MAE 4149 Thermal Systems Design

Final Project Status Report Team 3

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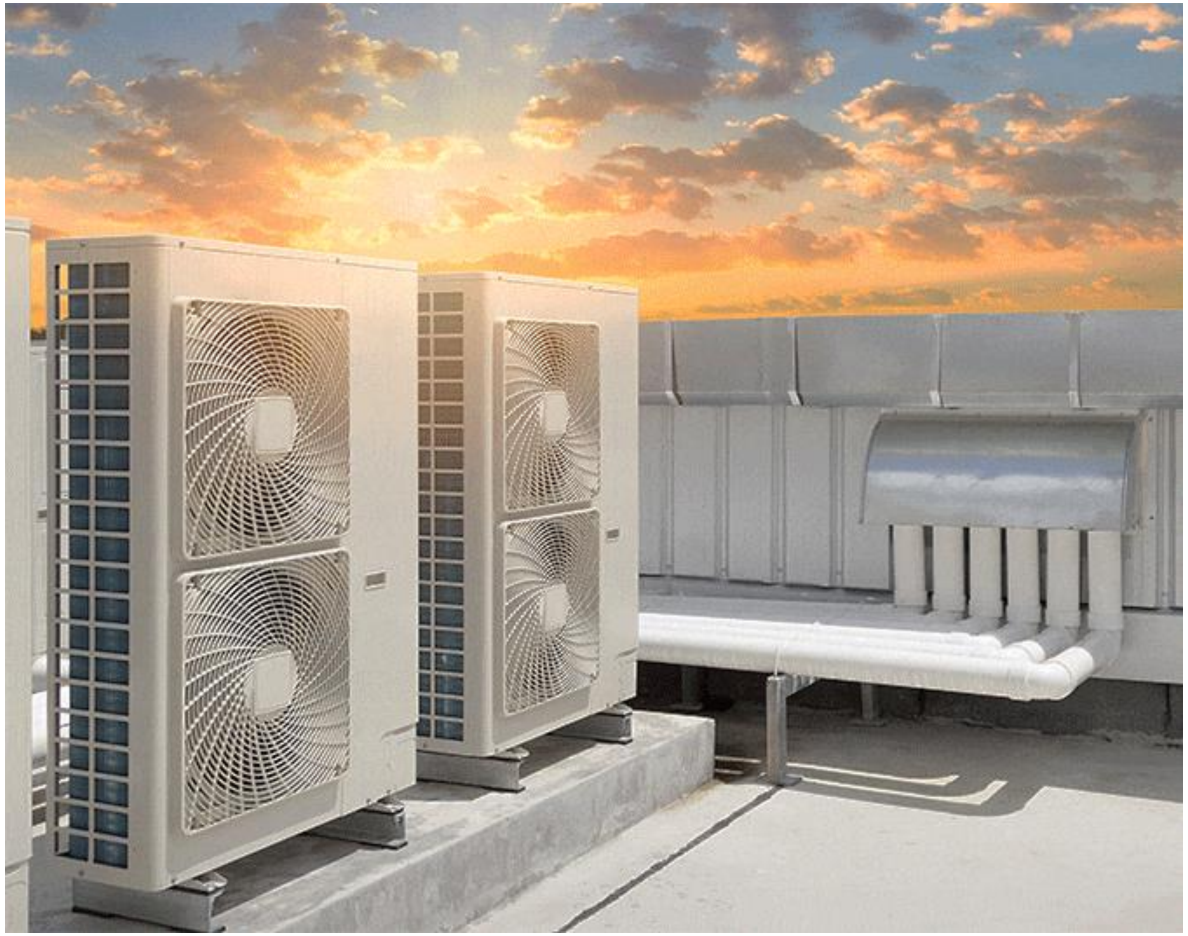


Project Approach & Structure

- This project can be broken down into 3 phases:
  - Background Research
    - Split up components among team members:
    - Research individual components
  - Conceptual Design
    - Design System Layout:
      - How components interact & are connected
      - Selection of components
  - Detailed Design
    - Select Specific Component Capacity to fit S.E.H
    - Select Operating Conditions ~ 65 – 75 degrees Fahrenheit
    - Select Pricing of each component

Team Roles

Dividing roles by system components

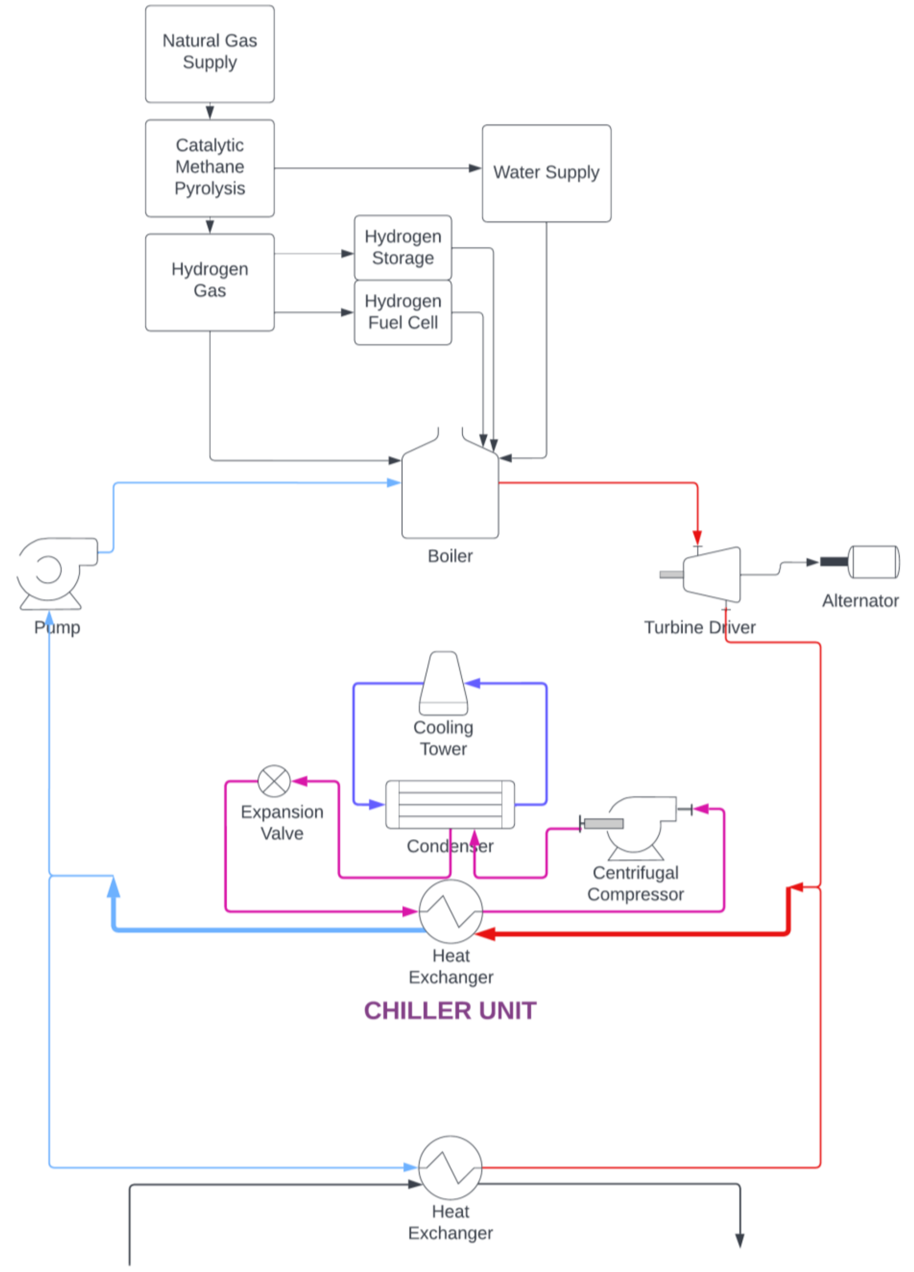
- Ahmed
  - Refrigerants, Turbine, Economic Analysis
- Joanna
  - Boilers, Research into S.E.H utilities, Economic Analysis
- Oscar
  - Evaporator, Performance analysis on system
- Anton
  - Condenser, Design of overall system layout, Research into LEED rating, Performance analysis on system
- Nii
  - Compressor, Design overall system layout, Economic Analysis
- Mahdi
  - Power Generation, Incorporation of Hydrogen Fuel Cell, Viability of technology being used

Objectives and Design Approach

- After the first round of Background Research, we were able to outline the following design objectives:
  - Design an environmentally friendly, energy efficient Heating, cooling and Power Generation System for the Science and Engineering hall
  - Design should make use of the components discussed in the patent
    - However, prioritize adapting already existing systems in S.E.H that work well
    - Utilize cutting edge technology where possible
  - Ensure that all component types selected are compatible(Use of converters where applicable)
  - Investigate ways to increase GWs LEED rating from gold to platinum

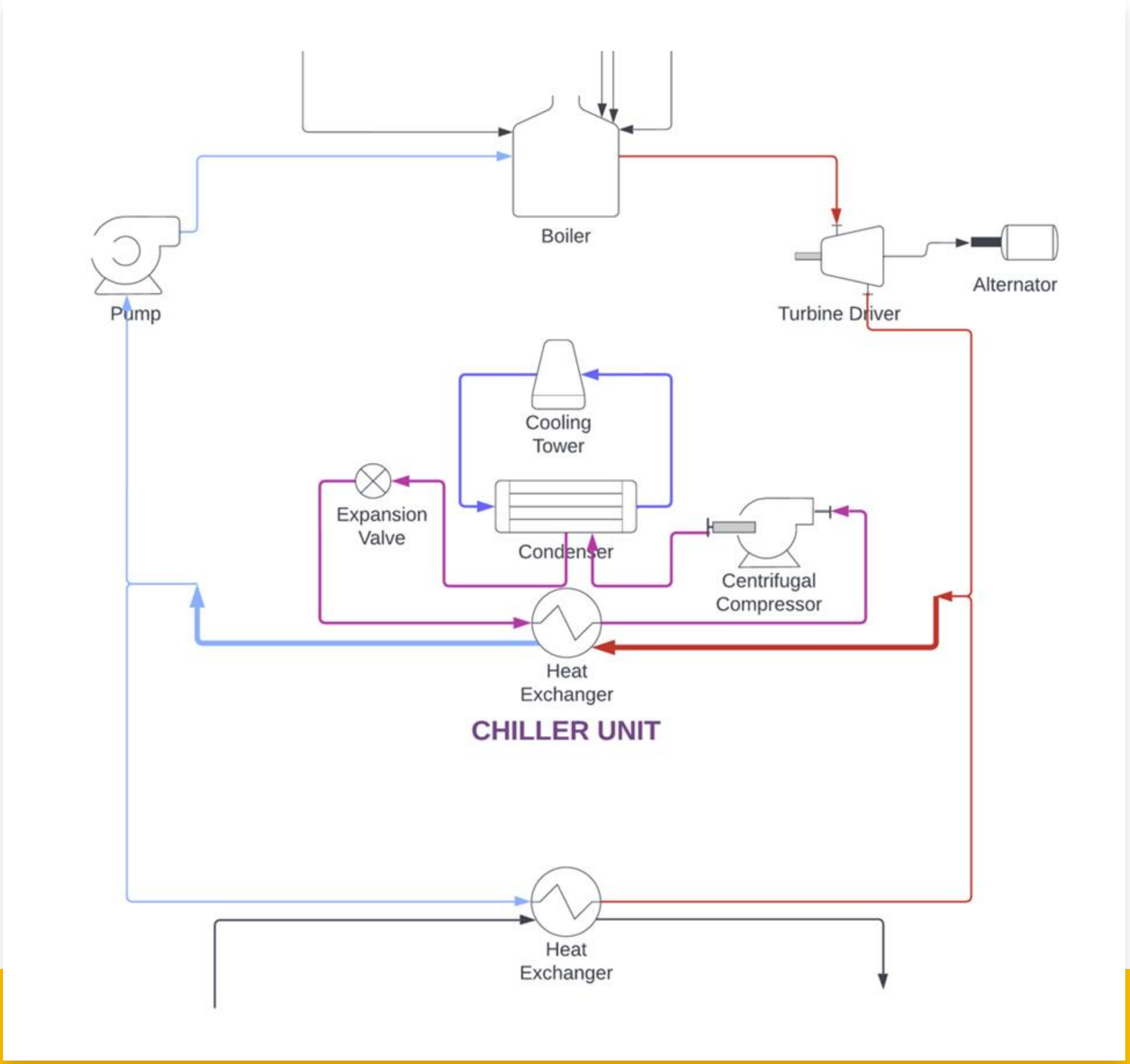
Overall System Layout

- **Capable of Cooling, Heating and providing power generation**
- **Follows basic principles of Rice Patent**
- **Uses a chiller unit for air conditioning**
- **Hydrogen Fuel Cell Powers HVAC system**
  - **Excess Power generated will be stored for when the system is down for maintenance**
- **Turbine produces power for S.E.H**



Design of overall system: A/C -- Power

- **A/C + Power Cycle:**
  - Hydrogen Boiler (Bosch)
  - R-1234ze Chiller (Johnson Controls)
  - Turbine (Siemens)
  - Alternator & Generator (Siemens)
  - Heat Exchanger (Ace Machinery)



Design of overall system: Heating -- Power

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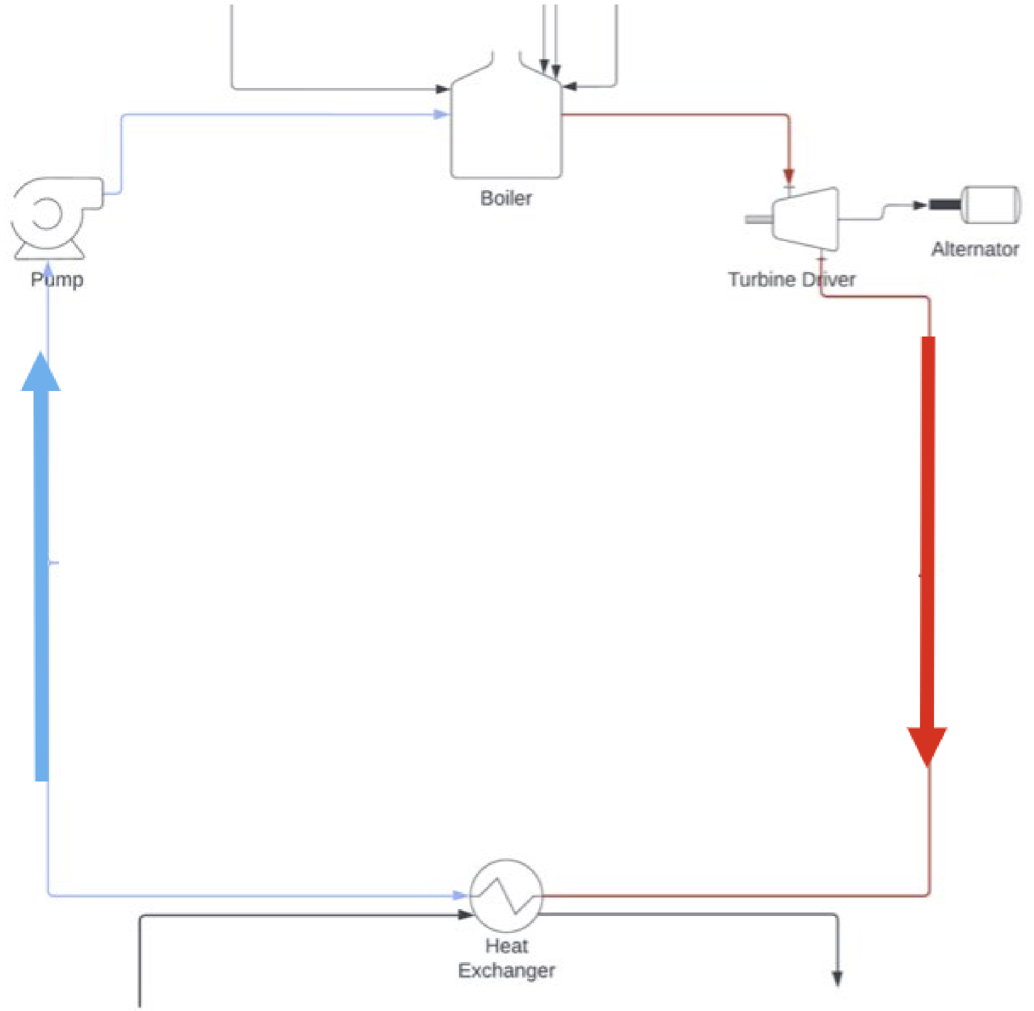
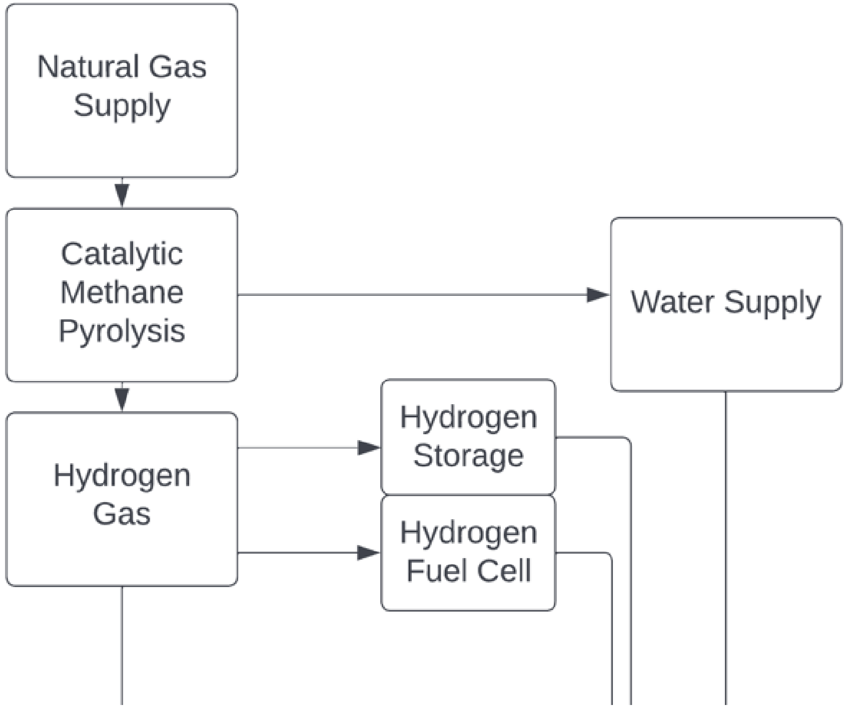


Incorporation of Hydrogen

- **Catalytic Methane Pyrolysis:** Natural Gas to Hydrogen Gas
  - Natural Gas Supply (Pepco)
  - Catalytic Methane Pyrolysis (Exxon Mobil)
  - Hydrogen Gas Storage & Fuel Cell
  - Water



Research

1. **Thermal cycle and design processes for AC's/Heat Pumps.**
2. **SEH Current system specifications and operating parameters.**
3. **LEED Certification.**
4. **Types of primary components and their functionalities**

   \- Boilers, Condensers, Compressors, Evaporators, Power Generators, Hydrogen Fuel Cells, Working Fluids)
5. **Compatibility of components with working fluids**
6. **Types of compatible secondary components**

   \- Heat Pumps, Heat Exchangers, Steam Turbines, Generator Interface
7. **Market analysis of base prices and operating costs of components.**

Boiler

- **Boiler:**
  - Water Tube Boiler
  - 40,000 lbs/hr of Steam
  - Fuel: Hydrogen
  - Power Source: Electric
  - Manufacturer: Bosch

Heat Exchanger

- **Heat Exchanger:** Hybrid Falling Film Evaporator
  - Evaporation Capacity: 100kg/h-10000kg/h
  - Power: 0.55kw-30kw
  - Working Effect: single-effect, double-effect, triple-effect(multi-effect)
  - Power Source: Steam And Electric
  - Voltage: 220V-480V
  - Material: stainless steel 304/316L/TI/2205
  - Cost: $50,000 USD per unit, $45,000 USD per unit for orders of 2 or more
  - Manufacturer: Wenzhou ACE Machinery Co., Ltd

Chiller

- **Chiller:**
    - Model YK Style H Centrifugal Liquid Chillers
    - 250 ton to 3,000 ton (879 kW to 10,500 kW)
        - SEH uses two 2500 tons Chillers
    - R-134a, R-513A, and R-1234ze Refrigerant
    - Power Source: Electric
    - Manufacturer: Johnson Controls

Working fluid

Benefits:

- Very Environmentally friendly: GWP = 7 (very low), ODP = Zero
- Compatibility: Compatible with our chiller unit that combines condenser and evaporator.
- Energy Efficient.

Drawbacks:

- Mild flammability (ASHRAE classification of A2L)
- Lower cooling capacity than R134a

Cost estimate:

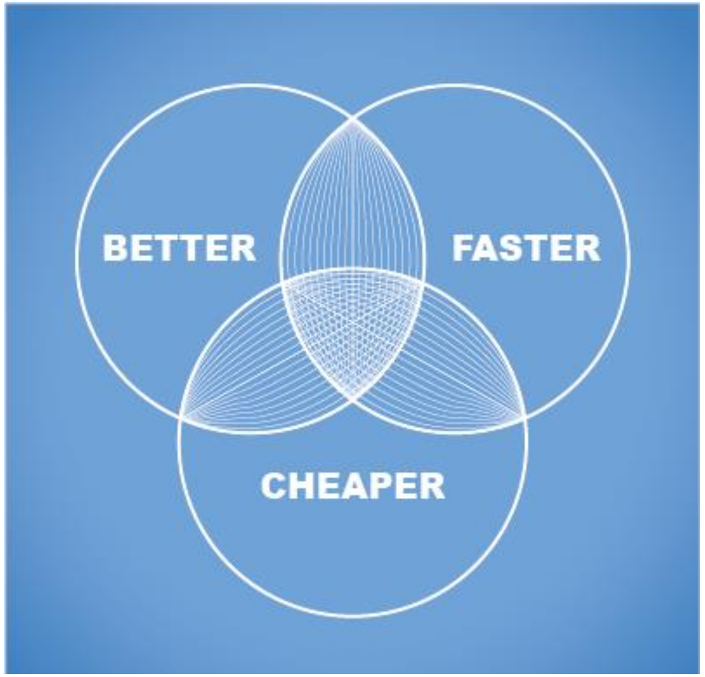
Due to unavailability of bulk costs to the general public, the cost was approximated based on unit prices at biggest volumes available.

Cost = RequiredMass * Price = 4535.924kg * $20.00/kg = **$90,000**

R1234ze

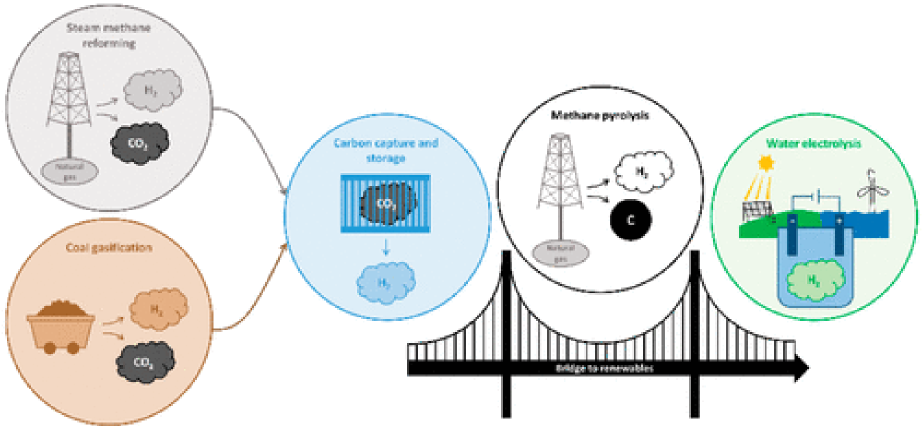
Tradeoffs

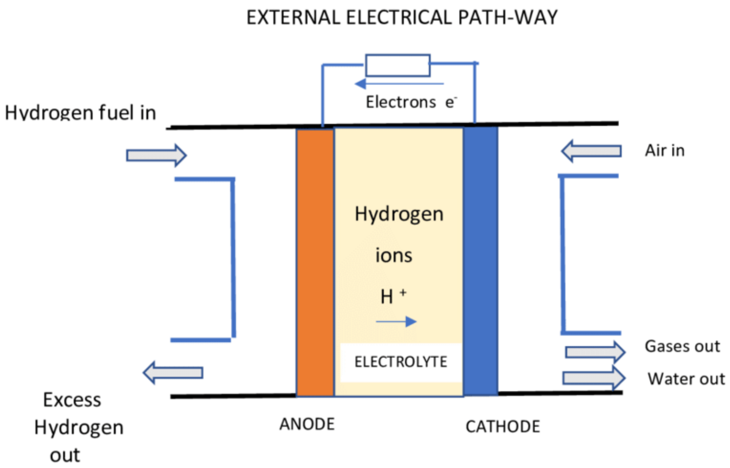
- **Better and Faster**
- **R-1234ze**
- **More expensive chiller**
  - More energy efficient than using smaller individual AC units for each thermal zones
  - Keeps refrigerant in centralized location rather than circulating it through building (safer)
  - Easy installation in larger buildings like S.E.H
- **More expensive boiler**
  - Hydrogen Boilers are new technology
  - Reduces Emissions and is more energy efficient
- **Additional components:** hydrogen methane pyrolysis



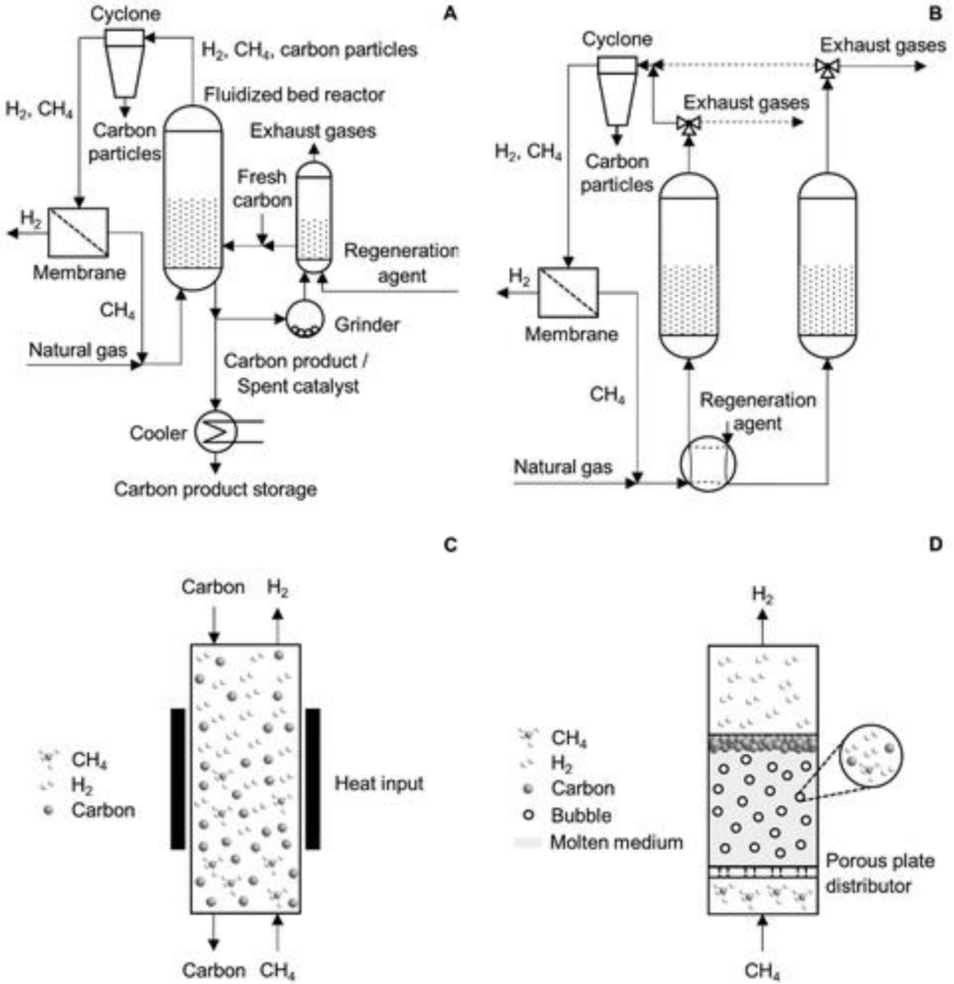
Benefits of Hydrogen fuel system using Methane Pyrolysis

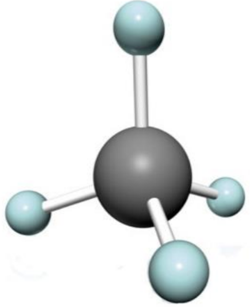
- Hydrogen: one of the cleanest, most promising energy carriers, produces only water
- Very efficient on an energy per mass basis, far more so than conventional fossil fuels.
- 96% of current hydrogen production from high C02 emission processes
- Methane Pyrolysis: chemical process for extracting hydrogen
- May help transition from fossil fuels to hydrogen-based energy





Benefits of Methane Pyrolysis





750 - 1200°C

Gaseous hydrogen

+

Solid carbon

$$CH_4 \longrightarrow 2\,H_2 + C\,(s)$$

Hydrogen is **produced** through a **chemical process** with **natural gas** as the **reactant**

- Causes **CO2 emissions**

Methane Pyrolysis reduces emissions by producing **solid carbon** rather than **gas**

- The **most effective zero footprint** system in modern **hydrogen technology**

$$\tfrac{1}{2}CH_4\,(g) \rightarrow H_2\,(g) + \tfrac{1}{2}C\,(s)$$

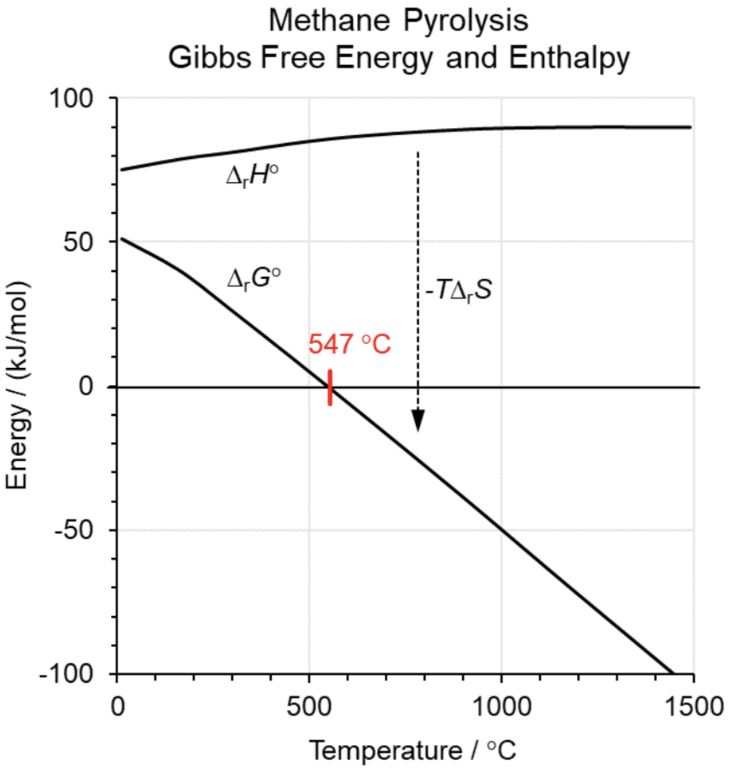
Methane | Hydrogen Gas | Solid Carbon

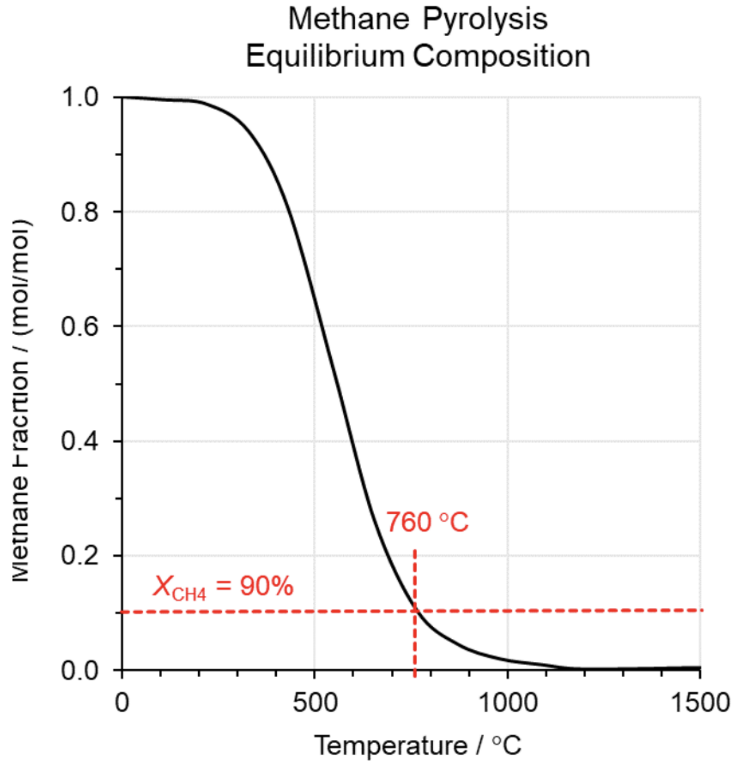
$\Delta_r H°_{298K}$ = +37.4 kJ/mol

$\Delta_r G°_{298K}$ = +25.4 kJ/mol

Target temp for favorable reaction is higher than 547°C

Temperatures above 760°C offer higher conversion rate





Economic Drawbacks of Methane Pyrolysis

Coal	50 $/ton	2.04 $/GJ
Natural Gas	3.00 $/MMBtu	2.84 $/GJ
Electricity	0.07 $/kWh	19.44 $/GJ
Grid Electricity (US, 2019)	**Assumed Carbon Intensity** 0.92 lb CO2 /kWh (116 kg/GJ)	

Although it is **better** for the **environment,** the **economic drawback** **scares companies** away from **switching over** and **risking** their **profit margins**

Name of method	Chemical Reaction		Energy Fuel	$/kg H_2
Methane Pyrolysis	**½CH_4(g)**	**H2(g) + ½C(s)**	H_2	0.72
Coal Gasification	½C(s) + H_2O(l)	H2(g) + ½CO2(g)	C	0.24
Steam Methane Reforming	½CH_4(g) + ½H_2O(l)	H2(g) + ½CO2(g)	CH_4	0.43
Water Electrolysis	H_2O(l)	H2(g) + ½O2(g)	Electricity	2.76

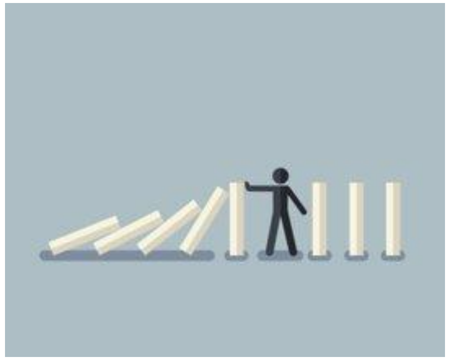
Breakdown of SEH Utilities

Meter Reading Date	Average Readings (MWh)	Average Usage (MWh)	Usage including Chiller Calculated (MWh)	SEH Total Utilities Amount Calculated ($)
Jan 22	47,044	596	1,275	127,173
Feb 22	47,419	376	827	98,382
Mar 22	47,874	455	1,063	352,965
Apr 22	48,341	467	1,207	177,482
May 22	49,045	705	2,410	217,846
Jun 22	49,605	561	2,149	242,692
July 22	50,113	507	1,234	N/A

Economics:
Estimation of operating costs and Capital Costs

	Boiler	**Turbine**	**Cent. Pump**	**Chiller**	**Heat Exg.**	**Hyd. Fuel Gen.**	**Generator**	**Refrigerant**	**Total**
Capital Costs	$345k	$38k	$2,671	$875k	$50k	$400k	-	$90k	**$1,816,807**
Operating Cost	$2-2.5M for Natural Gas								

Risk Analysis



- **Hydrogen Methane Pyrolysis**
    - Prototype level reliability
- **Refrigerant**
    - Less established than other options
- **Boiler**
    - New technology
- **Chiller & Cooling Towers**
    - New chillers
    - Old cooling towers

Viability of Technology usage in the present and future

- Turbine, pump, heat exchanger, etc. all from pre-existing technology
- Hydrogen Boilers are not used in the U.S because most Gas companies don't supply hydrogen as a utility gas
  - Methane Pyrolysis circumvents this issue
- Viability of overall design concept supported by rice patent
- Reality of Hydrogen fuel cells as an energy source questionable
- Methane pyrolysis currently not enough to meet energy demands
- Preexisting methods of hydrogen production significant sources of CO_2 emissions.
- Market is growing steadily, technology may be feasible in near-future