Hydrogen Production Utilizing Calcium Oxide Catalyst

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Introduction

Hydrogen, known for its environmentally friendly combustion and versatile applications, is becoming increasingly vital in the sustainable energy landscape. To address the specialized requirements of various industries, our senior design project integrates expertise in chemical, industrial, and electrical engineering to optimize hydrogen production processes.

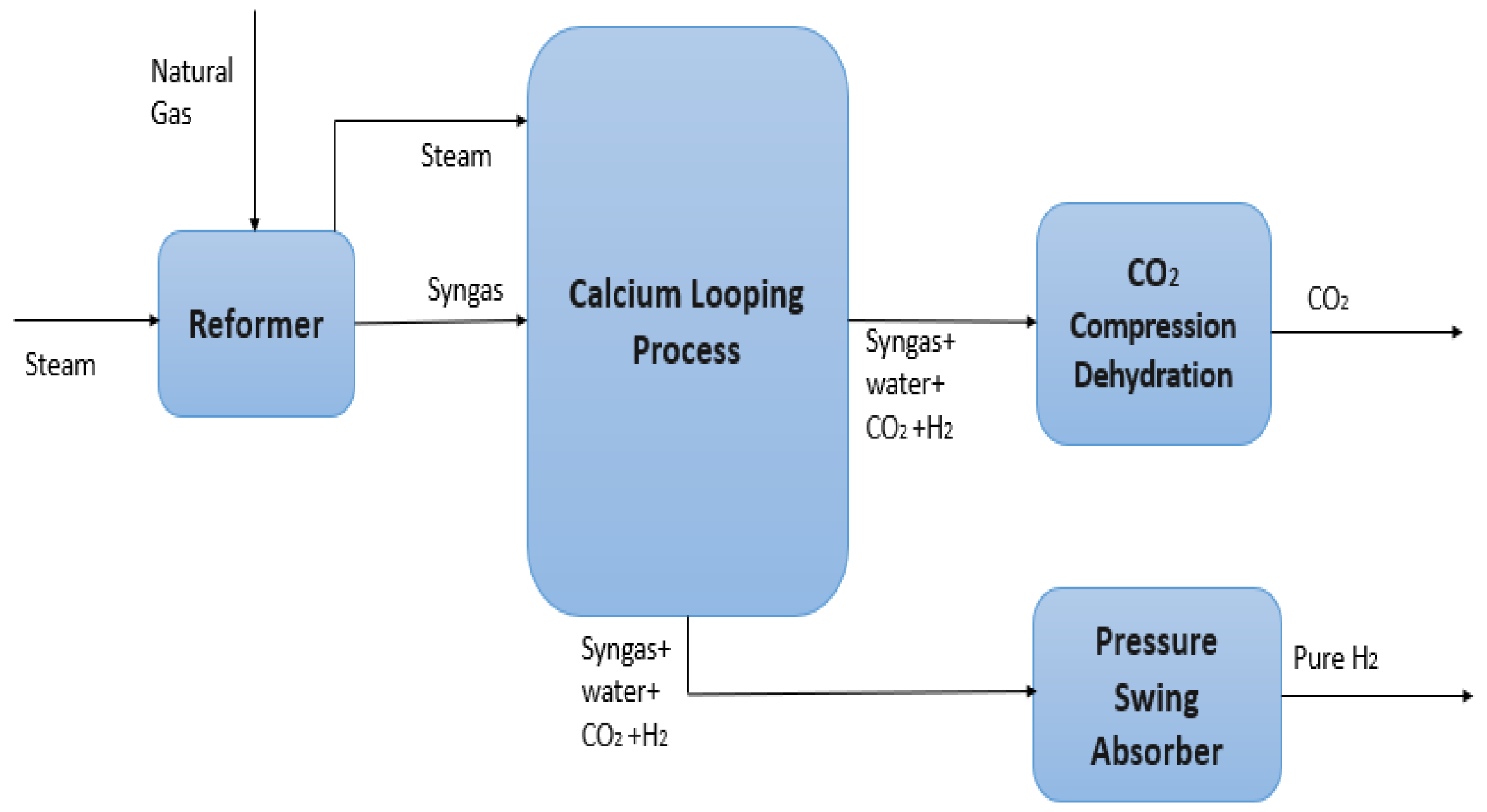
Problem Statement:

Traditional hydrogen production methods face challenges such as high costs, environmental impact, and the need for high-purity hydrogen. Our project aims to overcome these challenges by developing an integrated system that streamlines production, reduces environmental repercussions, and ensures the availability of high-quality hydrogen.

Constraints:

Throughout the project, we considered various constraints, including safety protocols, regulatory frameworks, and the need for cost-effective solutions. By addressing these constraints, we aimed to create a sustainable and efficient hydrogen production system.

Block Flow Diagram of Hydrogen Production Using Calcium Looping Process



Target Specifications:

Our project focused on achieving the following specifications:

High-Purity Hydrogen:

Ensuring hydrogen purity levels exceeding 99% to meet the stringent requirements of industries such as pharmaceuticals, fuel, and fertilizer production.

Environmental Sustainability:

Implementing clean methodologies and carbon capture mechanisms to minimize CO2 emissions and reduce the environmental footprint of hydrogen production.

Operational Excellence:

_Enhancing productivity, efficiency, and cost-effectiveness through the application of advanced engineering techniques and optimization strategies.

Prototype Design:

Our project encompasses three key engineering components:

Chemical Engineering:

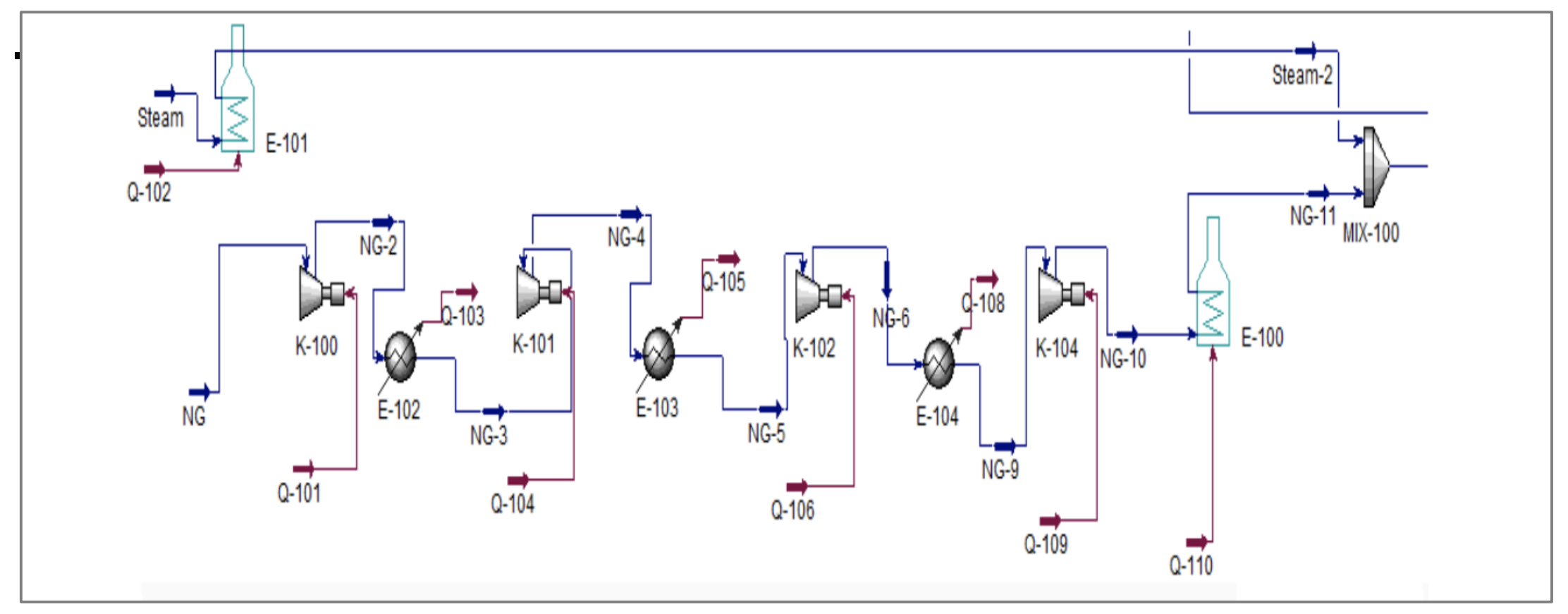
Developing simulations and the calcium looping process to enhance steam methane reforming and maximize hydrogen output while mitigating harmful by-products.

Industrial Engineering:

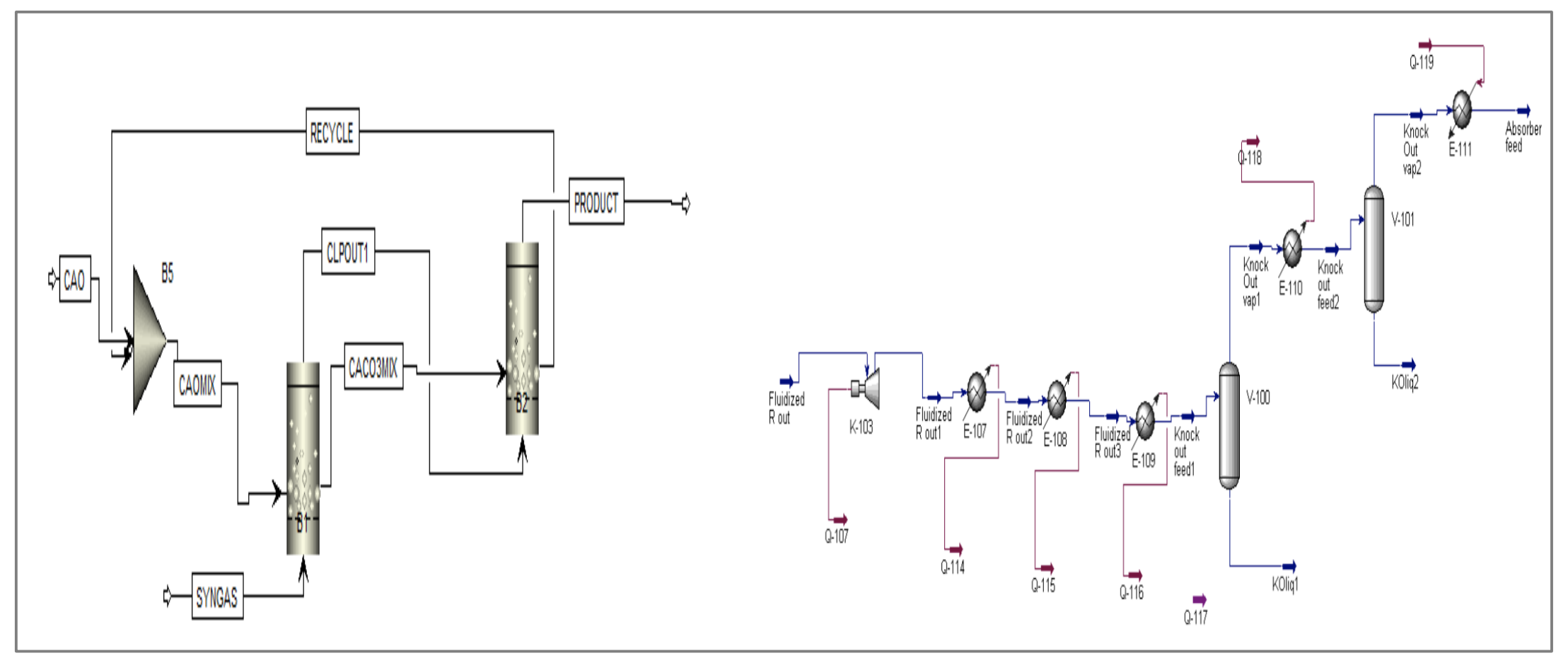
Developing a robust an optimization model to enhance operational parameters and drive productivity improvements in hydrogen production.

Electrical Engineering:

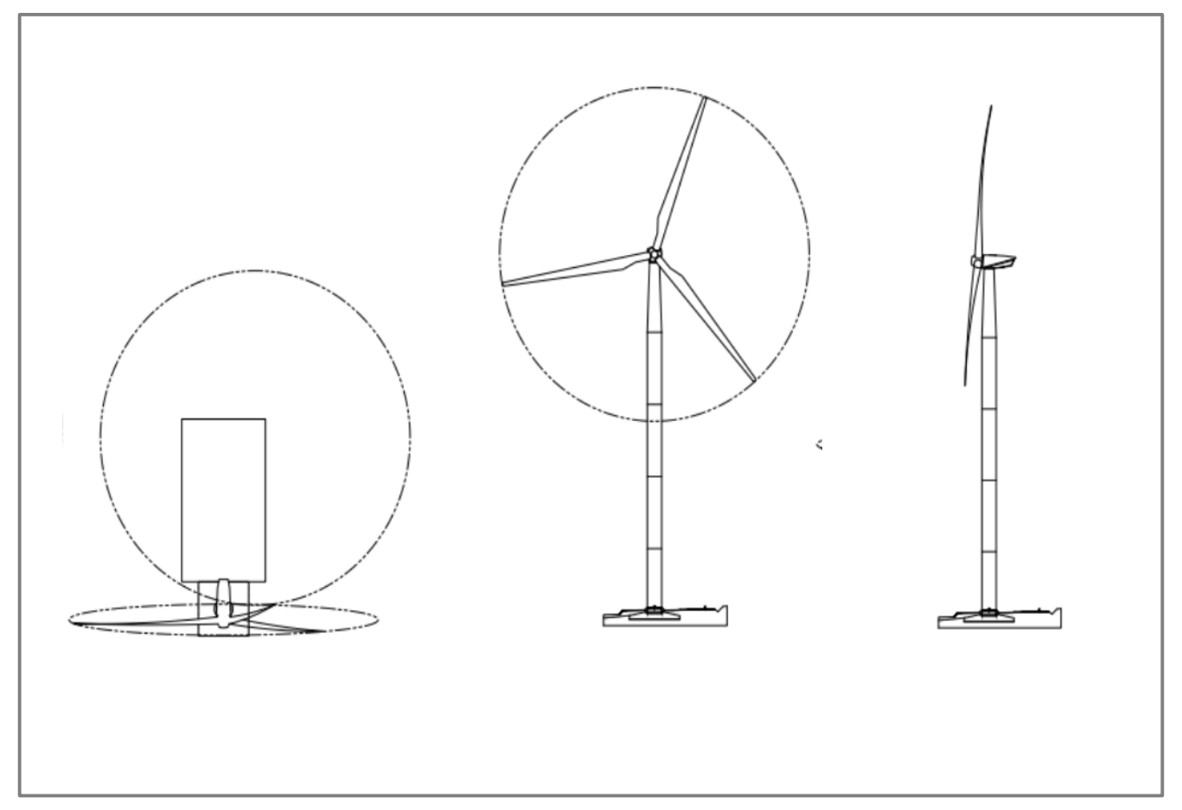
Designing a custom wind turbine to power the hydrogen production infrastructure, promoting sustainability and reducing operational costs.



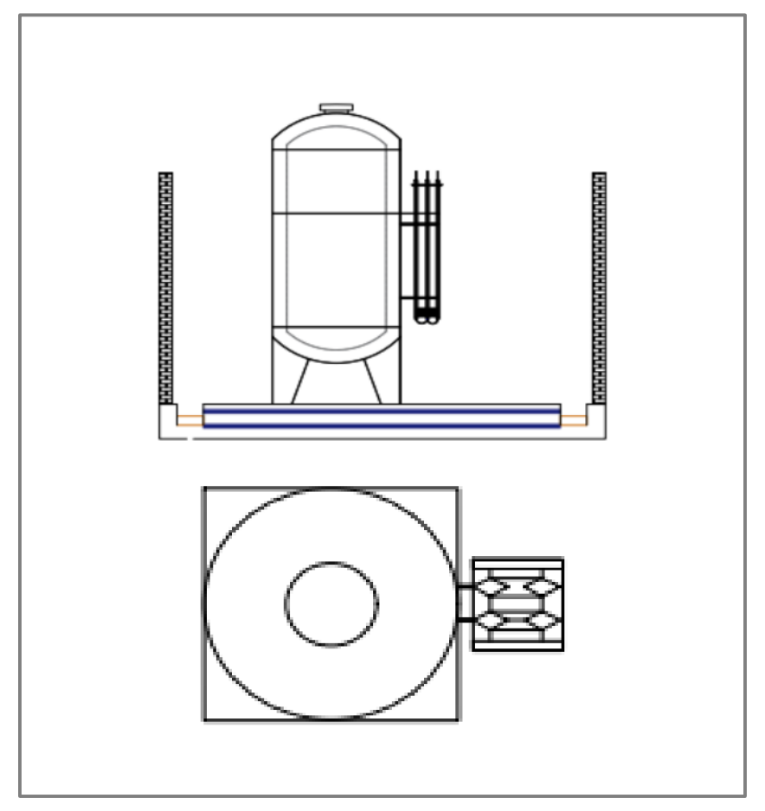
Feed preparation process



Purification unit



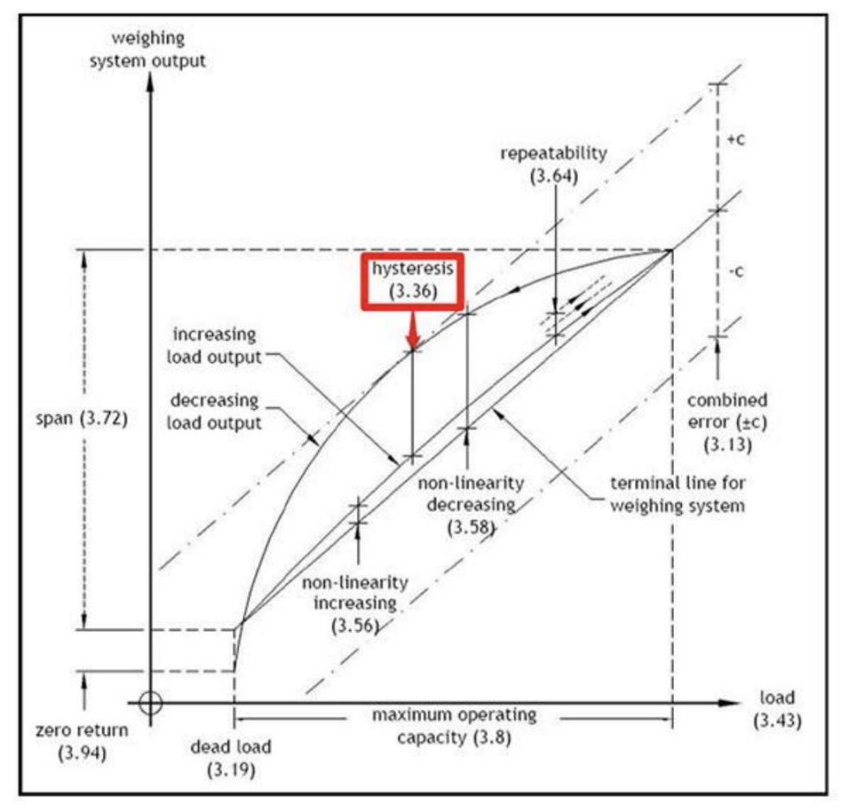
Wind turbine design



Hydrogen tank design

Testing and Results:

Equations and Assumptions (wind turbine):



Wind Energy

$$P_{in} = \frac{E}{t} = \frac{\frac{1}{2}mv^2}{t} = \frac{\frac{1}{2}\rho V v^2}{t} = \frac{1}{2}\rho A v^2\left(\frac{l}{t}\right) = \frac{1}{2}\rho A v^3 \quad (\rho = 1.29\frac{kg}{m^3})$$

$$P_{in} = \frac{1}{2}\left(1.29\frac{kg}{m^2}\right)(0.2\,m^2 \times 0.3\,m^2)\left(3\frac{m}{s^2}\right)^3 = 1.0449\,w$$

Wind Turbine Energy

$$P_{out} = F \cdot V$$

$$F = m \cdot g \quad (m = mass, g = 9.81\frac{m}{s^2})$$

$$V = \frac{\text{Conference}}{t} = 2\pi r f \quad (f = \frac{rotations}{sec})$$

$$P_{out} = 0.347\,kg \times 9.81\frac{m}{s^2} \times 2\pi \times 0.003175 \times 0.7 = 0.0475\,w$$

Efficiency

$$\text{Efficiency} = \frac{P_{out}}{P_{in}} \times 100 = \frac{0.0475\,w}{1.0449\,w} \times 100 = 4.55\,\%$$

Optimization:

- optimized the compressor duty by 19.8%. Also, this causes a lower capital cost since we now have a 3-stage compressor with 2 interstage coolers rather than a 4-stage compressor with 3 interstage coolers
- fuel requirements have gone down by 26.14% for the steam heater and 13.03% for the natural gas heater
- Hydrogen production after optimization has increased by 3.6% compared to the previous case

Simulation Data:

Data of Reactors	
	SMR
Inlet Flow rate(kmol/h)	5036.55
Outlet Flow Rate	4545.24
inlet Temperature(°C)	700
Outlet Temperature(°C)	624
Inlet Pressure (KPa)	400
Outlet Pressure(KPa)	200
Heat Duty(KJ/h)	645000000
Inlet Vapor fraction	1
Outlet Vapor fraction	1
Conversion (%)	65.12
Volume (m^3)	2.368
Reactor Type	PBR

SMR data

Data of Separators	
	Absorber
Tob inlet flow rate (Kg/h)	10000
Bottom Inlet flow rate (Kg/h)	1000
Tob Outlet flow rate (Kg/h)	10408.9
Bottom Inlet flow rate (Kg/h)	591.08
Tob inlet Temperature (°C)	25
Bottom inlet Temperature (°C)	65
Tob Outlet Temperature (°C)	41.4
Bottom Outlet Temperature (°C)	25.2
Tob Inlet Pressure(Kpa)	150
Bottom inlet pressure (Kpa)	120
Tob Outlet Pressure(Kpa)	120
Bottom Outlet Pressure (Kpa)	150
Column Pressure(Kpa)	150
Tob inlet vapor fraction	0
Bottom Inlet Vapor fraction	1
Tob Outlet Vapor fraction	0.93
Bottom Outlet Vapor fraction	0.14
Number of stages	100

Absorber column data

Data of Separators		
	V-100	V-101
Tob inlet flow rate (Kg/h)	425000	19589.77
Bottom Inlet flow rate (Kg/h)	-	-
Tob Outlet flow rate (Kg/h)	235039.3	17690.6
Bottom Inlet flow rate (Kg/h)	189960.7	1899.17
Tob inlet Temperature (°C)	65	20
Bottom inlet Temperature (°C)	-	-
Tob Outlet Temperature (°C)	63.56	20
Bottom Outlet Temperature (°C)	63.56	20
Tob Inlet Pressure(Kpa)	240	200
Bottom inlet pressure (Kpa)	-	-
Tob Outlet Pressure(Kpa)	220	200
Bottom Outlet Pressure (Kpa)	220	200
Column Pressure(Kpa)	220	200
Tob inlet vapor fraction	0.6485	0.9031
Bottom Inlet Vapor fraction	-	-
Tob Outlet Vapor fraction	1	1
Bottom Outlet Vapor fraction	0	0
Number of stages	-	-

Flash drums data

Conclusion

Our senior design project showcased the potential of an integrated hydrogen production system to cater to the diverse needs of industries such as pharmaceuticals, fuel, and fertilizer production. By addressing constraints, meeting target specifications, and developing a prototype, we have laid the foundation for a sustainable and efficient hydrogen production solution that aligns with the growing demand for clean energy.