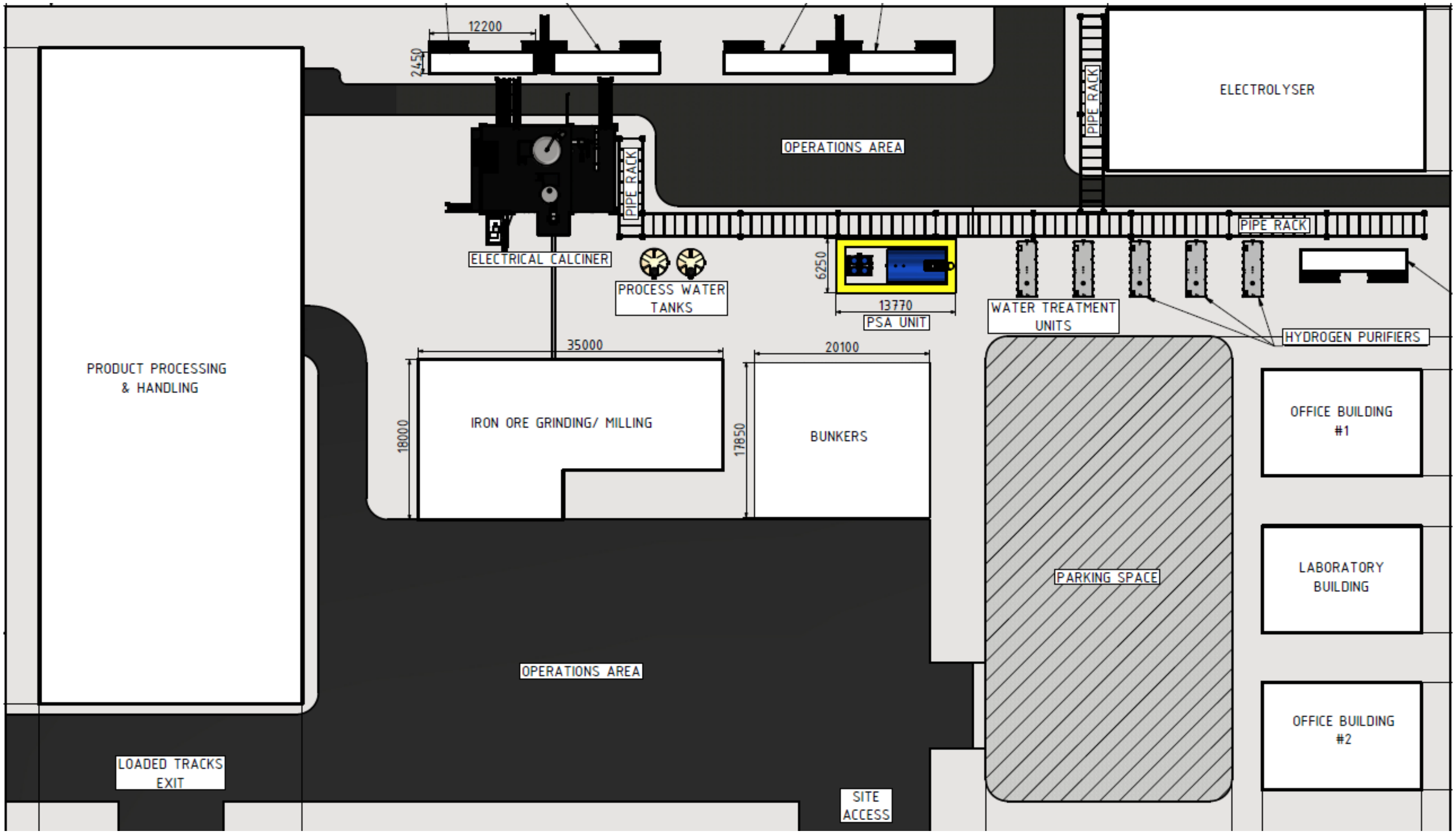

Figure 6-1 Aerial layout of proposed Full Site Integration Design noting the major usage of each area

6.3 High Level Process Flow Diagram

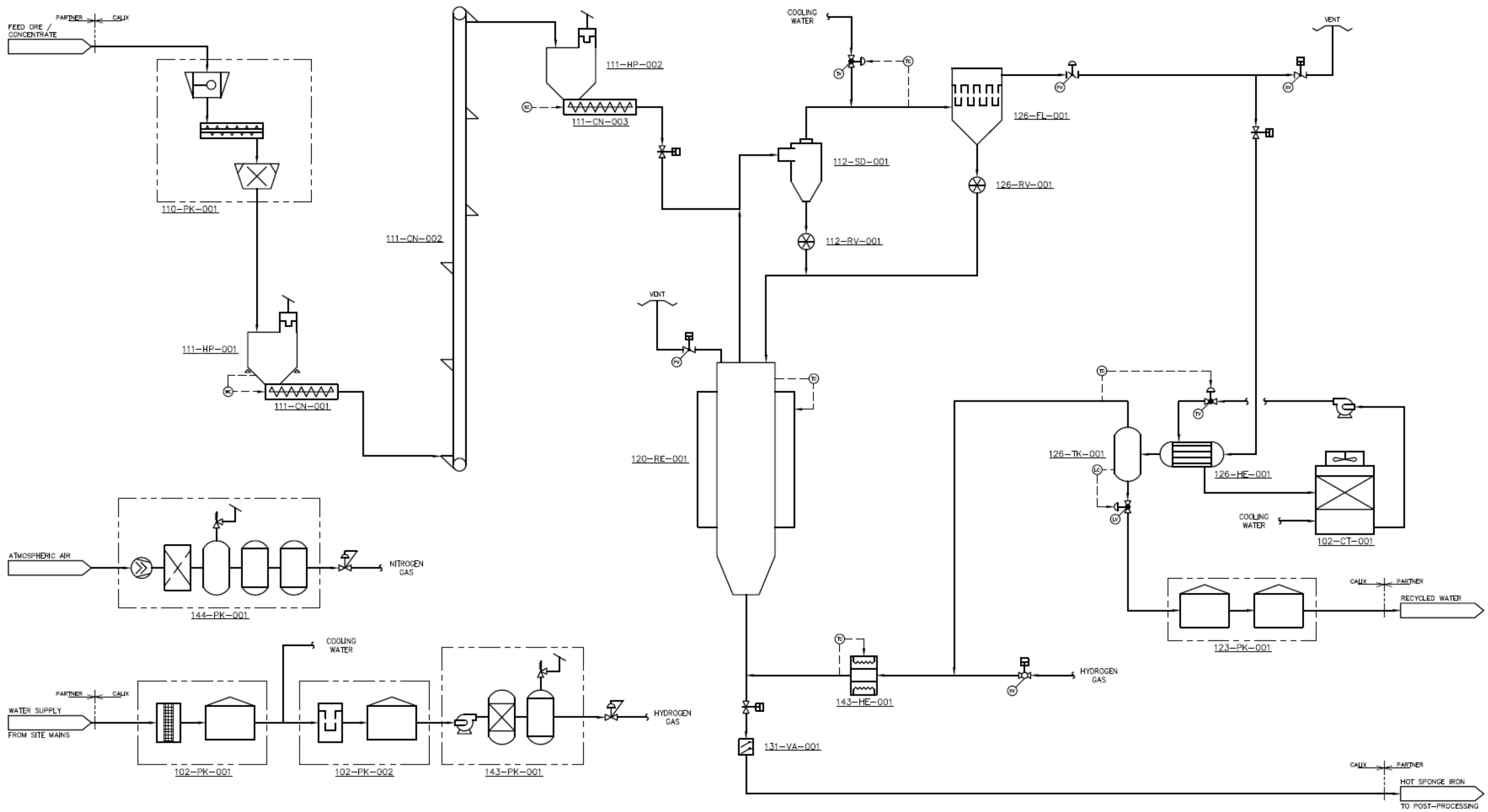

Figure 6-2 Simplified PFD

6.4 Final High Level Reactor Layout

The high-level reactor arrangement is comprised of the following key features (Figure 6-3):

1. Main reactor and furnace
2. Gas pre-heater
3. Preheat cyclone
4. Off gas bag filter
5. Gas cooler and condenser

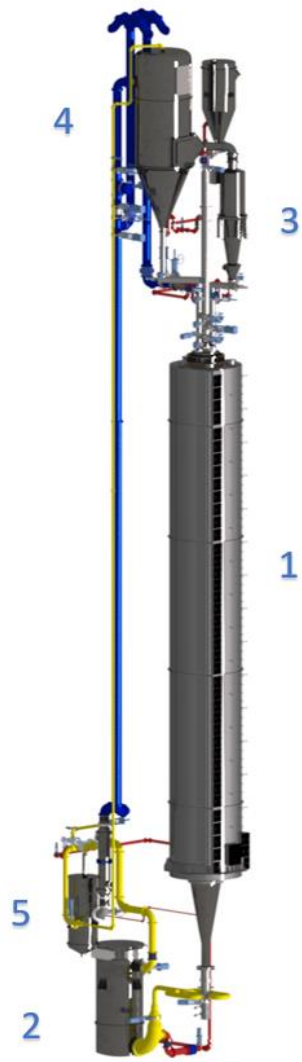

Figure 6-3 High Level Reactor Layout

6.5 Hydrogen Supply Source

Two hydrogen supply scenarios were considered as part of the ZESTY demonstration plant FEED study. Scenario 1 involved the sourcing of hydrogen over the fence - the preferred location for the ZESTY demonstration plant has access to over the fence hydrogen. Scenario 2 is a higher risk scenario that considers the generation of H_2 by an onsite electrolyser which would be procured as part of the project serving to de-risk the availability of hydrogen.

Scenario 2 involves the generation of green hydrogen by an alkaline-based electrolyser. The electrolyser is oversized relative to the steady-state demand of the ZESTY plant. A slip stream of hydrogen gas will be compressed to ~160 bar and stored to provide a process buffer, equivalent to the hydrogen required for 2 hours of continuous operation. The compressor was sized such that the 2-hour buffer will be recharged over a full day of operation.

Hydrogen gas is assumed to be supplied at a constant pressure via pipeline. Process H_2 consumption is controlled by a pressure valve on the hydrogen supply manifold. The hydrogen generation rate, compression and storage levels will be managed independently from the central ZESTY plant, but with coordination to accommodate fluctuations in either process.

In addition to the electrolyser, the system includes the following components with their corresponding functions:

H_2 / O_2 Separator and Washer:
Hydrogen and oxygen enter their respective separators, where they are cooled by water and separated from the gas-lye mixture through gravity. The hydrogen then passes into the washer to remove residual lye aerosol droplets entrained in the gas using demineralised (DM) water. The gas is further cooled by a coil-piped cooler within the washer before passing through a demister at the top of the washer to eliminate water droplets. The hydrogen is then dried and further purified via a PSA uni. The produced oxygen is expelled to atmosphere.

Lye Recycling System:
The alkaline solution, acting as an electrolyte, leaves the cell with the generated hydrogen and oxygen and moves to the gas-lye separators and into the collection pipes. After filtering out impurities, the solution is pumped back to the electrolyser.

Supplementary DM Water:
DM water is fed into both hydrogen and oxygen washers to replenish the system. Additionally, this system can deliver lye from the lye tank to the O_2 separator for refilling the lye solution if required.

Preparation of Lye:
The lye solution is prepared by adding solid caustic potash to the lye tank, which is two-thirds filled with DM water which is agitated by the lye pump to dissolve the caustic potash.

Normal Cooling Water System:

This system cools (i) the silicon controller rectifier (SCR) element in the rectifier, (ii) the lye in H_2/O_2 separators (controlling the electrolyser's operating temperature between 80 - 90°C), and (iii) the hydrogen and oxygen in both washers to maintain temperatures < 40°C at the outlet of the H_2 washer.

Feed and cooling water treatment for the electrolyser will be either:

- Sourced from a common cooling loop and reverse osmosis (RO) filtration system.
- Using a dedicated cooling loop and RO system.

Gas Analysis System:

Moisture levels in the electrolyser H_2 product are monitored via a humidity meter measuring dew point prior to introduction into the storage tank. The signal is sent to a programmable logic controller for display and monitoring. The control program determines whether the product H_2 and O_2 can be sent to their respective storage systems based on preset parameters.

The current plant design features a common supply for water filtration which will be re-evaluated during the detailed design phase.

6.6 Sponge Iron Handling / Post-Processing System (HBI Plant)

The demonstration plant will have the ability to handle sponge iron in one of two formats:

- Diversion of hot DRI fines directly to a HBI roller press to produce briquetted iron.
- The demonstration plant will also have the capability to bypass the HBI roller press allowing the production of small batches of DRI fines for testing in alternative downstream processing routes such as direct (s)melting and cold briquetting.
    - The gas-preheat and therefore product outlet temperature would need to be lowered at the expense of performance.
    - Production of DRI fines would be minimised to only what is needed for analysis and downstream process qualification purposes due to handling constraints and process safety considerations.

The DRI exiting the reactor will pass through a double flap valve and into a buffer bin. A vertical screw feeder controls the conveyance of the hot DRI fines from the buffer bin to the HBI press. The briquetting machine consists of two counter-rotating rollers one fixed, one floating enclosed within a housing as a safety measure to minimise dust emissions. Interchangeable press rings containing the HBI moulds are mounted to the rollers to control the dimensions of the briquettes. A hydraulic pressurising system is used to control the compressive force applied during briquetting. The fine DRI material is fed between the two rotating rollers and the speed of the roller press controls the rate of briquetting.

The individual briquettes are discharged onto a cooling conveyer. The cooling conveyor is made of steel mesh with welded edge plates such that it can withstand high temperatures >900 deg C. The speed of the cooling conveyor can be controlled in line with the output rate from the upstream briquetting machine. A high flow of air (motivated by cooling fans) is blown over the conveyor to accelerate the cooling of the HBI product.

Figure 6-4 below shows and example of the Köppern roller press. The press is set to apply a pressure of between 150 – 200 MPa to achieve the target HBI density of 5000 kg/m^3. Best results will be achieved by maintaining the inlet temperature at around 750°C or greater, which will be managed by varying the temperature of the preheated hydrogen.

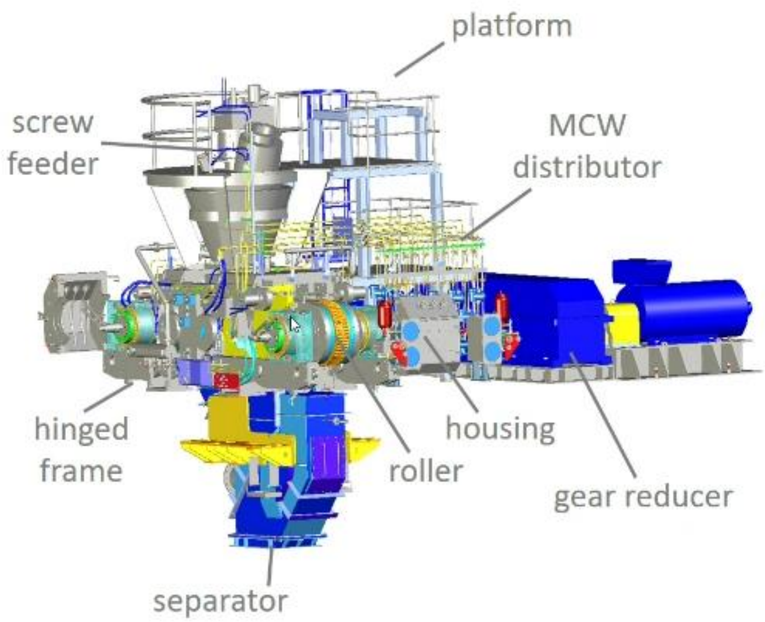

Figure 6-4 HBI Roller Press (Köppern)

6.7 General Integration

6.7.1 Permitting

Taking NSW legislation as an exemplary reference point, the NSW State Environmental Planning Policy (State and Regional Development) 2011 (SEPP) sets out the criteria for state significant development, state significant infrastructure, and regionally significant development projects. Several potential trigger points would lead to the project being considered a State Significant Development, namely a total CAPEX above $30 million. These thresholds will result in the requirement to prepare an Environmental Impact Statement (EIS) as part of the permitting process. Due to the demonstration nature of the plant, a staged permitting process will be investigated upon final site confirmation. An outline of the permitting process, responsibilities and indicative timings is presented in Table 6-1.

Table 6-1 Example timeframes required for permitting

Description	Party	Timeframe
1. Preparation and lodgement of request for Secretary's Environmental Assessment Requirements (SEAR's)	Calix	4 weeks
2. Community / Stakeholder Consultation	Calix	Typically 4 – 6 weeks
3. Preparation of Staged / Concept Development Application & Environmental Impact Statement (EIS)	Calix	4 weeks
4. Preliminary Review	The Department of Planning and Environment	3 weeks
5. Lodgement	Calix	N/A
6. Public Exhibition and Submissions	The Department of Planning and Environment	Typically 10 weeks
7. Response to Submissions		Within assessment period but not part of statutory requirements.
8a. Assessment (Department of Planning & Environment)	The Department of Planning and Environment	Typically 42 weeks
8b. Assessment (Referral to the NSW Independent Planning Commission)	NSW IPC	Typically 12 weeks
9. Determination	The Minister for Planning	2 weeks

6.7.2 Licencing

An Environmental Protection Licence (EPL) will likely be needed albeit the requirement is location dependent. Using the NSW *Protection of the Environment Operations Act* as a reference, the following criteria would mandate the submission of an EPL application:

- Production or use of 1000 tonnes of hazardous materials
- Milling and grinding of 30,000 tonnes

The following data will need to be provided as part of the EPL application process:

- The activity – general information
- Discharge of pollutants to air
- Discharge of pollutants to water
- Discharge of pollutants to land
- Proximity to dwellings and roads
- Generation, treatment, processing, reprocessing, storage, and disposal of waste
- Environmental outcomes
- Site contamination
- Locality and site plan
- Auditing compliance

6.7.3 Construction Process

6.7.3.1 Calciner Installation – Conceptual Methodology

This section presents a conceptual summary of the key actions required, to deliver a successful ZESTY demonstration plant as estimated based on FEED level information

6.7.3.2 Furnace Installation

The outer casing of the furnace is supported from a base ring girder situated 18m above ground. The actively heated length of the furnace will be 30m.

Appropriate space will be identified and allocated to provide a laydown area for construction materials and crane areas with suitable ground preparation for the construction phase of the project.

This study assumes that the individual segments will be dressed at site prior to assembly or installation into the structural tower. The furnace installation process will involve the following high-level activities:

- Installation of refractory module support
- Installation of backing refractory
- Installation of refractory modules
- Assembly of elements to heating modules
- Passage of element terminals through casing shell to electrical cabinet zone
- Passage of cables through exterior cabinet wall and installation of glands
- Attachment of cable to integral cable tray
- Local wiring of all elements and termination at a single junction box
- Installation and wiring to a single point of all element thermocouples.

6.7.3.3 Reactor Tube Installation

This FEED study considers two approaches for reactor tube installation:

(i) Delivered to site as a single complete tube to be lifted into position on the tower (the preferred approach) or;

(ii) Supplied as sections to be welded at ground level prior to installation.

The feasibility of the preferred option and delivery of a prefabricated reactor tube to site will depend on road access, available transport envelope, and local regulations. A final decision on the installation strategy will be taken on confirmation of the final site location and the outcomes of a review comparing site-specific access envelope and transport costs (to account for escort or custom dolly / bogie requirements in addition to other transport and logistical considerations) relative to on-site welding costs. The outcomes of the transport evaluation may also influence selection, which will therefore be completed early in the detailed design phase.

6.7.3.4 Transportable Calciner Switch room

The transportable switch rooms will be fabricated off-site using standard 40ft shipping containers to house all electrical switchgear for ease of installation. Each container houses controllers and thyristors for the heating zones along with switchboards to support the furnace, motors, and other electrical equipment. The transportable switch rooms will be fully constructed and Factory Acceptance Tested (FAT) off-site and transported to site as complete units.

Transformers and associated equipment will be installed on dedicated concrete pads as close as practically possible to the switch rooms to help reduce transmission losses and low voltage electrical cable installation costs.

6.7.3.5 Structural Steel Erection

The main structural tower is estimated at 260 tonnes for structural members, handrails, and joint platework. The assembly philosophy is nominally based on lifting the sections in pre-dressed modules. A 70-tonne crane would be used for most of the structural build which would need to be exchanged for a 120 or 140 tonne crane to support construction of the higher levels of the tower.

The structural steel design will need to be further developed in the detailed design phase of the project to ensure specific mechanical equipment installation requirements have been considered and can be accommodated.

6.8 High Level +/- 25% CAPEX Outline

An outline of the elements used in calculating the CAPEX of the project is given below. Actual total CAPEX and the preferred site for the ZESTY HBI Demonstration facility remains commercial in confidence while final commercial and financing contracts are negotiated leading to a final investment decision (FID) targeting 2024.

6.8.1 Scenario 1: Excluding Cost of Hydrogen Generation

Demonstration Plant Supply	Proportion
Process Package	5%
Raw Material Processing & Feed Transport	5%
Hydrogen Gas Conveying & Nitrogen Gas Generation	5%
Off-Gas Treatment, Cooling & Water Treatment	8%
Product Briquetting & Cooling	11%
Structural Steel Package	7%
Electrical, Instrumentation & Control	12%
Construction, Installation & Bulks	**Proportion**
Civil, Electrical, Mechanical & Piping	30%
Storage & Buildings Package	3%
Engineering Services	14%

Table 6-2 CAPEX Scenario 1

6.8.2 Scenario 2: Including Cost of Hydrogen Generation

Demonstration Plant Supply	Proportion
Process Package	4%
Raw Material Processing & Feed Transport	3%
Hydrogen & Nitrogen Gas Generation, Conveying	31%
Off-Gas Treatment, Cooling & Water Treatment	5%
Product Briquetting & Cooling	7%
Structural Steel Package	5%
Electrical, Instrumentation & Control	9%
Construction, Installation & Bulks	**Proportion**
Civil, Electrical, Mechanical & Piping	23%
Storage & Buildings Package	3%
Engineering Services	10%

Table 6-3 CAPEX Scenario 2

6.9 High Level OPEX Outline

The following Table 6-4 and Table 6-5 summarise the predicted operational costs of the plant.

Table 6-4 OPEX Costs from Fixed Costs

Fixed Costs	$ / year (AUD)	$ / tonne DRI (AUD)
Cooling Tower Dosing	$ 18,000	$ 0.6
Cooling Tower Cleaning	$ 6,600	$ 0.2
Mobile Plant Service	$ 10,000	$ 0.3
Mobile Plant Lease Cost	$ 198,000	$ 6.6
Site Rent	$ 300,000	$ 10.0
Staff (24/7 Operations)	$ 3,240,000	$ 108.0
Total	**$ 3,772,600**	**$ 125.8**

Table 6-5 OPEX Costs from Variable Costs

Variable Costs	$ / hr (AUD)	$ / tonne DRI (AUD)
Hydrogen	$ 1,342	$ 335.5
Electricity	$ 179	$ 44.8
Repairs and Maintenance	$ 387	$ 96.6
Consumables	$ 54	$ 13.5
FEL Operators and Labour Hire	$ 135	$ 33.8
Total	**$ 2,097**	**$ 524.1**

Commissioning and roll out of the ZESTY demonstration plant will be staged to ensure a safe ramp up to full operations. The operations plan will evolve as operational hurdles, availability of feed ores, and product offtake schedules clarify over the project lifetime. An early outline of the operations plan is shown in Figure 6-5 below and will continue to be iterated over the course of the detailed design and EPC stages of the project.

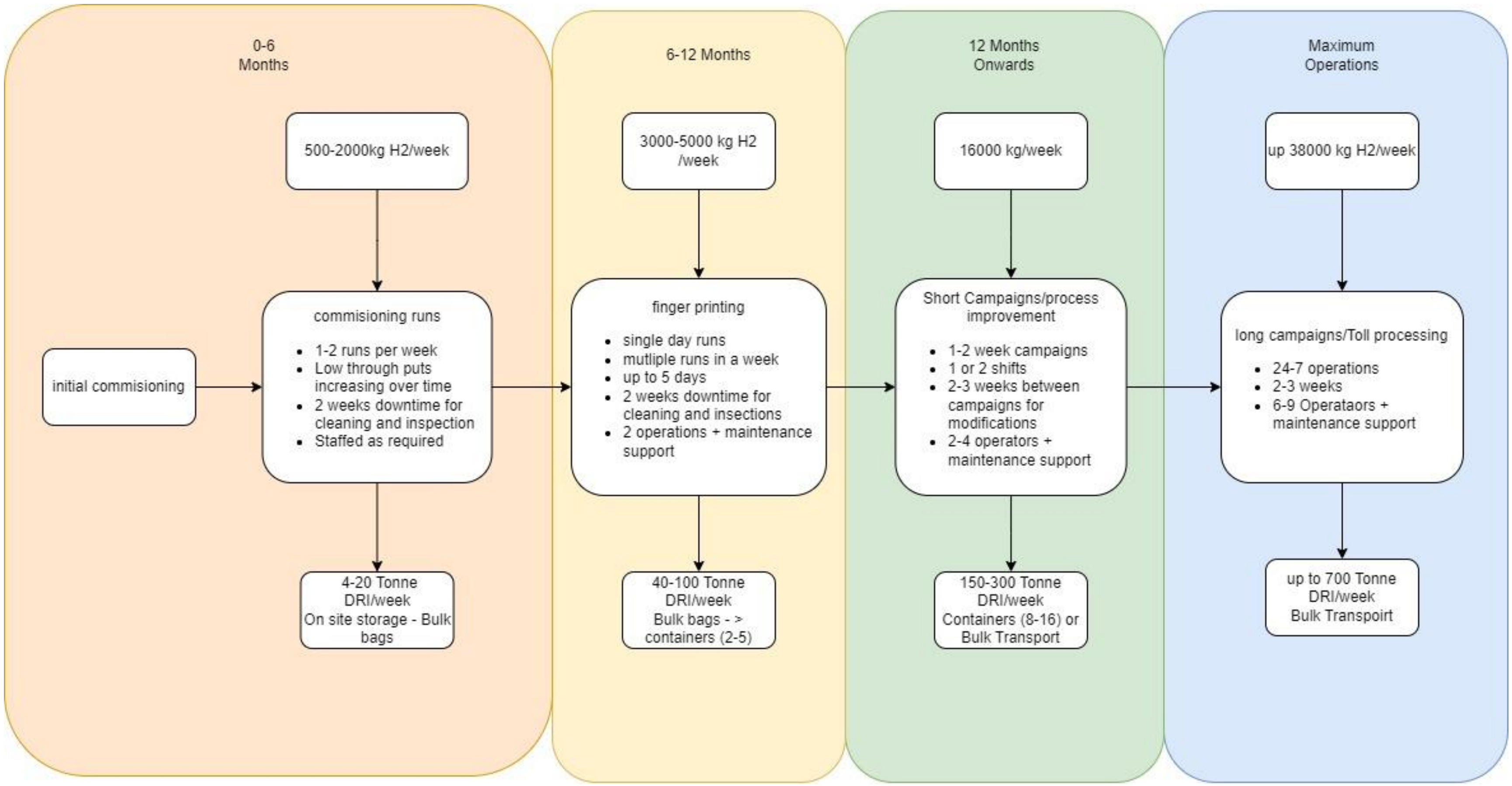

Figure 6-5 Demonstration Plant Staged Rollout Plan

6.10 Identification of Key Partners Required to Deliver the Demonstration Plant

Calix has identified a preferred plant location but is continuing to consider five potential plant locations for the purpose of this FEED until commercial agreements have been executed (currently under negotiation). The FEED has been completed on the basis that any one of these locations might be the final chosen site and requirements for all sites have been considered as part of the FEED study.

- Funding Partners

Calix is a listed company with a strong balance sheet with access to several mechanisms for funding the demonstration plant. Funding options being considered include government grant support, co-investment opportunities as well as several other financing mechanisms. A program of work is underway to secure financing by mid-2024.

- Ore supply partners

Calix's ZESTY technology has attracted interest from a large number of Australian and global ore suppliers through a business development outreach and testing program leveraging funding and activities supported through the ARENA funded FEED study and HILT CRC supported pilot plant ore testing programs.

The demonstration plant has been designed to maximise flexible operation such that it is able to accept a wide range of ore types from multiple Australian and global industry participants to support and accelerate the de-risking, demonstration and commercial uptake of the ZESTY process for decarbonising iron and steelmaking at a commercially relevant scale. Calix's approach is to develop an industry wide solution working with multiple upstream and downstream industry partners.

- Offtake partners

Whilst not mandatory for the demonstration plant to operate, offtake agreements for the HBI product are being explored. The demonstration plant is intended to provide an industry wide solution, so a toll processing approach will be used to maintain a non-exclusive operation. Pre-arranged offtake or processing agreements would significantly derisk the project on a cost, logistical and safety basis, removing the need to store and dispose of the product. Samples of the HBI product will be made available to downstream steelmakers for product qualification purposes. Alternatively, the end HBI product could be returned to the ore provider for their own further use.

- Green Hydrogen Supplier

Calix's preferred option is to enter into a green hydrogen supply agreement with a suitable supplier to reduce the cost, complexity and ultimately the risk profile of the project. The availability of and access to green hydrogen, ideally through on-site facilities, was a key criterion for selection and ranking of preferred site locations. Similar consideration is given to the availability of and access to renewable electricity. The FEED study also considers the procurement of an electrolyser to generate the hydrogen required for the project as a contingency measure in case access to over the fence H_2 is not possible or viable.

7 KEY RISKS AND MITIGATIONS

The following table summarises the identified future key risks for the project:

Table 7-1 Key Risks and Mitigations

Key Risk	Mitigation
Unable to appropriately address safety concerns in design, commissioning and operations phases of the project	Have hired expert external consultants to take part in HAZOP and creating safe work procedures. Additional safety reviews (HAZOP, ENVID, SIL, LOPA) will be undertaken continuously through detailed design to ensure safe design. Designs and operating practices will be in line with appropriate standards with a paramount focus on safety at every stage of the project.
Inability to access / secure an appropriate site	The study proactively considers multiple sites, ensuring a comprehensive evaluation.
Inability to source Iron Ore	To mitigate this risk, the strategy involves liaising and building relationships with multiple iron suppliers globally, including processing a range of ores.
Emergence of alternate disruptive technologies	Targeting early market entry, accelerating development, and staying vigilant to adapt to emerging technologies.
Pilot plant work does not accurately represent scale-up and continuous operation	Extensive test work already conducted and scale-up programs Calix has demonstrated on its core technology in other applications.
Green Hydrogen prices do not fall to economic levels	Continuous evaluation of the economic landscape to respond effectively to fluctuations in green hydrogen prices. This risk is relevant to all hydrogen-based reduction technologies.
Inability to raise capital for the demonstration plant	Progress towards funding pathways underway, diversifying funding sources, and adjusting the funding strategy based on market dynamics are crucial steps.

8 SCALE-UP & COMMERCIALISATION PATHWAYS

The demonstration plant will represent the first full-scale implementation of a single-tube ZESTY reactor that forms the basis of Calix's modular scale-up approach. Larger-scale, multi-tube modules are under development as part of the commercialisation and scale-up programs for several other product lines based on Calix's platform technology, most notably LEILAC who will demonstrate a 4-tube module in Europe as part of the LEILAC 2 project. Calix will draw on this experience to de-risk and accelerate the scale-up and commercialisation of its ZESTY technology and will explore opportunities, both for full-scale commercial deployment and smaller niche applications to facilitate the commercial rollout of the ZESTY technology at various scales including single and multitube modules in the near- to mid- term. The modular nature of the ZESTY technology means that additional modules can be added in parallel to support increased production in conjunction with the increasing availability of green hydrogen as the technology is scaled towards a multi-module design for deployment at the several megaton production scale consistent with existing steelmaking operations. Economies of scale will be achieved with common infrastructure for utilities and services.

Potential commercial opportunities for deployment of the ZESTY technology at various scales include:

(i) Small scale and niche applications such as the processing of steel mill waste streams or the production of virgin ore-based metal to supplement iron and steel scrap in EAF steelmaking

(ii) Technology offering to complement/reduce the carbon intensity of existing blast furnaces, traditional DRI shaft furnace operations for processing ultra fine ore feeds and waste streams minimising the pelletisation and sintering requirement

(iii) Australian (on-shore) processing of iron ore to a green HBI for global export, to support decarbonisation of existing steelmaking operations, both BF-BOF and EAF, through partial or full feedstock substitution. ZESTY HBI plants could be located at sites with access to low cost renewable energy and hydrogen as well as appropriate transport infrastructure/port access;

(iv) On-site integration with steelmakers;

The demonstration plant will validate onshore processing of iron into a green HBI product for qualification and testing purposes, and worldwide distribution. The ZESTY demonstration plant's toll processing functionality will support the testing and qualification of the technology with a wide range of iron ores sourced in Australia and globally supporting the ongoing scale-up, de-risking and commercialisation of the technology. The demonstration plant will enable commercial partners interested in licencing the ZESTY technology to test their ores and the green DRI products to assess compatibility and support integration of the technology into existing and developing supply chains. The data collected will be used to inform the optimisation of a scaled ZESTY DRI plant design to meet the requirements of the prospective customer. The demonstration plant will further serve as a test bed for the ongoing development of the ZESTY technology providing a facility to test alternative upstream and downstream processing steps e.g. alternative pre-treatment, beneficiation, carburisation and (s)melting methods.

9 CONCLUSIONS AND NEXT STEPS

9.1 Pathway for Hydrogen-based DRI Processing of Australian Iron Ore

ZESTY is an efficient, electrically heated hydrogen direct reduction technology for the processing of iron ore fines and ultra-fines to a decarbonised metallic iron product. This report provides a summary of the non-confidential key outcomes from the Front-End Engineering Design (FEED) study for a 30,000 tpa equivalent ZESTY demonstration plant for producing decarbonised HBI and DRI fines that was undertaken with funding support from the Australian renewable Energy Agency (ARENA). The demonstration plant will represent the first full-scale implementation of a single-tube ZESTY reactor that forms the basis of Calix's modular scale-up approach.

The FEED study defines the scope of work and preliminary design for the ZESTY demonstration plant to enable the project to proceed on a de-risked and costed basis, through development of capital and operating cost estimates (+/-25%). The FEED study includes details of the general plant and site layout considerations, process design, major equipment sizing and high-level construction methodologies.

Five potential sites (one preferred) are being considered for the location of the demonstration project and as such, a generic design and cost-estimate was developed through the FEED study to satisfy site specific requirements across all identified potential sites. The demonstration facility will be capable of receiving unprocessed ore from multiple suppliers and producing decarbonised HBI and DRI fines as the products. The demonstration plant will serve to validate onshore processing of iron into a green HBI product for qualification and testing purposes, and worldwide distribution. The ZESTY demonstration plant's toll processing functionality will support the testing and qualification of the technology with a wide range of iron ores sourced in Australia and globally supporting the ongoing scale-up, de-risking and commercialisation of the technology.

The FEED study and cost estimations consider two scenarios for the supply of hydrogen; the preferred over the fence option and a scenario that includes procurement of an electrolyser to produce the green hydrogen needed where over the fence hydrogen is either unavailable or unviable. CAPEX for the ZESTY demonstration plant was estimated for a standalone demonstration plant, fully installed on a greenfield site with the lower bound estimate assuming over the fence supply of hydrogen with the upper bound including the procurement of an electrolyser for self-generation of green hydrogen. Actual total CAPEX and the preferred site for the ZESTY HBI Demonstration facility remains commercial in confidence while final commercial and financing contracts are negotiated leading to a final investment decision (FID) targeting 2024. A technoeconomic analysis concluded that the ZESTY demonstration plant could produce a decarbonised HBI product at a levelised cost of ~AUD$630-$800 / tonne iron which is close to the range of existing conventional HBI processing costs. This value includes the capital cost of the plant and the processing cost. It does not include the cost of land or the cost of transport of the input and output materials. ZESTY is therefore a potential economic proposition to produce HBI before the cost of carbon is taken into account, even at small scale.

9.2 Next Steps

The key next steps to move the project forward into the demonstration phase are:

- Securing an appropriate site with access to the required power utilities
- Access to over the fence green hydrogen
- Continuous development of pilot testing and process flow to further optimise the plant design
- Securing the required funding to facilitate a final investment decision
- Progress project to detailed design and execution phase

In addition, the following aspects are being developed in parallel to progress the ZESTY technology:

- Further development of downstream processing including test work on the application of ZESTY DRI and HBI in melters, EAFs, BOFs and substitution into blast furnaces.
- Parallel work streams to develop magnetite processing opportunities
- Ongoing engagement with local and international steel producers to coordinate qualification and testing of ZESTY DRI and HBI products
- Ongoing engagement with local and international ore providers to coordinate material testing of various ores
- Scaling of the modular design for full scale commercial applications of the ZESTY technology and enable like for like evaluation of incumbent technologies

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