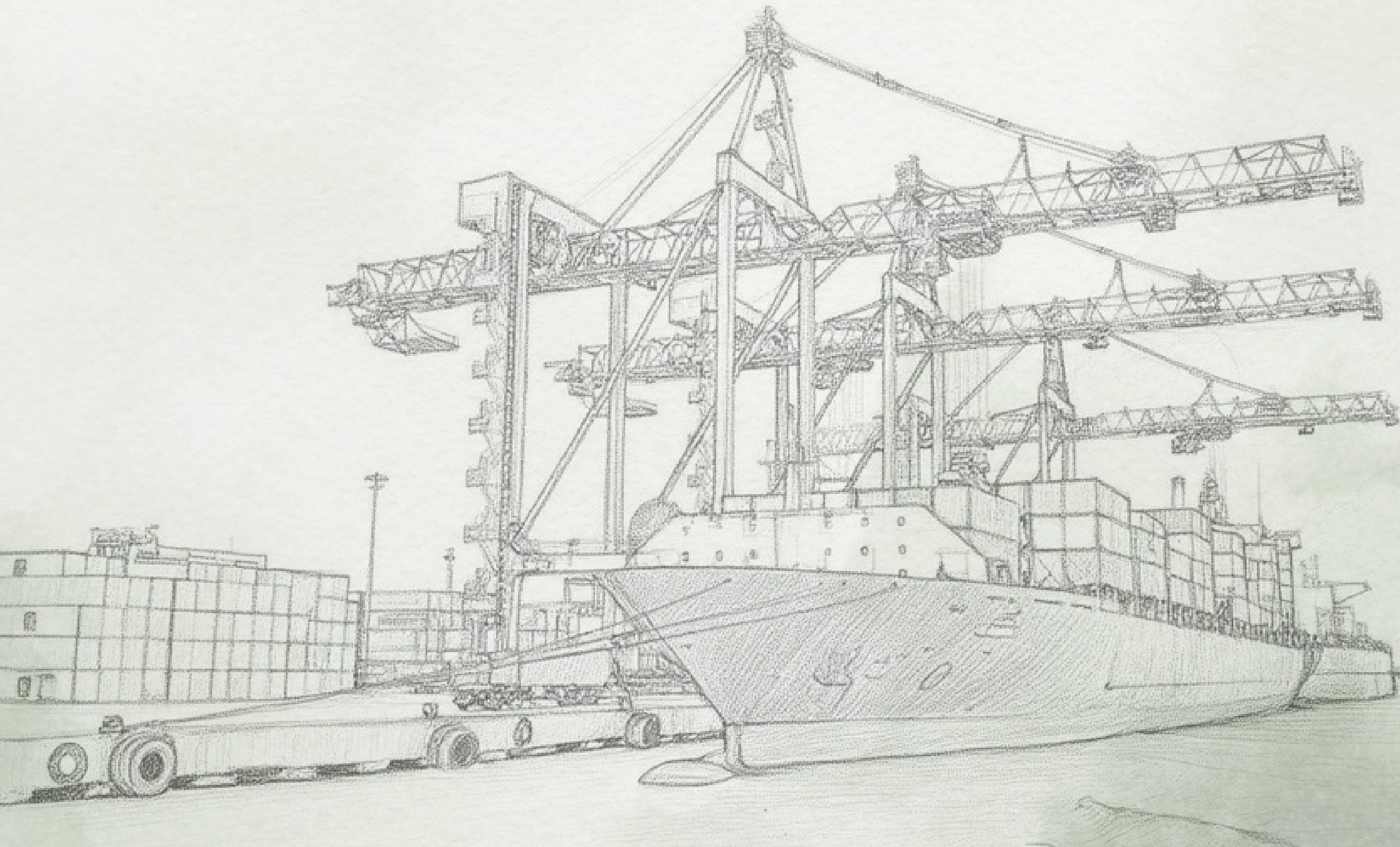
सत्यमेव जयते

पत्तन, पोत परिवहन
एवं जलमार्ग मंत्रालय
MINISTRY OF
**PORTS, SHIPPING
AND WATERWAYS**

வ.உ.சி துறைமுக ஆணையம்
वी.ओ.सी पत्तन प्राधिकरण
V.O.C Port Authority
Global Connect

SAGARMALA
PORT-LED PROSPERITY

GREEN HYDROGEN PLANT



#GREENPORT

DEDICATION

Dedicated to the visionaries and teams whose expertise and perseverance made the Green Hydrogen Pilot Plant at VOC Port possible.

For those who dared to imagine cleaner seas, greener ports, and steadier horizons — to the engineers, technicians, port staff, and partners who turned a bold idea into a working reality. This plant exists because people showed up, learned fast, and worked together — lighting the way towards a cleaner future.

HONB’LE SHRI. NARENDRA MODI

PRIME MINISTER, GOVERNMENT OF INDIA

COP26 MESSAGE CHARTING A SUSTAINABLE FUTURE

As the world gathers to address the shared challenge of climate change, Hon’ Prime Minister of India Shri Narendra Modi delivered a pioneering vision at the 26th UN Climate Change Conference (COP26) in Glasgow, inviting every individual to take part in shaping our planet’s future.

“I propose before you a one-word movement: LI.F.E — Lifestyle for Environment. Today, there is a need for all of us to come together and take Lifestyle for Environment forward as a campaign.”

India's approach highlights a shift from abstract policy to everyday practice. The Prime Minister emphasized that the fight against climate change isn’t only about global pledges — millions of individual decisions power made daily, choices that together can transform sectors from energy and water management to agriculture, fashion, tourism, and beyond.

“What is needed today is mindful and deliberate utilization, instead of mindless and destructive consumption.”

Furthermore, PM Modi delivers India 'Panchamrit' gift at COP26 to fight climate change: Five commitments

- To raise the non-fossil fuel based energy capacity of the country to 500 GW by 2030.
- Also, by 2030, 50% of the country’s energy requirements would be met using renewable energy sources.
- The country will reduce the total projected carbon emission by one billion tonnes between now and the year 2030.
- The carbon intensity of the economy would be reduced to less than 45% by 2030, Modi said as the fourth point.
- As the final agenda, he said the country would become carbon neutral and achieve net zero emissions by the year 2070.

HON'BLE SHRI. SARBANANDA SONOWAL

UNION MINISTER OF PORTS, SHIPPING AND WATERWAYS

Union Minister of Ports, Shipping and Waterways, Hon'ble Shri Sarbananda Sonowal, highlighted that India today stands at the forefront of a global maritime revolution—one that prioritises sustainability, innovation, and environmental stewardship. He emphasised,

"Under the visionary leadership of Hon'ble Prime Minister Shri Narendra Modi ji, India is not merely adapting to change; we are driving it."

The Minister pointed out that through initiatives such as the Harit Sagar Green Port Guidelines, the Green Tug Transition Programme (GTTP) under Panch Karma Sankalp', and the National Green Hydrogen Mission, India is transforming its ports and shipping industry into beacons of sustainability. He announced ₹25,000 crore Maritime Development Fund and said, "This fund will catalyse investments in green infrastructure, alternative fuels, and fleet modernisation, ensuring India's leadership in maritime decarbonisation."

He reaffirmed that sustainability is not merely a regulatory obligation but an economic opportunity and a moral responsibility.

"Our ports are not just enablers of economic growth but torchbearers of environmental stewardship on the global stage," the Minister remarked.

The Minister reiterated that India's maritime sector is undergoing a remarkable transformation—not just as a gateway for commerce but as a champion of climate resilience and environmental stewardship. He reaffirmed India's commitment to achieving Net Zero emissions at all major ports by 2047, powered by green hydrogen, renewable energy, and digital technologies. He noted that India's rise as the world's fourth-largest economy strengthens its resolve to become a global maritime hub through green ports, multimodal connectivity, and digital infrastructure. He also highlighted the vital role of India's maritime workforce, projected to reach 40 million by 2047, with growing opportunities for women.

Hon'ble Shri Sonowal remarked,

"Sustainability is at the heart of our maritime policy, and we are committed to achieving Net Zero emissions at major ports by 2047. From green hydrogen to digital shipping, our roadmap is ambitious yet inclusive."

HON'BLE SHRI. SHANTANU THAKUR

MINISTER OF STATE, MINISTRY OF PORTS, SHIPPING AND WATERWAYS

CHARTING A SUSTAINABLE FUTURE

The saga of V.O. Chidambaranar Port in Tuticorin is a vivid chronicle of India's relentless pursuit of progress, sustainability, and self-reliance. From its humble origins as a coastal trading hub to its emergence as a vanguard of the global green revolution, the port exemplifies a remarkable journey of transformation and innovation. At its core, this journey embodies the Ministry of Ports, Shipping and Waterways' (MoPSW) vision, brought to life through landmark efforts such as the Harit Sagar Green Port and Harit Nauka Green Transition Guidelines. These frameworks reflect India's unwavering commitment to forging a sustainable, self-reliant, and forward-looking maritime ecosystem.

At the heart of this transformation lies V.O. Chidambaranar Port's trailblazing efforts in establishing a green hydrogen ecosystem, a bold stride toward redefining the future of energy. This report is not just the documentation of a project but it is a narrative of ambition, ingenuity and resilience. It showcases how the port is harnessing clean energy to produce a fuel that promises to power a sustainable tomorrow, setting an unparalleled standard for operational excellence and environmental stewardship.

The story of V.O. Chidambaranar Port is a powerful testament to the potential of ports to serve as dynamic laboratories for sustainable development. By seamlessly blending economic vitality with ecological responsibility, the port stands as a model for the world.

May the insights herein inspire and illuminate the path ahead as we collectively strive to realise India's vision of a greener, stronger and self-reliant nation.

SHRI. T.K. RAMACHANDRAN

SECRETARY, MINISTRY OF PORTS, SHIPPING AND WATERWAYS

CHARTING A SUSTAINABLE FUTURE

V.O. Chidambaranar Port stands at the forefront of India’s green maritime transition, emerging as a lighthouse for sustainability under the Green Ports initiative. Among its most transformative steps is its pioneering role as the country’s first designated Green Hydrogen Hub. In alignment with the vision of Hon’ble Union Minister Shri Sarbananda Sonowal, the port has earmarked 500 acres of dedicated land for green hydrogen and its derivatives, thereby laying the foundation for a future-ready maritime ecosystem. An MoU with NTPC is already in place to operationalize large-scale production, signaling a decisive step towards positioning India as a global hub for green fuels.

This bold move not only accelerates the decarbonization of port operations but also contributes to the wider clean energy transition envisioned in the Maritime Amrit Kaal Vision 2047. Yet, the ambition of VOC Port goes beyond production. It is steadily building a comprehensive green hydrogen ecosystem, integrating innovation, infrastructure, and application. Already, green hydrogen is being utilized for street lighting and EV charging within the port premises, serving as a living demonstration of how ports can translate climate goals into operational realities. In parallel, the port has introduced 20 electric vehicles, five EV charging stations, and a CNG-powered school bus donated under CSR, a clear signal that sustainable mobility is becoming part of its daily operations.

By weaving together renewable energy adoption, clean fuel integration, and community-oriented sustainability initiatives, V.O. Chidambaranar Port is creating a model that other ports can emulate. Its green hydrogen strategy is not confined to energy generation but extends into logistics, transport, and port services ensures that decarbonization is pursued in a holistic and scalable manner.

In doing so, VOC Port is not just reducing emissions, it is redefining the role of ports in shaping a low-carbon future. It exemplifies how port-led growth, when guided by innovation and responsibility, can balance economic progress with environmental stewardship. As India moves towards a greener maritime landscape, V.O. Chidambaranar Port is leading by example, proving that bold vision backed by concrete action can turn the tide towards sustainability.

SHRI. SUSANTA KUMAR PUROHIT

CHAIRPERSON, V.O. CHIDAMBARANAR PORT AUTHORITY

FOREWORD & VISION

In the bustling harbour of Tamil Nadu's Tuticorin, where the salty breeze carries the sounds of cargo cranes and ships' horns, a quiet revolution has begun. The V.O. Chidambaranar Port Authority (VoCPA), one of India's key maritime gateways, has set its sights beyond ships and cargo — towards clean energy, sustainability, and the green ports of the future.

With the world racing towards net-zero targets, the shipping industry—a sector often overlooked in climate discussions — faces mounting pressure to decarbonize. VOCPA saw this not as a challenge, but as an opportunity.

And so, the vision was born: to become a pioneer in green hydrogen production in the Indian port sector, making VOC Port a testing ground for cutting-edge clean fuel technology. The Green Hydrogen Pilot Plant stands as a testament to that vision — a project where technology, determination, and environmental responsibility converged.

> ***"I am also proud to share that VOC Port is taking bold steps in advancing its Green Port mission. We have successfully completed a pilot green hydrogen project, now powering several streetlights and an electric vehicle charging station."***

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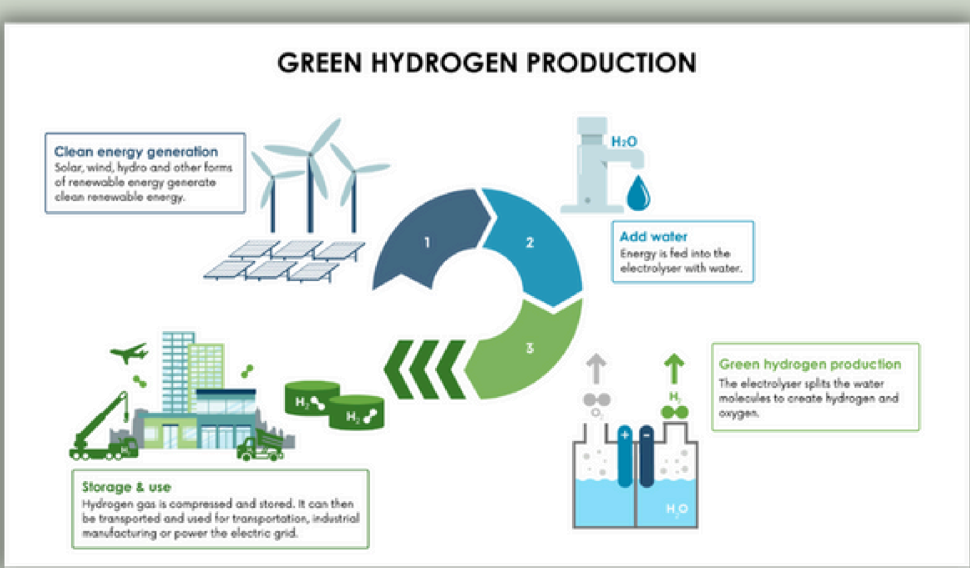
CHAPTER 1

GREEN HYDROGEN AT A GLANCE AND VOC PORT'S ROLE

1.1. GREEN HYDROGEN – THE BASICS

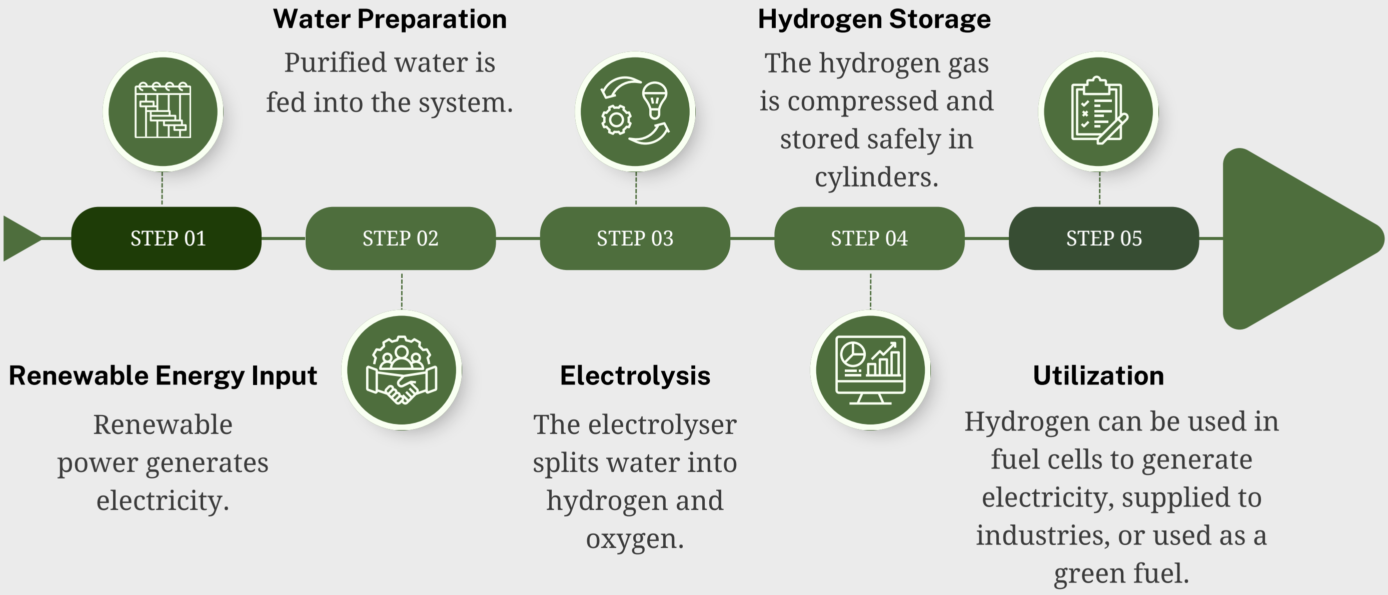
Green Hydrogen is produced by splitting water into hydrogen (H_2) and oxygen (O_2) through electrolysis powered by renewable energy. Unlike grey hydrogen, this process emits no carbon, making it a clean, future-ready fuel.

Beyond pure hydrogen, derivatives such as Green Ammonia (NH_3) and Green Methanol (CH_3OH) are gaining importance. These compounds, synthesized using green hydrogen, are easier to store and transport, and can serve as marine fuels, fertilizers, or chemical feedstocks. For a port environment, such derivatives open global trade opportunities in green energy exports.



Green Hydrogen Production Process

The production process in simple steps:



1.2 BENEFITS OF GREEN HYDROGEN

Hydrogen is the universe's most abundant element, yet in the modern energy sector, its production has been anything but green. Traditionally, hydrogen comes from fossil fuel processes like steam methane reforming, producing significant carbon emissions. But green hydrogen, made from water using renewable electricity, offers a truly zero-carbon alternative.

For ports, the potential is game-changing:

- **As fuel** for ships in the future.
- **As power** for onshore operations.
- **As a symbol** of a sustainable maritime transition.

1.3 V.O.CHIDAMBARANAR PORT: GREEN HYDROGEN HUB

The Ministry of Ports, Shipping and Waterways (MoPSW) declared Deendayal, Paradip, and V.O. Chidambaranar Ports as green hydrogen hubs in May 2023. This was announced as part of the broader Harit Sagar Guidelines and the Maritime India Vision 2030, which aim to transform India into a global hub for green shipping and to promote India's clean energy transition. These efforts are part of the National Green Hydrogen Mission, which aims to make India a global hub for green hydrogen production and utilization.

Purpose

The goal is to build infrastructure and promote the large-scale production and utilization of green hydrogen within the Indian port ecosystem.

Part of National Mission

The development of these hubs is a strategic component of the National Green Hydrogen Mission, which seeks to decarbonize the economy and reduce fossil fuel dependence.

Strategic Advantage of VOCPA being a Green Hydrogen Hub:

- **Geographic and Connectivity Advantage:** VOC Port's all-weather access, pivotal location on the East-West sea route, and seamless rail-road links made it ideal for green fuel handling and distribution.

- **Policy Alignment:** In step with India's National Green Hydrogen Mission and Harit Sagar Green Port guidelines, VOC Port took a leadership role in practical clean energy adoption being the early mover by installation of 1st Shore to Ship power supply, achieving 100% renewable energy, electrification of equipment, etc

- **Strategic Government Backing:** The Ministry's support and positioning of the port as a national hub anchored its plans with policy legitimacy and funding momentum.

CHAPTER 2

VOCPA – 1ST MOVER TO CREATE A GREEN HYDROGEN ECO SYSTEM.

Every landmark project begins with a spark- a vision that slowly takes shape through planning, approvals, and persistence. The Green Hydrogen Pilot Plant at VOC Port was no different. Its journey from concept to sanctioned reality was a step-by-step transformation, each stage building upon the last.

2.1. PLANTING THE SEED– CONCEPTUAL STAGE

The story began with a bold idea: to create a **demonstration-scale green hydrogen facility** that could showcase VOC Port's readiness for the clean energy era. At this stage, the focus was on possibilities, not yet on hardware. Engineers, port planners, and sustainability experts sat around the table, sketching possibilities, debating technology choices, and weighing the impact on the port's future energy mix. **This was where questions were asked and answered:**

- What capacity should we target for a pilot plant?
- Which technology would best suit our coastal operating environment?
- How could the plant integrate into existing port activities without disruption?

2.2. DEFINING THE SPECIFICATIONS – FROM CONCEPT TO BLUEPRINT

Once the concept felt solid, it was time to translate ambition into technical language. The team worked to define the specifications of the system:

- The electrolyser's type, capacity, and operational parameters.
- Water treatment needs to ensure ultra-pure feedwater.
- Hydrogen storage pressure and capacity for on-site use.
- Integration with a fuel cell for electricity generation.

This was more than a shopping list — it was a design framework that would guide every technical and commercial decision that followed.

This was more than a shopping list — it was a design framework that would guide every technical and commercial decision that followed.

VOCPA identified as Green Hydrogen Hub and 100% renewable energy Port had a brainstorming session in the month of April ’2024 with Top, Middle and bottom management on Production, Storage and pilot scale of application pf green hydrogen. The goal of green hydrogen plant in pilot scale is to prove the technical viability using green hydrogen on a pre-commercial scale. This pilot acts as an operational proof-of-concept informing and de-risking future investments in full-scale green hydrogen and its derivative facilities. These future developments promise to transform VOC Port from a traditional cargo hub into a green energy nucleus, paving the way for India’s green maritime future.

Subsequent to brainstorming session, industry partners were consulted and it was decided to develop Green Hydrogen Demonstration Plant enabling the integration of renewable energy, electrolyser-based hydrogen production, fuel-cell electricity generation, and storage within the port area having following broad Technical Specifications.

Salient Features Green Hydrogen Demonstration Plant envisaged:

Hydrogen Generation Unit.

Sr No	Description	Parameters
1	Hydrogen generation capacity	10 Nm3/hr
2	Operating hours	24 hrs
3	Electrolyzer technology	PEM
4	Hydrogen generation pressure	Minimum 30 Bar
6	Purity of hydrogen gas	99.99%

It should be fully assembled, ready to run and packaged in cabinets or a container:

Configuration: Fully assembled, packaged in series-connected cabinets or container

a) **Material:** Corrosion-resistant

b) **Safety:** Explosion-proof temperature switch per cell for high-temperature alarm

c) **Temperature Control:** Transmitter/RTD to maintain preset temperature

d) **Monitoring:** Local temperature gauge, off-line specific gravity measuring instrument

e) **Operational Flexibility:** Designed for part load operation without interruption

e) **Operational Flexibility:** Designed for part load operation without interruption

f) **Control:** Includes measuring instruments, controllers, and control valves

g) **Pressure Relief:** Safety devices on collecting pipes for gas pressure release

h) **Maintenance:** Designed for easy cleaning and maintenance

i) **Gas Handling:** Proper sealing to prevent leakage, electrical leakage minimization

j) **Integration:** Cells module integrated into gas generating station

k) **Instrumentation:** Triple redundant for protection, dual redundant for interlock/permissive

l) **Oxygen Handling:** Safely vented or provided with collection interface

Fuel Cell

Sr No	Description	Parameters
1	Technology	PEM Type Fuel Cell
2	Capacity	10KW
3	Construction	Containerized
4	Output Power	415V AC

Hydrogen Storage

Sr No	Description	Parameters
1	Storage capacity	8 kg
2	Type of storage	PESO approved Storage System /cylinders

Electrolyser BOP:

- DM water, Instrument air, Chiller etc

Plant BOP:

- High-pressure drains to be terminated through hydrogen traps, low-pressure drains through U-bends.
- Necessary connections and isolation devices for purging with nitrogen.
- Process & utility piping, tubing, valves, instruments, fittings, insulation, and compliance with pressure piping codes and relevant standards.

Electrical:

- Provision of rectifier, transformer, DC bus duct/cable, PLC-based control system, instrumentation, power, control, signal cables, cable trays, lugs, supports, glands, etc., within the battery limit
- All electrical equipment, systems, and structures complied with IS 3043:2018.

- Separate earthing grids for instrument and electrical power.
- Covers tubing, earthing, lighting, etc., within the proposed plant area.
- Required lighting in Hazardous as well as safe area as per hazardous area classification.

Instrumentation:

- Plant to be designed for fully automatic operation.
- HMI-based PLC panel for plant operation.
- Provision of I/O signals (soft & hard) required for main PLC integration.
- Control system with minimum 30 mins UPS backup.
- All wetted parts in contact with hydrogen to be compatible for hydrogen service.
- Continuous display/record of hydrogen purity, oxygen content, moisture content, and dew point required.
- Installation of Hydrogen Gas detectors at strategic locations to detect any gas leakage and provide suitable alarms in control systems and tripping of equipment. In case of any abnormalities in the process alarm will be generated and system should be shutdown.
- Internal electrical, control & signal cabling, wiring, earthing, lighting, emergency stop push button, LCS, field instruments.
- All necessary instrumentation equipment as per norms and standard.

2.3. BUDGETARY OFFER – TESTING THE MARKET

With specifications in hand, potential suppliers were approached for budgetary offers. These weren't yet binding contracts, but indicative price ranges that would help the port authority gauge the financial feasibility of the project.

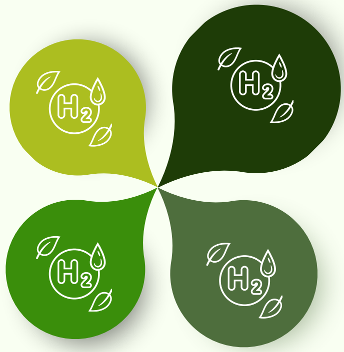
The responses painted a clearer picture of capital costs, installation timelines, and long-term maintenance considerations.

2.4. SANCTION FOR ESTIMATE – PUTTING NUMBERS TO PAPER

Armed with budgetary inputs, the next step was to prepare a formal project estimate. This document balanced the technical ambitions with realistic cost expectations, factoring in:

Equipment procurement.

Civil works for foundations and structures.



Installation and commissioning.

Contingencies for unforeseen site adjustments.

This estimate became the financial backbone of the project proposal, ready for internal review.

2.5. INVITING THE BEST TO COMPETE – A TRANSPARENT TENDERING PROCESS

With the estimate approved, the project moved into a transparent procurement phase. An open tender was issued, inviting qualified vendors to submit detailed proposals.

This stage was more than a simple bidding process — it was the port's way of ensuring that the best technology and value would be chosen in a fair and competitive environment.

2.6. EVALUATION AND AWARD – CHOOSING THE RIGHT PARTNER

Once tenders were received, each proposal underwent a rigorous evaluation:

- Technical compliance with the specified requirements.
- Supplier experience with hydrogen projects.
- Delivery timelines and after-sales support.
- Financial competitiveness.

Only after meeting these benchmarks was the contract awarded, marking the official green light for the project's execution phase.

From the first sketches of a hydrogen plant to the moment the winning bidder was declared, the sanctioning process was a journey of vision meeting structure- a path where ideas evolved into actionable plans, and plans became an approved reality.

From Paper to Plant – Approved Design

The approved plant layout was more than a set of diagrams — it was a carefully considered integration of all systems:

- **Electrolyser Hall** – Housing the PEM stack, water treatment, purification units.
- **Hydrogen Storage Area** – Low-pressure Type 1 steel cylinders arranged in cascades.
- **Fuel Cell Section** – 15kW unit with inverter for AC output.
- **Cooling Towers** – Mounted for temperature control.
- **PLC & HMI Control Room** – The digital brain of the operation.

Every pipe, cable, and valve had its place, with routing planned to minimise risk, ease maintenance, and optimise performance.

From Concept to Award —
the first milestone in VOC Port's green hydrogen journey has been achieved.

CHAPTER 3

GREEN HYDROGEN PLANT – A DEEP DIVE

3.1. PROJECT SUMMARY

Rhizome Energy Limited (RHIZOME) is contracted to design and commission a 10Nm3/hr Electrolyser(50kW) and a Fuel Cell Generator (10kW net Output) to be installed on V.O. Chidambaranar Port premises located in Tamil Nadu, India.

International Codes and Standards:

RHIZOME's hydrogen equipment is designed and fabricated according to the following directives:

- ISO 22734-1 – Hydrogen Generators Using Water Electrolysis Process –

Part 1: Industrial and Commercial Applications

- ISO 14687 – Hydrogen Fuel Quality
- ISO 26142 - Hydrogen Detector Apparatus – Stationary Applications
- ISO 15916 – Basic Considerations for the Safety of Hydrogen Systems
- ASME B31.12 – Hydrogen Piping and Pipelines
- ISO 80079-36 – Explosive Atmospheres - Part 36: Non-electrical equipment for explosive atmospheres – Basic method and requirements
- IEC 60079 – Explosive Atmospheres – General Requirements
- IEC 60079-10 – Electrical Apparatus for Explosive Gas Atmospheres

Part-10 Classification of Hazardous Areas.

- BS EN 1127 – Explosive Atmospheres – Explosion prevention and protection
- NFPA 55 - Piping Systems, Valves, Hydrogen-Venting Systems, Venting Requirements
- NFPA 853 - The standard for the Installation of Stationary Fuel Cell
- RR 715 – Installation Permitting Guidance for Hydrogen and Fuel Cell Stationary Applications: UK Version

When you step into the VOC Port Green Hydrogen Pilot Plant, you're not just looking at machines and metal frames — you're stepping into a space where engineering decisions meet environmental vision. Every vessel, pump, and control panel you see has a story. It reflects a choice made after carefully balancing technology maturity, safety considerations, operational costs, and the unique environmental and logistical conditions of a working Indian port.

This section takes you inside the plant to understand its various components and why a specific technology was chosen after evaluating global options.

3.2. THE ELECTROLYSER – THE HEART OF THE PLANT

An electrolyser is to a hydrogen plant what a heart is to the human body — the central unit that drives the core process. Its job is simple in principle but complex in execution: split water into hydrogen and oxygen using electricity. However, not all electrolysers are the same. Around the world, three main technologies dominate the commercial and pilot-scale hydrogen production landscape.

TYPES OF ELECTROLYSERS

1. ALKALINE WATER ELECTROLYSER (AWE)

Maturity: : The most established hydrogen production technology, widely used in industries for decades.

How it works: Uses a liquid alkaline electrolyte, typically potassium hydroxide (KOH) or sodium hydroxide (NaOH), with electrodes submerged in the solution.

Pros:

- Lower capital cost compared to other types.
- Long track record with proven operational stability.
- Tolerant to a wider range of water purity compared to PEM.

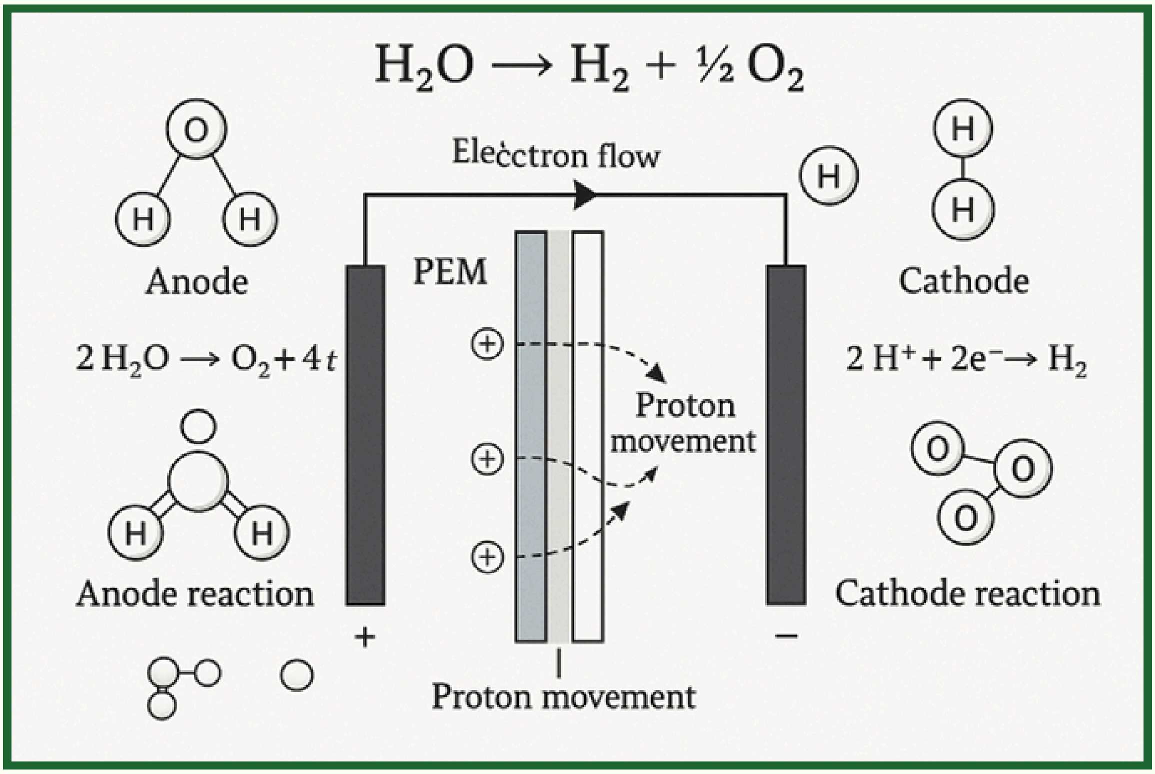
Cons:

- Slower ramp-up time — less suitable for fluctuating renewable power inputs.
- Produces hydrogen of slightly lower purity without extra purification steps.
- Larger physical footprint for the same hydrogen output.

2. PROTON EXCHANGE MEMBRANE (PEM) ELECTROLYSER

Maturity: A more recent but rapidly growing technology in the clean hydrogen sector.

How it works: Uses a solid polymer membrane (typically perfluorosulfonic acid – PFSA) as the electrolyte. Hydrogen ions pass through the membrane, while electrons are routed through an external circuit, generating usable power in the process.



Chemical Reaction in PEM Electrolyser

Pros:

- Can achieve very high electrical efficiency.
- Can integrate with industrial processes that generate waste heat.

Cons:

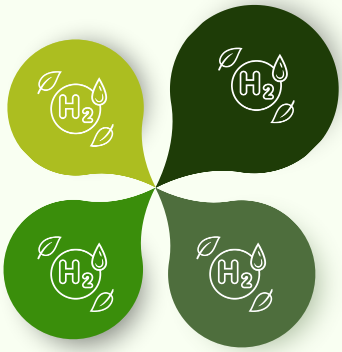
- Requires specialised high-temperature materials.
- Limited commercial track record and long-term operational data

WHY PEM FOR VOC PORT?

For a pilot-scale demonstration plant aimed at showcasing advanced technology and future compatibility with renewable energy sources, the Proton Exchange Membrane (PEM) electrolyser was the clear choice.

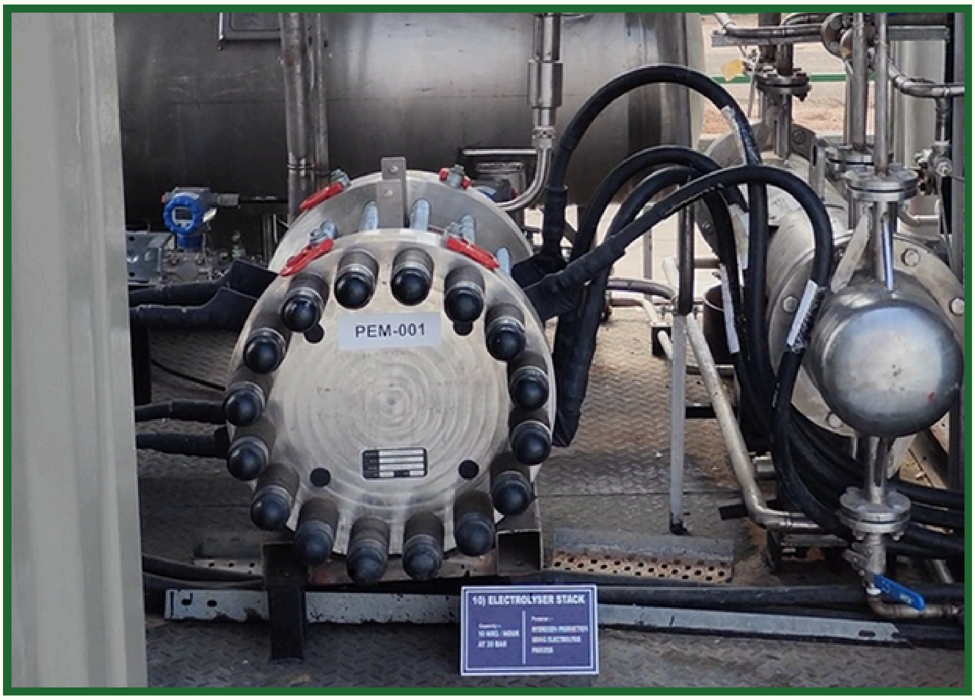
Handles dynamic power inputs
Can operate effectively even when electricity supply varies, making it suitable for renewable energy integration.

Compact footprint
Space inside an active port is at a premium; PEM's smaller size compared to AWE allows more efficient use of the available area.



High-purity hydrogen output
Directly meets ISO 14687 fuel quality standards, which is crucial for downstream applications like fuel cells.

Fast ramp-up
Enables the plant to start producing hydrogen within minutes, supporting flexible operation during tests and demonstrations.



Electrolyser Stack

3.3. WATER INPUT SYSTEM – FROM SOURCE TO STACK

If hydrogen is the final fuel of this plant, water is its primary feedstock. The quality of that water is not just a technical detail — it's the difference between an electrolyser that runs efficiently for years and one that fails prematurely.

At VOC Port's Green Hydrogen Pilot Plant, the Water Input System — also called the Water Treatment Unit (WTU) — plays a critical role before the first bubble of hydrogen is ever produced. Its mission is simple but uncompromising: deliver water so pure that it meets the highest standard applicable for electrolysis anywhere in the world.

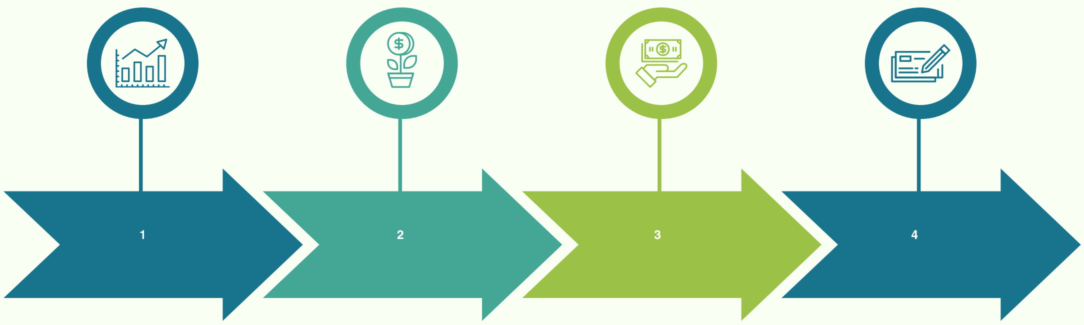
Function and Importance

The Water Input System treats and pumps water into the process, which is later electrolysed in the PEM stacks. Unlike other industrial systems that can tolerate a degree of mineral or organic content, PEM electrolysers are highly susceptible to contamination. Even trace amounts of dissolved salts, silica, or organics can clog membranes, poison catalysts, or degrade the stack's polymer electrolyte. Once damaged, these stacks are expensive to repair or replace.

For this reason, the water entering the electrolyser must meet stringent purity standards and the VOC Port plant has committed to nothing less than ASTM D1193-91 Type I ultrapure water, with a resistivity of 18.2 MΩ·cm. This is a level of purity typically reserved for semiconductor manufacturing, pharmaceutical processes, and advanced laboratory work.

HOW PURIFICATION IS ACHIEVED

At VOC Port, water purification is a multi-stage process designed for reliability, efficiency, and compliance with the standard:



Carbon Filters
Remove chlorine, chloramine, and organic matter, protecting downstream membranes from oxidation damage.

Softeners
Remove hardness-causing calcium and magnesium ions, preventing scale buildup on RO membranes and piping.

Reverse Osmosis Unit
The workhorse of the system, rejecting over 99% of dissolved salts, bacteria, and particulates.

Polishing Stage (Deionisation)
Achieves final resistivity target by removing any remaining ions through ion-exchange resins.

Every drop of water entering the electrolyser has passed through this treatment train, ensuring that it is **free from minerals, organic matter, and microbial contamination.**

TYPES OF WATER PURIFICATION FOR ELECTROLYSIS

Electrolysers, regardless of technology type, demand ultra-pure water to maintain performance and efficiency. Common purification methods include:

1. Reverse Osmosis (RO) + Deionisation (DI)

- **Industry Standard**: Widely adopted for hydrogen plants.
- **Effectiveness:** Removes salts, minerals, organic compounds, and many microorganisms.
- **Advantages:** Balanced in cost, performance, and scalability.

2. Distillation Systems

- **Principle:** Boils water and condenses steam, leaving most impurities behind.
- **Advantages**: Produces extremely pure water without ion exchange resins.
- **Drawbacks:** Very high energy consumption, making it less attractive for medium-scale continuous hydrogen production.

3. Electrodeionisation (EDI)

- **Principle:** Uses electricity and ion-exchange membranes to continuously remove ions.
- **Advantages:** No need for chemical regeneration of resins, environmentally friendlier.
- **Drawbacks:** Higher initial cost, requires pre-treatment via RO to be effective.

WHY RO + DI FOR VOC PORT?

The choice of purification system was guided by practicality, cost-efficiency, and proven reliability:

- **Cost-effective for medium-scale plants** – Balances CAPEX and OPEX while achieving ultrapure quality.
- **Proven track record** – Well-established in both industrial hydrogen plants and laboratory systems for achieving ASTM D1193-91 Type I water quality.
- **Modular and maintainable** – Filters, membranes, and resin beds can be replaced without plant downtime, and capacity can be scaled up by adding units.

THE VOC SYSTEM USES A THREE-STAGE APPROACH

1. **Sump Tank** - The sump tank typically acts as a collection reservoir for raw potable water or partially treated water that will be further purified before being used in the electrolyser. It provides a steady and buffered supply of water to downstream treatment units like RO (Reverse Osmosis) or deionization units.

Sump Tank

2. **Potable Water Pump-** It is primarily used to deliver raw potable water (meeting potable water standards) from the sump tank to electrolyser DI Water Unit.

Portable Water Pump

3. DI Water Unit- Water consumption requirement for production in electrolysis is approximately 9kg H2O per 1kg H2. The water source on site is a local river, the installation of a Reverse Osmosis (RO) system upstream of the water treatment process is permitted to produce Type 1 water.

Design Insight: The choice of RO + DI also accounts for Tuticorin's local water supply profile, balancing treatment capability with operational cost.

DI Water Unit

3.4. WATER & OXYGEN MANAGEMENT – COOLING AND SAFE VENTING

Running an electrolyser is a balancing act. While the primary goal is to generate hydrogen, every second of operation also produces heat and oxygen — both of which must be managed safely and efficiently.

At VOC Port's Green Hydrogen Pilot Plant, water and oxygen management is an integrated process that ensures the PEM stacks remain at their optimal operating temperature while oxygen, the inevitable by-product of electrolysis, is handled in a way that is both safe for the plant and harmless to the environment.

TEMPERATURE CONTROL – KEEPING THE STACK IN THE SWEET SPOT

Electrolysis stacks are designed to operate at a constant temperature of approximately 50°C (the exact value depends on the stack configuration and technology used).

Why 50°C?

- At this temperature, electrochemical efficiency is maximised.
- Membrane hydration is maintained, preventing both drying out (which reduces conductivity) and excessive swelling (which can damage the membrane).
- Catalyst activity is stable, ensuring consistent hydrogen production rates.

If the stack runs too hot, membrane degradation accelerates; too cold, and efficiency drops. Temperature stability is therefore critical.

COOLING AT VOC PORT – THE CLOSED-LOOP ADVANTAGE

Cooling is achieved through a closed-loop circuit that circulates treated water between the stack and cooling towers mounted on the roof of the electrolyser building. This system ensures continuous removal of excess heat without introducing contaminants back into the process.

Cooling Options for Electrolysers

1. **Air Cooling**

- **Principle**: Uses fans to blow ambient air across heat exchangers.
- **Advantages**: Simple, low maintenance.
- **Drawbacks**: Efficiency drops sharply in hot or humid climates; less effective for large-scale systems.

2. Water Cooling

- **Principle:** Transfers heat from the process fluid to water, which is then cooled by air or another medium.
- **Advantages**: Higher heat transfer efficiency than air cooling.
- **Drawbacks**: Requires careful water treatment to prevent fouling and scaling.

3. Closed-Loop Cooling Towers

- P**rinciple**: Circulates process water in a sealed loop through a heat exchanger inside the tower, while a secondary water/air stream removes heat.
- **Advantages**: Prevents direct exposure of process water to ambient air, reducing contamination risk; supports stable operation in varied climates.
- **Drawbacks**: Slightly higher initial cost than open-loop systems, but pays off in operational reliability.

WHY CLOSED-LOOP COOLING TOWERS AT VOC PORT?

Tuticorin's coastal climate brings both high humidity and elevated ambient temperatures for much of the year. In such conditions, open-loop or air-based cooling would struggle to maintain stable electrolyser temperatures.

Closed-loop cooling towers were chosen because they:

- Maintain a stable ~50°C stack temperature regardless of external fluctuations.
- Prevent contamination by keeping process water isolated from airborne dust, salt spray, and microorganisms.
- Reduce make-up water demand, aligning with the port's sustainability objectives in water usage.

Oxygen – The Other Product of Electrolysis

Tuticorin's coastal climate brings both high humidity and elevated ambient temperatures for much of the year. In such conditions, open-loop or air-based cooling would struggle to maintain stable electrolyser temperatures.

OXYGEN MANAGEMENT AT VOC PORT

1. Gas/Water Separation

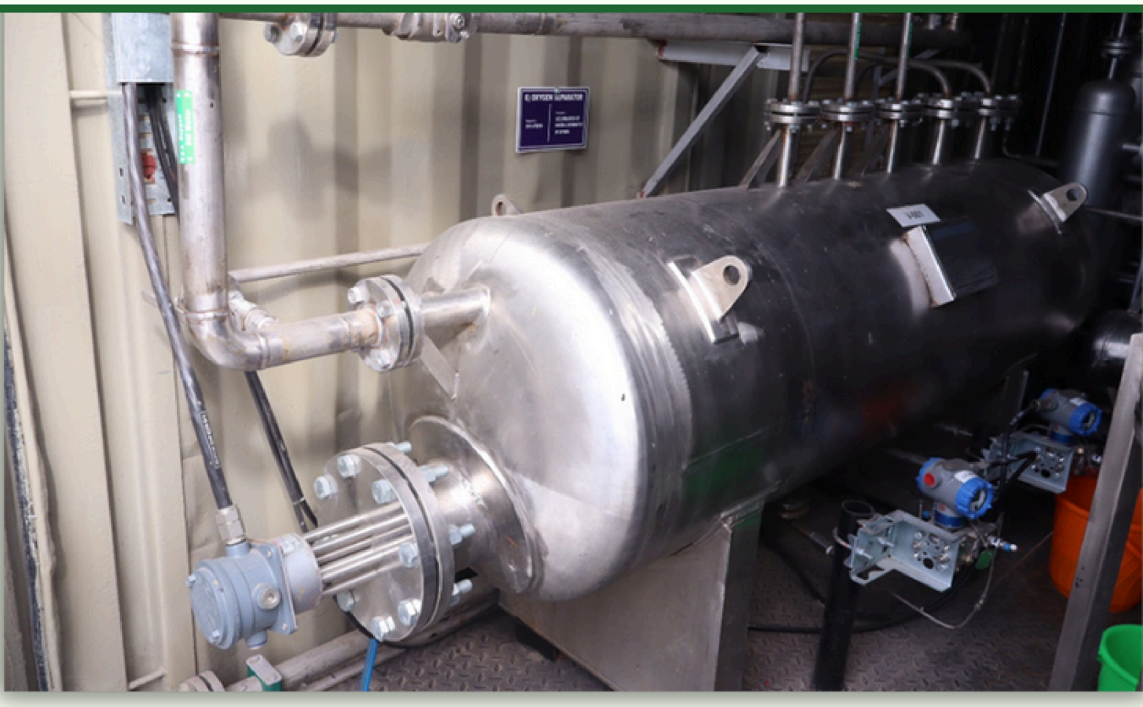
- The oxygen stream leaving the anode is saturated with water vapour and droplets.
- A gas/water separator removes this moisture, ensuring the oxygen leaves the stack area dry and preventing water carryover into the vent lines.

2. Safe Venting

- Once separated from water, oxygen is safely vented to the atmosphere through a controlled outlet, positioned to avoid re-entrainment into process areas.

- This ensures zero oxygen crossover into the hydrogen streams — a critical safety requirement, as even trace amounts of oxygen in hydrogen can create explosive mixtures.

Oxygen and Water Management System



Oxygen Separator

3.5. HYDROGEN GAS & WATER MANAGEMENT – ENSURING FUEL-CELL READY PURITY

PURIFICATION METHODS

Hydrogen gas produced at the cathode must be processed due to the water content resulting from proton drag (electro-osmotic transportation of water across the PFSA membrane). Produced gas with associated water content is collected in a hydrogen gas/water separator, this allows the water to settle at bottom of tank and hydrogen to rise up to demister, i.e. another layer to eliminate risk of water vapours passing on.

Hydrogen Purification Unit

Hydrogen is then further cooled down, deoxidised, and purified of any oxygen in order to meet the ISO 14687 fuel quality requirement. It is then stored in H_2 Type 1 storage (approx. 30 Bar). The collected water is then safely recycled back into the oxygen separator tank, i.e. described in previous section.

COMMON HYDROGEN PURIFICATION TECHNOLOGIES

In the hydrogen industry, several purification routes are available:

1. Pressure Swing Adsorption (PSA)

- **How it works**: Passes hydrogen through beds of adsorbent material that selectively traps impurities.
- **Pros**: Produces very high purity hydrogen.
- **Cons**: More complex and better suited for large-scale plants.

2. Palladium Membrane Purification

- **How it works**: Hydrogen passes through a heated palladium alloy membrane, leaving impurities behind.
- **Pros:** Produces extremely high purity hydrogen (99.9999%).
- **Cons**: High cost, sensitive to contaminants, slow ramp-up.

3. Dryers + Catalytic Deoxidisers

- **How it works**: Oxygen is catalytically reacted with hydrogen to form water, which is then removed via dryers.
- **Pros**: Simple, compact, and effective for small to medium-scale plants.
- **Cons**: Limited to moderate flow rates.

WHY DRYER + CATALYTIC DEOXIDISER FOR VOC PORT?

The VOC Port plant is medium-scale, so oversized or highly complex purification systems would be unnecessary. The dryer + catalytic deoxidiser combination was chosen because it:

- Achieves the ISO 14687 specification (<6.5 ppm O_2, dew point < -55°C) without over-engineering.
- Has a compact footprint, fitting within the tight layout constraints of the pilot plant.
- Integrates seamlessly with the existing Balance of Plant (BoP) systems.

Hydrogen Purification Unit (Before Installation to the system)

3.6. STORAGE – KEEPING HYDROGEN SAFE AND READY

Producing hydrogen is only part of the story — keeping it safe, stable, and ready for use is equally important. In any hydrogen facility, the storage system acts as the plant's battery, holding energy in chemical form until it's needed.

At VOC Port's Green Hydrogen Pilot Plant, the storage system is designed with safety, operational efficiency, and project purpose in mind. Because this is a pilot-scale demonstration facility in an operational port environment, the storage configuration prioritises controlled pressure, ease of inspection, and seamless integration with the fuel cell.

TYPES OF HYDROGEN STORAGE

Hydrogen can be stored in various ways depending on application, scale, and safety requirements:

1. Low-Pressure Storage (up to ~30 bar)

- Stored in steel cylinders or tanks.
- Safer and less costly than high-pressure or cryogenic options.
- Used when the storage volume is relatively small and hydrogen is consumed close to the production site.

2. Medium-Pressure Storage (~200–300 bar)

- Common in industrial supply cylinders used for welding gases or laboratory hydrogen.
- Requires thicker cylinder walls and more robust fittings.

3. High-Pressure Storage (~350–700 bar)

- Used primarily for hydrogen vehicle refuelling stations and long-distance hydrogen transport.
- Requires composite cylinders (Type III or IV) and advanced safety valves.
- Involves greater storage energy, making safety systems more complex.

4. Cryogenic Liquid Hydrogen Storage

- Stores hydrogen as a liquid at -253°C, dramatically increasing density.
- Often used for space applications or where ultra-high energy density is essential.
- Requires continuous boil-off management to handle evaporating hydrogen.

CHOSEN AT VOC PORT – TYPE 1 STEEL CYLINDER CASCADE

For VOC Port's pilot project, the storage system uses Type 1 all-steel cylinders arranged in a cascade configuration.

- **Nominal storage pressure**: 30 bar.
- **Total capacity**: Approximately 8 kg of hydrogen — enough to store the output of about 10 hours of continuous electrolyser operation.
- The cascade arrangement allows operators to control filling and withdrawal efficiently, equalising pressure between cylinders to optimise storage use.

Why 30 Bar?

The choice of 30 bar storage pressure was deliberate, balancing safety, operational needs, and project scope.

- **Safety for a Pilot Project**

Lower pressures mean less stored energy per cylinder, which reduces potential hazards in case of leakage or equipment failure. In a busy port environment, safety margins are especially critical.

- **Integration with Fuel Cell**

The downstream PEM fuel cell in the plant operates most efficiently at around 10 bar. Storing at 30 bar means that only simple pressure regulation is needed, without the energy penalties of decompressing from very high pressures.

- **No Long-Distance Transport Requirement**

Since all hydrogen is consumed on-site, there is no need for high-pressure cylinders typical of commercial delivery systems or vehicle fuelling stations.

- **Lower Equipment Stress**

Lower pressures mean less stored energy per cylinder, which reduces potential hazards in case of leakage or equipment failure. In a busy port environment, safety margins are especially critical.

- **Cost-Effectiveness**

High-pressure or cryogenic systems require more expensive materials, composite cylinders, and complex safety measures. For this scale of operation, such investments would offer no operational benefit.

Cylinder Cascade for Storage

3.7. FUEL CELL SYSTEM – ELECTRICITY ON DEMAND

While the electrolyser is the heart of the plant, the fuel cell is its showcase — converting stored hydrogen back into clean electricity on demand. At VOC Port's Green Hydrogen Pilot Plant, the Proton Exchange Membrane Fuel Cell (PEMFC) serves as a live demonstration of how hydrogen can be used as a practical, zero-emission energy carrier.

HOW THE PEM FUEL CELL WORKS

A PEM fuel cell generates electricity through an **electrochemical reaction** between hydrogen and oxygen — a reverse process of electrolysis.

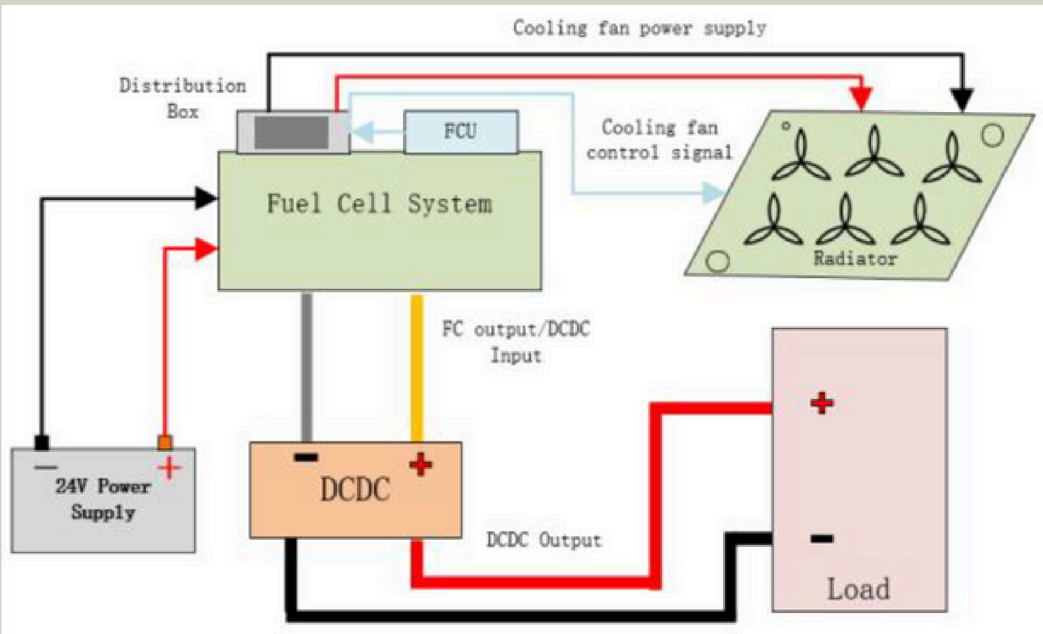
- **Anode side**: Hydrogen gas is fed to the anode, where it is split into protons (H^+) and electrons (e^-) by a catalyst layer.

- **Membrane function**: The thin polymer electrolyte membrane — typically made from perfluorosulfonic acid (PFSA) — acts as a proton conductor, allowing only H^+ ions to pass through while blocking electrons.

- **Cathode side**: Oxygen (from air) is fed to the cathode. The protons pass through the membrane and combine with oxygen and the electrons (traveling through an external circuit) to form pure water.

- **Electricity generation**: The flow of electrons through the external circuit is what provides usable electrical power.

The only outputs from this process are electricity, water, and low-grade heat — making the PEMFC a truly clean energy device.



Electrical connection diagram of fuel cell system

FACTORS AFFECTING FUEL CELL SIZING

The size of the fuel cell is determined by more than just desired electrical output:

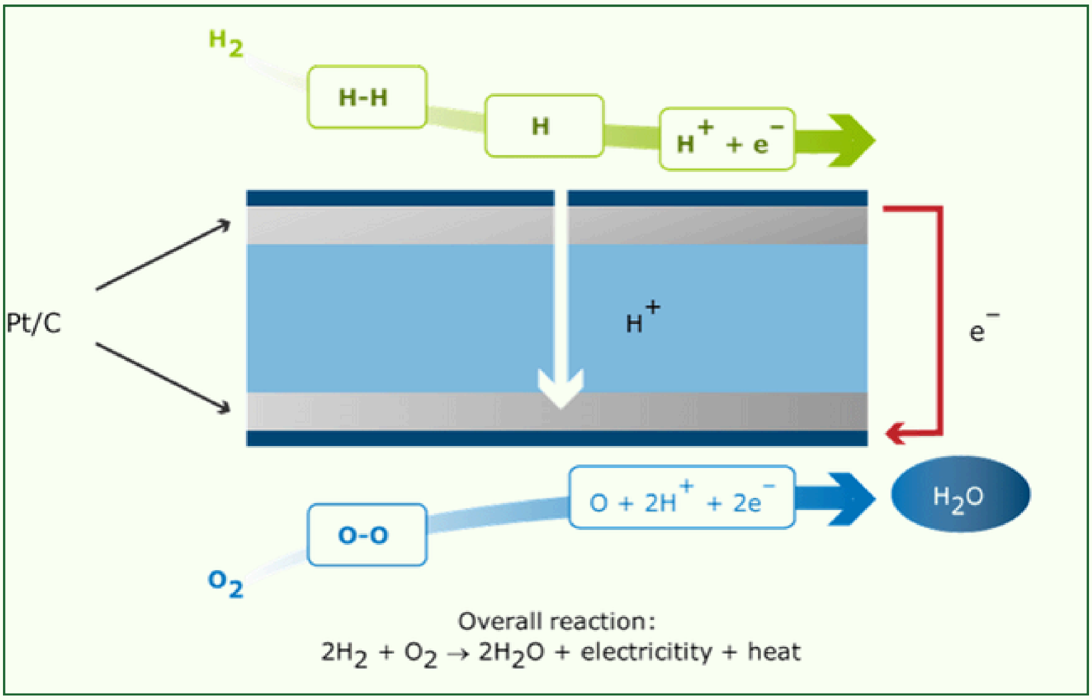
- **Net AC power requirement** – The target electrical output after accounting for internal system losses.

- **Balance of Plant (BoP) consumption** – Components like pumps, cooling systems, and controllers consume a share of the generated power.

- **Elevation** – Higher altitudes reduce available oxygen in air, requiring larger cathode areas to maintain output.

- **Weather conditions** – Extreme temperatures can influence cooling load, start-up time, and membrane hydration.

These factors ensure that the fuel cell is not just powerful enough for its intended use but also resilient to local environmental conditions.



PEM Fuel Cell Principle

COMMON FUEL CELL TYPES

PEMFC – Proton Exchange Membrane Fuel Cell

- **Operating temperature**: Low (50–80°C).
- **Advantages**: Quick start-up, compact design, low noise.
- **Common uses**: Vehicles, portable generators, and small to medium-scale stationary power.

SOFC – Solid Oxide Fuel Cell

- **Operating temperature**: High (700–1,000°C).
- **Advantages**: High electrical efficiency, can use a variety of fuels.
- **Drawbacks**: Long warm-up times, sensitive to thermal cycling.

AFC – Alkaline Fuel Cell

- **Operating temperature**: 60–90°C.
- **Advantages**: High efficiency at low temperatures.
- **Drawbacks**: Highly sensitive to CO_2 contamination, limiting practical deployment.

WHY PEMFC AT VOC PORT?

The choice of PEM fuel cell for VOC Port was strategic:

- **Technology synergy** – Matches the PEM electrolyser, allowing direct integration without compatibility issues.
- **Rapid start-up** – Ideal for demonstration purposes, where the fuel cell must be operational within minutes.
- **Compact and low-noise** – Fits neatly into the port's operational environment without causing disturbances or taking excessive space.

Fuel Cell Generato

Inverter

3.8. INSTRUMENTATION & CONTROLS – THE NERVE CENTRE

At VOC Port's Green Hydrogen Pilot Plant, the instrumentation and control systems form the central nervous system of the entire operation. From starting up the electrolyser to managing water circulation, every decision is made through a network of sensors, controllers, and automated responses — all designed for precision, reliability, and efficiency.

RECTIFIER – POWER TRANSFORMATION FOR ELECTROLYSIS

While grid or generator power arrives as Alternating Current (AC), the electrolyser operates exclusively on Direct Current (DC). The rectifier serves as the critical interface between the plant's power source and its hydrogen-producing stacks:

- Converts **incoming high-voltage AC** into a **controlled DC output** suitable for electrolysis.
- Regulates **current and voltage** precisely to match the operating requirements of the PEM electrolyser stacks.
- Ensures power stability during varying load conditions — essential for maintaining hydrogen production quality and efficiency.

The rectifier's performance directly affects **gas purity**, **stack longevity**, and **system reliability.**

Rectifier

PLC – THE PLANT'S DIGITAL BRAIN

The **Programmable Logic Controller (PLC)** is the **command centre** of the hydrogen production facility. Acting as the decision-maker, it coordinates the operation of all subsystems in real time.

The PLC continuously monitors and controls:

- **Electrolyser operation** – Start/stop sequences, ramp-up, and ramp-down procedures.
- **Rectifier coordination** – Current and voltage regulation for optimum stack performance.
- **Water treatment and circulation** – Sump tank levels, reverse osmosis system, and feedwater pumps.
- **Cooling systems** – Chiller operations, cooling tower fans, and coolant pump performance.
- **Other Balance of Plant (BoP) functions** – Including gas handling and system interlocks.

It executes logic-based decisions instantly, using feedback from sensors and comparing them with setpoint conditions, ensuring that every subsystem operates in harmony.

PLC

WHY PLC + HMI FOR VOC PORT?

The integration of a **PLC with a Human-Machine Interface (HMI)** was chosen for several reasons:

Full automation

Ideal for pilot demonstrations where minimal manual intervention is desired.

Process visibility

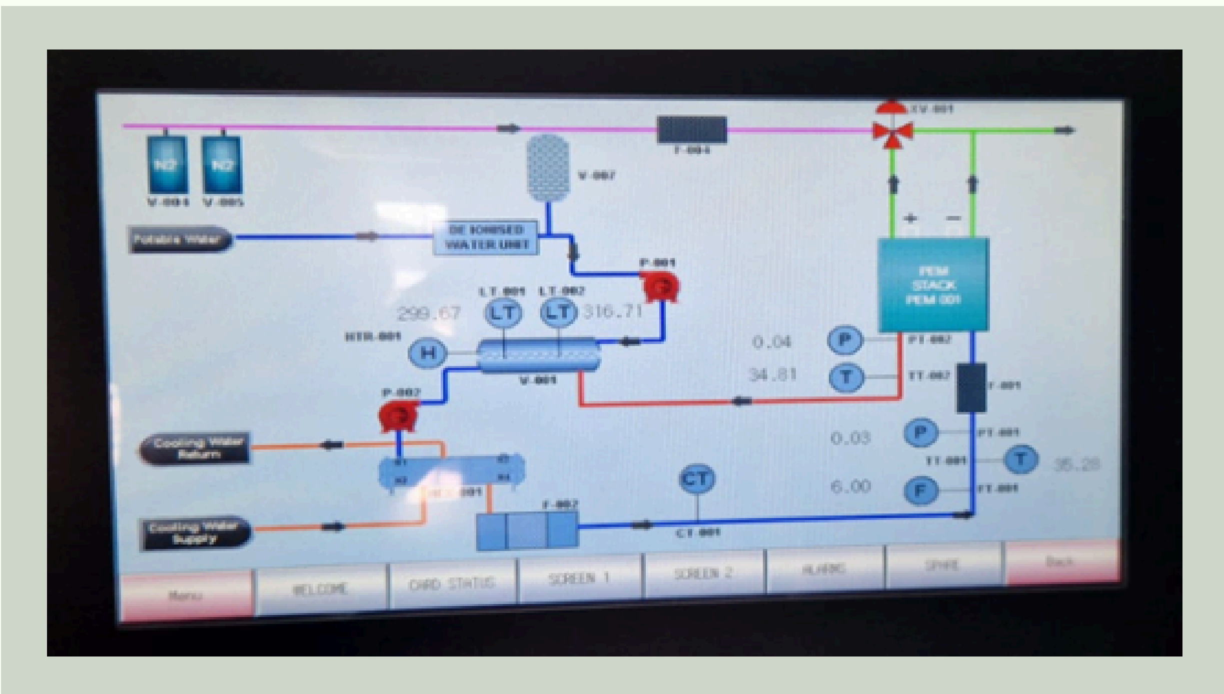
The HMI provides a live graphical display of plant performance, making it easier for operators to understand and interact with the system.

Future scalability

The control system can be expanded to manage **port-wide hydrogen networks** as the green hydrogen programme grows.

Embedded safety logic

While the dedicated safety system is covered separately, the PLC also incorporates process interlocks to maintain operational integrity.



HMI Screen

OPERATIONAL CONTINUITY AND BACKUP

To prevent uncontrolled shutdowns, the PLC is supported by a battery backup pack capable of 30 minutes of operation during power loss. This ensures a safe, sequenced shutdown of equipment without stressing components or compromising hydrogen containment.

FIELD INSTRUMENTATION – THE PLANT'S SENSES

The hydrogen plant's awareness of its own health comes from its network of field instruments:

- **Pressure transmitters** for monitoring pressures in electrolyser stacks, pipelines, and storage vessels.
- **Temperature transmitters** for keeping stack and coolant loops within optimal ranges.
- **Flow transmitters** for tracking water and hydrogen movement.
- **Conductivity transmitters** to verify ultra-pure water quality.
- **Level transmitters** to manage storage tanks and avoid overflows or shortages.

Each instrument communicates with the PLC, creating a real-time operational picture.

LOCAL AND REMOTE-CONTROL CAPABILITY

While centralised automation is the default mode, Local Control Stations (LCS) are provided near critical equipment. These enable technicians to perform maintenance, calibration, or manual operation during testing without needing to return to the main control room.

ELECTRICAL AND COMMUNICATION INFRASTRUCTURE

The reliability of plant operations is underpinned by its electrical and communication backbone:

- **Well-organised internal wiring and cabling** to prevent interference and allow quick maintenance.
- **Proper earthing and bonding** to ensure electrical stability and protect sensitive electronics.
- **Clearly labelled circuits** to speed up troubleshooting.
- **Integration-ready design** for future connection to broader port control systems.

CHAPTER 4

CONSTRUCTION & INSTALLATION – BUILDING THE FOUNDATION OF CHANGE

Every great project begins with the ground beneath it. For the Green Hydrogen Pilot Plant at VOC Port, the first step was laying a strong civil foundation. Dedicated plots were carefully marked and bounded — not just to define space, but to ensure safety, accessibility, and seamless integration of the plant's diverse systems.

Within this foundation, the essential modules of the plant began to take their place. **The storage system, electrolyser container with its purification unit, the fuel cell container, and the E-House with control room** were all positioned with precision. These were not custom-built on-site; instead, each came as an "off-the-shelf" solution, engineered, tested, and ready to be installed. This modular approach saved time, reduced risks, and ensured that proven, high-quality systems were being deployed.

Construction Photo 1

Once the containers stood firmly in their designated zones, the real choreography began — connecting them into a single, living system. Pipelines were laid to carry water, hydrogen, and oxygen flows, while cables spread like nerves and arteries, transmitting power and signals between the units. Each connection was a link in the chain, bringing the plant closer to its first breath of operation.

Construction Photo 2

Step by step, the construction and installation phase transformed the site from a bare civil foundation into a complete ecosystem — a space where technology, infrastructure, and vision converged. What had once been an idea on paper was now taking visible, physical shape, ready for the commissioning stage that would bring it fully to life.

Installation of Various units

CHAPTER 5

COMMISSIONING – BRINGING THE PLANT TO LIFE

The commissioning phase was both a technical test and a moment of anticipation — like seeing a ship float for the first time. The checklist from the VOC Port records reads like a story in itself:

5.1. CIVIL & MECHANICAL READINESS

5.1.1. CIVIL FOUNDATIONS (ELECTROLYSER, HYDROGEN STORAGE, FUEL CELL)

- **What was checked:** Visual inspection of foundation pads for the electrolyser skid, hydrogen storage bundle area, and fuel-cell foundation. Checks included levelness, concrete finish, anchor bolt locations and cleanliness of mounting surfaces.
- **Why it matters:** Proper foundations ensure mechanical stability, correct alignment of skid equipment and safe transfer of loads. Poor foundations can cause vibration, misalignment, and premature equipment wear.
- **Criteria:** Visual inspection.
- **Result:** Satisfactory

5.1.2. ERECTION OF EQUIPMENT ON FOUNDATIONS (ELECTROLYSER, STORAGE, FUEL CELL)

- **What was checked:** Placement and mechanical mounting of the electrolyser module, Type-1 cylinder cascade (storage) and the 10-kW fuel-cell unit — including bolting, grouting (if applicable), and skids alignment.
- **Why it matters:** Correct erection prevents mechanical stresses, ensures sealing of fluid connections and prepares the plant for piping/electrical interconnections.
- **Criteria:** Visual inspection.
- **Result:** Satisfactory

5.1.3. PIPING INTERCONNECTION BETWEEN ELECTROLYSER, STORAGE AND FUEL CELL

- **What was checked:** All process piping connections for hydrogen, water and instrument lines were installed and subjected to integrity testing. Pressure testing (as per project/test procedure) and visual inspection were performed to confirm leak-tight joints and correct routing.
- **Why it matters:** Leak-free piping is critical for safety (hydrogen leakage), performance (no pressure loss) and compliance.
- **Criteria:** Visual inspection & pressure testing.
- **Result:** Satisfactory

5.2. ELECTRICAL & CONTROL SYSTEMS

5.2.1. INSTALLATION OF ELECTRICAL PANELS & EQUIPMENT

- **What was checked**: Installation of MCCs/DBs, power distribution panels, rectifier input panels and other electrical cabinets. Inspections included wiring terminations, clearances, labelling and power availability. Functional checks were performed to verify panel health.
- **Why it matters:** Robust electrical installation is essential to feed the electrolyser and support all BOP (Balance of Plant) loads safely.
- **Criteria:** Operational verification.
- **Result**: Satisfactory

5.2.2. PLC PANEL INSTALLATION & CONFIGURATION

- **What was checked:** PLC rack installation, I/O mapping, interlocks and logic verified for cause-and-effect scenarios (start/stop, alarms, safety trips). Redundancies where required were validated.
- **Why it matters:** PLC governs automated sequences and safety responses — incorrect logic can lead to unsafe or damaging operations.
- **Criteria**: Control & operational verification as per cause-and-effect matrix.
- **Result:** Satisfactory

5.2.3. HMI PANEL INSTALLATION & CONFIGURATION

- **What was checked:** HMI screens configured and linked to PLC tags; live instrument readings (pressure, temperature, flow, conductivity, gas concentrations) displayed and logged. Alarm annunciation and operator controls validated.

- **Why it matters:** HMI provides operators situational awareness and manual control when needed. Accurate feedback is vital for safe operation.

- **Criteria:** Feedback as per field instruments.

- **Result:** Satisfactory

5.2.4. CCTV INSTALLATION & VERIFICATION

- **What was checked**: Security and process cameras installed at strategic locations (electrolyser area, storage, control room) and tested for field of view, recording and remote access.

- **Why it matters**: Visual monitoring supports safety, security and troubleshooting during operation.

- **Criteria:** Operational verification

- **Result**: Satisfactory

5.3. WATER TREATMENT & UTILITIES

5.3.1. DEMINERALISATION (DM) UNIT FUNCTIONING

- **What was checked**: DM/RO/DI system output conductivity measured to verify water purity for the PEM stack. The commissioning criterion logged was Conductivity ≤ 0 µS/cm (ultra-pure condition per project requirement).

- **Why it matters:** PEM stacks are highly sensitive to ionic contamination; ultra-pure water prevents catalyst poisoning and prolongs stack life.

- **Criteria:** Conductivity ≤ 0 µS/cm.

- **Result:** Satisfactory. (Completed: Yes)

5.3.2. DM PUMP PERFORMANCE

- **What was checked:** Demineralised water feed pumps verified for flow capability sufficient to supply the electrolyser and flushing needs. Measured flow required to exceed 0.5 m^3/hr.
- **Why it matters:** Adequate flow ensures stable stack feed and supports purification & flushing operations.
- **Criteria:** Flow > 0.5 m^3/hr.
- **Result:** Satisfactory

5.4. POWER CONVERSION & THERMAL MANAGEMENT

5.4.1. RECTIFIER FUNCTIONING ACROSS DYNAMIC RANGE

- **What was checked:** Rectifier tested for AC→DC conversion, stability of voltage/current control, and ability to operate across the stated dynamic range (10–100%). Control response and ripple levels were observed and logged.
- **Why it matters:** Stable DC supply is essential for safe electrolyser operation and to permit flexible load following (important with renewables).
- **Criteria:** Dynamic range 10–100% with stable current/voltage control.
- **Result:** Satisfactory

5.4.2. COOLING TOWERS / COOLING SYSTEM FUNCTIONING

- **What was checked:** Closed-loop cooling system commissioned to verify coolant circulation, pump operation and capacity of cooling towers to maintain stack operating temperature. Operational checks run under anticipated load.
- **Why it matters:** Temperature control (approx. 50°C stack target) ensures electrolyser efficiency and stack longevity.
- **Criteria:** Operational verification.
- **Result:** Satisfactory

5.5. HYDROGEN PURIFICATION, INSTRUMENTATION & SEQUENCES

5.5.1 HYDROGEN PURIFICATION (INCLUDING DRYER) – INITIAL VERIFICATION

- **What was checked:** Purification train (demister, dryer, deoxidiser or other purifiers) tested for final hydrogen quality. Measured parameters: $O_2 \leq 6.5$ ppm and Dew Point ≤ –55°C.
- **Why it matters:** Fuel-quality specification (ISO 14687 compatibility) is required for safe storage and for feeding the fuel cell without damage.
- **Criteria:** O_2 PPM < 6.5; Dew Point < –55°C.
- **Result:** Satisfactory

5.5.2. FIELD INSTRUMENTS & HMI FEEDBACK

- **What was checked:** All transmitters (pressure, temperature, flow, conductivity, level) and gas concentrators were tested for accuracy and connectivity. Each instrument's signal was validated on the HMI and logging systems.
- **Why it matters:** Reliable instrumentation is the sensor foundation for control, safety trips and performance monitoring.
- **Criteria:** Correct feedback display in HMI.
- **Result:** Satisfactory

5.5.3. ELECTRICAL ACTUATED VALVES & SEQUENCES

- **What was checked:** All electrically actuated valves were run through their operational sequences and interlocks; response times and position feedback verified. Sequence logic (e.g., purge → pressurise → run) validated.
- **Why it matters**: Valve sequencing ensures safe pressurisation, isolation and avoidance of dangerous gas mixing during transitions.
- **Criteria:** Operational verification.
- **Result:** Satisfactory

5.5.4. HYDROGEN PURIFICATION (INCLUDING DRYER) – SECONDARY VERIFICATION

- **What was checked:** A repeat or follow-up verification of the purification system to confirm stable performance after system warm-up and during integrated tests. Reconfirmed O_2 ≤ 6.5 ppm and Dew Point ≤ –55°C.

- **Why it matters**: Repetition confirms purification remains within spec under integrated conditions (not just in isolation).

- **Criteria**: O_2 PPM < 6.5; Dew Point < –55°C.

- **Result:** Satisfactory

5.6. STORAGE & GAS HANDLING

5.6.1. HYDROGEN STORAGE (PRESSURE VESSEL)

- **What was checked**: Hydrogen cylinder cascade and manifold system pressurised and gauge verified to 30 bar (design nominal). Mechanical supports, isolation valves and leak checks confirmed.

- **Why it matters:** Correct storage pressure and secure vessels are fundamental to safe availability of hydrogen for fuel cell use and demonstrations.

- **Criteria:** 30 bar at pressure gauge.

- **Result:** Satisfactory

5.6.2. OXYGEN SEPARATOR & REGULATOR

- **What was checked:** Oxygen separator operation and regulator set-up verified to maintain required positive pressure on the oxygen side during stack operation. Function and regulator response checked.

- **Why it matters:** Proper O_2 handling prevents backflow or cross-contamination and ensures safe venting.

- **Criteria:** Operational verification.

- **Result:** Satisfactory

Operational Sequences, Venting & Fuel Cell Integration

5.6.3. STARTUP & SHUTDOWN SEQUENCES

- **What was checked:** Full start-up and shutdown procedures were executed and observed. This included pre-start checks, controlled ramping of rectifier/current, purging sequences and safe depressurisation.
- **Why it matters:** Correct sequences avoid pressure shocks, prevent unsafe gas pockets and protect the stack and downstream systems.
- **Criteria:** Operational verification.
- **Result:** Satisfactory

5.6.4. VENTING SEQUENCE TESTING FOLLOWING SHUTDOWN

- **What was checked:** The post-shutdown venting sequence was exercised to ensure controlled release of gases and avoidance of accumulation in plant enclosures. Vent paths and vents' check valves/regulators were verified.
- **Why it matters:** Safe venting prevents hazardous concentrations and supports controlled plant depressurisation.
- **Criteria:** Operational verification.
- **Result:** Satisfactory

5.6.5. PRESSURE REDUCTION VALVE TO FUEL CELL

- **What was checked:** The pressure reduction arrangement feeding the fuel cell was validated: Upstream at 30 bar, Downstream at ~10 bar (fuel-cell feed). Valve response and pressure stability under load were verified.
- **Why it matters:** Fuel cells require a controlled lower-pressure feed; correct regulation avoids cell damage and ensures efficient power generation.
- **Criteria:** Upstream = 30 bar; Downstream = 10 bar (as per design).
- **Result:** Satisfactory

5.6.6. ELECTRICITY GENERATION FROM THE FUEL CELL

- **What was checked:** Fuel cell operated and produced electrical output. The maximum net AC output was tested and confirmed at 10 kW. Inverter and grid/loads interfacing were verified.
- **Why it matters:** Demonstrates whole-chain operation: water → hydrogen → electricity (proof of concept).
- **Criteria:** Max output = 10 kW.
- **Result:** Satisfactory

5.7. FINAL SAFETY & COMPLIANCE CHECKS

5.7.1. EARTHING PITS COMPLIANCE

- **What was checked**: Grounding system resistance measured at earthing pits; value required to be below 1 ohm for compliance with electrical safety practice stated in the commissioning table.
- **Why it matters:** Low ground resistance prevents static buildup and provides a safe path for fault currents — critical in environments with flammable gases.
- **Criteria:** Range < 1 ohm.
- **Result:** Satisfactory

5.7.2. FIRE ALARM SYSTEM FUNCTIONING

- **What was checked:** Fire detection and alarm system tested in operational mode; alarms, notification and integration with plant control were verified.
- **Why it matters:** Rapid fire detection and alarm ensures timely operator action and emergency response coordination.
- **Criteria:** Operational verification.
- **Result:** Satisfactory

All 23 commissioning stages were executed and recorded as Satisfactory and Completed. The commissioning sequence covered civil/mechanical readiness, process piping, water quality, electrical and control systems, gas purification and storage, operational sequences, fuel-cell power generation and final safety checks — confirming the plant's readiness for demonstration and operation.

CHAPTER 6

SAFETY SYSTEMS & PROTOCOLS- GUARDING THE INVISIBLE FLAME

Hydrogen is a marvel of clean energy — but it's also a gas with unique hazards. It's colourless, odourless, lighter than air, and has a wide flammability range (4–75% in air). These properties make it efficient as a fuel but demand meticulous safety engineering.

At VOC Port's Green Hydrogen Pilot Plant, safety isn't an afterthought — it's woven into every pipe, valve, and control screen.

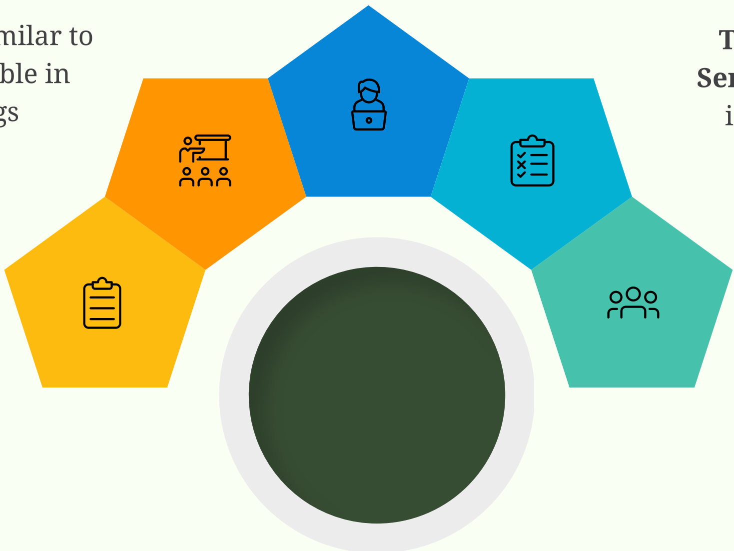
6.1. HYDROGEN DETECTION SYSTEMS

DETECTION TECHNOLOGIES IN INDUSTRY

Electrochemical Sensors – Detect hydrogen through chemical reaction; highly sensitive.

Pellistor Sensors – Similar to catalytic beads, reliable in industrial settings

Thermal Conductivity Sensors – Measure change in heat transfer due to hydrogen presence.



Catalytic Bead Sensors – Measure temperature change from hydrogen

Optical Sensors – Detect hydrogen using changes in light absorption or reflectance.

CHOSEN AT VOC PORT (AS IMPLEMENTED AT VOC PORT)

- Hydrogen gas detectors placed at strategic leak-prone locations.
- Integrated directly into the PLC control system.
- Immediate alarm generation & equipment shutdown upon detection.

6.2. VENTING & PRESSURE RELIEF SYSTEMS

TYPES OF VENTING DESIGNS

- **Open Vent Stacks** – Direct release to atmosphere at a safe height.
- **Flare Stacks** – Burns hydrogen before release.
- **Vented Enclosures** – Localised venting inside a protective housing.

CHOSEN AT VOC PORT (AS IMPLEMENTED AT VOC PORT)

- Safe atmospheric venting through elevated vent stacks for both oxygen and hydrogen.
- Vent lines designed per NFPA 55 & ASME B31.12.
- Venting sequence testing included in commissioning.

WHY THIS CHOICE?

- Hydrogen volume at this pilot scale does not require flaring.
- Elevated venting prevents accumulation in operational zones.

6.3. FIRE DETECTION & SUPPRESSION

OPTIONS IN HYDROGEN FACILITIES

- **UV/IR Flame Detectors** – Detect hydrogen's almost invisible flame.
- **Multi-spectrum Infrared Detectors** – High reliability in outdoor sunlight.
- **Gas-triggered Suppression Systems** – Flood area with inert gas like nitrogen.

CHOSEN AT VOC PORT (AS IMPLEMENTED AT VOC PORT)

- Fire alarm system with operational verification during commissioning.
- Designed for rapid operator notification rather than full automatic suppression, aligning with pilot plant risk profile.

WHY THIS CHOICE?

- Hydrogen burns with low radiant heat; rapid detection & evacuation are more effective than water or foam suppression.
- Inert gas systems were unnecessary given the plant's open, well-ventilated design.

6.4. ELECTRICAL SAFETY & EARTHING

ELECTRICAL RISK MITIGATION METHODS

- **Intrinsically Safe (IS) Circuits** – Limit electrical energy in hazardous areas.
- **Explosion-Proof Enclosures** – Contain sparks or arcs.
- **Purge & Pressurisation Systems** – Keep enclosures free of flammable gas.

CHOSEN AT VOC PORT (AS IMPLEMENTED AT VOC PORT)

- All internal electrical, control, and signal cabling follow hazardous area classification per IEC 60079.
- Earthing pits maintained at <1 ohm resistance.
- Emergency stop push buttons installed at critical points.

WHY THIS CHOICE?

- Ensures compliance with both IEC and NFPA standards.
- Low earthing resistance prevents static discharge in hydrogen areas.

6.5. OPERATIONAL SAFETY LOGIC – THE PLC SHIELD

At VOC Port, safety isn't just hardware — it's software.

The PLC logic is programmed for:

- Immediate shutdown on high hydrogen concentration, low water quality, or abnormal pressures.
- Safe venting before complete shutdown.
- Sequenced startup & shutdown to avoid pressure surges.

This **"digital safety net"** ensures that even if human operators miss something, the plant doesn't.

WHY THIS LAYERED SAFETY APPROACH WORKS FOR A PORT ENVIRONMENT

Ports are high-traffic industrial zones — forklifts, trucks, cranes, and ships operate just metres from sensitive equipment. By combining physical separation, automated controls, and fail-safe venting, VOC Port's design ensures that the hydrogen plant operates safely without disrupting other port activities.

Safety Insight: Hydrogen safety here follows the defence-in-depth principle — multiple barriers (detection, shutdown, venting) are in place so no single failure can cause an incident.

CHAPTER 7

PROJECT CHALLENGES, SOLUTIONS, LEARNINGS

The production of hydrogen via electrolysis remains relatively limited, as the majority of hydrogen currently available is derived from steam methane reforming or other fossil fuel-based processes. These conventional methods are associated with substantial carbon emissions. In contrast, electrolysis represents the only commercially viable pathway for producing hydrogen without any direct carbon emissions. When powered by renewable energy sources, the process ensures that hydrogen remains entirely green—from energy input to end use—thus offering a truly sustainable solution.

In this project, Proton Exchange Membrane (PEM) electrolyser technology was employed. PEM is a state-of-the-art and advanced form of electrolysis that provides enhanced operational flexibility compared to conventional technologies.

However, due to its relatively recent adoption, the construction and commissioning of a PEM-based plant pose several technical and logistical challenges. These were effectively addressed through the exemplary support of the site team and the VOC Port authority, enabling the successful implementation of appropriate and timely solutions:

S. NO	Project Challenges	Solutions	Lesson Learnt Completed
01	Contamination of piping and process vessels, due to site environment	All pipe and process vessels were thoroughly flushed with demineralised water, with conductivity of “0 µS/cm” It took multiple flushes more than what was expected. In addition, particulate filter was cleaned multiple times.	All process vessels and pipes shall be manufactured in dust free environment. Equipment shall be fully assembled and sealed when brought to site, to avoid any contamination or ingress of sand.
02	Availability of Skilled labour locally.	In general, local labour was closely supervised to ensure good quality work. Respective Labour was brought in from other towns/cities for special tasks.	System shall come to site fully assembled, as much as possible, with minimal integration to be done on site, eliminating the need of any fabrication work onsite
03	Water quality was not as per expectation, resulting in damages to the demineralisation plant (water purification)	Upgrades to the existing system to cope with current water supply and providing the required Type 1 quality ultra-pure water.	It shall be absolutely ensured that information available for quality of the raw potable water supplied shall be accurate.
04	Vendor supplied equipment not performing	Vendor’s engineers were called to site on a short notice to resolve respective problems	All vendor equipment shall be fully tested as FAT by trained technicians.
05	Lack of sufficient availability of demineralised water, considering site team had to do extensive flushing due to contamination. Water purification system within plant was not able to cope with requirement.	With kind support from VOC Port Officials, water was arranged locally with appropriate quality.	During commission activities, site engineers shall be available onsite. Additional Type 1 quality water shall be arranged for flushing of system, number of times, to be able to achieve, right levels of conductivity.

CHAPTER 8

THE VOYAGE FORWARD

This pilot plant is not the finish line; it is the first mile of a much longer voyage. What began as a bold idea and careful engineering will now become a living experiment that teaches, inspires, and scales. VOC Port will use the lessons learned here to shape clearer choices, bolder investments, and wider partnerships-all aimed at making green hydrogen a routine part of port life.

Looking further ahead, this pilot will become a stepping stone. It will inform decisions on larger plants, renewable energy links, and new business models that turn clean fuel into local jobs, services, and economic opportunities. Other ports and industrial hubs will look to VOC Port not just for technology, but for a tested pathway to transition- practical, phased, and people-centred.

Above all, VOC Port’s pilot is a signal to the maritime world: the shift to cleaner fuels is practical, achievable, and worth pursuing. The next chapters will be written through steady operational progress, transparent reporting, and a willingness to share success and setbacks alike. If this pilot proves anything, it is that transformation begins when a place chooses to try.

Building on this foundation, the port will now look toward scaling — not only larger electrolyser capacity but also complementary technologies such as green ammonia production, bunkering infrastructure, and integrated renewable generation. These next steps will convert demonstration learning into durable services: reliable refuelling options for visiting vessels, on-site industrial feedstocks, and exportable energy products that broaden the port’s economic footprint.

The practical pathway will be phased and data-driven: optimise operations from this pilot, expand capacity where demand and renewables align, and pilot ammonia conversion and storage when safety, economics and market signals converge. As capacity grows, so will the opportunity to standardise procedures, attract private investment, and create specialised local supply chains- from maintenance services to logistics and training that anchor green jobs to the region.

The journey continues — and VOC Port is ready to lead it. With this pilot as proof, the port will move from demonstration to deployment, turning a harbour of trade into a hub of clean energy for shipping, industry and communities alike.

GREEN TUG AT VOC PORT

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