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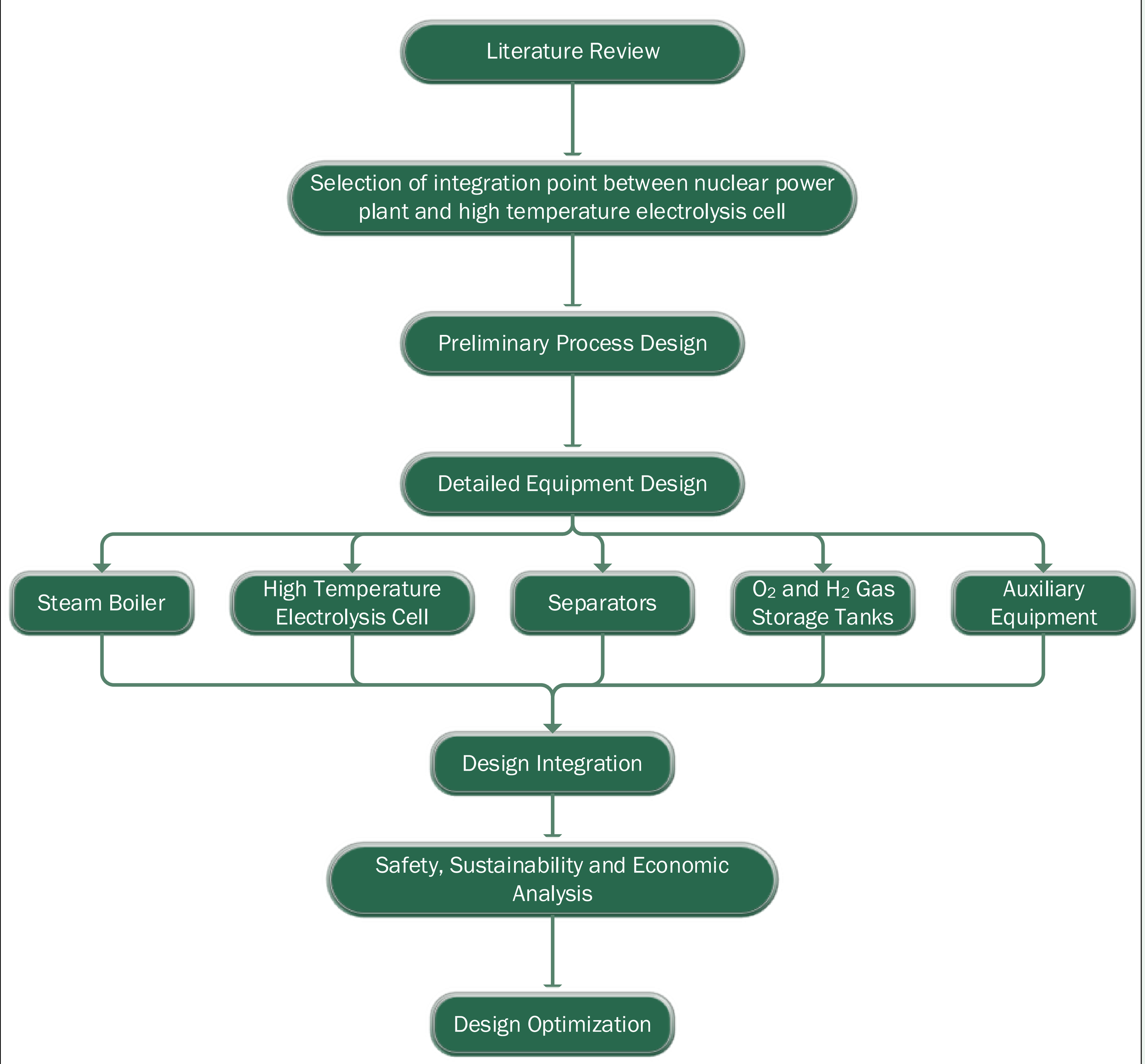
Hydrogen Production Using Canadian Nuclear Reactors

Introduction

- Demand for **hydrogen** as a **sustainable and storable energy source** is emerging in Canada
- Excess thermal and electrical energy from **nuclear power plants (NPP)** can be used for hydrogen production at low grid demands, and hydrogen can be used to generate electricity at high-demand periods
- **High temperature steam electrolysis (HTSE)** offers an efficient and economically viable option to produce hydrogen
- The primary **objective** of this project is to design a plant to produce hydrogen and oxygen using the HTSE process, and integrate this process with a Canadian nuclear reactor - **CANDU Subcritical Water-Cooled Reactor (Sub-WCR)** investigated

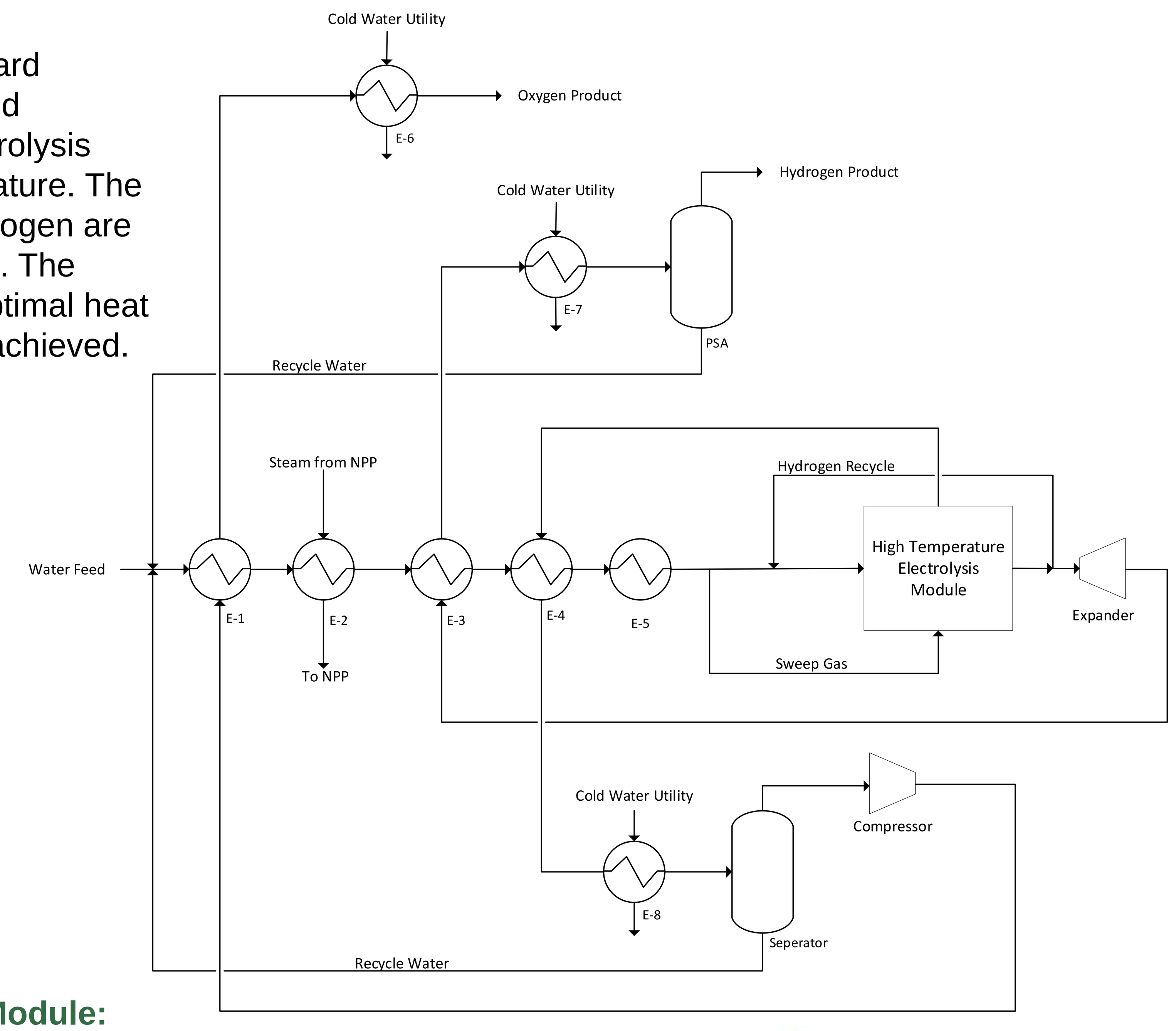
Design Process



Details of Design

Process Overview:

The process feed is water at standard conditions, which is then heated and vaporized before entering the electrolysis stage at high pressure and temperature. The exiting streams of oxygen and hydrogen are then further processed and purified. The process was designed such that optimal heat recovery and material recycling is achieved.



Heat Integration:

Heat exchangers were necessary to design an efficient process and meet pre-heating requirements for HTSE, and aid in cooling the product streams:

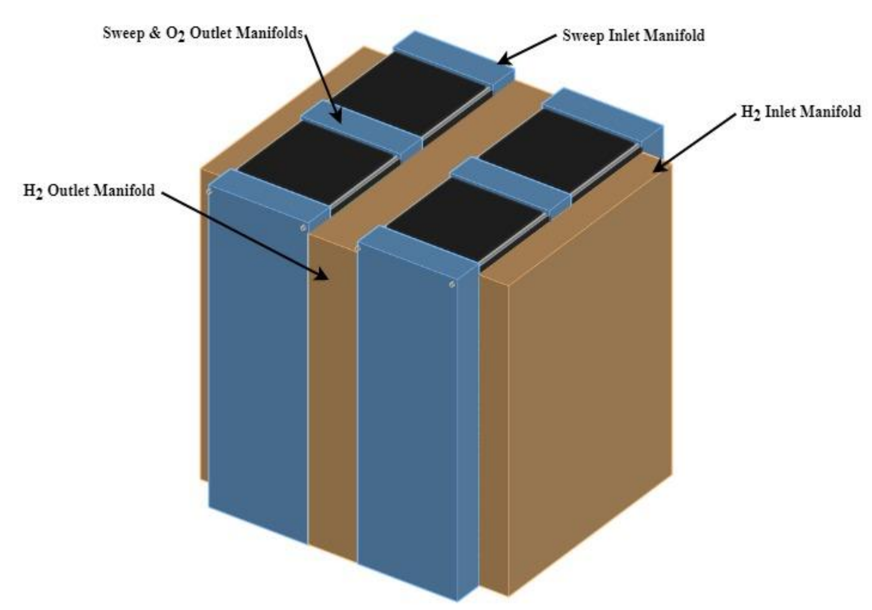
- E-1 exchanges heat with the tail end of the oxygen purification
- E-2 exchanges heat with NPP steam
- E-3 exchanges heat with the hydrogen product stream
- Exchangers E-6, E-7, and E-8 use cold utility to cool the product streams.

High Temperature Electrolysis Module:

- Electrolysis reaction separates the incoming steam into hydrogen and oxygen through the balanced equation:

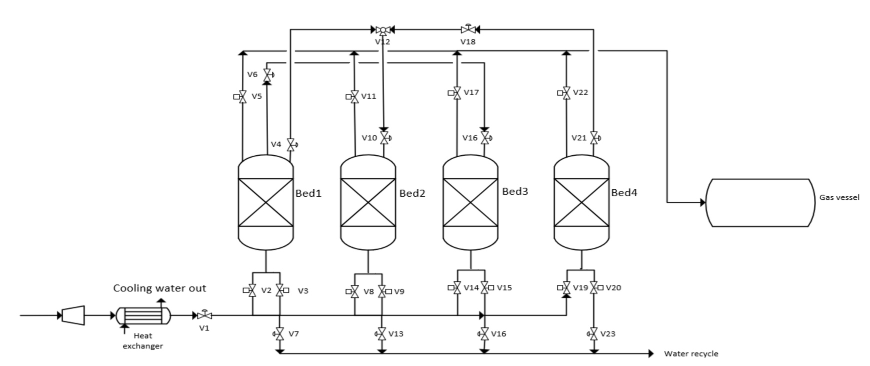
$$2H_2O \rightarrow 2H_2 + O_2$$

- Module: 1280 electrolysis cells, split into 64 stacks, arranged into 4 towers.
- Cells separate 89% of incoming steam into oxygen and hydrogen, while avoiding cell starvation and degradation (2% per 1000 hours).
- Cell operated at 1.29V and a current density of 0.41 Amp/cm^2
- At 1.29V (thermoneutral voltage), heat sources released in the cell are counterbalanced by the endothermic nature of the reaction, thus the electrolysis unit is assumed to operate isothermally with no heat addition necessary.
- Electrical energy requirement of the HTSE module approximated to be 67.70 kW.



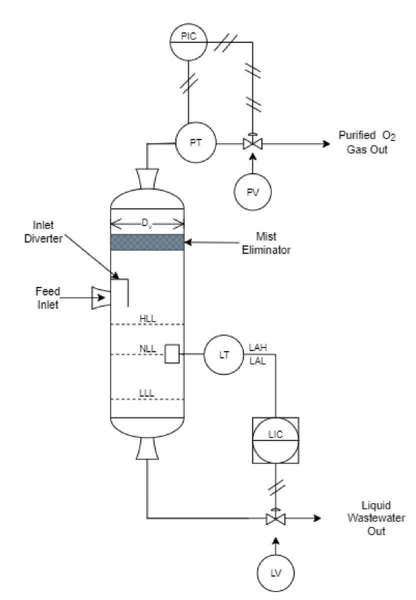
Hydrogen Gas Purification and Storage:

- H_2 generated from electrolysis is depressurized and cooled to the optimal condition of PSA at 83.3°C and 5.51 atm
- H_2 gas and water separated using a 4-bed PSA process over 5A zeolite. >99.9% H_2 gas product achieved.
- Purified H_2 gas stored in tank at -1.25°C and 74.9 atm for selling



Oxygen Gas Purification and Storage:

- O_2 and sweep gas mixture from electrolysis is cooled to condense sweep gas using heat exchangers
- O_2 gas and water separated using a stainless steel vertical vapour-liquid separator with 0.95 m diameter and 4.73 m height. >99% separation efficiency achieved. Vessel pressure and level control systems integrated.
- Purified O_2 gas stored in tank at 30°C and 150 atm for selling



Conclusion and Recommendations

H_2 and O_2 Gas Production Rate

- 3971 kg/h of H_2 gas with >99% purity produced for selling. 1003 kg/h of product H_2 is used for energy production
- 31,520 kg/h of O_2 gas with >99% purity produced for selling

Process Sustainability

- Plant designed to operate at off-peak energy demands to limit fossil fuel contributions
- Heat integration and material recycling applied to reduce feed heating energy requirement by 58% (from 382,799 MJ/h to 139,986 MJ/h), and water feed input by 37% (from 3185 mol/h to 1991 mol/h).
- System successful in producing 4040 kg H_2/h, which has the potential of reducing CO_2 emissions from gasoline consumption in Canada by approximately 4 million kg annually

Potential Hazards

- Electrolysis cell shutdown
  - Mitigated by using easily replaceable cell parts for the electrolysis unit
- Process unit contamination with O_2/ H_2 gas
  - Mitigated by the implementation of physical barriers to isolate each process unit and equipment.
- Ignition or explosion of O_2/H_2 stream
  - Mitigated by the implementation of ventilation system to the diluted gas and fire extinguish systems.

Cost

- High initial capital costs investments – upwards of $1,000,000
- Operational costs include power for pumps, separators and compressors, heating/cooling utilities, and labour/maintenance

Recommendations for Future Design Iterations

- Research key assumptions made throughout design process:
  - Assumed no heat addition required for electrolysis reaction
  - Conversion rate of electrolysis set from literature
- Perform experimental studies to confirm performance of electrolysis cell

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