ENERGY INTERNET CORPORATION

Scalable Platform for New Zero Carbon Economy

Low-cost green Ammonia

Dated 11/14/22

Table of Contents

1. Executive Summary

EIC helps energy providers and consumers accelerate their decarbonization by enabling:

- **Economics**: Green ammonia & Hydrogen at cost parity[1] for greenfield consumers;
- **Technology**: Easy operation & maintenance, and low costs, across wide scales (1 to thousands of Metric Tons per Day[2]); and
- **Platform**: Smooth market expansion with cost-effective green ammonia applications - such as green steel, cement, chemicals/fertilizer and fuels.

Aspirants to global leadership can shape their market and lock in their early mover advantages, with EIC technology and system.

While renewable power is becoming increasingly cheaper, the current cost of its conversion to Hydrogen or Ammonia makes them over 3X as expensive as current carbon-pathways. Many end-users, such as farms, must also pay a premium for timely availability of product, and for their remoteness and small-scale requirement. There are technical challenges also – such as, safe and inexpensive compression of Hydrogen, and synthesis of Ammonia using just electrical power, ambient air, and water, at-scale-. In addition, green steel, cement, fertilizer/chemical, and fuels industries, would need to develop and test their carbon-pathway substitutes.

EIC's Zero Carbon Energy System (ZCES) achieves cost-parity[(1)], while enabling reliable, scalable, modular, and simpler design with fewer moving parts. This is accomplished, by:

- Using Long Duration Energy Storage (LDES) to store the surplus renewable power, and deliver firm power or energy for weeks, even when the sun does not shine, or wind does not blow. LDES is in the form of compressed air and ammonia.
- Employing only commercially available engineering components (such as, pump-turbines) and processes (e.g., Haber Bosch or HB, for Ammonia synthesis).
- Eliminating 75%+ equipment and costs for Hydrogen compression and the HB process; and operating the entire HB process at higher capacity factors[3] and energy efficiencies.

---

[1] Cost parity, as used in this white paper, is parity as compared with grey H2 or Ammonia for a given consumer.

[2] MTPD – Metric Ton(nes) per Day. This whitepaper uses MTPD as the measure of a plant size and Gigajoules (GJ) to measure the chemical energy for MT scale of H2 or Ammonia

[3] Capacity Factor, CF, is the ratio of average output of a system to its rated output. A HB process operating only on renewable power will operate at best at the CF of the renewable power plant (20-40%). With EIC's ZCES it operates near 24X7, and thus requires a fraction of the entire Haber Bosch process (from Hydrogen and Air compression, N2 separation, HB reactor, etc.).

2. Considerations in adopting Green Ammonia (GA[4])

2.1. Switching costs

Choosing a Green Ammonia Plant (GAP) design for purely economic reasons over a grey Ammonia process must address three challenges (further described in Table 1):

1. Reach cost parity with grey ammonia (or Hydrogen), across wide scales of operation.
2. Achieve operations across a wide scale, including ease of maintenance across these scales. Today's systems operate at larger scales - higher than 100 MTPD. GAP must satisfy applications at smaller scales of 1 MTPD, to optimize the logistics of local supply-demand, including the local availability renewable power sources.
3. Provide strong economic justification for downstream users (of Green Ammonia) to switch from, or choose over, a carbon-based solution, such as, for decarbonized power, data center, chemicals/fertilizer, and metallurgical industry.

2.2. Reaching cost parity

Traditional Carbon-paths to NH3 employ the chemical energy of its feedstock – Coal, Methane, etc. Unlike GAP, they do not need solar/wind generators for the energy. GAP on the other hand, must produce all the energy, to power the entire production chain –converting Water & Air to NH3. The challenges to cost parity, and EIC's GAP solution is described below in Table 1.

Table 1: Green Ammonia Challenges and Problems

#	Challenge	EIC GAP Solution
a	Green energy sources are intermittent and seasonally available (such as, solar and wind, and on smaller scales, biogas). Thus, a given amount of ammonia production requires i. 20-40% CF, resulting in 300%+ of ammonia plant capacity, across the entire GAP production chain.	EIC's versatile platforms perform multiple functions of energy and gas storage, and energy recovery, enabling: Elimination of 75%+ of equipment in the GAP chain. Also ZCES's high pressure, H2 storage is 75% less expensive, safer and scalable. This enables 95%+ CF of GAP.
	ii. the use of higher cost PEM Electrolyzers to operate with intermittent power availability.	Mitigating the impact of power intermittency to operate lower cost alkaline electrolyzers

[4] EIC's GAP system delivers both Green Hydrogen and Ammonia. EIC Plant compresses and stores the Green Hydrogen produced by an Electrolyzer. Hydrogen storage is expensive. EIC Plant uses it primarily as capacitance for the HB process. Third party solutions may effectively leverage the plant's stored Hydrogen for a 24X7 liquefaction process. EIC's Plant delivers lower cost Green Hydrogen at any scale through its commercially available pathways- transportation to site and cracking at site of liquid green Ammonia-.

b	Today's Green Ammonia Cycles are inefficient. As Figure 1 shows Ammonia's internal energy content of 18.6 GigaJoules (GJ or 5.2 MWH)/MT, reflects over 50% energy loss, with today's green ammonia processes. They consume 36% more energy in comparison to the best achievable of 24GJ/MT. In other words, 36% more solar plant and gas management systems is needed for a given ammonia output.	EIC systems are highly efficient, with systems of energy recovery at each stage in the process. The increased efficiencies, lower the solar/wind footprint for a given Ammonia output by 30-40%, and reduce the power ratings of systems of compression, and expansion.
c	Expensive energy recovery: Unlike traditional Ammonia processes (see Figure 1), where steam turbines already employed for power generation from tail gases, harvest the heat of the exothermic reactor (~ 2.7 GJ/MT, 15% of stored energy in NH3), a green ammonia route incurs either the expense of steam turbines to harvest reactor heat, or 15% more solar plant.	EIC's versatile platform harvests the heat of the exothermic reaction and recycles energy from produced in the high-pressure cycles, as electrical power, without the expense of a steam turbine or a pressure exchanger. This provides the baseline power to operate an Alkaline Electrolyzer.

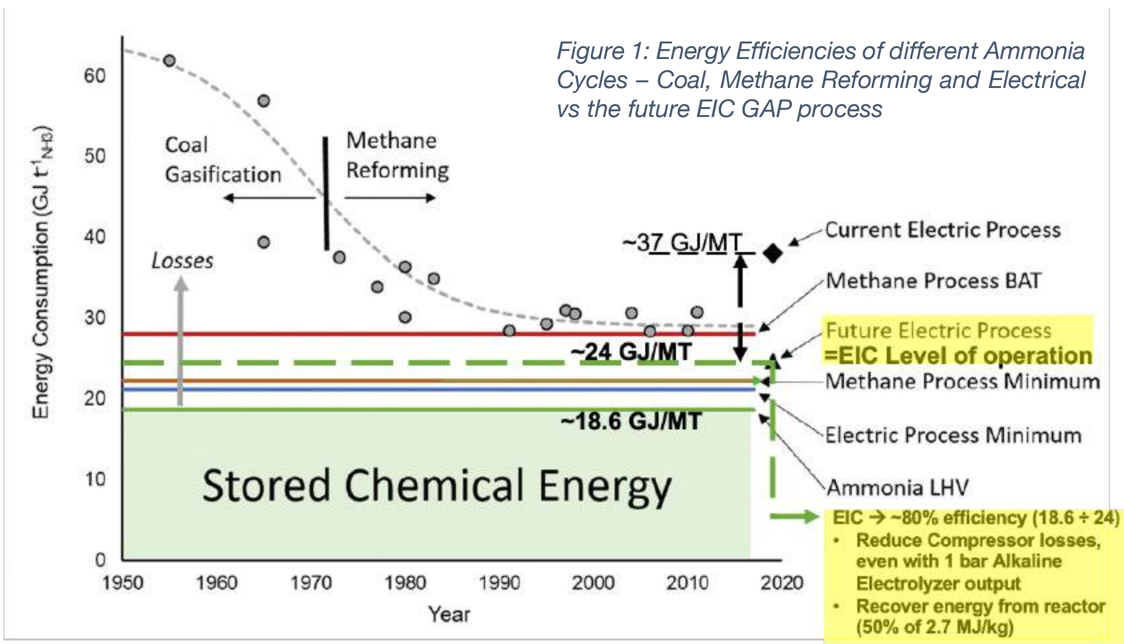


Figure 1: Energy Efficiencies of different Ammonia Cycles – Coal, Methane Reforming and Electrical vs the future EIC GAP process

2.3. Safe, small & large-scale plants, easy operation & low maintenance

Table 2: Scalable and modular plants

#	Challenge	EIC GAP Solution
a	Traditional Carbon path Ammonia processes operate only at larger	EIC GAP Solution is modular and scales up and down, across a wide range.

	scales. Smaller scale plants are not available or are too expensive. Thus NH3 is expensive for smaller scale use -such as at a farm (for fertilizer) or data center (for energy storage and cooling). On the other end of the scale, larger scale GAPs for end-use applications such as power, metallurgical and chemical plants, are 3X+ more expensive than current carbon-path solutions.	Green ammonia achieves cost parity more easily with grey ammonia at lower scales of operation. At larger scales, many end-use applications achieve overall cost-parity, considering the economic and capability advantages a functionally versatile ZCES plant can provide the customer. As the industry matures, the reduction in the costs of renewable power and ZCES plants can be expected to provide a clear cost parity across the entire breadth of end-use applications.
b	H2 needs to be stored in large quantities to ensure continuous feed to the HB process. Traditional H2 compression has extensive safety provisions to guard against the risks of spontaneous combustion/explosion from leaks and plant integrity from the risks of insidious embrittlement.	ZCES' anaerobic compression, and smooth gas flow (laminar) at near-ambient temperatures makes the process safer and minimizes the risks of embrittlement.

2.4. Downstream user : Ease of switching to Green Ammonia from a Carbon path

Table 3: Ease of switching

Challenge	EIC GAP Solution
Potential new applications of Green Ammonia, in decarbonizing end-user industry, incurs substantial switching costs. This inhibits adoption. For instance:	ZCES's addresses this challenge at two levels: making cheaper green Ammonia & Hydrogen and power, and providing customer side cost reductions and easier integration, by use of ZCES' versatile platform.
i. A steel producer using Coke to provide the heat for melting the ore and reducing it to iron, will have to retrofit the process to accommodate H2	ZCES provides low cost green Ammonia, that can be used both as a reliable feedstock (Hydrogen being used to melt ore and reducing iron) and a power source. The control and system interfaces easily integrate with customer's process.
ii. Fertilizer industry currently using grey Ammonia	ZCES's provides both a low-cost the feedstock of green Ammonia and CO2 (from direct capture and liquefaction from flue gases in thermal power or cement plants) and green power. Customer

iii. H2 for transportation in Trucks, Ships and vehicles	processes can be integrated efficiently with ZCES. Cheaper and safer Liquid NH3 fuel tanks on board to serve H2 through a cracker, for its fuel cells; as well as lower-cost green NH3 generation and dispensation stations.

2.5. Measuring cost parity

(EIC GAP) Customers will measure cost parity in terms of final cost of their product at their end-user's doorstep. Figure 2 shows a generic factor-based model to assess an end-user's cost parity. P1 though P5 are different levels of parity attainment dependent on the process stage shown across the bottom of the graphic represented as 1A though 5 or 1B though 5. The end-user consumer (for ammonia/hydrogen) will measure cost parity in terms of their total cost of product. The end-user will first compare input factor costs of Green H2/Ammonia for their

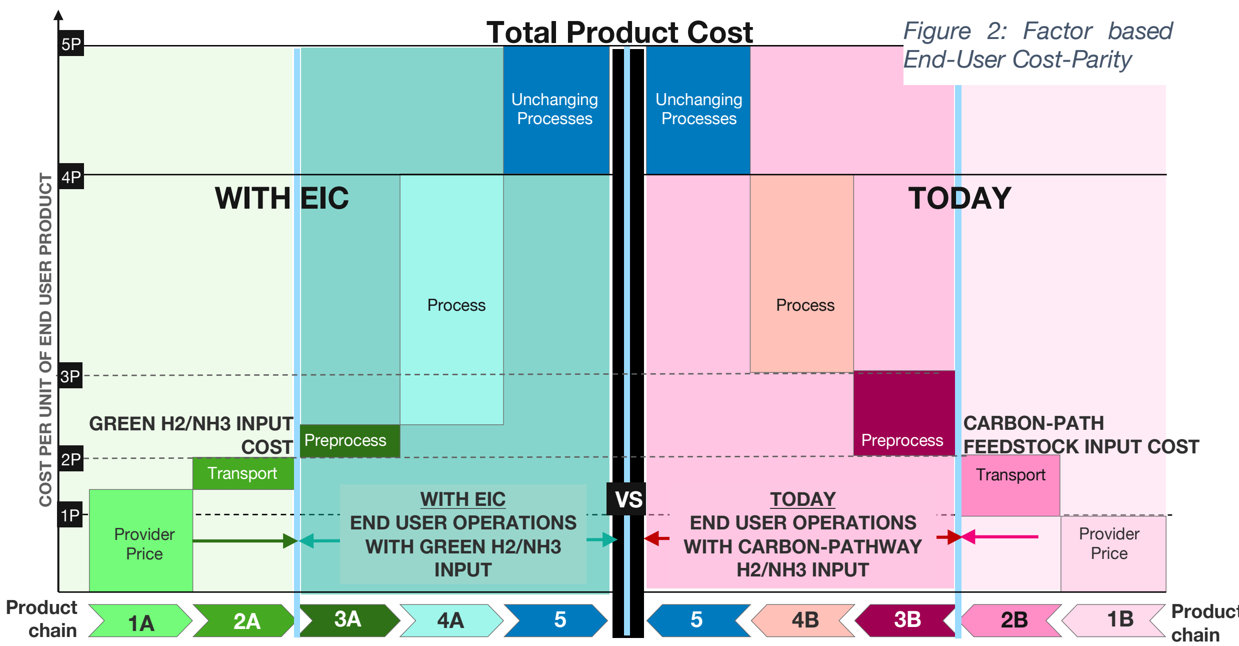


Figure 2: Factor based End-User Cost-Parity

plant/factory (costs 1A and 2A with EIC), against the costs with feedstock on a current a Carbon-based path (costs of 1B and 2B today). The end-user plant or operations can change with the feedstock - for instance, an operation with green H2/NH3 as feedstock vs one with a feedstock from a current carbon-path, such as, Coke for a steel plant or grey Hydrogen + CO2 for a urea-fertilizer plant. The end user plant operations costs will carry appropriate preprocessing and inventory cost- segment (3A with EIC and 3B on Today's model), and the main process cost-segment (4A and 4B). There may be segments with unchanging process (5).

The EIC GA solution, must deliver cost-parity for end-users – measured in levelized terms[5], per Figure 2-. End users will arrive at cost parity (at 4P or 5P) based on either lower cost inputs (1A+2A vs 1B+2B); or lower process costs (3A + 4A vs 3B + 4B); or both.

2.6. Other considerations to switch

Input leverage: End-users who have high input costs (1B+2B), on account of their small scale of operation or high transportation cost, will be the quickest to reach cost parity. A wheat or a corn farmer who uses anhydrous NH_3 directly as fertilizer, will for instance measure parity at 2P, as illustrated in Figure 2. Thus, cost parity can be achieved with first generation of commercial EIC GAPs (plan small scale – 2024, 1-10 TPD). Large scale end-users, with low process costs, and able to produce cost-parity Green Ammonia for captive use, may also see the benefits of early adoption.

Process leverage: End-users that achieve lower process costs with green Ammonia/Hydrogen that compensate for any adverse cost impact on the input side (1B + 2B) may be well positioned to exercise their process leverage for industry leadership. Likewise, large scale operations, that can take advantage of both factors (input and process), may be best positioned, not only achieve cost-parity earlier, but also develop a cost advantage. These openings can be inflection points for industry entrants with a novel process advantage to push for global leadership. Incumbents in the industry will be the most susceptible to the challengers if they do not likewise act. Consider, for instance, the steel industry. An input cost parity at 2P, does not guarantee their cost-parity with legacy Carbon-path plants. The steel plant would compare the costs of a H_2 direct reduction plus arc furnace smelting (3A+4A) vs the current costs of traditional blast furnace (3B +4B). Early movers can achieve cost parity with captive first generation of commercial EIC GAPs (plan at scale - 2025) and a potential lock in of their advantages.

Grant and credit leverage: Government or industry subsidies/grants and carbon credits for green ammonia/hydrogen, or the development of processes using them, can serve as an added incentive to switch.

---

[5] Called Levelized cost of energy, Ammonia or Hydrogen, it is net cash outflows, discounted at end-user's opportunity cost of capital. This paper uses cost parity to mean the levelized costs being at the same level, of say a GAP based service vs a current grey Ammonia service.

Early adopters spawn accelerated general adoption as green Ammonia/Hydrogen input costs experience steep reductions through their early evolution cycles.

The input leverage for earlier cost parity is primarily enabled by ZCES **Technology**, that scales up and down, and is easy to operate and maintain. The process leverage for earlier cost parity is enabled by a combination of ZCES **Technology** and **Platform** that enables easy integration of an end-user application – such as, a Green Steel, Trucks, Fertilizer, eFuels or Cement Plant-.

3. Zero Carbon Energy System (ZCES) - Green Ammonia Plant (GAP) Solution

3.1. The ZCES system

EIC's ZCES has three subsystems (see Figure 3):

a. ZCES Power Plant: Draw from renewable sources of power, to:
   - Compress hydrogen & nitrogen for Haber Bosch (HB) Ammonia synthesis process;
   - Store compressed hydrogen and air to run the HB process 24X7
   - Recover waste heat and gas expansion energy to drive continuous Electrolyzer operation, during zero renewable periods. Also recover energy of gas expansion for gas compression and heating and refrigerant condenser functions.
   - Liquefy and separate Ammonia from the HV process and Cool Electrolyzer.

b. ZCES Ammonia Plant: Operate the HB process with feeds of pressurized heated Hydrogen and Nitrogen, to produce pressurized liquid Ammonia at ambient temperature.

c. An Intelligent Control System (Ei Software) uses predictive analytics and learning to manage ZCES and coordinate with customer, grid, renewable, and Electrolyzer systems.

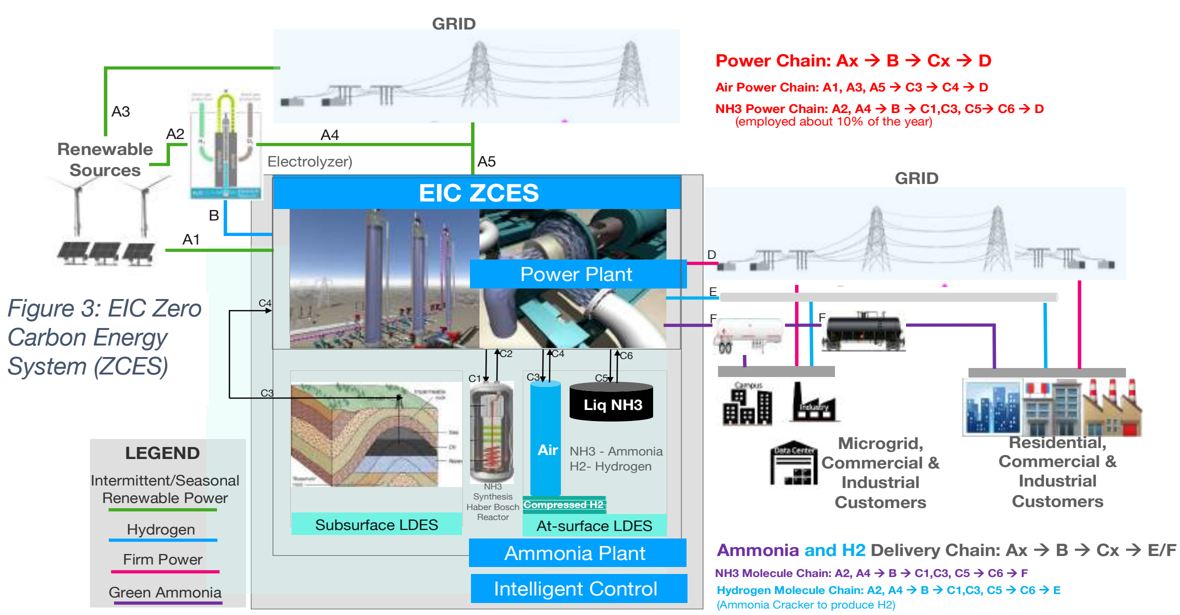


Figure 3: EIC Zero Carbon Energy System (ZCES)

The ZCES system uses only renewable source power, water and air to produce liquid Ammonia. The renewable source and ZCES-recovered energy powers the electrolysis to produce Hydrogen from water. The ZCES power plant feeds the Ammonia-plant subsystem the hydrogen and nitrogen, to produce ammonia. ZCES Intelligent Control systems operate the plant and interface/enable end-user processes.

3.2. How ZCES enables cost parity

Table 4, below illustrates points where ZCES offers cost reductions on a green Ammonia path in their early commercial cycles (expected 2024/25). The points, unlike traditional methods (mature

Table 4: An illustrative comparison of Traditional Compressor operated and ZCES HB Process with renewable power

	System	Today		EIC - CF 95-98%	
A	Electrolyzer	885 MWH/day			
B	HB NH3 production	100 MTPD			
1	Capacity Factor	30%		95%	
2	Electrolyzer	123 MW	$86 Mill	123 MW	$52 Mill
3	Solar Plant	220 MW	$154 Mill	140 MW	$98 Mill
4	HB Plant	333 TPD	$83 Mill	106 TPD	$8 Mill
5	Accessories/EIC Plant		$30 Mill		$71 Mill
	TOTAL		$353 Mill		$229 Mill

in their market evolution and technology) offer an opportunity for steep ongoing reductions, as the technologies and scale of adoption are in early stages of evolution. As the illustration shows, a 100 MTPD ZCES Ammonia plant, costs at least 35% less in upfront capital expenses ($229 Mill vs $353 Mill) compared to a green Ammonia plant employing traditional gas compressors, heat exchangers and condensers/chillers. The ZCES solution has fewer components, lower maintenance, and fewer moving parts, and operating costs are at least 40% less. This translates to ZCES cost of Ammonia on a levelized basis to be at least 50% less expensive than today's green Ammonia strategy.

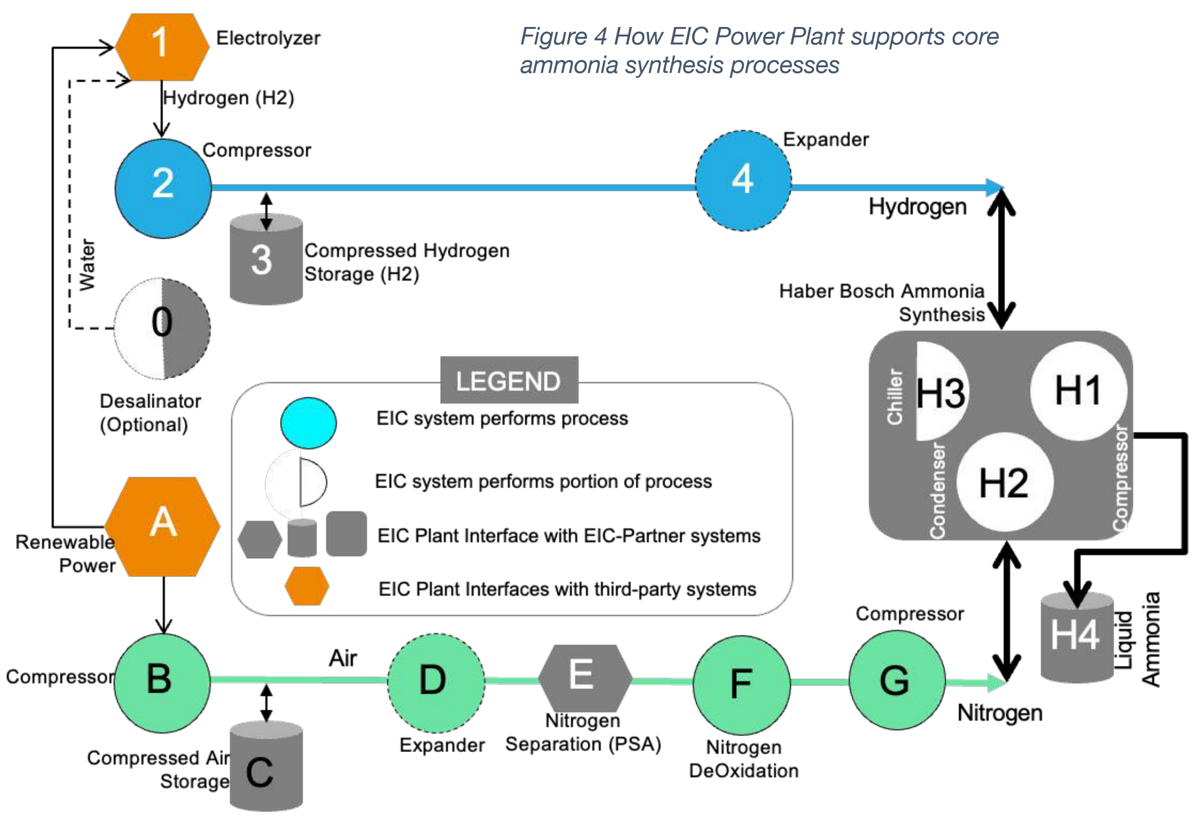
Table 4 compares ZCES against a lowest cost process baseline of a green Ammonia plant today, that operates the HB plant only when the solar/wind renewable power source is available (at 30% capacity factor). An alternate approach of storing compressed H2 and Air to operate the HB plant continuously will cost more (at least 10%). The points of cost reductions are explained below. (ZCES costs refer to estimated costs at commercial launch in 2024/25):

1. HB Plant – A ZCES Ammonia plant operating at 95%+ Capacity Factor (CF) will require a 106 MTPD ZCES plant, rather than 333 MTPD for the baseline operating at 30% CF, to produce an

average 100 MTPD Ammonia. The ZCES Ammonia plant, primarily a HB reactor with interfaces to the ZCES power plant is estimated to cost $8 Million, less than a traditional $25 Mill for the 106 MTPD rated capacity. The baseline plant will therefore cost about $83 Million [(333/106) X $25 M], over 10X the ZCES Ammonia Plant. Specialized equipment avoided by the ZCES Ammonia are 2,B,F, G that feed pressurized Nitrogen and Hydrogen to the HB, and the HB processes H1, H2 and H3 as shown in Figure 4.

2. The Accessories: Accessory systems (terminology used for purposes of this whitepaper) as shown in Figure 4, include water feeds (0) and Nitrogen separation (E). Not shown in the figure are the control interfaces with/among HB, Electrolyzer and the Renewable plants, and electrical systems. ZCES power plant functions of compressing the air and hydrogen for storage, and releasing them as needed for the HB process, perform the energy storage function

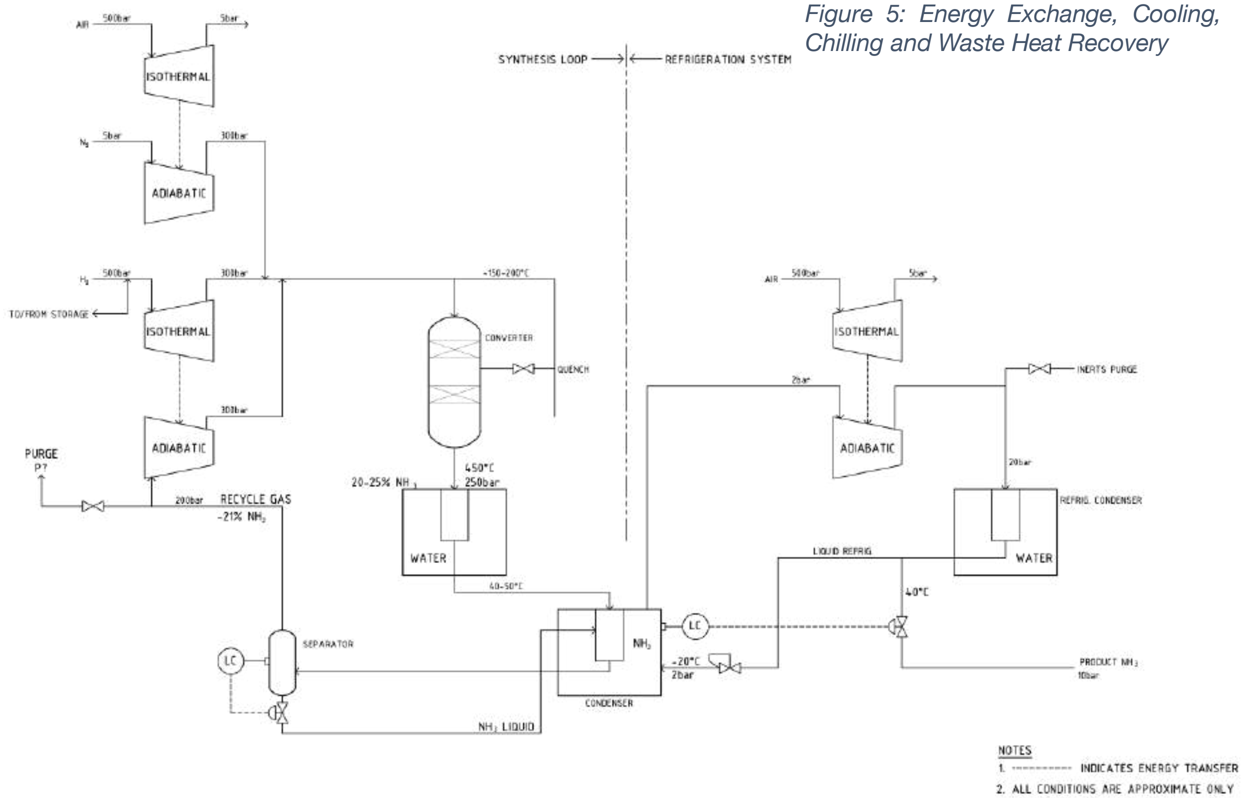
Figure 4 How EIC Power Plant supports core ammonia synthesis processes



3. Energy and Equipment efficient process – As Figure 5 shows, the EIC Power Plant recaptures energy efficiently by three methods:

i) Allow expanding gases to transfer their energy to compressing gases, isothermally, adiabatically or polytropically, to achieve the desired temperature and pressure conditions

Figure 5: Energy Exchange, Cooling, Chilling and Waste Heat Recovery



ii) Recover waste heat from the HB reactor to deliver electrical power to produce Hydrogen in electrolyzers, or transfer energy to compress a gas

iii) Provide cooling and refrigeration for ammonia liquefaction and extraction, performing both the condenser and expander functions.

This approach of energy exchange also avoids the need for separate equipment for each compression or expansion, waste heat exchanger and steam turbine or chiller/condenser functions. A single system of EIC Power plant provides these functions.

3.3. How ZCES enables open architecture and up and down scalability

The ZCES system is modular. Capacity can be increased by adding standardized modules. All engineering components used are commercially available at the desired scales of operation. As Figure 6 shows ZCES's open architecture allows multiple technologies to interface with the core EIC plant. These interfaces are standard physical modules and programmable control scripts that can operate across different systems – such as different electrolyzers, hydrogen and air storage systems and even different HB reactors. The core EIC plant is also modular and plug and play and can be scaled by connecting as many modules at appropriate sizes as needed.

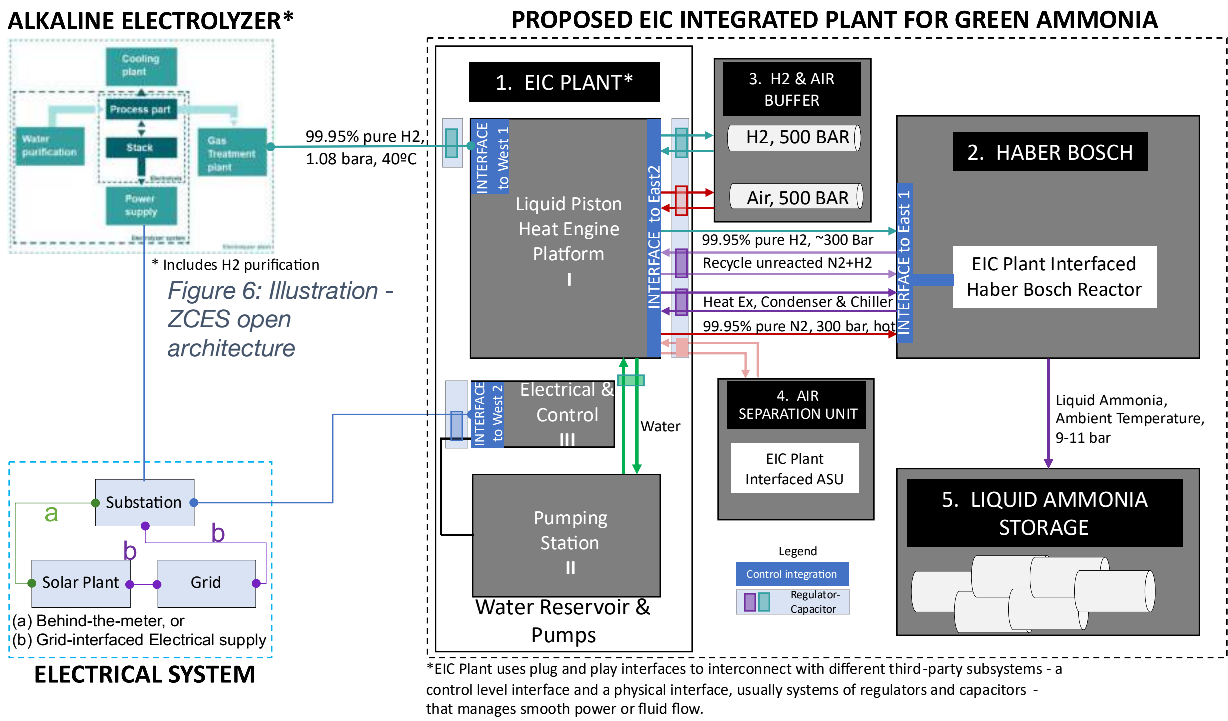


Figure 6: Illustration - ZCES open architecture

Unlike traditional HB processes that are not effective or available below or above a size, ZCES systems do not face such limitations. Its systems of compression and expansion, cooling and chilling operate at any scale, powered by water pumps available at any scale.

4. Annexure: Frequently Asked Questions

4.1. EIC LPHE Gas compressors vs centrifugal & direct reciprocating compressors

The following table captures key differences between LPHE and traditional compression.

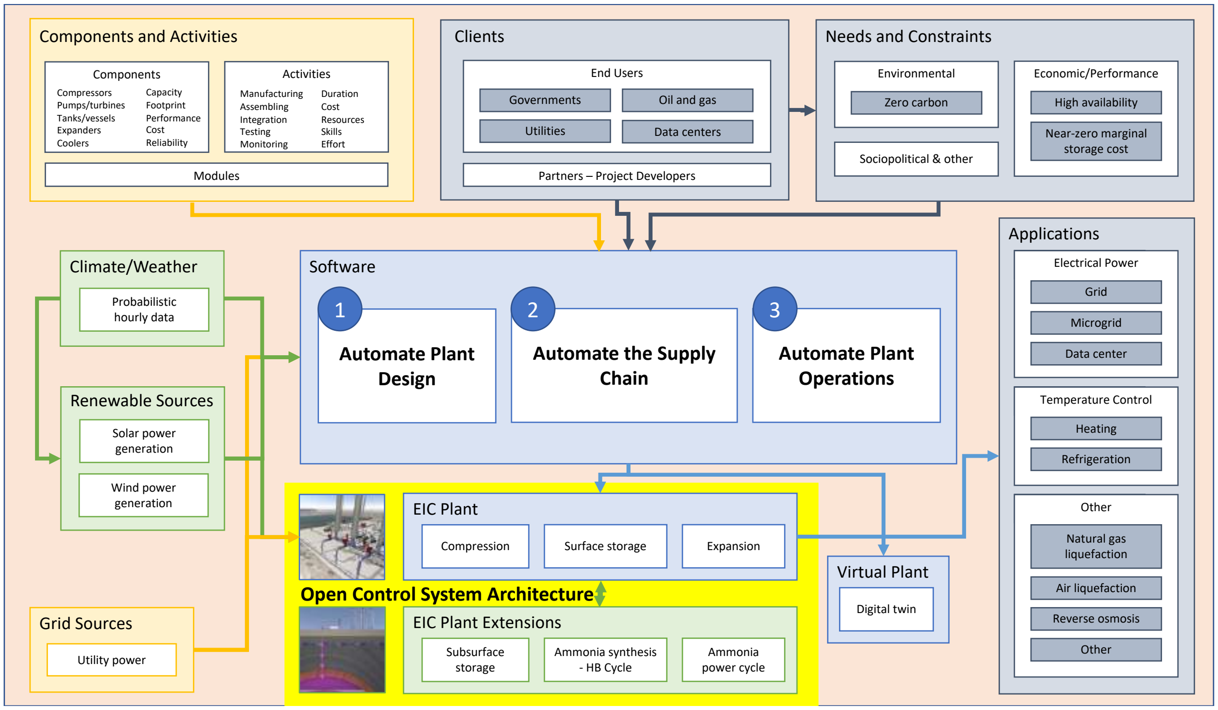
#	Item	EIC LPHE	Traditional Centrifugal Compressors	Traditional Reciprocating Compressors
1	Cycle Speed RPM)	0.75 - 0.1	2000+	2000+
2	Gas	Agnostic, no special provision for gases	Special provisions for different gases	
3	Inter stage cooling	None	Yes	Yes
4	Reliability	Very High, because: - No moving parts in the pressure vessel - Array of Centrifugal pumps operating at optimal points (EIC use of DFIG motor generators, and an array of pumps at each stage)	High reliability	Low, due to fast moving parts with high gas temperatures, lubrication & seal failure and parts wearing out.
5	Number of stages of compression for H2 to 500 bar	4	10-20	
6	Seals for H2, NH3 compression	None	Special hermetic seals	
7	Gas flow	Laminar	Turbulent	
8	Compressor, expander, cooling, chilling, heat-exchangers	One single platform to perform all these functions	Individual equipment for each item function	
9	Energy Efficiency	70-90% energy recovery of all gas compression Efficient isothermal compression	No energy recovery Inefficient adiabatic compression and heat loss	

EIC LPHE, unlike reciprocating compressors as the above table summarizes, are safer, cheaper, extremely reliable, and efficient. They operate at 1000X lower speeds/cycles, laminar flow and ambient temperature gases, are highly efficient compressors, and recover most of the compression energy exercised. The cost, number, and types of equipment for the entire HB process, of compression, expansion, condensation, chilling and heat exchange with EIC is a small fraction of those with traditional compressors, as a single EIC platform provides all the functions and requires fewer equipment for the HB process. In addition, the higher efficiency of the system means that fewer equipment both for the HB processes and upstream systems (solar/wind power capacity and lower cost electrolyzers).

4.2. How does EIC manage high system reliability, with so many parts and subsystems involved

1. Proportional and multilevel redundancy: EIC's proprietary control architecture is a modular fault tolerant and redundant (Triple Modular Redundant) Distributed Control System with an over lay of intelligent EI Software with embedded AI for optimized controls, operation and predictive diagnostics. Redundancies are built at various levels – distributed controllers, high speed communication, I/O modules, switches, and primary sensors. Safety function loops are separate from process controls and can meet required SIL (Safety Integrity Level) standards. Thus, the EIC system design is forgiving of multiple component and subsystem failures. EIC systems have few rotating parts (only liquid pumps) or moving parts (like valves). In addition, EIC's LPHE designs have appropriate provisions of redundancy, to survive single or serial instances of failures, as well as safety operations on escalating or undetected failures.

2. Intelligent Control Systems: In addition to traditional robust plant and component control designs, EIC systems have prediction and anomaly detection software layer to improve safety, system life and optimal operation. EIC control architecture below illustrates this idea, where, machine learning and AI occurs in multiple places such as 'Virtual Plant', Applications, etc. (The traditional EIC control is highlighted in yellow… rest is EIC's intelligent software layer).



Components and Activities
Components
Compressors
Pumps/turbines
Tanks/vessels
Expanders
Coolers
Capacity
Footprint
Performance
Cost
Reliability
Activities
Manufacturing
Assembling
Integration
Testing
Monitoring
Duration
Cost
Resources
Skills
Effort
Modules
Clients
End Users
Governments
Oil and gas
Utilities
Data centers
Partners – Project Developers
Needs and Constraints
Environmental
Zero carbon
Sociopolitical & other
Economic/Performance
High availability
Near-zero marginal storage cost
Climate/Weather
Probabilistic hourly data
Renewable Sources
Solar power generation
Wind power generation
Grid Sources
Utility power
Software
1
Automate Plant Design
2
Automate the Supply Chain
3
Automate Plant Operations
Applications
Electrical Power
Grid
Microgrid
Data center
Temperature Control
Heating
Refrigeration
Other
Natural gas liquefaction
Air liquefaction
Reverse osmosis
Other
EIC Plant
Compression
Surface storage
Expansion
Open Control System Architecture
EIC Plant Extensions
Subsurface storage
Ammonia synthesis - HB Cycle
Ammonia power cycle
Virtual Plant
Digital twin