Technical Appendix 1.1: Process Description

CROMARTY HYDROGEN PROJECT

OCTOBER 2023

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1 PROCESS DESCRIPTION

1.1 Overview

Cromarty Hydrogen will use electrolysis which uses electricity to break water into hydrogen and oxygen. Electrolysis is a carbon-free (Green) hydrogen when produced solely from renewable power.

The schematic below shows a high-level depiction of the process facilities which will be located on Beinn Tharsuinn.

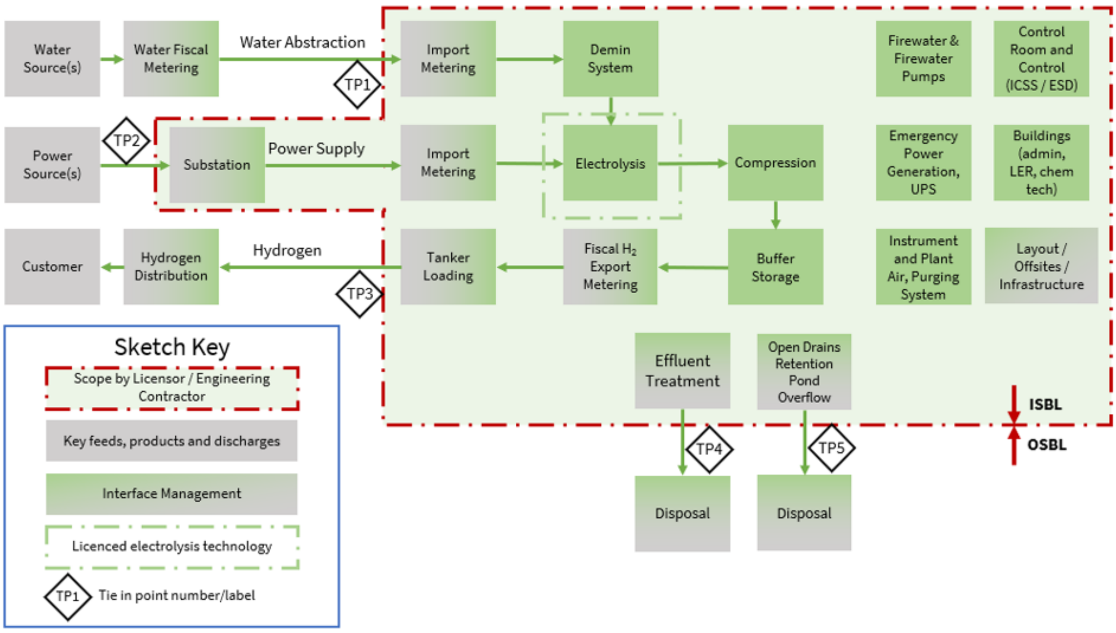

Figure 1.1.1: Cromarty Hydrogen Beinn Tharsuinn Site Process Schematic

1.2 Water Supply and Purification

The raw water source for Cromarty hydrogen is abstracted from the River Glass near Alness and transported by a new pipeline to the electrolyser plant at Beinn Tharsuinn, where water is first metered, filtered and deionised in a packaged demineralization unit before being pumped to 30 barg; the operating pressure of the electrolyser.

1.3 Electrolysis

The project is considering containerised modular units of electrolysers to provide hydrogen generated from renewable electricity. The hydrogen will be >99.9998% pure. Two types of electrolyser technology are being considered by the project:

- Pressurised Alkaline Electrolysis
- Proton Exchange Membrane (PEM)

The selection of technology will be made considering several factors including:

- Cost (Capex and Opex)
- Efficiency of hydrogen generation versus power consumption
- Availability/Reliability

- Water consumption
- Delivery schedule
- Safety
- Environmental

1.3.1 Alkaline Electrolysis

Alkaline electrolysers have historically been the primary method used to produce hydrogen. A Potassium Hydroxide (Lye) solution is added to the demineralised water to provide the ions for the electricity to be conducted between the electrodes.

Water molecules are dissociated at the negative cathode into H^+ and hydroxide OH^- with further recombination of H^+ into gaseous H_2 in presence of electrons e^- from the electric supply.

$$2\ H_2O\ (l) + 2\ e^- \leftrightharpoons H_2\ (g) + 2\ OH^-\ (aq)$$

Hydroxide OH^- ions in the electrolyte are attracted towards the positive anode by the electric field. There is a separator or diaphragm between electrodes which ensures that only hydroxide OH^- ions can travel from one side to the other. Both electron transport and gaseous H_2/O_2 transport are largely prevented by the membrane. If electron transport occurred it would create a short-circuit, while contact between H_2 and O_2 would lead to an immediate recombination into H_2O.

Once transported to the anode, OH^- anions are oxidised, producing gaseous oxygen and liberating electrons which flow out to the external electric circuit.

$$2\ OH^-\ (aq) \leftrightharpoons ½\ O_2\ (g) + H_2O\ (l) + 2\ e^-$$

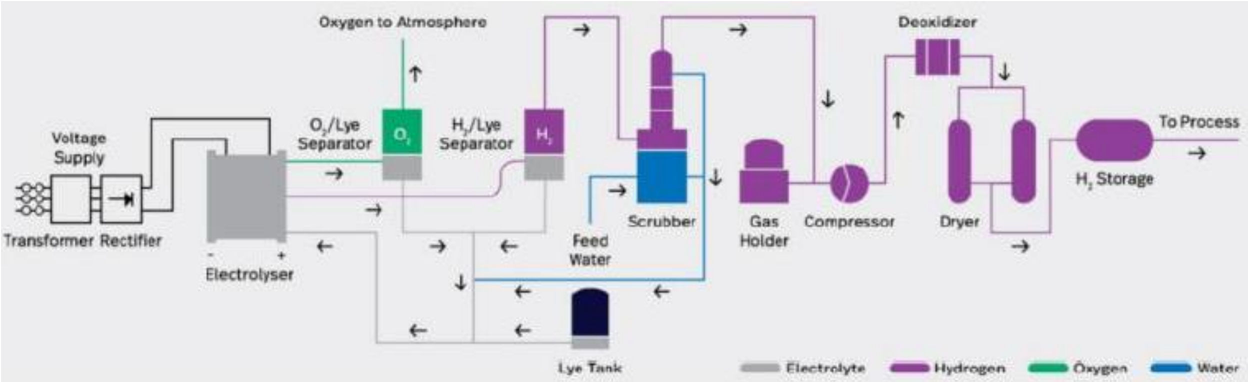

Figure 1-2: Alkaline Electrolyser Process Schematic

Alkaline electrolysis deploy low-cost, porous diaphragm separator and catalyst materials. The low cost of alkaline electrolysers comes at the cost of more limited operational flexibility: the diaphragm is permeable to gases dissolved in the electrolyte, limiting the lower operational load to ~20% of the nominal load and requiring gas purging cycles during cold starts, which results in long start-up times. In addition, the efficiency of the electrolyser declines during turndown operation. pressure. The ideal project environment for alkaline electrolysers are large-scale industrial installations requiring a steady hydrogen output at low pressure levels.

1.3.2 Proton Exchange Membrane (PEM) Electrolysis

In contrast to alkaline, Proton Exchange Membrane (PEM) electrolysers use a solid polymer or composite electrolyte. The solid membrane also prevents the transfer of oxygen and hydrogen produced from the electrodes but unlike alkaline allows the movement of positive hydrogen ions and electrons. Unlike alkaline oxygen is liberated this time at the anode which is coated with a catalyst to help speed up the reaction.

$$2\ H_2O\ (l)^- \leftrightharpoons O_2\ (g) + 4H^+\ (aq) + 4\ e^-$$

The acidic hydrogen ions and electrons pass through the polymer electrolyte to the cathode where they combine to liberate hydrogen.

$$4H^+\ (aq) + 4\ e^- \leftrightharpoons 2H_2(g)$$

The acidic environment of PEM and operating temperature of 80^{o}C entails the need for costly electrode materials such as platinum-based catalysts, an ion exchange membrane, and titanium-based electrodes. This leads to PEM usually being more expensive than alkaline. The key advantages of PEM electrolysers result from the membrane's high gas barrier properties that enable a rapid cold-start, and a wide operational load window. The ramp up/down response time of a PEM is around 10 times faster than alkaline. PEM also uses only demineralised water negating the requirement to handle chemicals. The energy demand of PEM electrolysers is typically slightly higher than alkaline however this can be compensated by a lower compression demand.

PEM electrolysers are therefore well suited for off-grid installations powered by highly variable renewable energy sources (e.g., wind turbines or solar panels). The fast start-up and wide operational load window enable an increased utilization compared to an alkaline system.

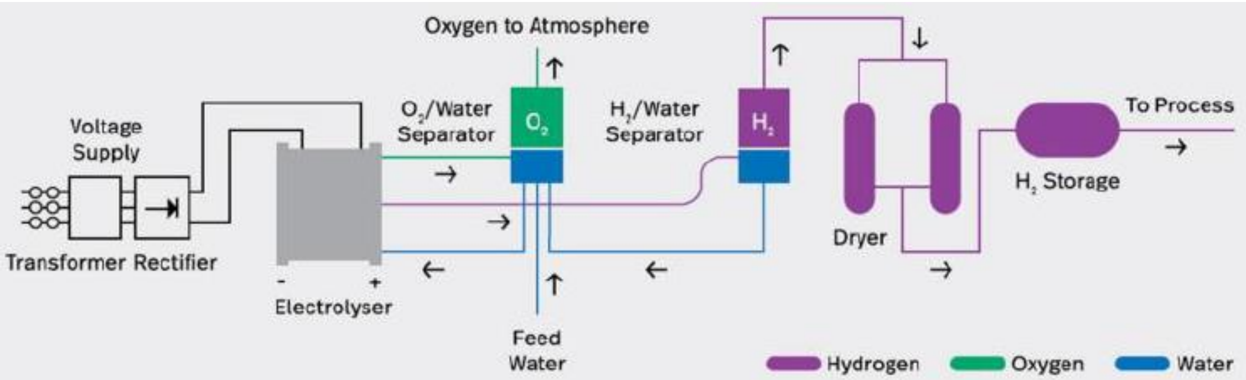

Figure 1-3: PEM Electrolyser Process Schematic

1.4 Hydrogen Drying, Compression and Storage

The hydrogen will be dried to remove any residual water before being cooled using air coolers to around 35^{o}C. The hydrogen is then compressed to 350barg using a multi-stage reciprocating compressor and again cooled to 35^{o}C before being routed to high pressure buffer tube storage. The storage will be sized to ensure the demand of consumes can be met whilst fully utilising the renewable power available.

The hydrogen is exported via metering to tube trailers filled with 350bar compressed hydrogen. The contracted Transporter drives low carbon fuelled tankers to Offtaker sites connecting to a Tanker Discharge Compound with hydrogen then flowing through a Hydrogen Cabinet to end use interface point(s).

1.5 Other Utilities

To service the hydrogen process a number of other utilities are required on the site:

- Nitrogen supply for purging;

- Air supply for instruments and utility points;
- Firewater storage, pumps, and deployment system (to be defined);
- Wastewater treatment and disposal;
- Chemical storage (for alkaline electrolysers);
- Emergency power generation;
- Uninterruptible Power Supply (UPS); and
- Hydrogen vent system.