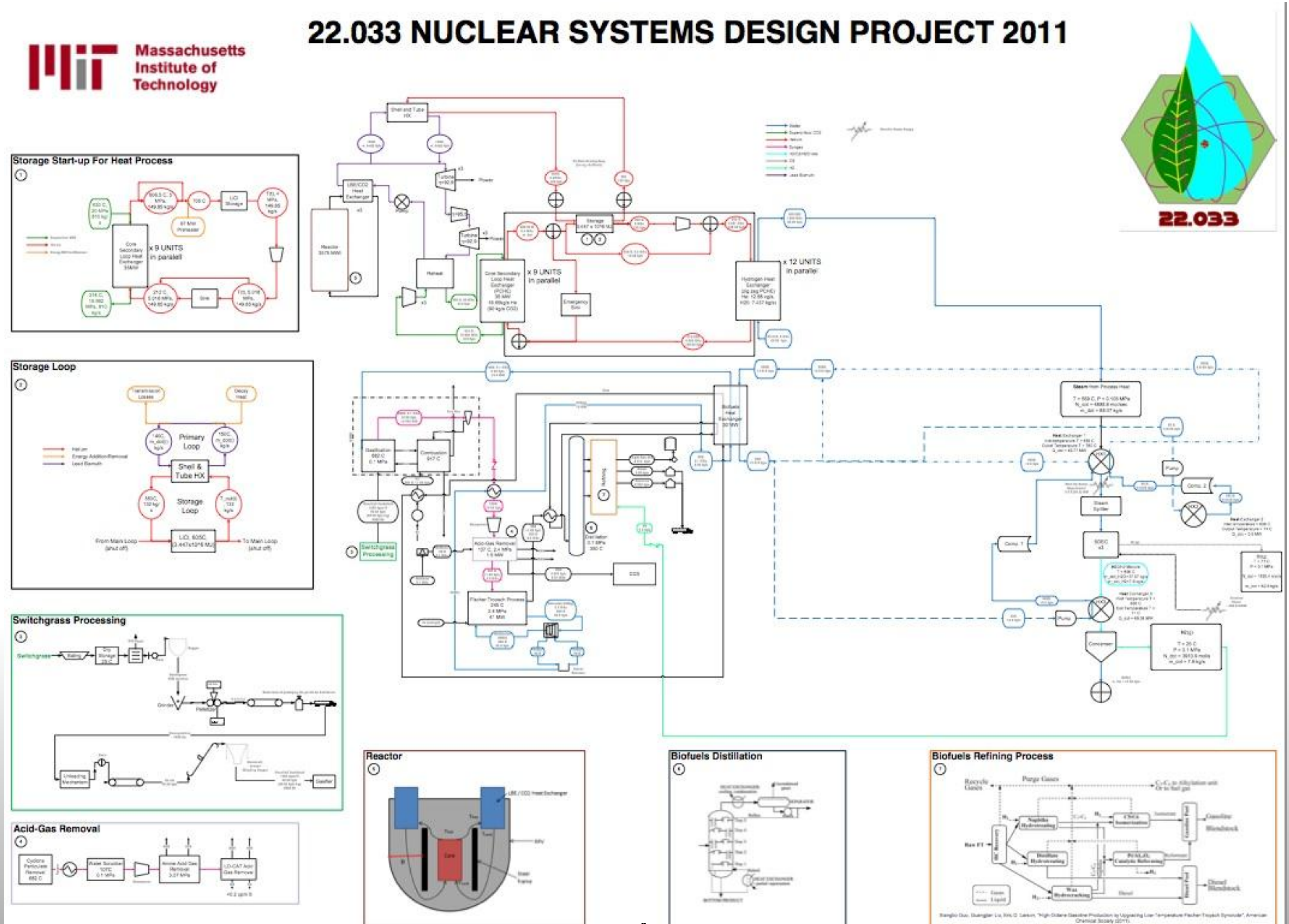
# 22.033 Design Course

Considerations in Designing a Nuclear Power Plant with a Hydrogen and Biofuels Facility

# Why this project?

- Green energy policy climate
- Oil quickly depleting
- Nuclear high energy/electricity output versus maintenance costs

# System Layout



# Reactor Core

# Outline

1. Goals
2. Overall Design of Reactor Core
3. Radial and Axial Overview of Core
4. Fuel
5. Heat Removal
6. Core Depletion
7. Secondary System
8. Turbines and Heat Exchangers
9. Future Work

# Reactor Core Goals

- Provide enough electricity and process heat for hydrogen and biofuels production
- Choose and design a reactor that will operate at temperatures larger than what is in use
- Produce a unique and innovative reactor
- Final design must be feasible for electrical production

# Core Designs Considered

- Supercritical $H_2O$
- Supercritical $CO_2$
- Traveling Wave Reactor
- Sodium-Cooled Fast Reactor (SFR)
- Lead-Cooled Fast Reactor (LFR) (LBEFR)
- CANDU Reactor
- Molten Salt Reactor
- Gas-Cooled Fast Reactor
- Pebble Bed Modular Reactor (PBMR)
- Very High Temperature Reactor (VHTR)

# Major Reactor Design Choices

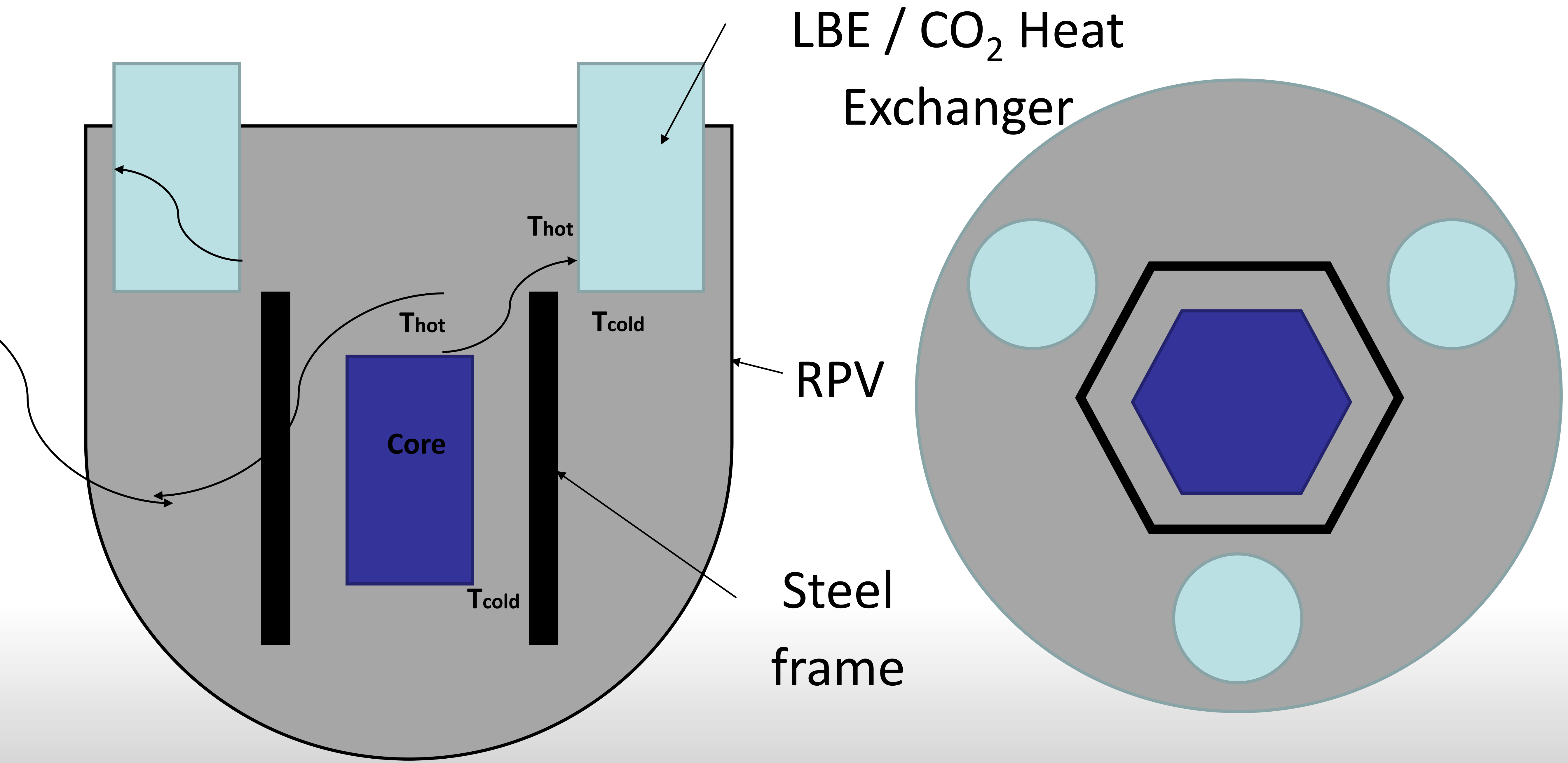
- Lead-Bismuth Eutectic Cooled Fast Reactor (LBEFR)
  - High heat capacity
  - Operates at ~ atmospheric pressure
  - High power density
  - Natural convection
  - Self-shielding
  - Essentially no coolant voiding possible

- Supercritical Carbon Dioxide (S-$CO_2$) for Secondary Cycle
  - Brayton cycle
  - Single phase working fluid
  - Smaller turbines
  - Higher cycle efficiency

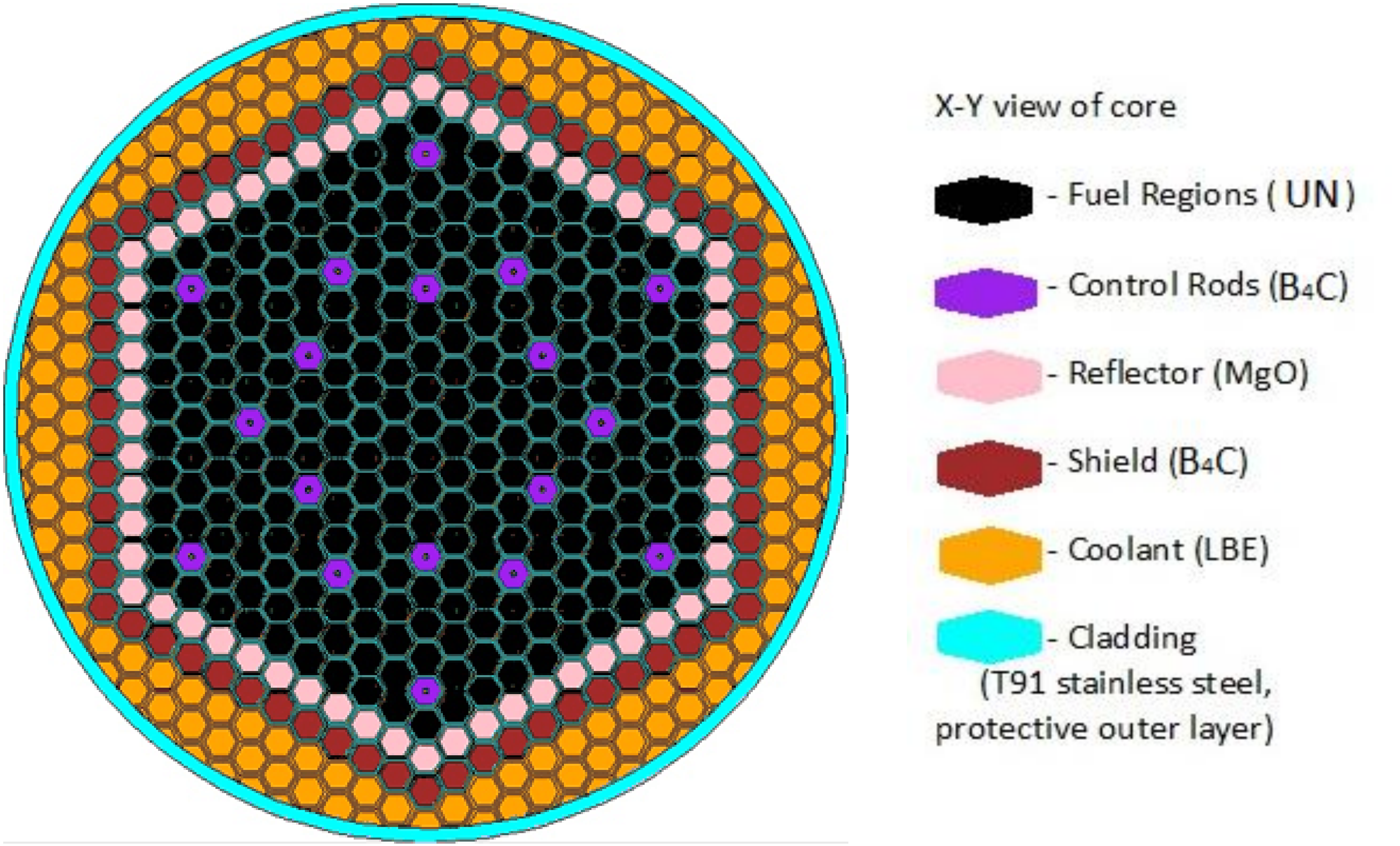
# Reactor Core Final Design

- Lead-Bismuth Eutectic (LBE) Cooled Fast Reactor with Supercritical $CO_2$ Secondary Loop
- 3575 MWt (1500 MWe)
  - Limited by velocity of LBE (2.5 m/s) due to flow assisted corrosion
  - Will provide only 1000 MWe to grid, remaining energy will be used for hydrogen and biofuel production

# Core Overview

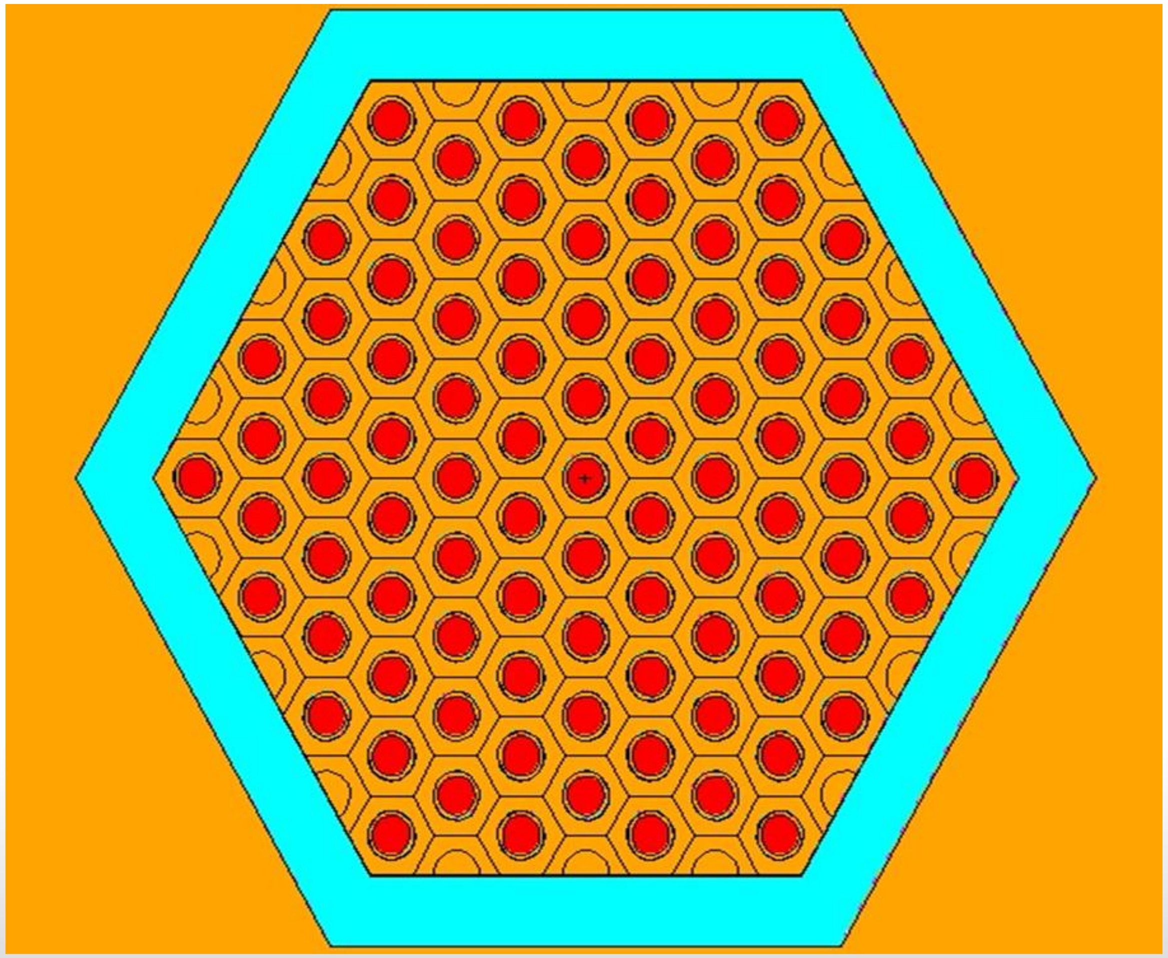


# Radial Overview of Core



# Fuel Assembly and Zoning

Pitch/Pin = 1.6



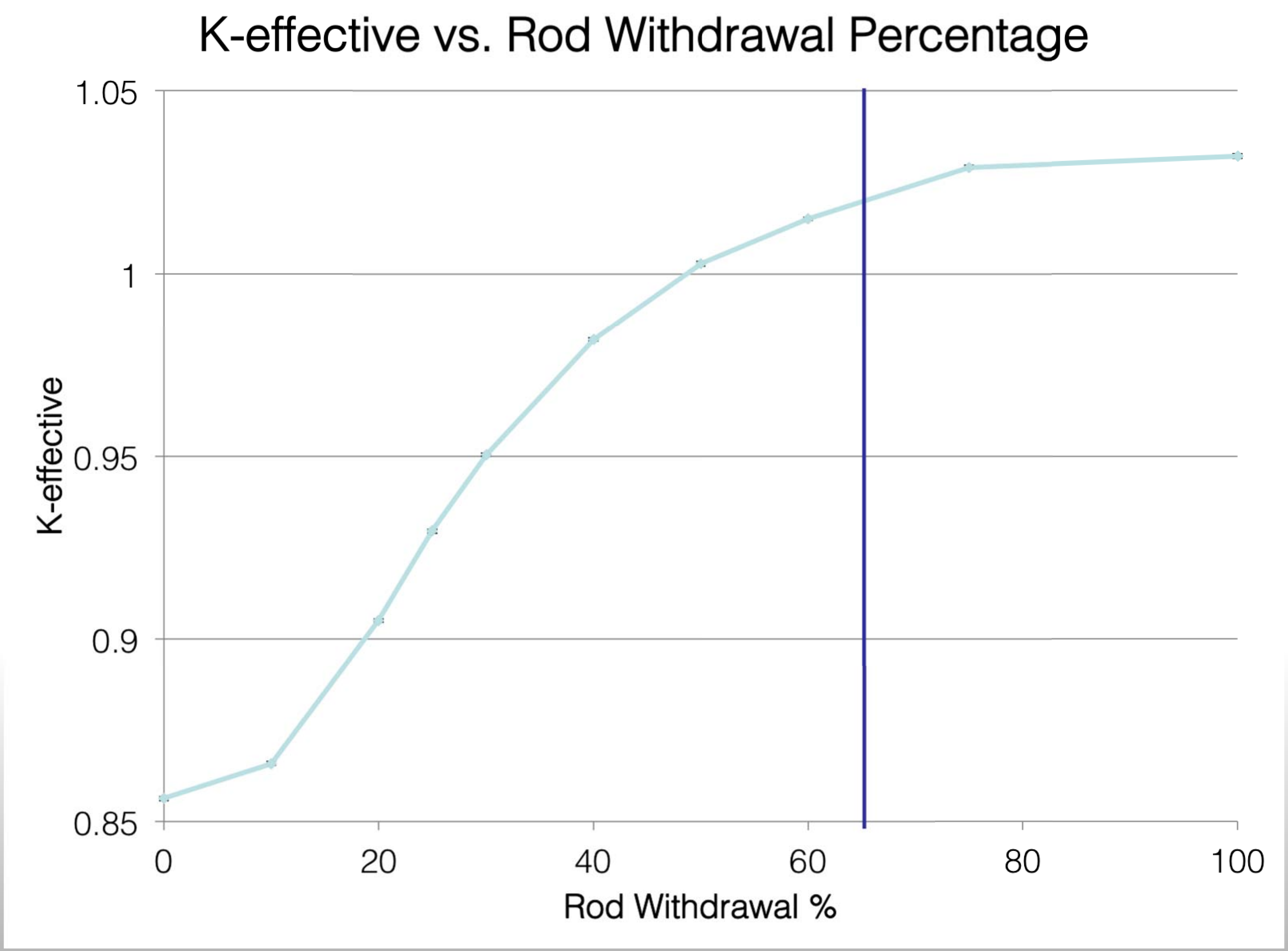
## Axial and Radial Zoning

| | Rings 1-4 | Rings 5-10 |
|---|---|---|
| **Top 33%** | 10% | 12.5% |
| **Lower 67%** | 12.5% | 15% |

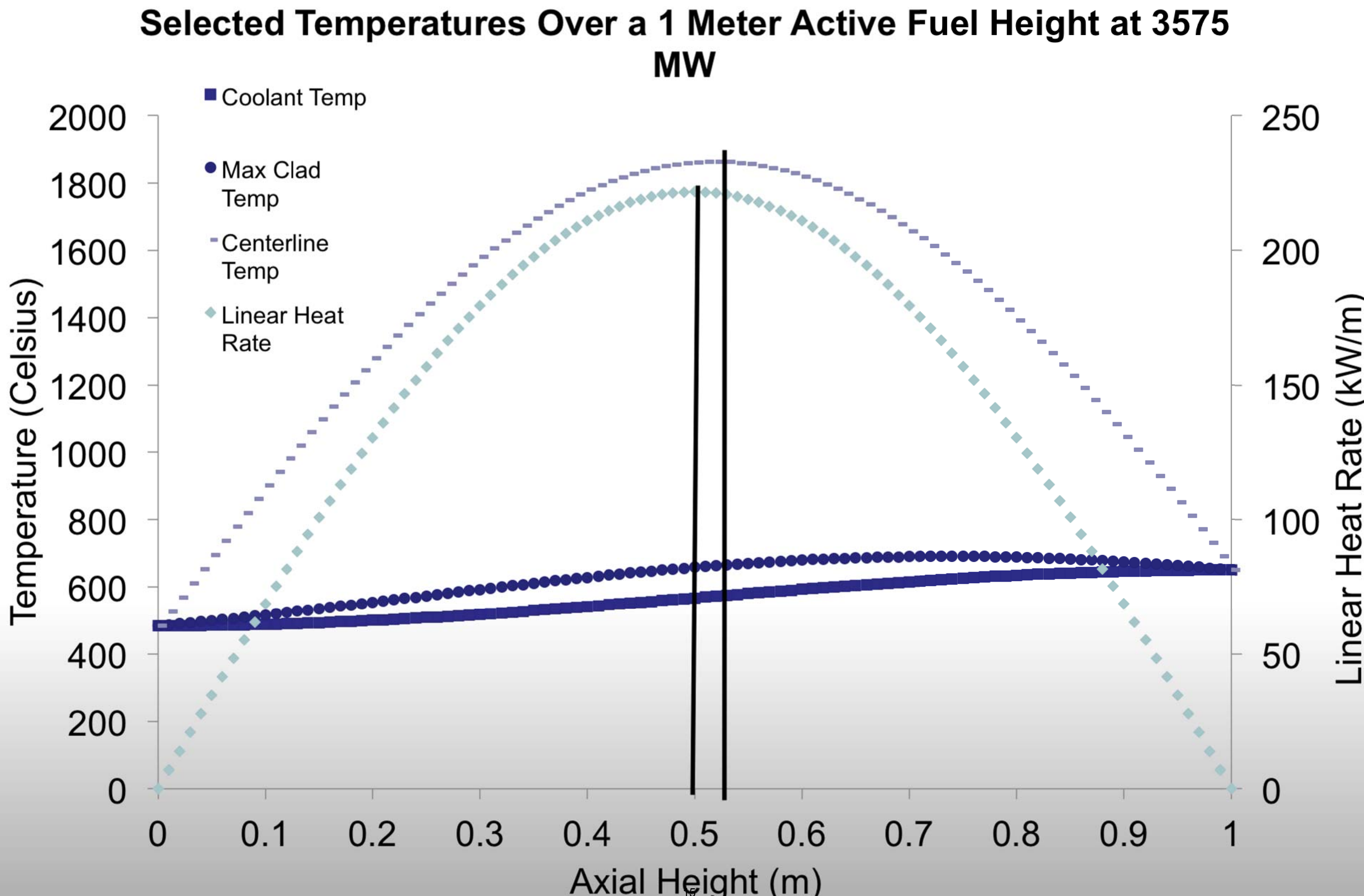
# Reactor Core Final Design

| | |
|---|---|
| **Outlet Temperature** | 650° C |
| **Inlet Temperature** | 484° C |
| **Operating Pressure** | Atmospheric |
| **Full Power Operating Mass Flow Rate** | 143,600 kg/s |
| **Max Fuel Enrichment** | 15% |
| **Minimum Fuel Enrich** | 10% |
| **Linear Heat Rate BOL** | 74.3 kW/m |
| **Fuel Material** | UN |

# Reactor Core Final Design



# Reactor Core Final Design

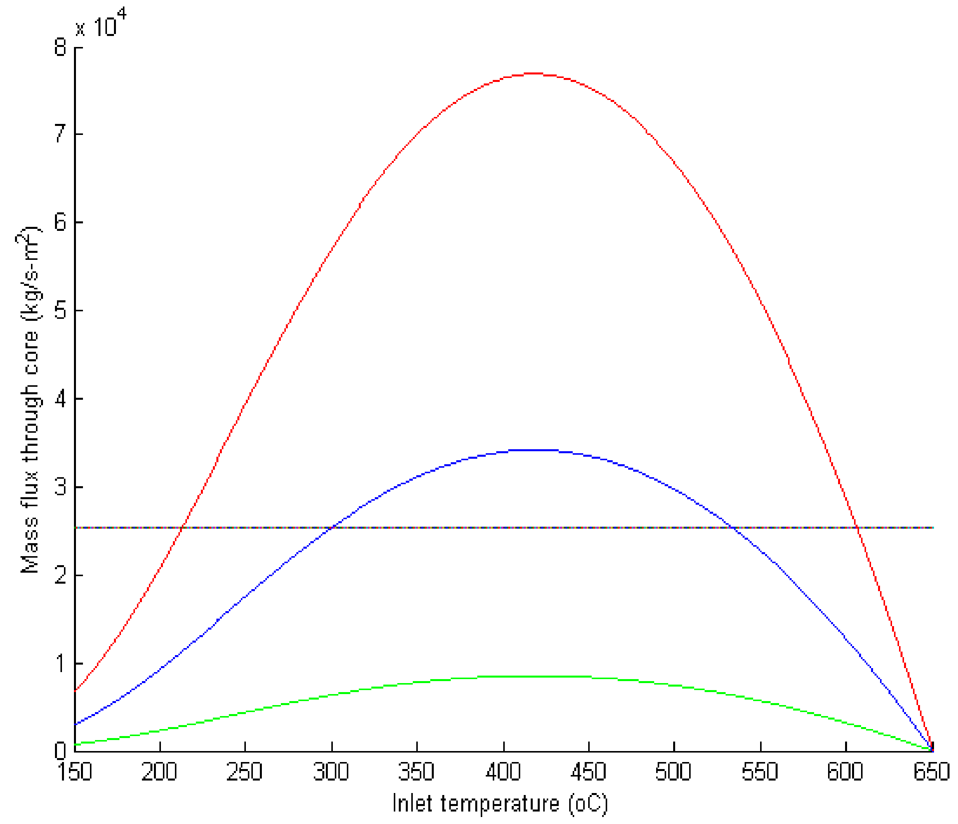


# Comparison of UN and $UO_2$

| | UN | $UO_2$ |
|---|---|---|
| Thermal Conductivity | 21 W/mK | 3-4 W/mK |
| Melting Point | 2800° C | 2800° C |
| Uranium Metal Density | 13.60 $g/cm^3$ | 9.67 $g/cm^3$ |
| Other | Need to enrich the nitrogen | Long and safe operating history |

# Natural Circulation

- Natural circulation appears sufficient for heat removal at full power.
- It is likely that pumping power/ extra heat insertion from the PCM will be needed to maintain flow during shutdown.
- Further analysis needed to determine benefits of laminar vs. turbulent regimes.




Plot of mass flux vs. inlet temperature given an outlet temperature of 650° C for varying down channel diameters.
R = 3m. B = 2m. G = 1m

# Core Depletion

- Analysis done by comparison to previous cores: EISY, STAR & 2400MWt MIT design
- 24000 MWt achieved 1800 days lifetime with $k_{eff}$ = 1.02 at BOL with rods removed.
- Likely that our reactor can achieve longer given greater fertile inventory and $k_{eff}$ = 1.04 at BOL with rods removed.
- Needs formal core depletion code analysis

| | Zone 1 (kg) | Zone 2 (kg) | Zone 3 (kg) | Total (kg) |
|---|---|---|---|---|
| BOL Pu | 3342 | 2807 | 1982 | 8131 |
| EOL Pu | 3375 | 2849 | 2044 | 8268 |
| **% change** | **0.99** | **1.50** | **3.13** | **1.68** |
| BOL U | 19356 | 16254 | 11476 | 47086 |
| EOL U | 17935 | 14568 | 10154 | 42657 |
| **% change** | **-7.34** | **-10.37** | **-11.52** | **-9.41** |
| BOL MA | 516 | 433 | 306 | 1255 |
| EOL MA | 423 | 316 | 214 | 953 |
| **% change** | **-18.02** | **-27.02** | **-30.07** | **-24.06** |

Estimated inventory changes from 2400MWt MIT core after 1800 days

# Core Reactivity Coefficients

- Estimated again from ELSY, STAR and MIT cores

- Doppler coefficient was found to be -0.111+/-0.03 for MIT core
  - Hard spectrum makes this less negative than other LMFBR cores

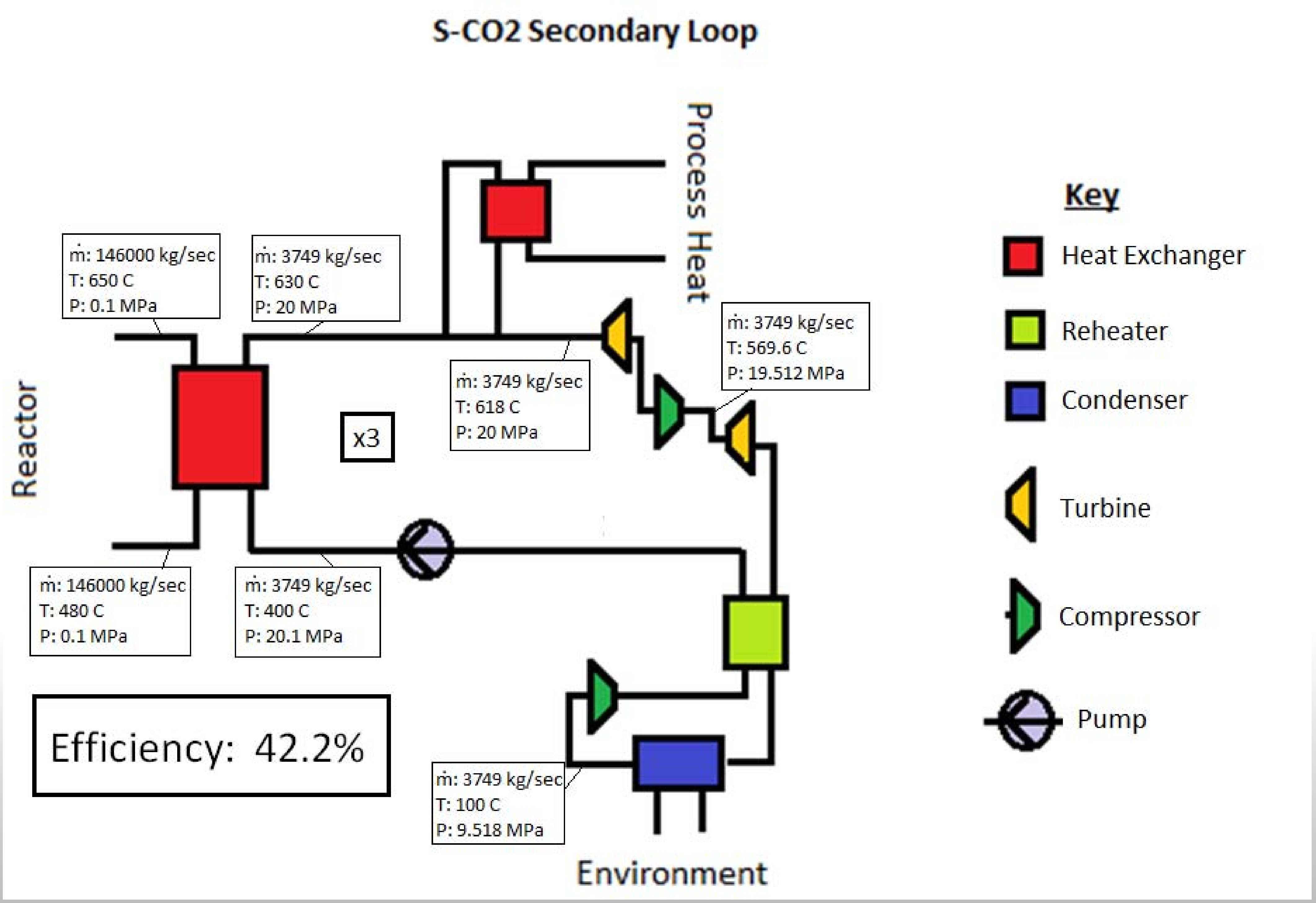
- Temperature coefficient was found to be +0.131 +/-0.052 for MIT core
  - Reactivity insertion at low lead densities not countered by increased scattering and leakage cross sections at higher temperatures.

- Needs to be explicitly calculated for our core. Use of MgO reflector has reduced our required enrichment which may change these values significantly based on work by Driscoll et al.

# Outlays of the System

- Electric Power
  - 1000 MWe
- Plant Power
  - 500 MWe
- Process Heat
  - 315 MWt

# Secondary System

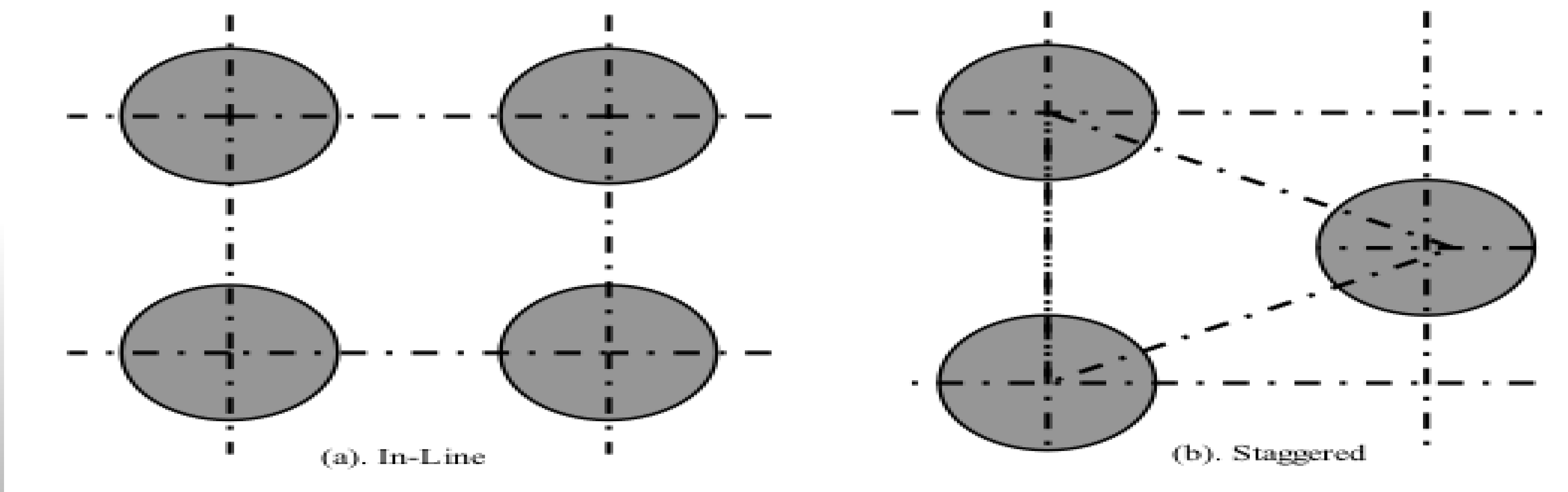


# Secondary System

- Modeled in EES
  - Temperature and mass flow calculations
  - Allows for faster optimization
  - Database provided enthalpy information for S-$CO_2$
- Second turbine added to allow for greater efficiency
- Energy diverted to the Process Heat group does not significantly affect the secondary system (efficiency changes from 45.8% to 42.2%)

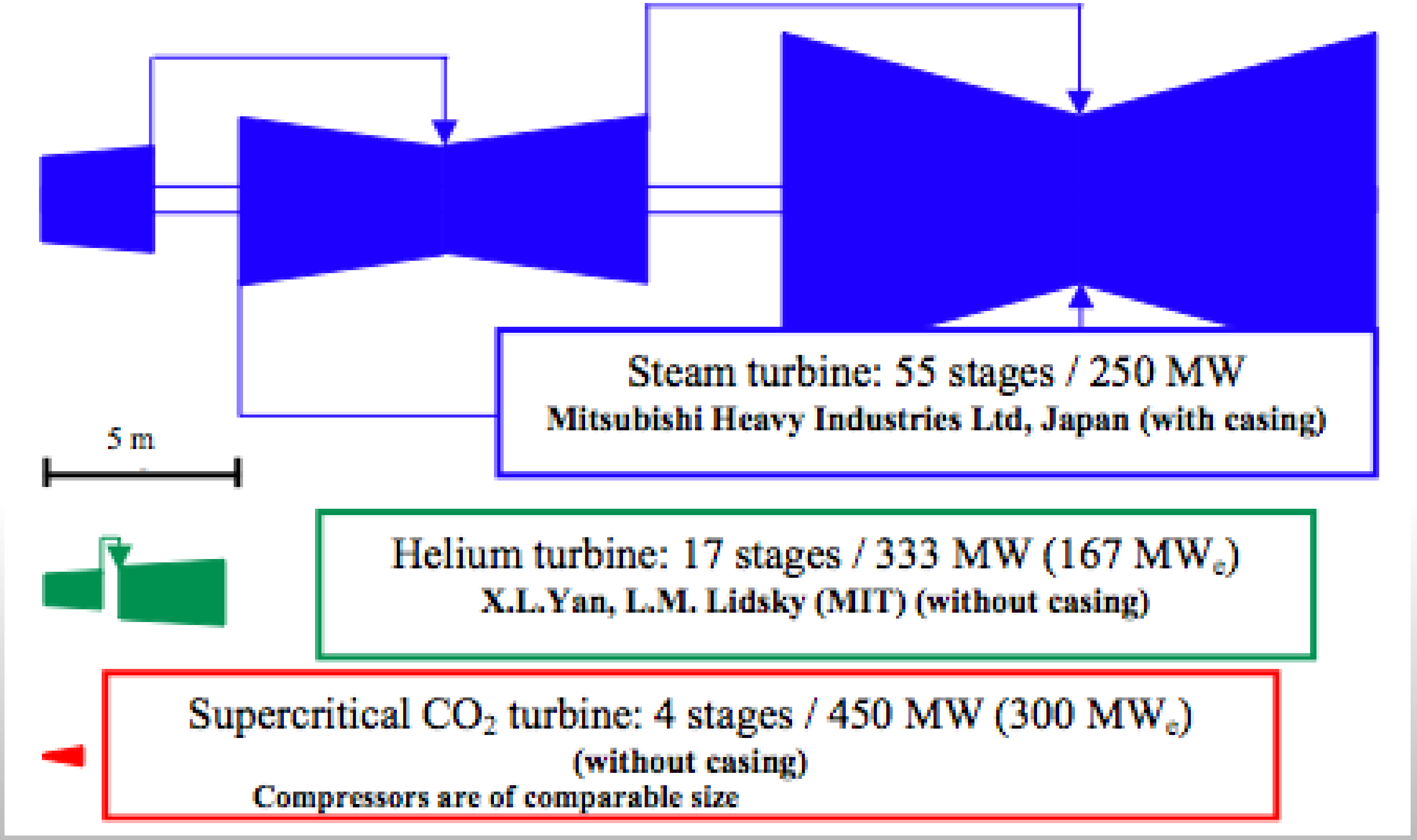
# Shell and Tube Heat Exchanger

- Simple design (easy to make, low cost, etc.)
- Larger than PCHE
- Friction effects of LBE reduced



# Turbines

- Compact due to Brayton Cycle
- Reduces size of turbomachinery




Source: Dostal, V. "A Supercritical Carbon Dioxide Cycle for Next Generation Nuclear Reactors." MIT Sc. D. Thesis, January 2004.

# Future Work for Core

- Switch to alternate clad material or lower operating temperature OR both.
- Look at efficiency improvements in secondary system.
- Look at Uranium Carbide as alternate fuel.
- Full depletion and kinematic calculation.
- Determine if decay natural convection possible.

# Process Heat

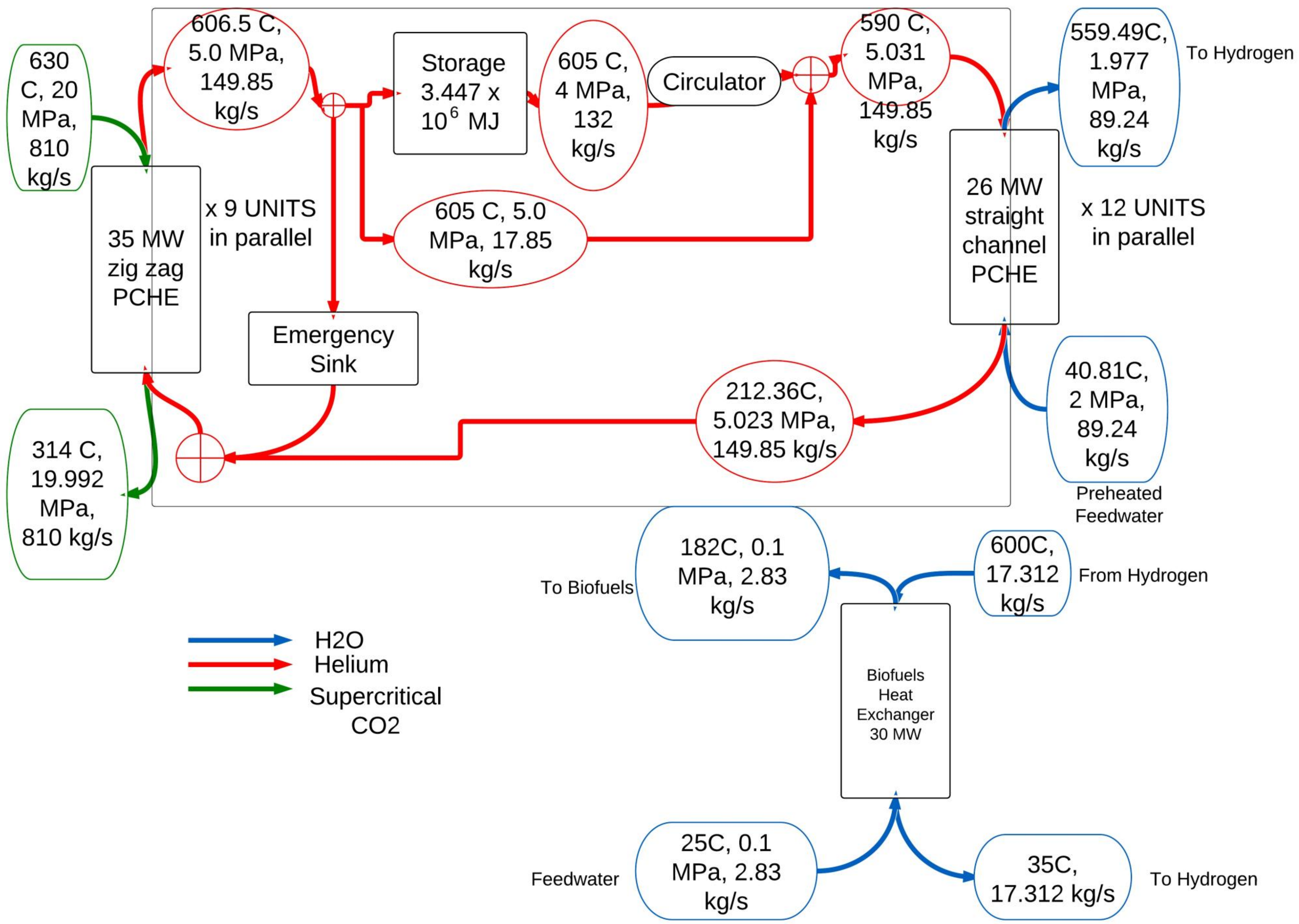
# Outline

1. Goals
2. Heat Exchangers
3. Piping
4. Heat Storage
5. Future Work

# Process Heat Goals

- Draw heat from the Core to provide steam to the Hydrogen and Biofuels plants
- Keep the LBE melted during reactor outage
- Design system for operation at high temperatures and pressures

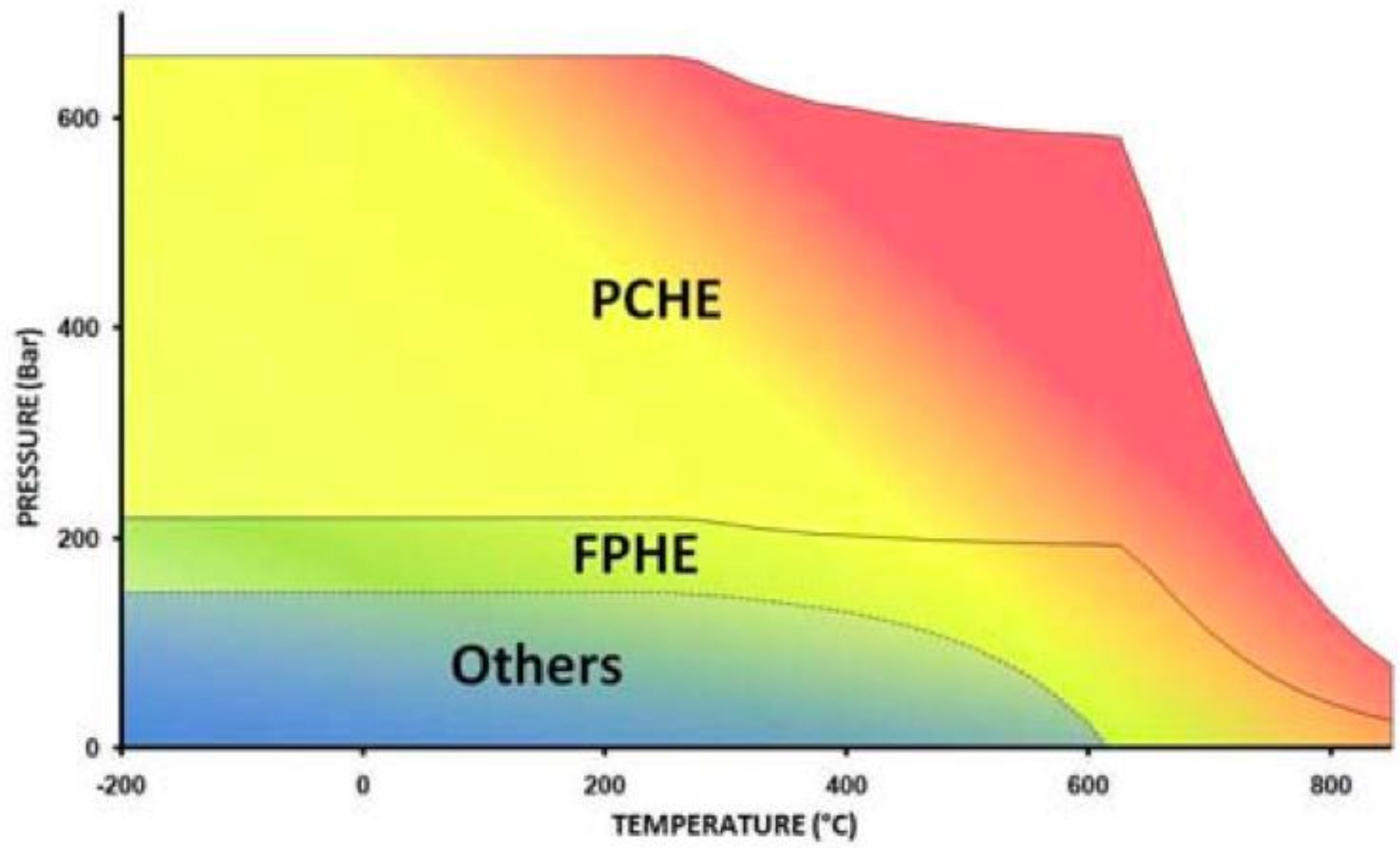
# System Layout



# System Pressure and Temperature Drops

| System component | | Pressure drop [ kPa ] | Temperature change [ ° C ] |
|---|---|---|---|
| PCHE1 | Hot side | 8.043 | -316 |
| | Cold side | 23.749 | +405.47 |
| PCHE2 | Hot side | 9.812 | -388 |
| | Cold side | 13.874 | +518.67 |
| Heat storage | | 1000 | -1.5 |
| Piping (30m) | | 2.047 | -0.041 |

# Heat Exchangers




$T_{high}$= 630° C
$P_{high}$=20 MPa

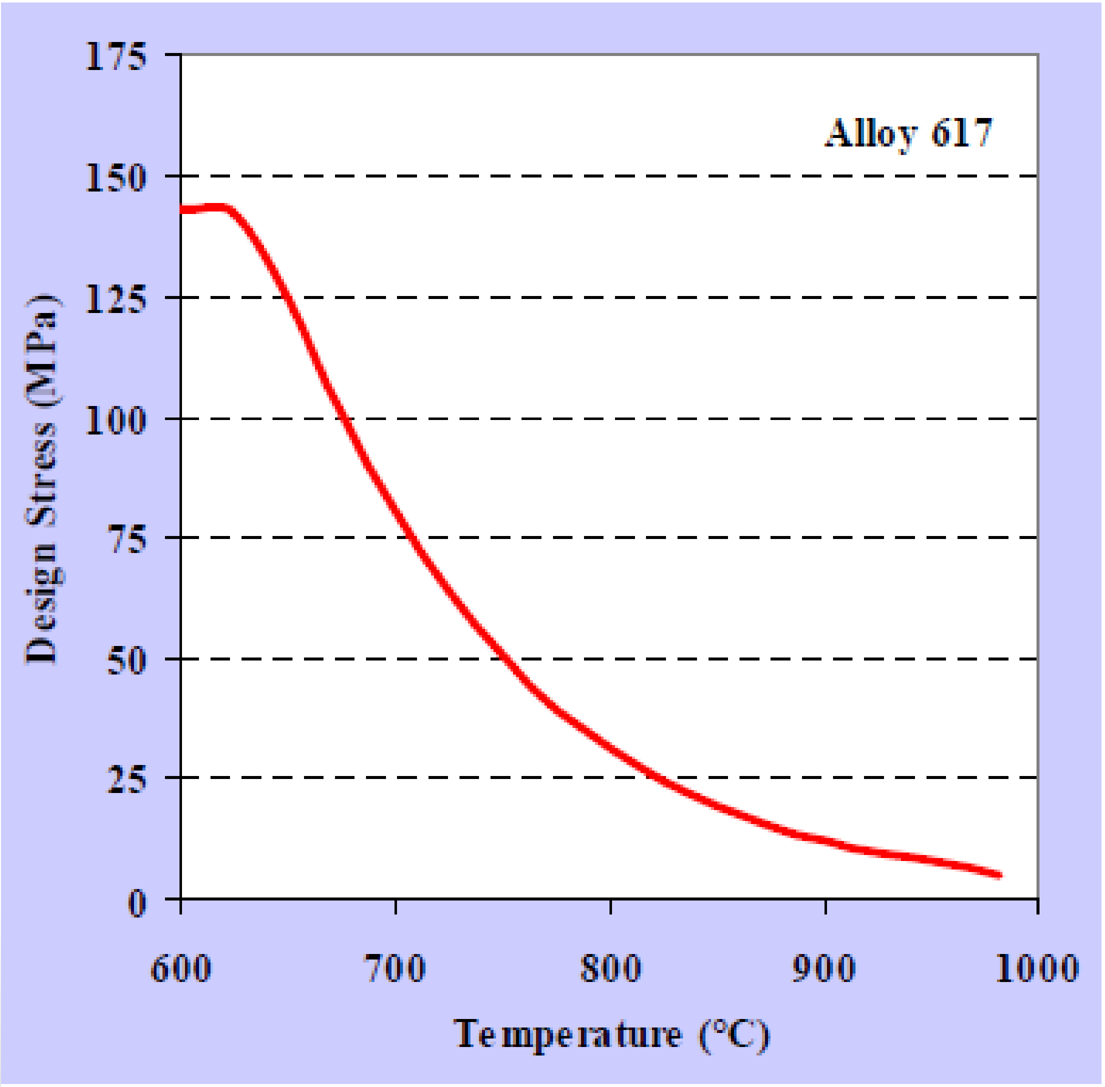
PCHEs chosen for their:
- High operating temperatures
- Small volumes
- High effectiveness

# Working Fluid: Helium

| Fluid at 5MPa [200◎ C, 700◎ C] | Heat Capacity [J/kg-K] | Viscosity [Pa-s] |
|---|---|---|
| Carbon Dioxide ($CO_2$) | 1079.5, 1237.8 | 2.337 $10^{-5}$, 4.064 $10^{-5}$ |
| Water/Steam ($H_2O$) | 4476.1, 2351.5 | 1.35 $10^{-4}$, 3.678 $10^{-5}$ |
| Helium (He) | 5188.9, 5190.6 | 2.74 $10^{-5}$, 4.533 $10^{-5}$ |

***data from webbook.nist.gov

# PCHE Material: Alloy 617




Reasons for choosing Alloy 617:
- Tensile strength
- Thermal conductivity
- Thermal expansion
- Corrosion resistance
- Ease of manufacturing
- Design life of up to 60 years

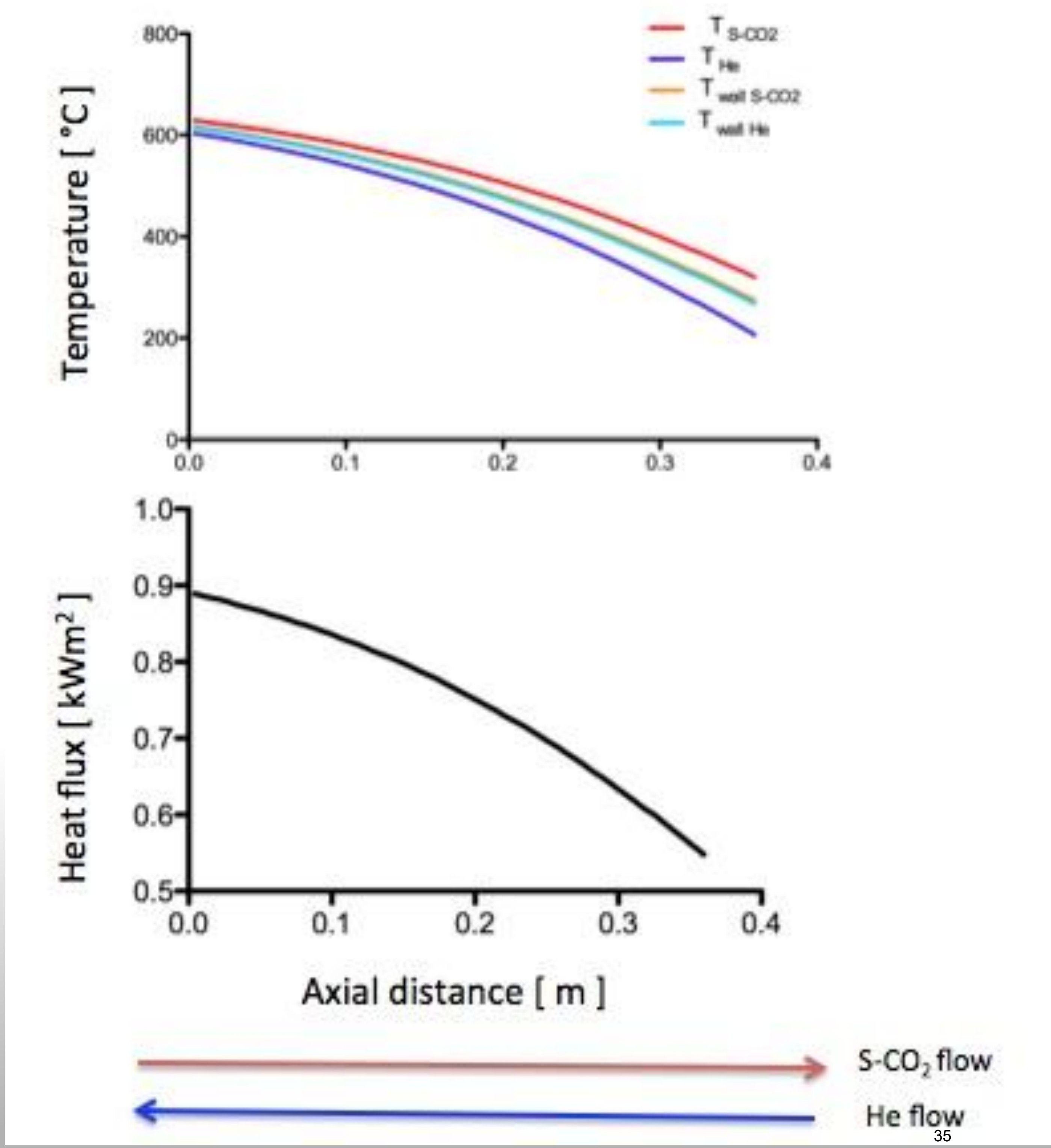
PCHEs will operate well below design stresses at all points in system

# Process Heat PCHEs

| Parameter | PCHE1 | PCHE2 |
|---|---|---|
| **Heat rate/unit** | 35 MW | 26 MW |
| **Number of units** | **9** | **12** |
| **Total heat rate** | 315 MW | 312 MW |
| **Hot fluid** | S-$CO_2$ | He |
| **Cold fluid** | He | $H_2O$ |
| **Channel configuration** | zigzag | straight |
| **location** | S-$CO_2$ loop | Hydrogen plant |
| **Total htc** | 1087.71 $W/m^2K$ | 735 $W/m^2K$ |
| **Volume** | 8.25 $m^3$ | 15.6 $m^3$ |

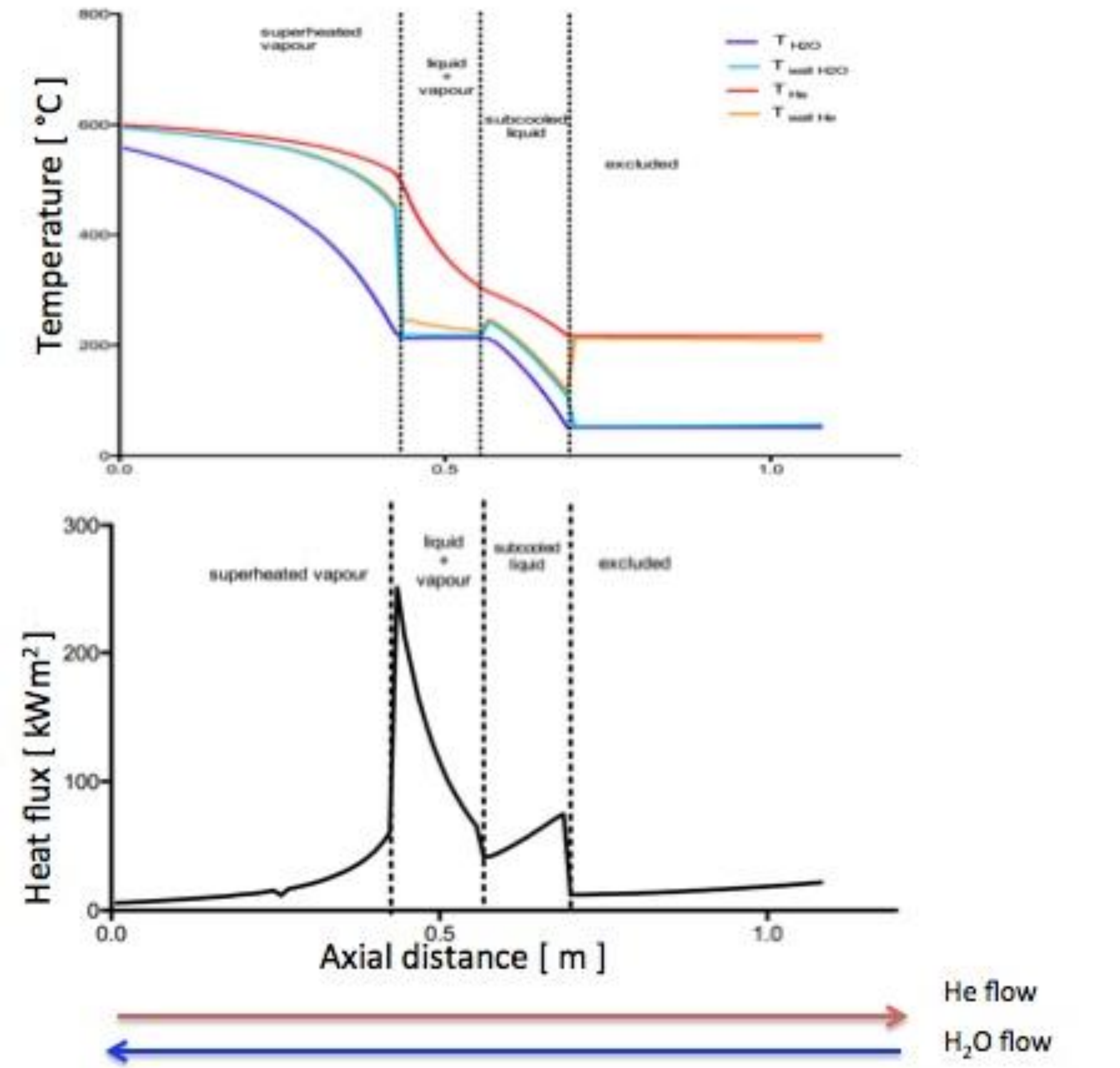
*HEATRIC's quote for steel $/kg cost used

# PCHE1: Temperature and Heat Flux Profiles




- Zigzag flow channels
- Counterflow
- Single-phase forced convection
- No swings in temperature or heat flux
- S-$CO_2$: turbulent
- He: laminar

# PCHE1: Temperature and Heat Flux Profiles




- Straight channels
- Counterflow
- Two-phase flow
- Unphysical behavior to the left of x=0.68m
- Exclude this region
- Both fluids laminar
- Large swings in temperature and heat flux!
- Design as three separate HXs?

# Fouling and Design Life

Fouling affects heat rate and pressure drops

PCHE operation up to 500 – 660 hours:

- no change in effectiveness
- 55% increase in pressure drop!

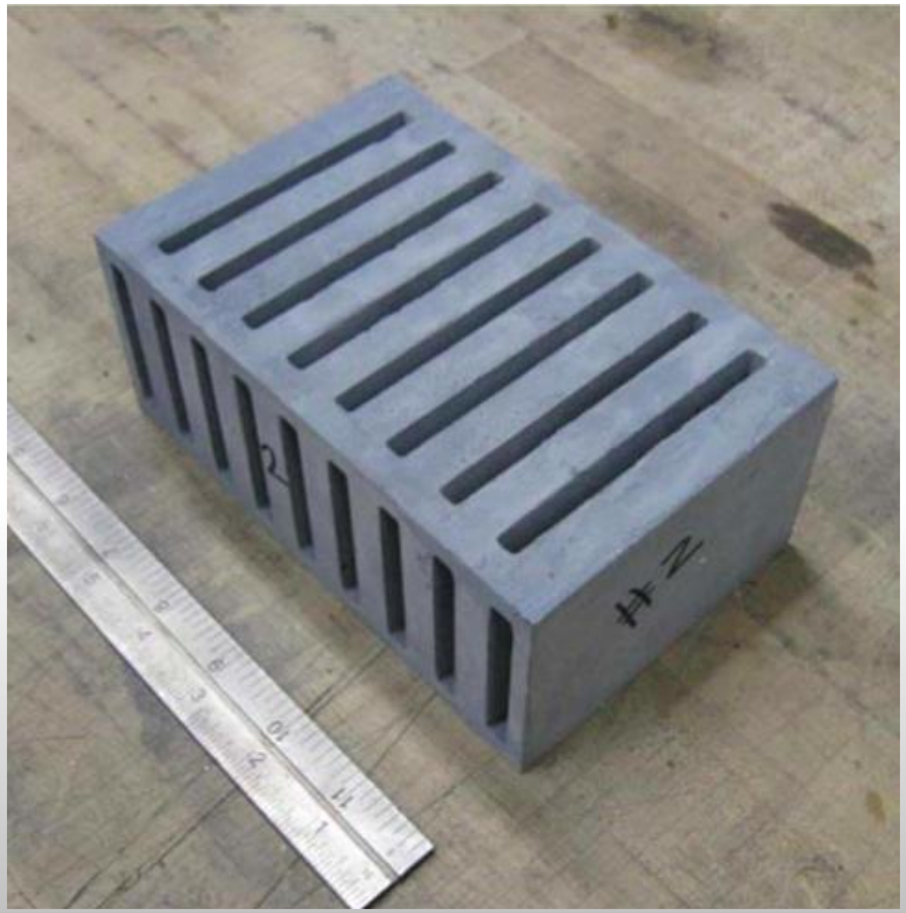
18 month fuel cycle = ~12,960 hours

Solutions:

- Installation of redundant units
- Addition of Cl to fluid streams to reduce biofouling

# Biofuels Heat Exchanger

- Recover heat from $H_2O + H_2$ and $O_2$ streams at the Hydrogen plant
- Produce steam at 182° C and 0.1MPa for Biofuels
- Highly oxidative and reductive environment!
- Prospective materials: RBSiC and SiSiC



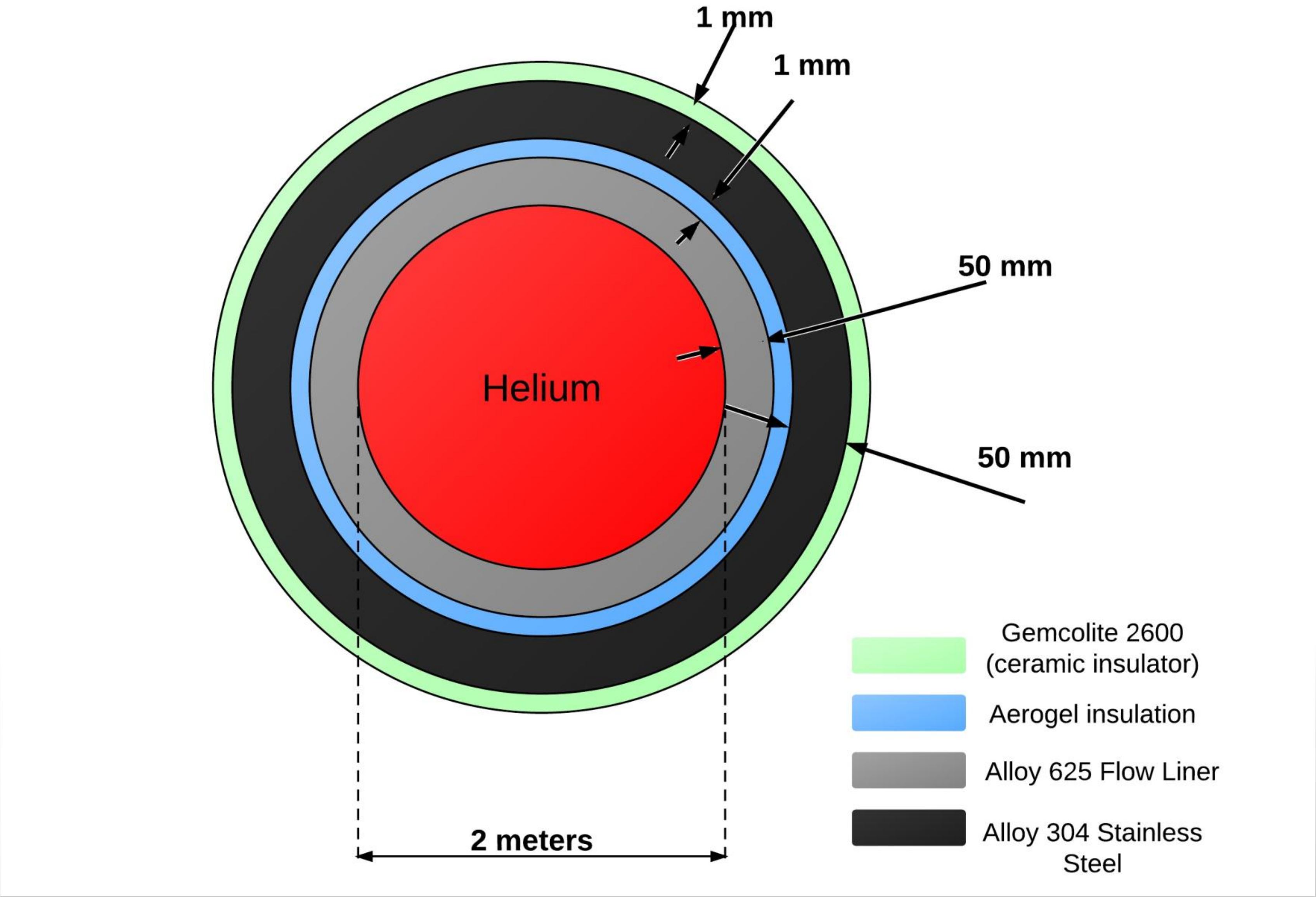


Ceramic monolith for a cross flow HX fabrication



Source: Litka, A. F. Presentation slides for "Ceramic/Metallic Heat Exchanger Development." 9th Annual SECA Workshop, Pittsburgh PA, 2008. (PDF)

# Piping Insulation




Adapted from tests and design in "Conceptual Design for a High Temperature Gas Loop Test Facility." Idaho National Laboratory Report INL/EXT-06-11648, 2006

# PCM: Lithium Chloride (LiCl)

| Property | Value |
|---|---|
| Melting Point | 605° C |
| Δh° fusion | 470 kJ/kg |
| c_p (solid) | 1.132 kJ/kg-K |



Source: http://en.wikipedia.org/wiki/File:Lithium_chloride.jpg (public domain image)

# Containment Material: Alloy 20

Nickel-Chromium-Molybdenum alloy

Resistant to chloride ion corrosion

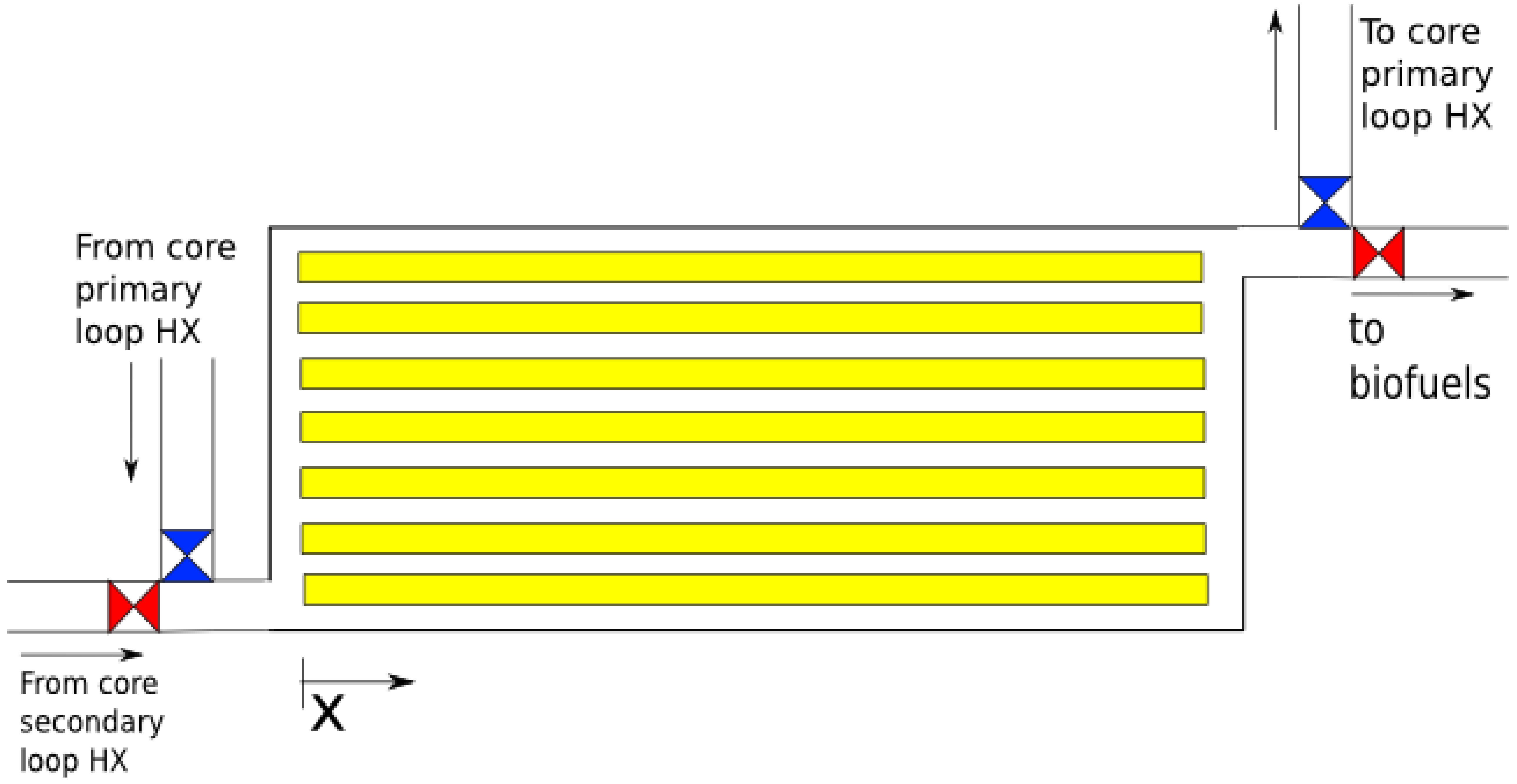
MP >1380° C

k = 18.15 W/m-K

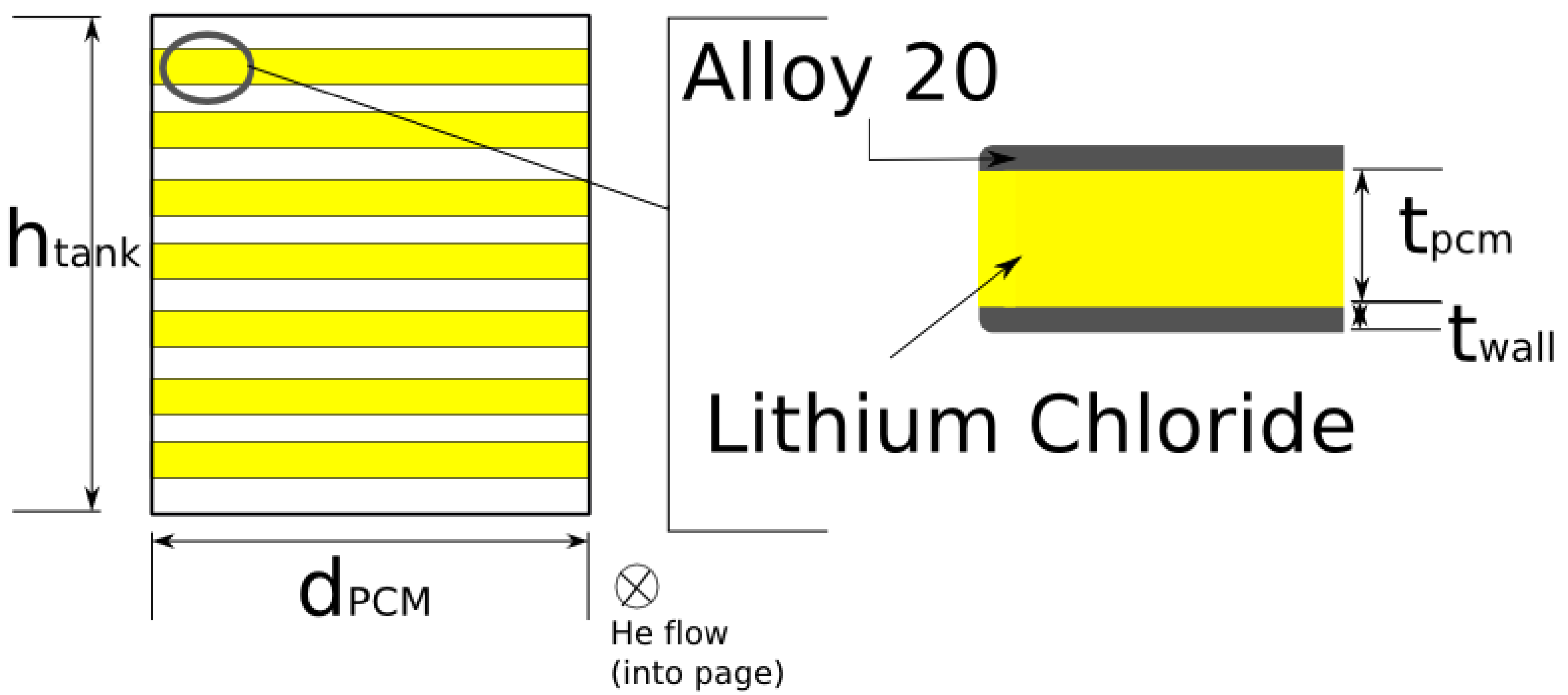
| | Min (%) | Max (%) |
|---|---|---|
| Nickel | 32.5 | 35.0 |
| Chromium | 19.0 | 21.0 |
| Molybdenum | 2.0 | 3.0 |
| Manganese | 0.0 | 2.0 |
| Copper | 3.0 | 4.0 |
| Silicon | 0.0 | 1.0 |
| Carbon | 0.0 | 0.06 |
| Sulfur | 0.0 | 0.035 |
| Phosphorus | 0.0 | 0.035 |
| Niobium | 1.0 | none |
| Iron | 0.0 | balance |

Adapted from: http://www.rolledalloys.com/products/nickel-alloys/alloy-20

# Storage – Heat Exchanger

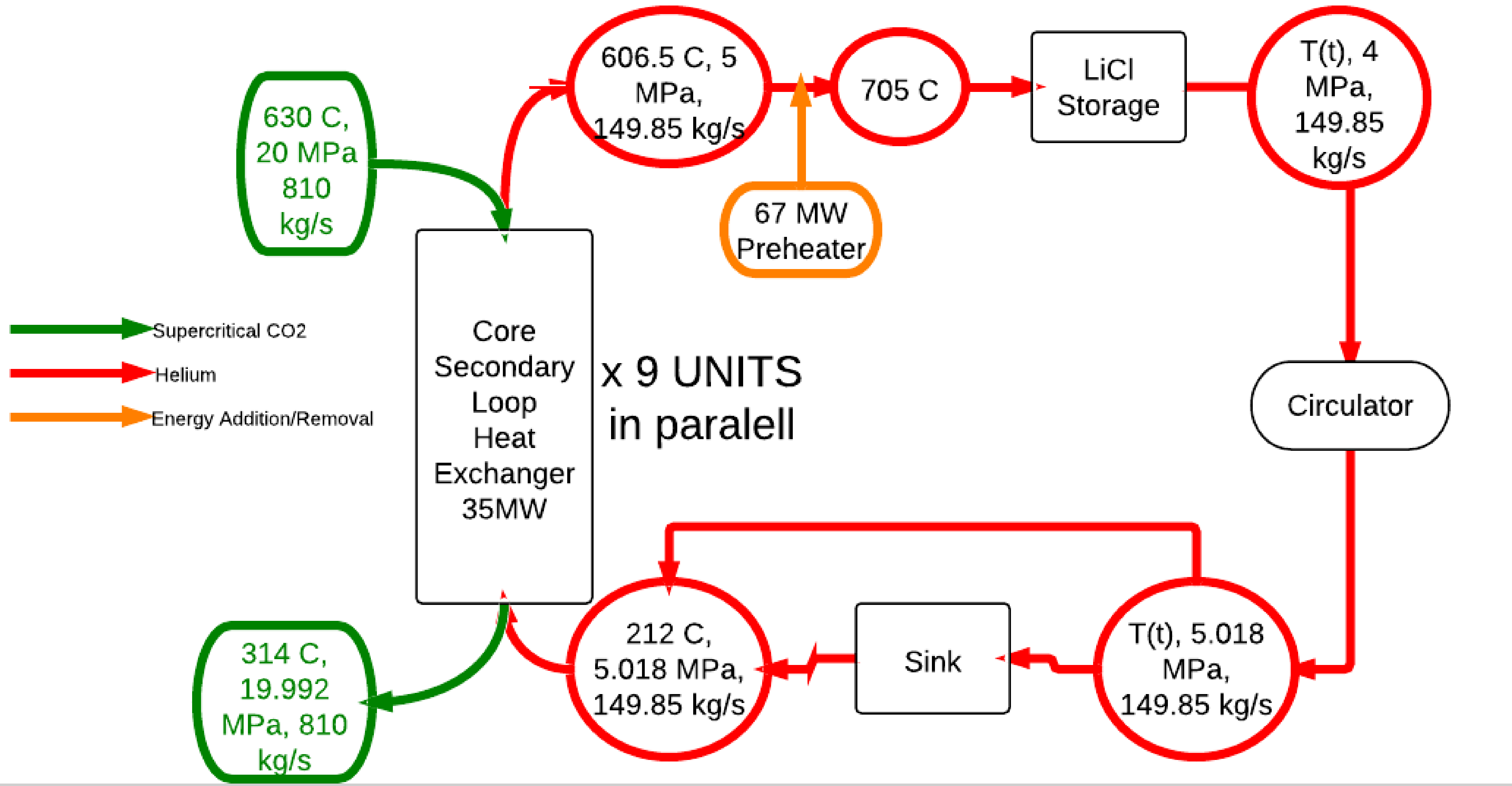


# Storage – Heat Exchanger



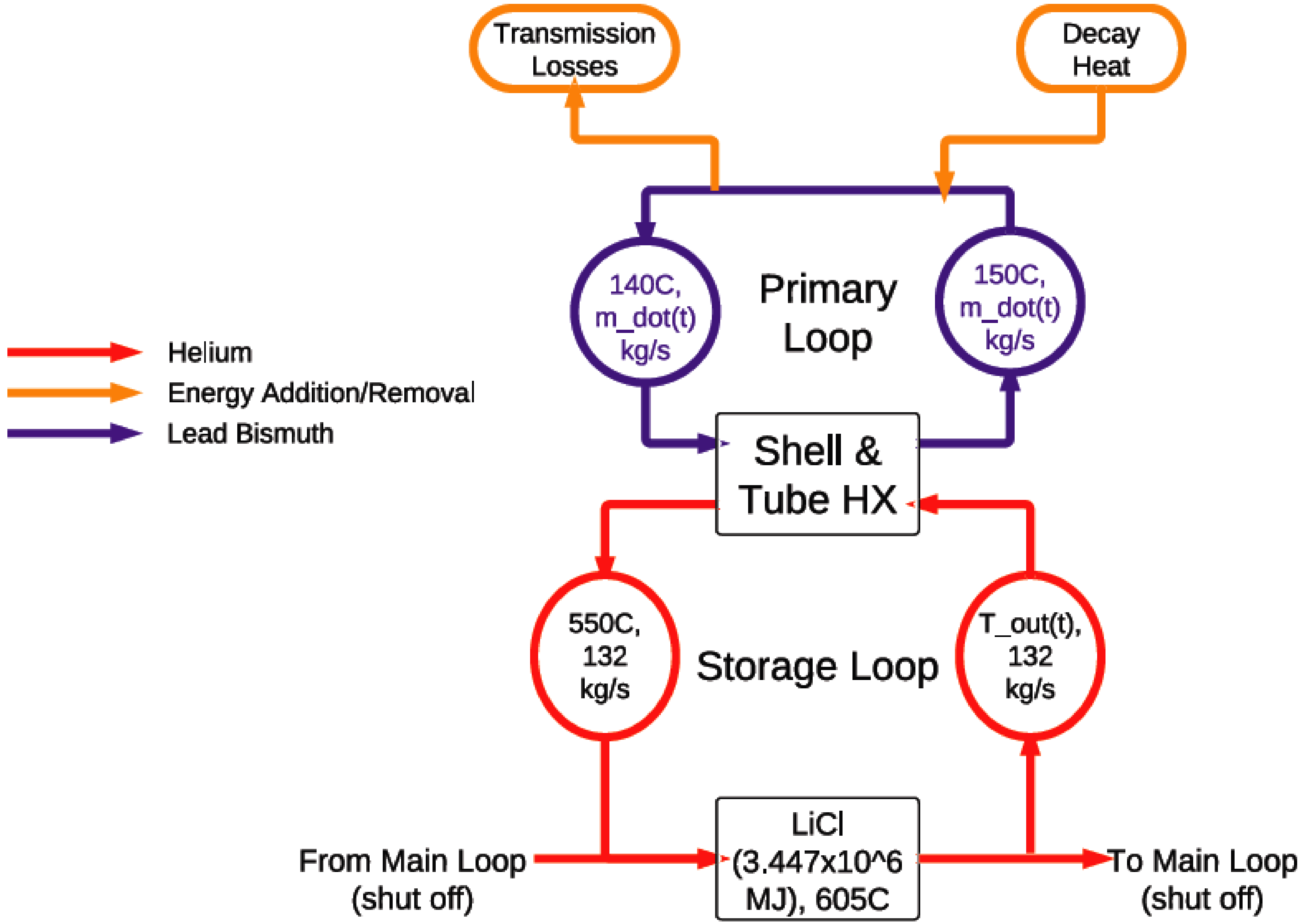

| Dimension | Value |
|---|---|
| $h_{tank}$ | 11.41 m |
| $d_{PCM}$ | 18 m |
| $t_{PCM}$ | 1.13 m |
| $t_{wall}$ | 1 cm |
| Length of tank | 20 m |
| Gap height | 1 cm |

# Charging Layout




Charging Time (with 67 MW preheater): 33 days, 12 hours

# Discharging Layout



# Emergency Scenarios

Storage: LiCl leak

- Reroute He flow around storage and compressor

Heat Sink

- Average Decay Heat from core → process heat 1 hr after shutdown: 5MW
- Maximum temperature change of water : 10° C
- Volumetric flow rate of seawater : 455 gallons/second
- Ti plate type HX specifically for marine applications
- Outlet diffusers to reach thermal equilibrium quicker/minimize environmental impact

# Future Work: Process Heat

- Compare PCHEs with Shell and Tube designs
- Split PCHE2 into multiple stages
- PCHE fouling factors
- Correction factors for determining CHF values for semi-circular channels
- $m_{dot}(t)$ of LBE
- Ensure that ΔT of 10°C is enough to keep LBE molten even for lowest $m_{dot}$
- Effects of a support system on He flow
- Insulation: steady state and during shutdown

22.033

# Hydrogen Production Plant

# Outline

1. Engineering Objectives
2. Options for Hydrogen Production
3. UT-3
    - Plant Diagram
4. HTSE
    - Plant Diagram
    - Materials
5. Future Work

# Engineering Objectives

- Meet biofuel's hydrogen requirement
- Maximize use of process heat
- Minimize electricity use
- Zero greenhouse emissions

# Options for Hydrogen Production

| Process | Materials | Temp [°C] | Efficiency [%] | Feasibility |
|---|---|---|---|---|
| ES | Water, Electrolytes, Anode/Cathode | ~100 | 25-45 | Drastic scaling required |
| HTSE | Solid Oxide Electrolysis Cell | >500 | 90-95 (at 800°C) | Only small scale |
| SI | Ceramics | >850 | 34-37 | Commercially viable, but too high temp |
| SMR | Ni catalyst | 700-800 | 60 | Commercially viable, but polluting |
| UT-3 | Ceramics, chemical reactants | 760 | >40 | Commercially viable |

ES: Water Electrolysis
HTSE: High Temperature Steam Electrolysis
SI: Sulfur-Iodine Process

SMR:Steam Methane Reforming
UT-3:University of Tokyo-3
(Ca-Br-Fe Thermochemical Cycle)

# UT-3 Hydrogen Production Process[1]

$$CaBr_2(s) + H_2O(g) \rightarrow CaO(s) + 2HBr(g)\ (760\,C)$$

$$CaO(s) + Br_2(g) \rightarrow CaBr_2(s) + 0.5O(g)\ (571\,C)$$

$$Fe_3O_4(s) + 8HBr(g) \rightarrow 3FeBr_2(s) + 4H_2O(g) + Br_2(g)\ (220\,C)$$

$$3FeBr_2(s) + 4H_2O(g) \rightarrow Fe_3O_4(s) + 6HBr(g) + H_2(g)\ (560\,C)$$

- Bromination of calcium oxide, acidity, leads to material concerns.

[1]H.Kameyama and K. Yoshida. Br-ca-fe water decomposition cycles for hydrogen production. Proc. 2nd, WHEC., pages 829–850, 1978.

# UT-3 Hydrogen Production Process[1]

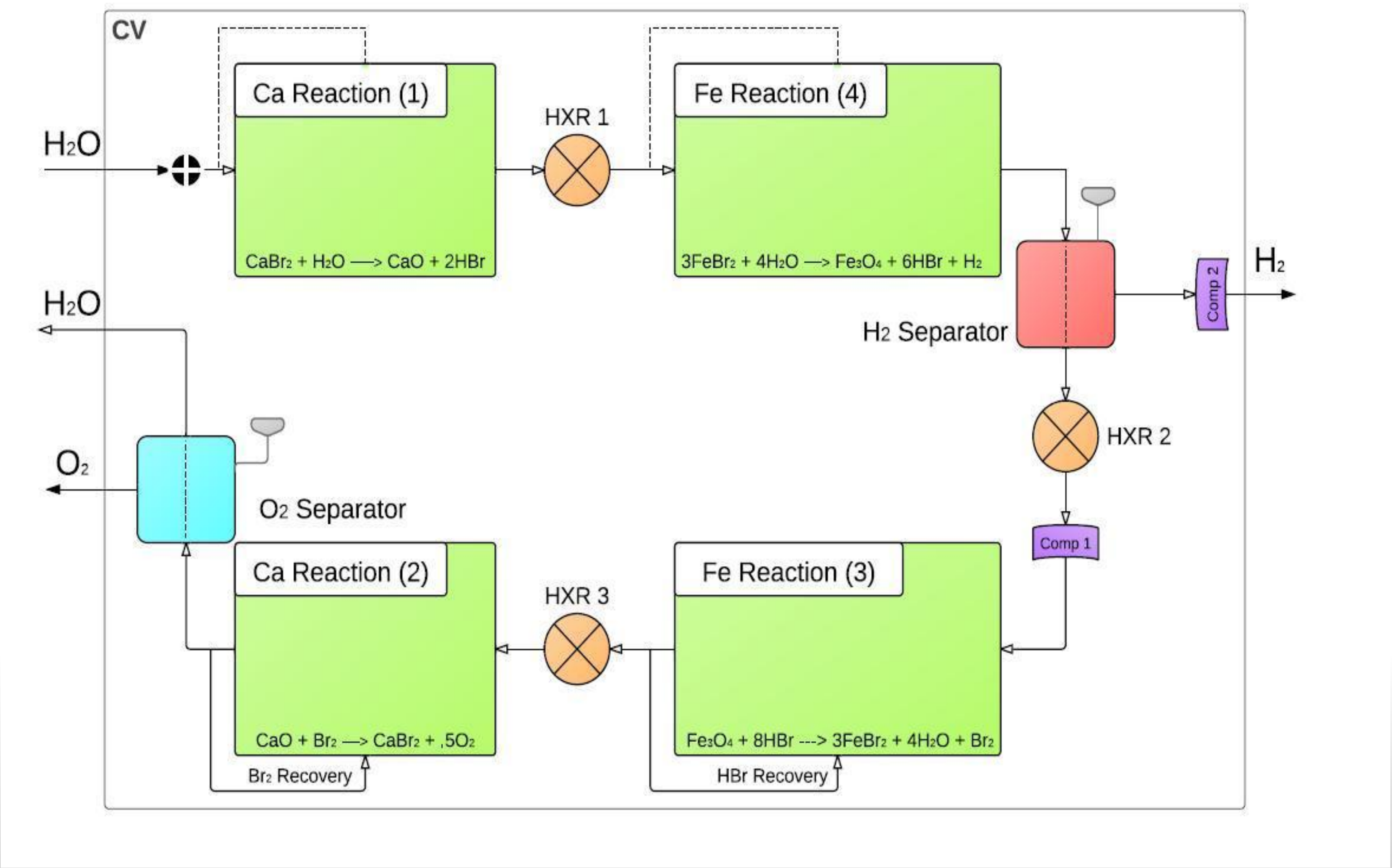



Image adapted from: Sakurai, M. "Adiabatic UT-3 Thermochemical Process for Hydrogen Production". Energy. 2(10), 865-870 (1996).

# Complications

- Necessary steam temperature could no longer be provided.
- Electric power required larger than reactor output.
- New hydrogen production design required

# High Temperature Steam Electrolysis

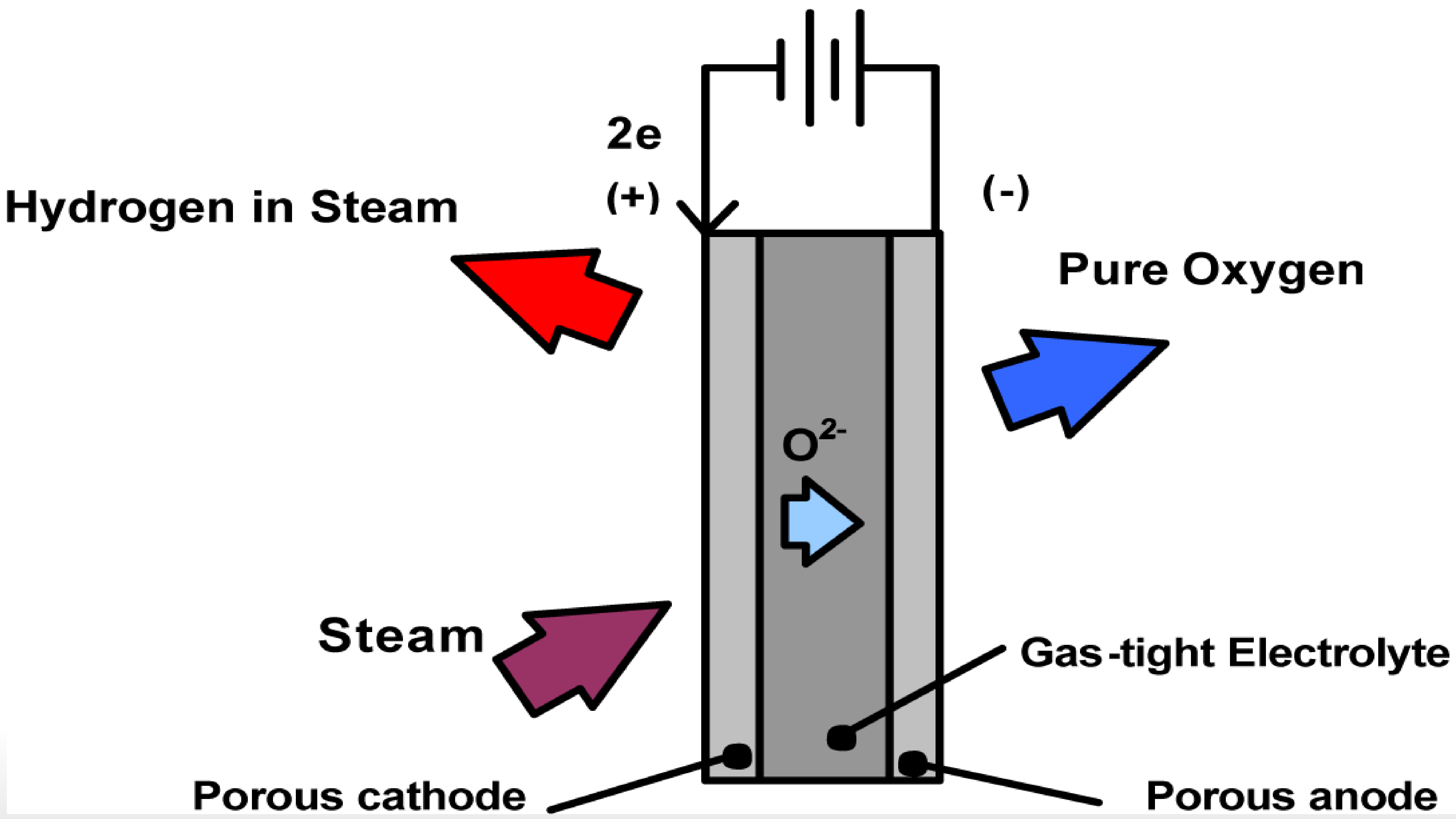
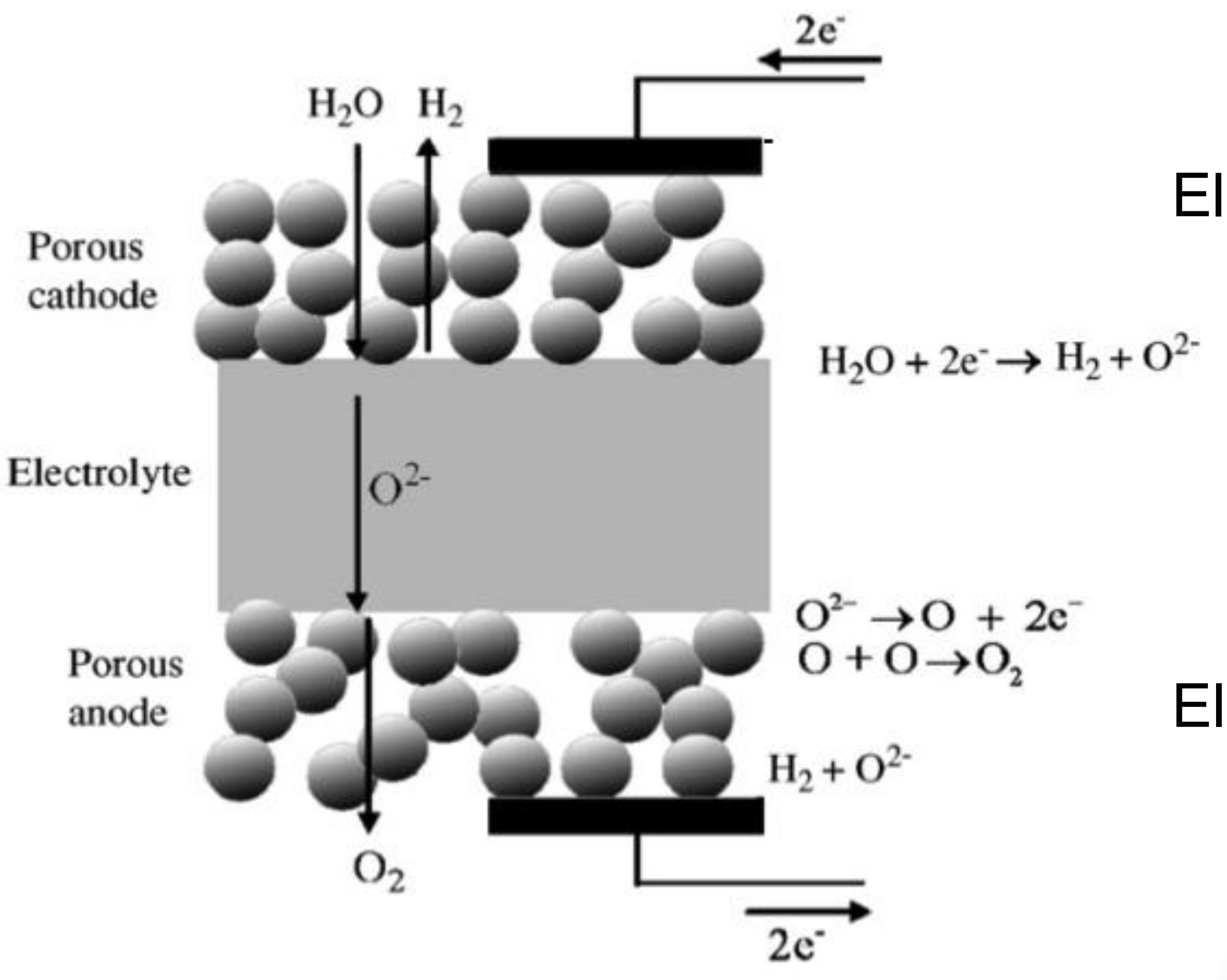



Image from: U.S. DOE fact sheet for high-temperature electrolysis

# Solid Oxide Electrolysis Cell (SOEC)




Courtesy of Elsevier, Inc., http://www.sciencedirect.com. Used with permission.

Material Requirements

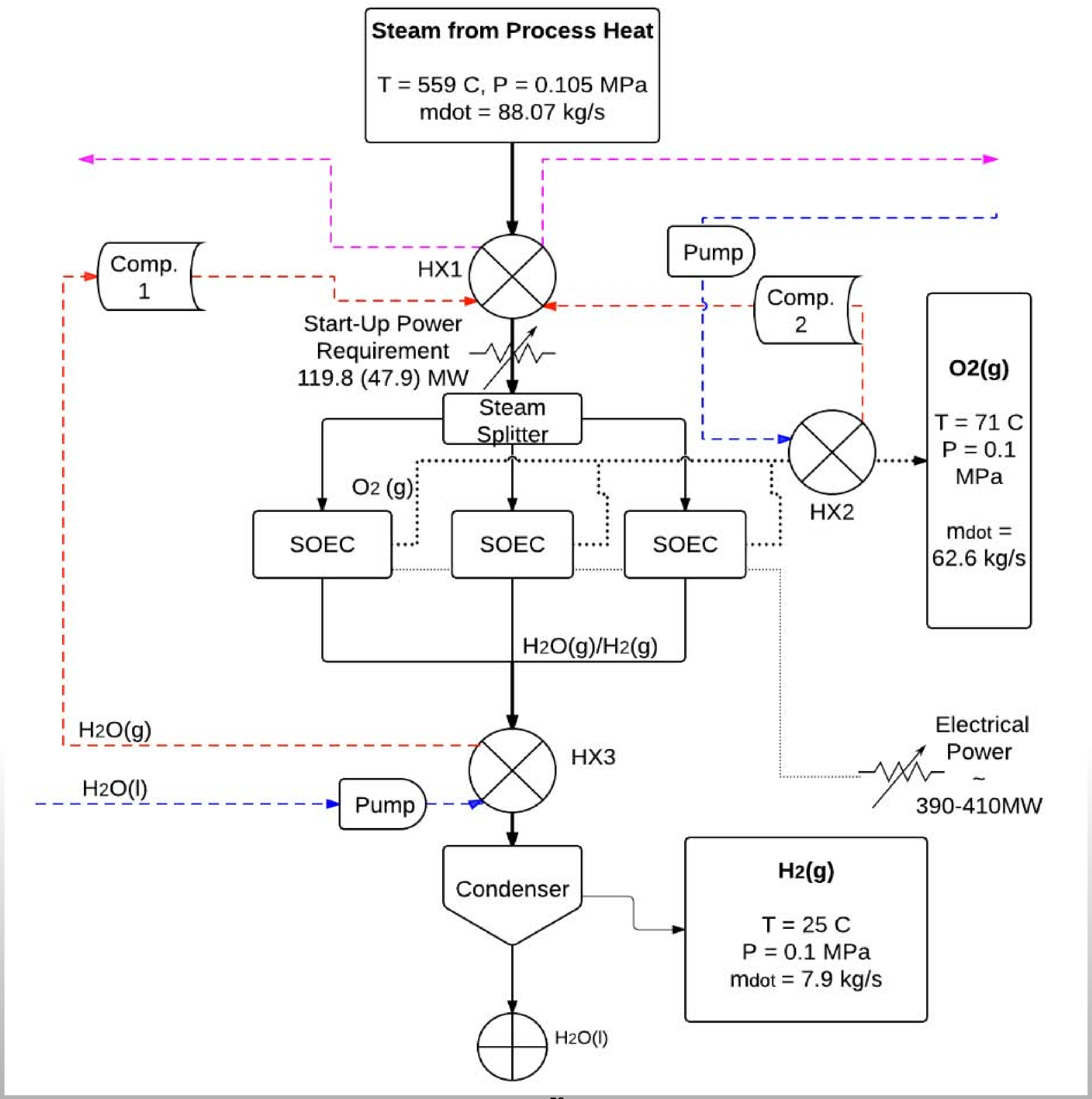
Electrolyte:
- Dense
- Chemically stable
- High ionic conductivity
- Gas-tight (no H-O recombination)
- Thin (minimize Ohmic resistance)

Electrodes:
- Porous, allows gas transportation
- Similar thermal expansion coefficient to electrolyte

# Electrolyte Material

| Name | Type | Ionic Conductivity (S/cm) | Optimal Temperature (K) | Comments |
|---|---|---|---|---|
| YSZ | Stabilized zirconia | 0.13 | 1273 | Overall best choice |
| ScSZ | Stabilized zirconia | 0.18 | 1273 | Exorbitant cost |
| LSGM | Doped $LaGaO_3$ | 0.17 | 973 | Requires reduced operating temperature; problematic reaction between LSGM and Ni |
| GDC | Ceria-based oxides | 0.10 | 1073 | Chemically unstable |
| SDC | Ceria-based oxide | 0.08 | 1073 | Chemically unstable |
| $BaCeO_3$ | Proton-conducting electrolyte | 0.08 | 1073 | Low conductivity |

# HTSE with Regenerative Heating



# Future Work: Hydrogen Plant

- Determine electrical requirement to better accuracy.
- Possibly simulate HTSE plant to address efficiency.

22.033

# Biofuels Production Plant

# Outline

1. Goals
2. Overall Design of Biofuels Plant
3. Switchgrass
4. Gasification
5. Acid Gas Removal
6. Fischer-Tropsch Reactor
7. Distillation and Refining
8. Final Products and Concluding Thoughts

# Biofuels Production Plant Goal

- Produce biofuels
- Large scale
- High quality
- Use nuclear power plant
    - Process heat
    - Electricity
- Hydrogen production plant

# Biofuels Process Overview

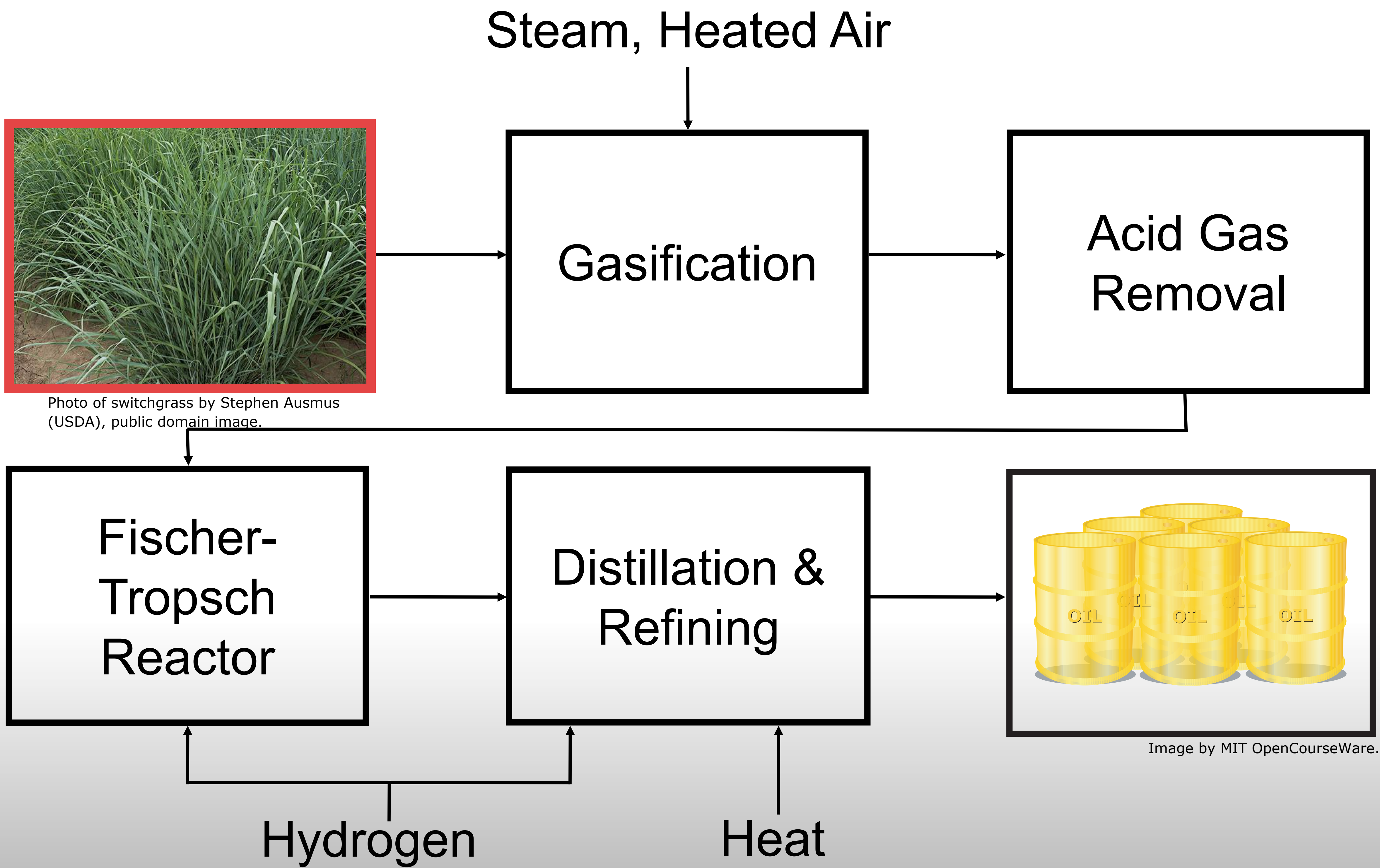



Photo of switchgrass by Stephen Ausmus (USDA), public domain image.

Image by MIT OpenCourseWare.

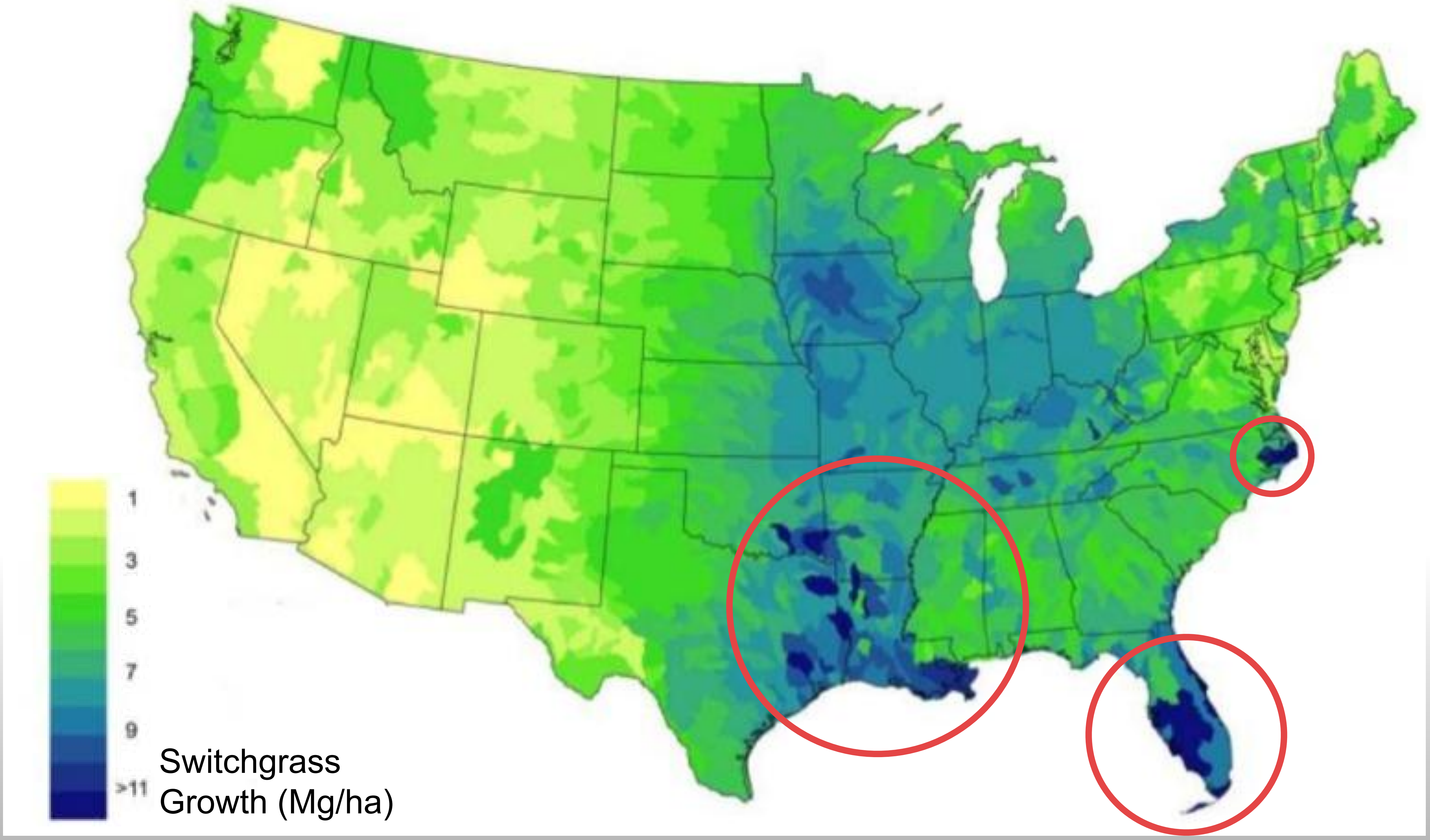
# Choice of Biomass

## Feedstock Comparison

| | Current Cost ($/ton | Energy Density (MJ/kg) | Agriculture Yield (tons/acre) | Food Source? |
|---|---|---|---|---|
| Switchgrass | $40 | 17 | 11.5 | no |
| Sorghum | $40 | 17 | 20 | yes |
| Energy Cane | $34 | 13 | 30 | no |
| Sugar Cane | $34 | 13 | 17 | yes |
| Corn | $40-50 | 13.5 | 3.4 | yes |
| Algae | | | 58700 L/ha | no |

# Switchgrass

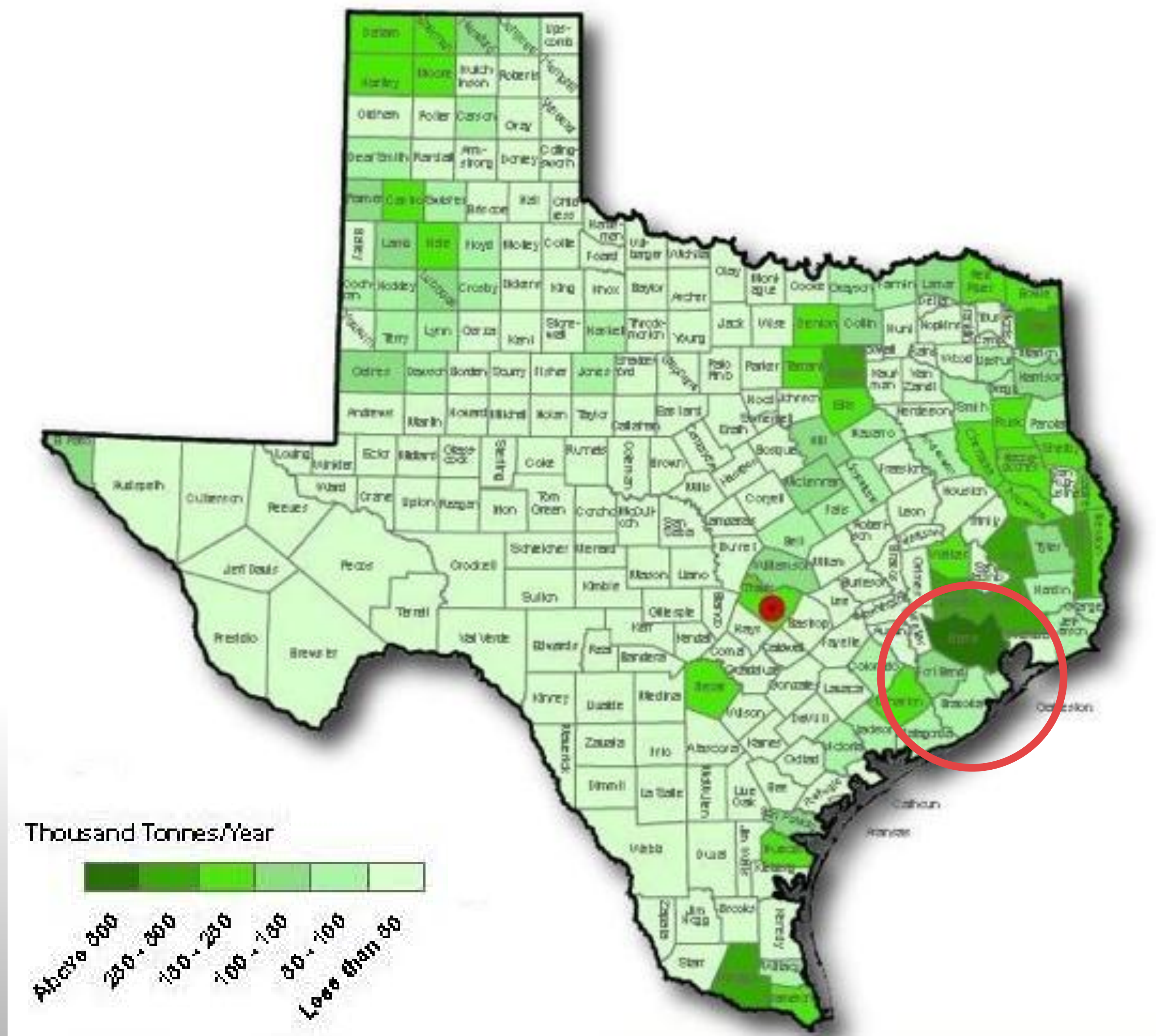
## Optimal Growing Locations in U.S.




Map courtesy of Pacific Northwest National Laboratory, operated by Battelle for the U.S. Department of Energy.

# Switchgrass

## Optimal Growing Location in Texas




Map produced by the National Renewable Energy Laboratory for the U.S. Department of Energy.

# Switchgrass

## Growth and Transportation

- Outsource to local farmers → job creation
- Quantity: 2903 tons/day →
    - 85 flat bed trucks/day carrying 33.3 tons each
    - 13 closed hopper cars at full capacity
- Pelletize to 1300 kg/m$^3$

# Biofuels Process Overview

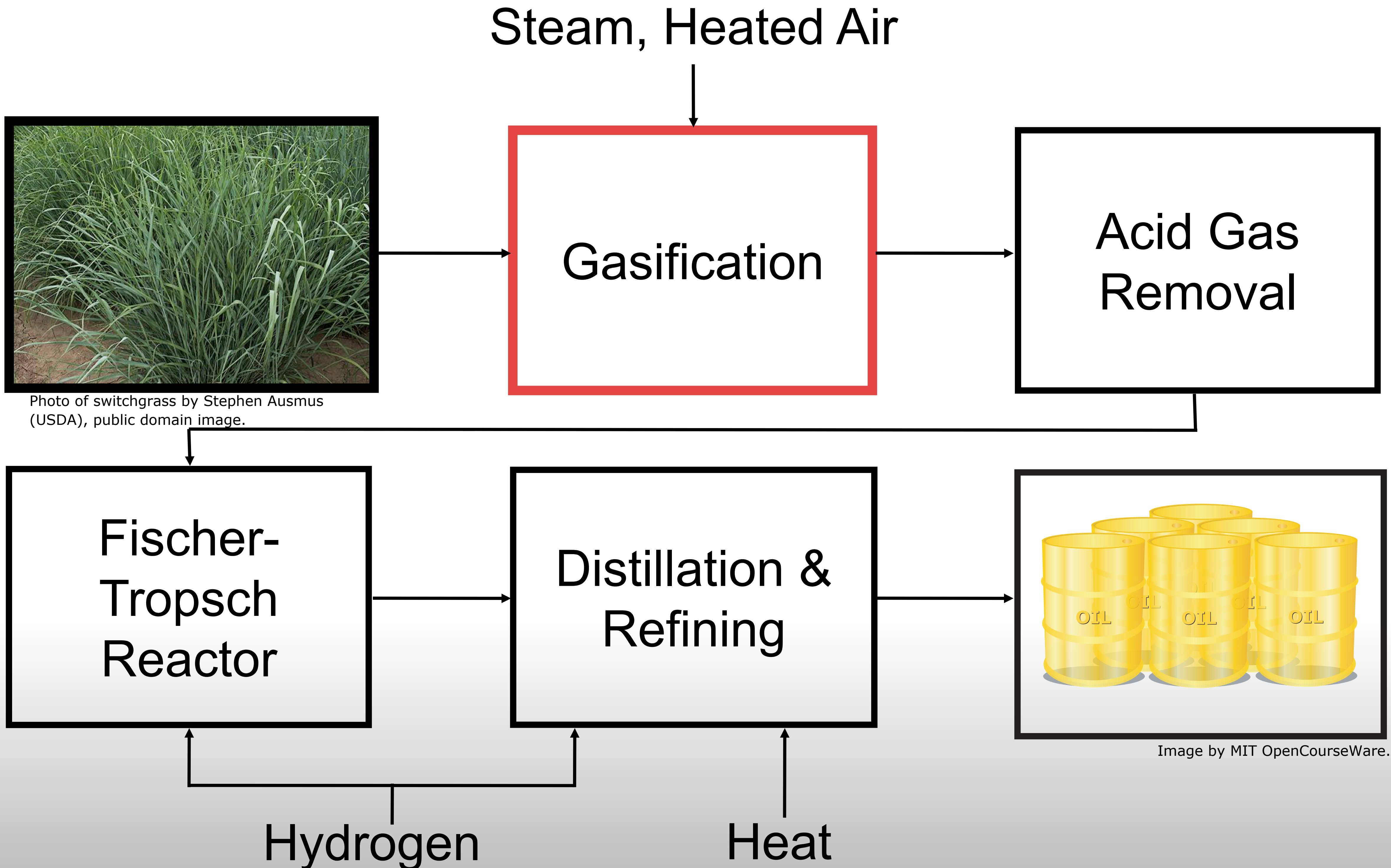
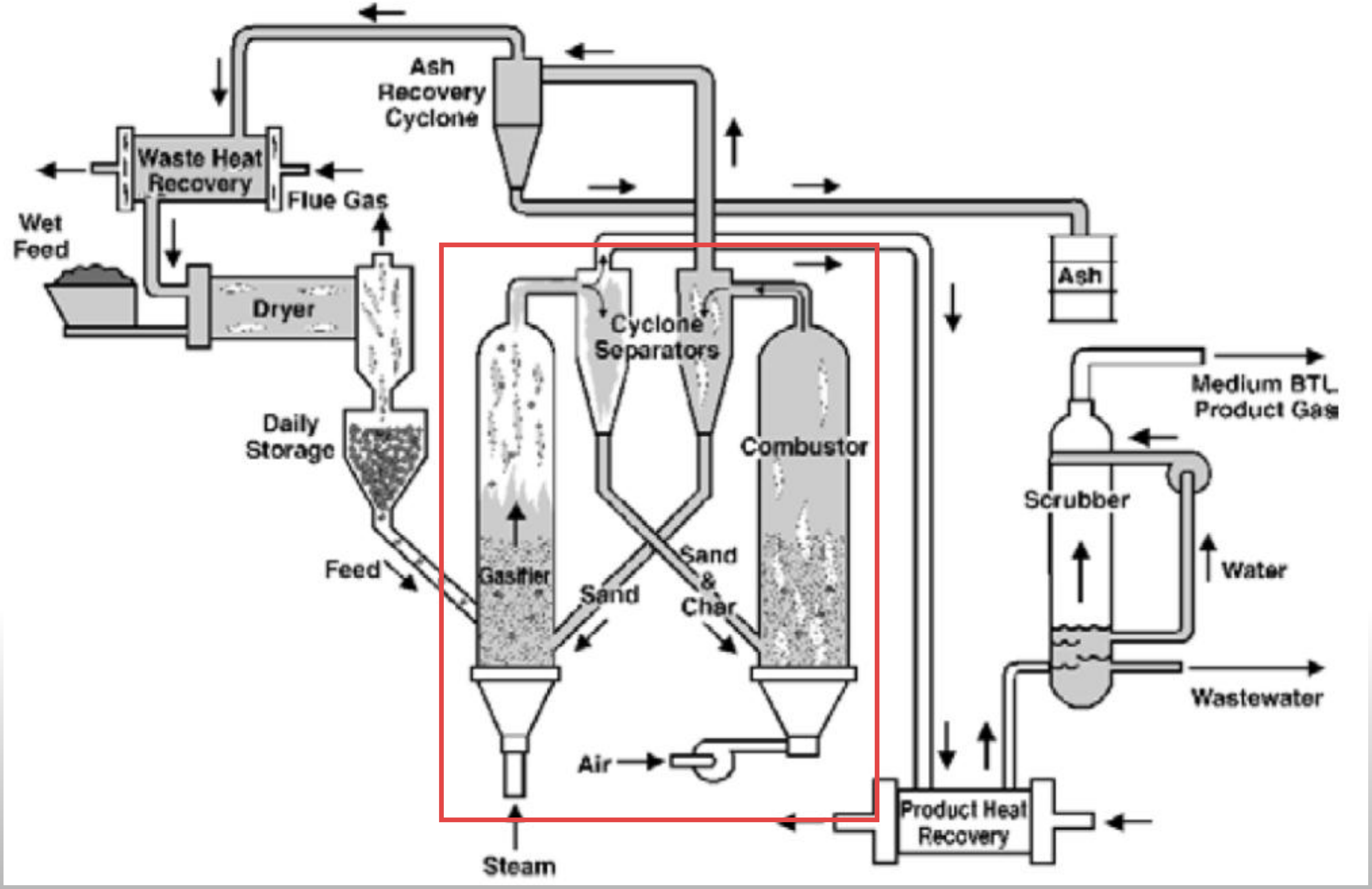



Photo of switchgrass by Stephen Ausmus (USDA), public domain image.

Image by MIT OpenCourseWare.

# Gasification

## Rentech Silvagas Dual Fluidized Bed Cycle

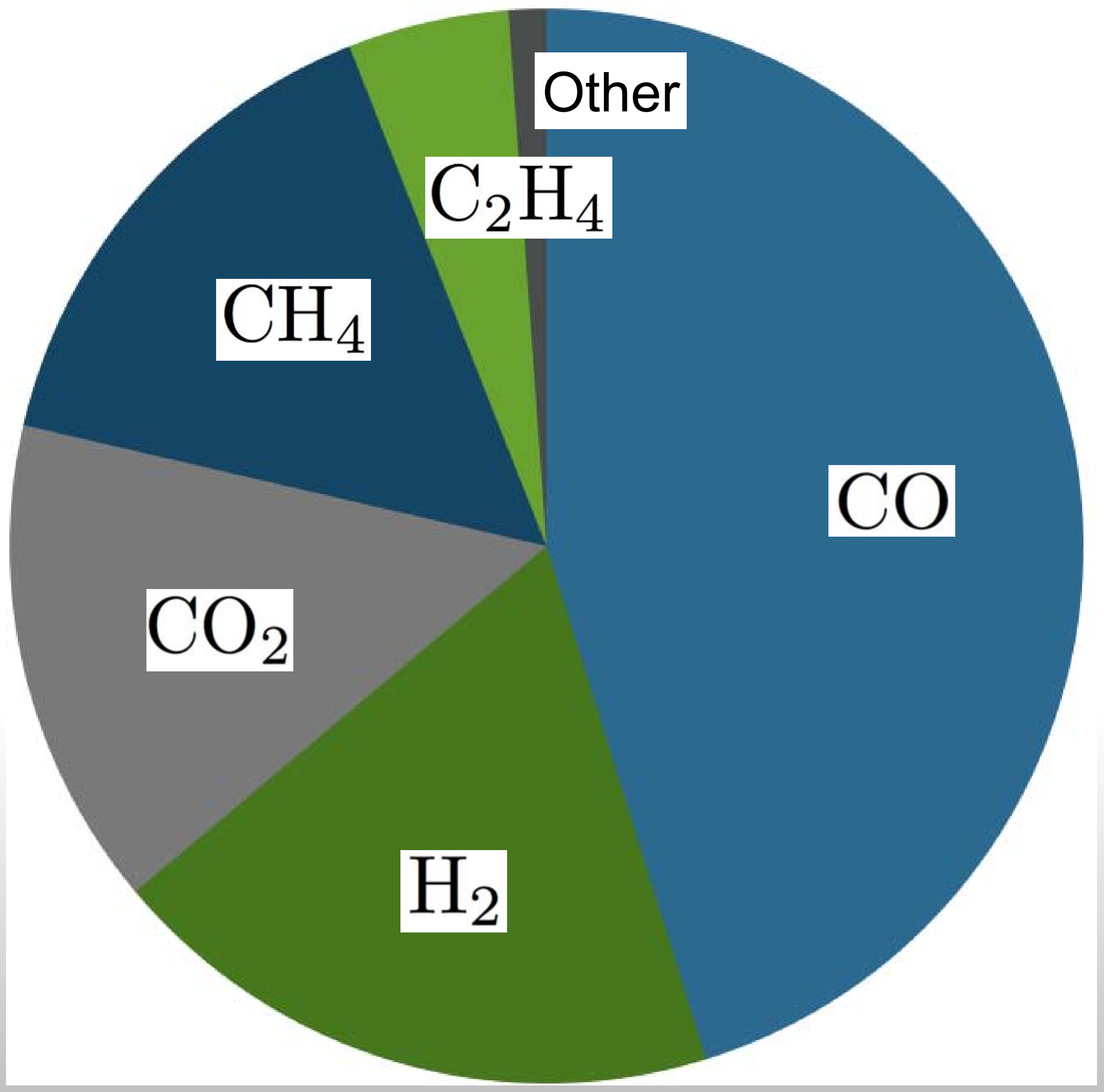


# Gasification

## Inputs and Outputs

| | Mass flow (kg/s) | Temperature (° C) |
|---|---|---|
| **Biomass In** | 24.4 | 25 |
| **Steam In** | 2.6 | 182 |
| **Air In** | 11.9 | 354 |
| **Syngas Out** | 19.9 | 862 |
| **Flue Gas Out** | 19 | 916 |

Composition of Syngas (by volume):






Estimated flow rates calculated using http://chippewa.gtsav.gatech.edu/outreach/workshop/presentations/gfarris.pdf &Twin-Bed Gasification Concepts for Bio-SNG Production (Paisely)

# Biofuels Process Overview

Steam, Heated Air

Photo of switchgrass by Stephen Ausmus (USDA), public domain image.

Gasification

Acid Gas Removal

Fischer-Tropsch Reactor

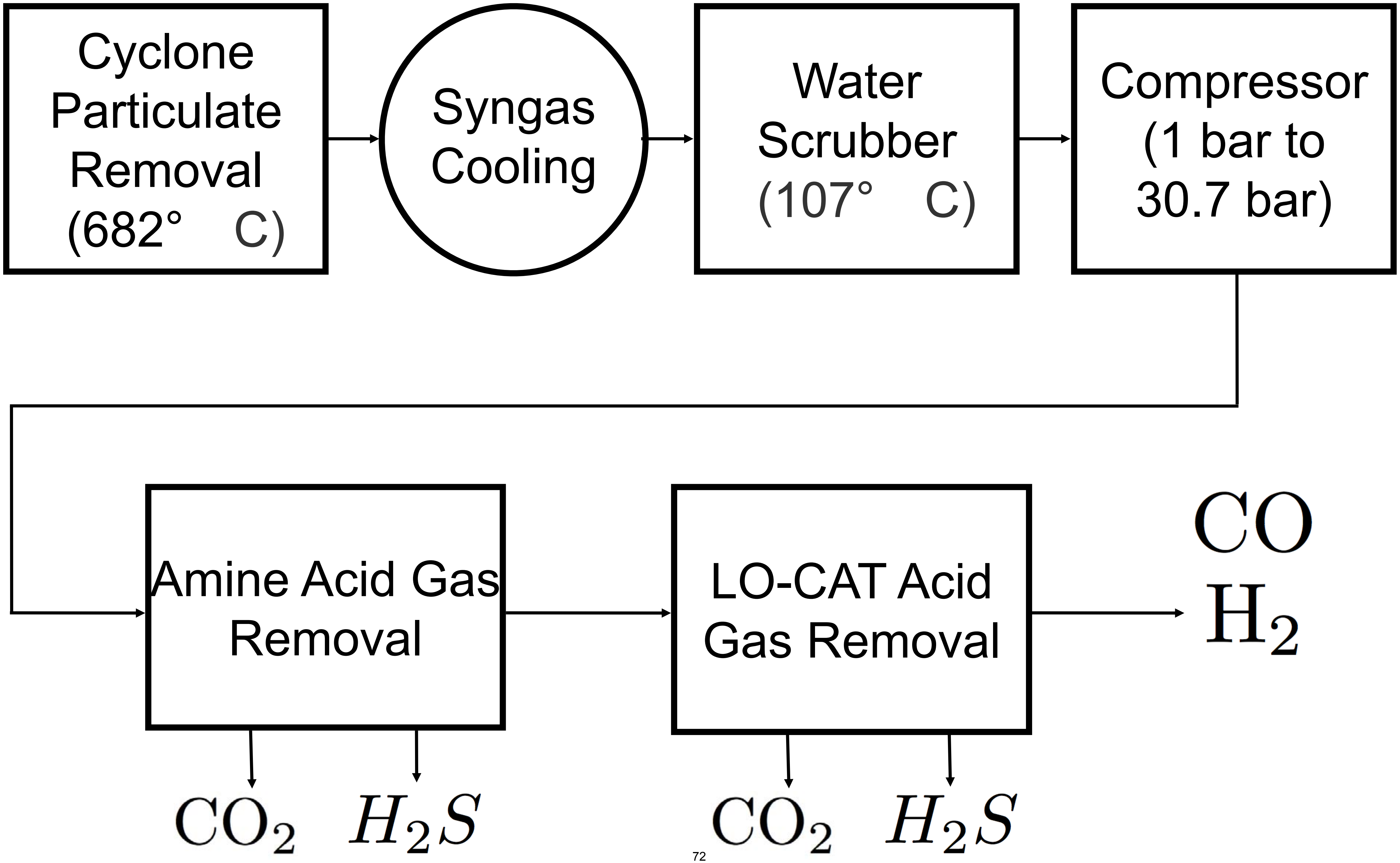
Distillation & Refining


Image by MIT OpenCourseWare.

Hydrogen

Heat

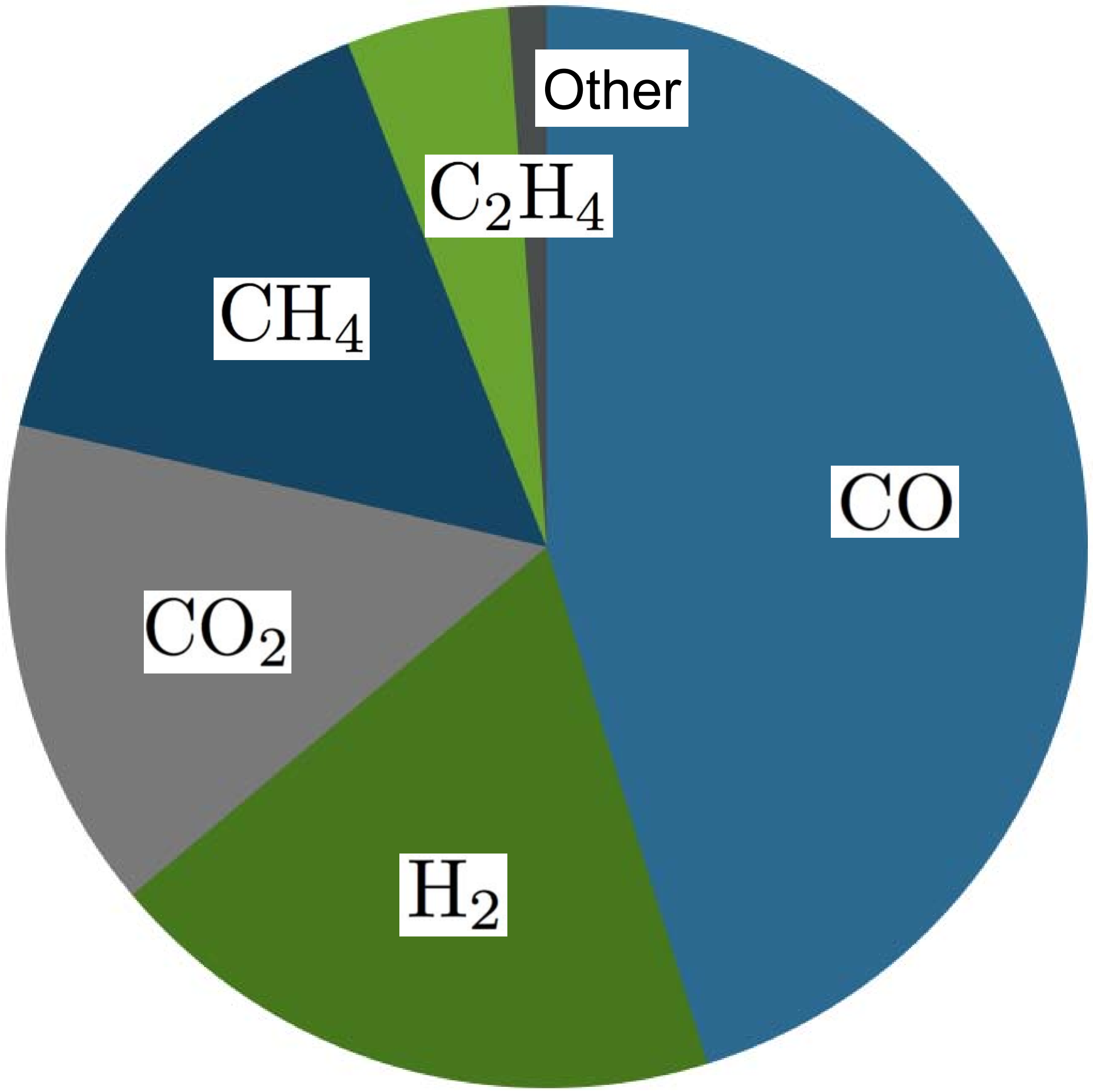
# Acid Gas Cleanup Process



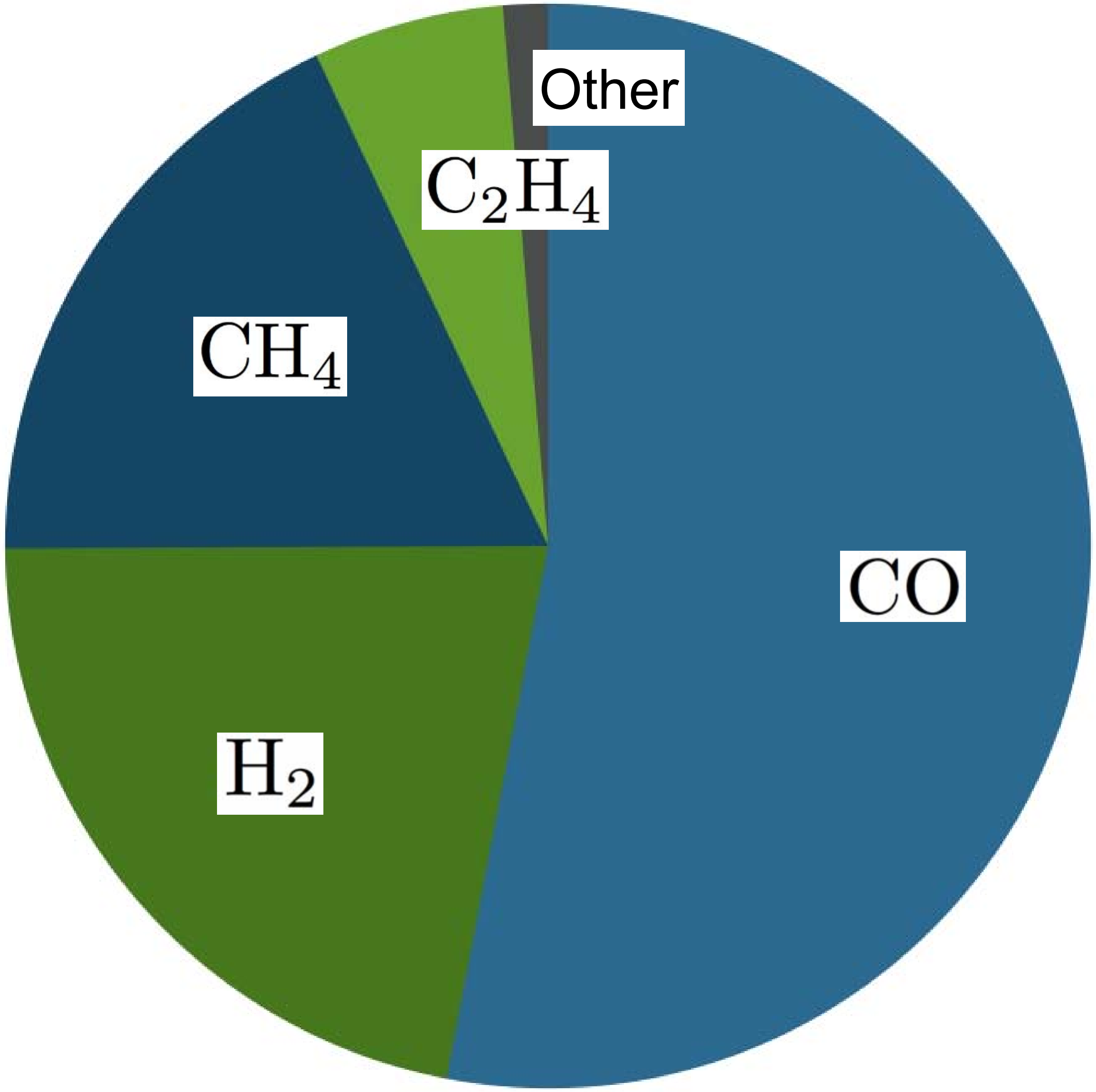
# Acid Gas Removal Output

## Composition of Input to F-T Reactor

After gasification:
19.9 kg/s




After acid gas removal:
14.6 kg/s



# Biofuels Process Overview

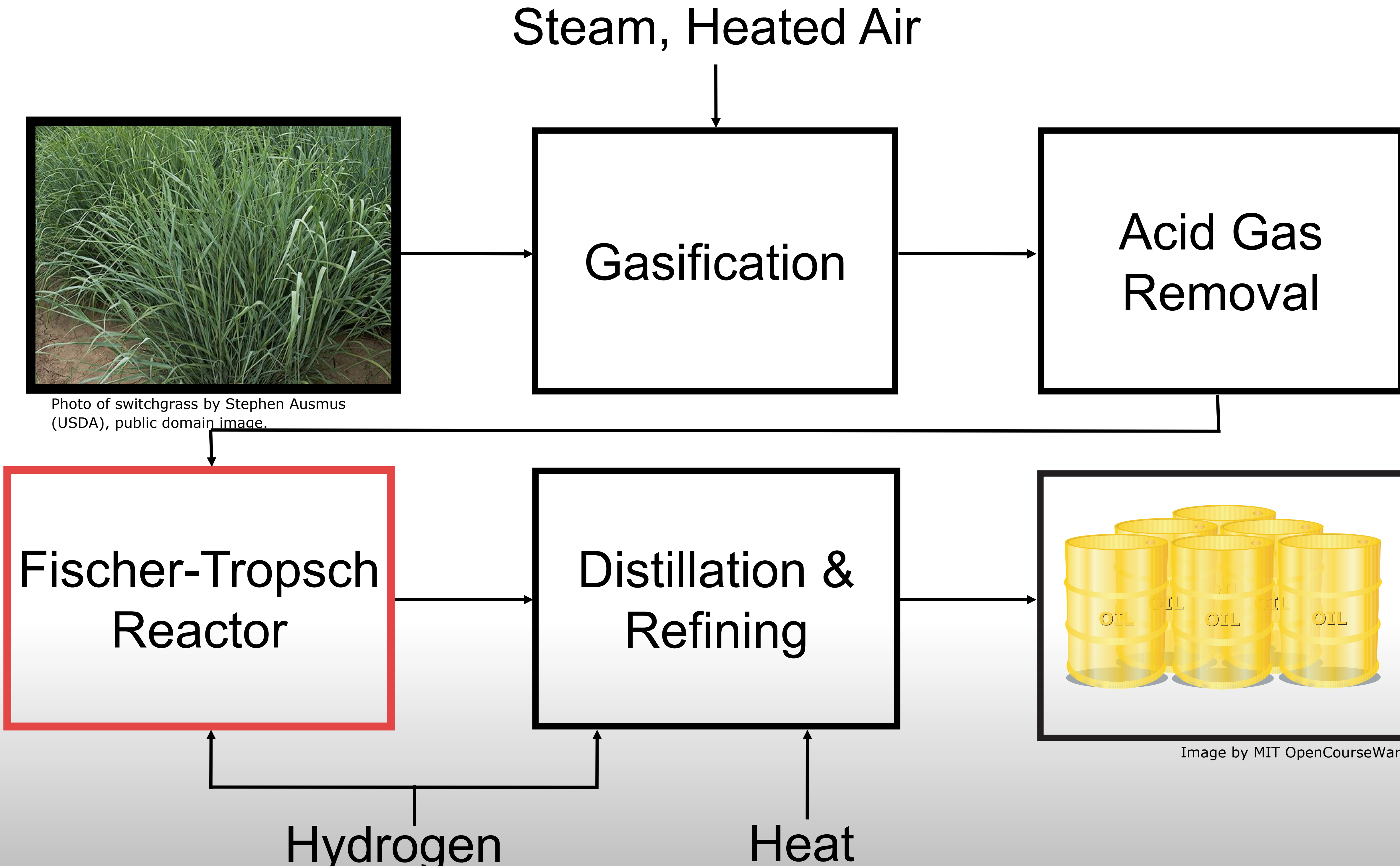



Photo of switchgrass by Stephen Ausmus (USDA), public domain image.

Image by MIT OpenCourseWare.

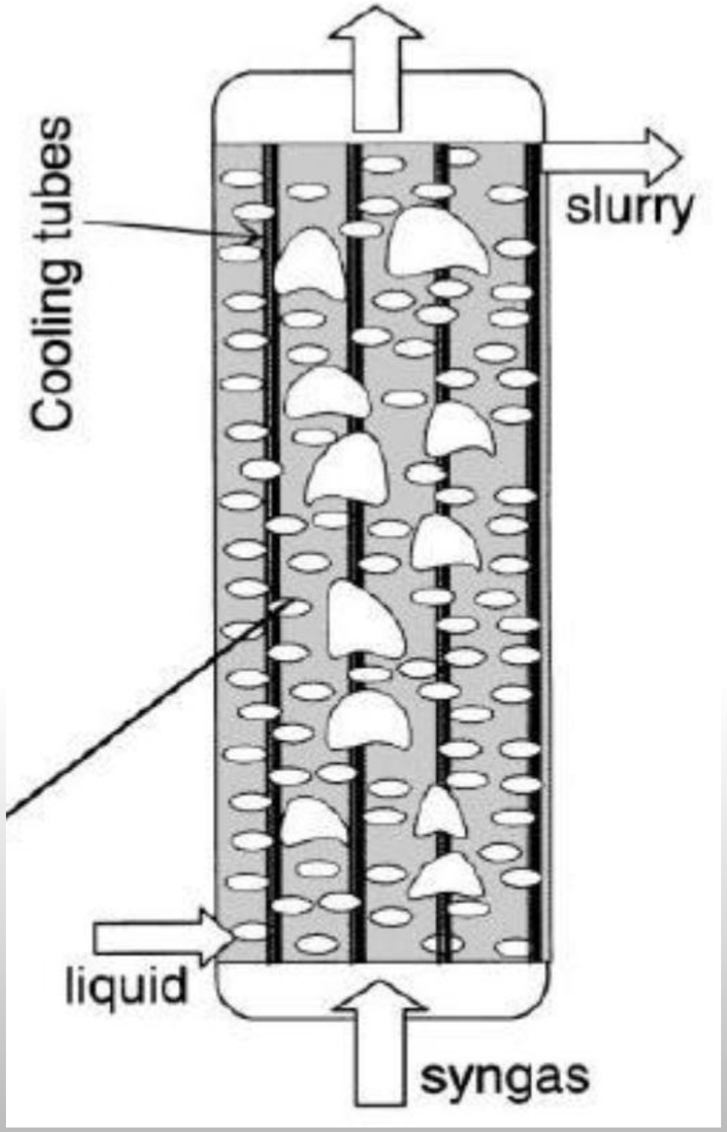
# Fischer-Tropsch Reactor

## Slurry Phase Bubble Column Design

$$CO + 2H_2 \rightarrow -(CH_2)- + H_2O + 170\,kJ$$

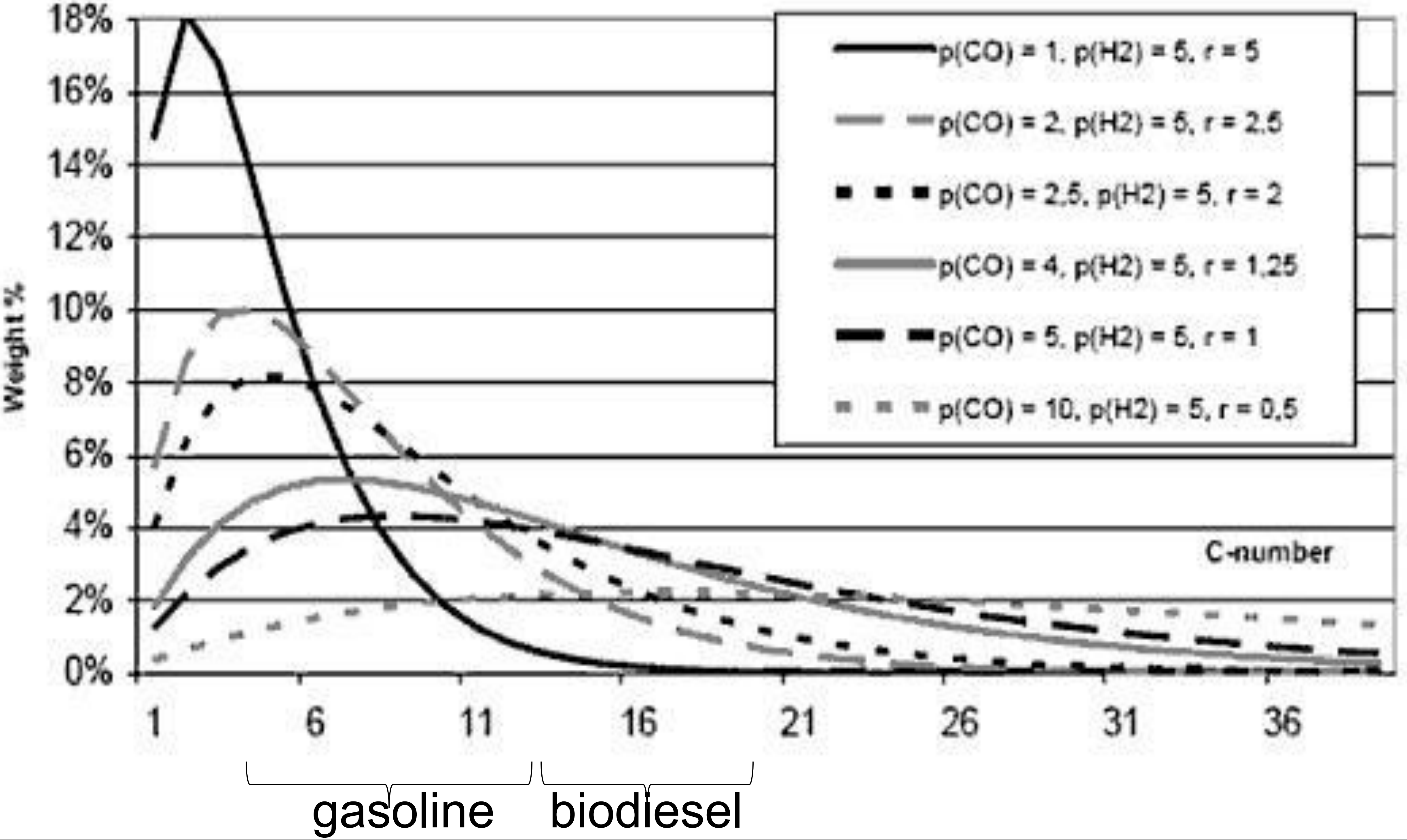
$$H_2O + CO \rightarrow CO_2 + H_2$$

- Fe catalyst
- Heat generated: 21.8 MW



# Fischer-Tropsch Reactor

## Product Selectivity



# Fischer-Tropsch Reactor

## Reactor Outputs

| Carbon Content | Product Classification | Mass Flow (kg/s) |
|---|---|---|
| $C_1$ - $C_5$ | Light Gas | 2.02 |
| $C_5$ - $C_{12}$ | Naphtha (Gasoline) | 5.09 |
| $C_{12}$ - $C_{20}$ | Distillate (Biodiesel) | 2.65 |
| $C_{20+}$ | Heavy wax | 1.46 |

# Biofuels Process Overview

Steam, Heated Air

Photo of switchgrass by Stephen Ausmus (USDA), public domain image.

Gasification

Acid Gas Removal

Fischer-Tropsch Reactor

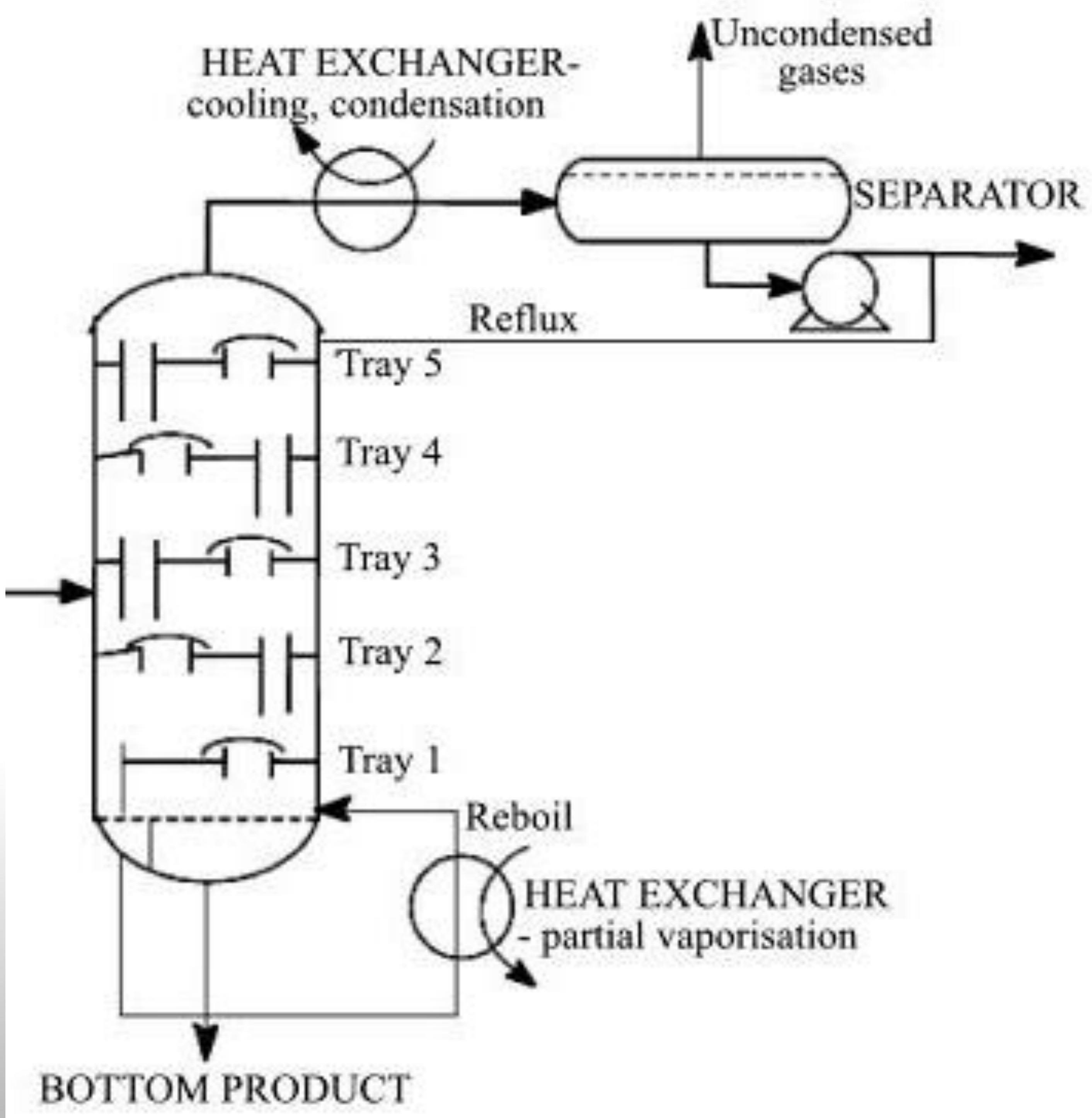
Distillation & Refining


Image by MIT OpenCourseWare.

Hydrogen

Heat

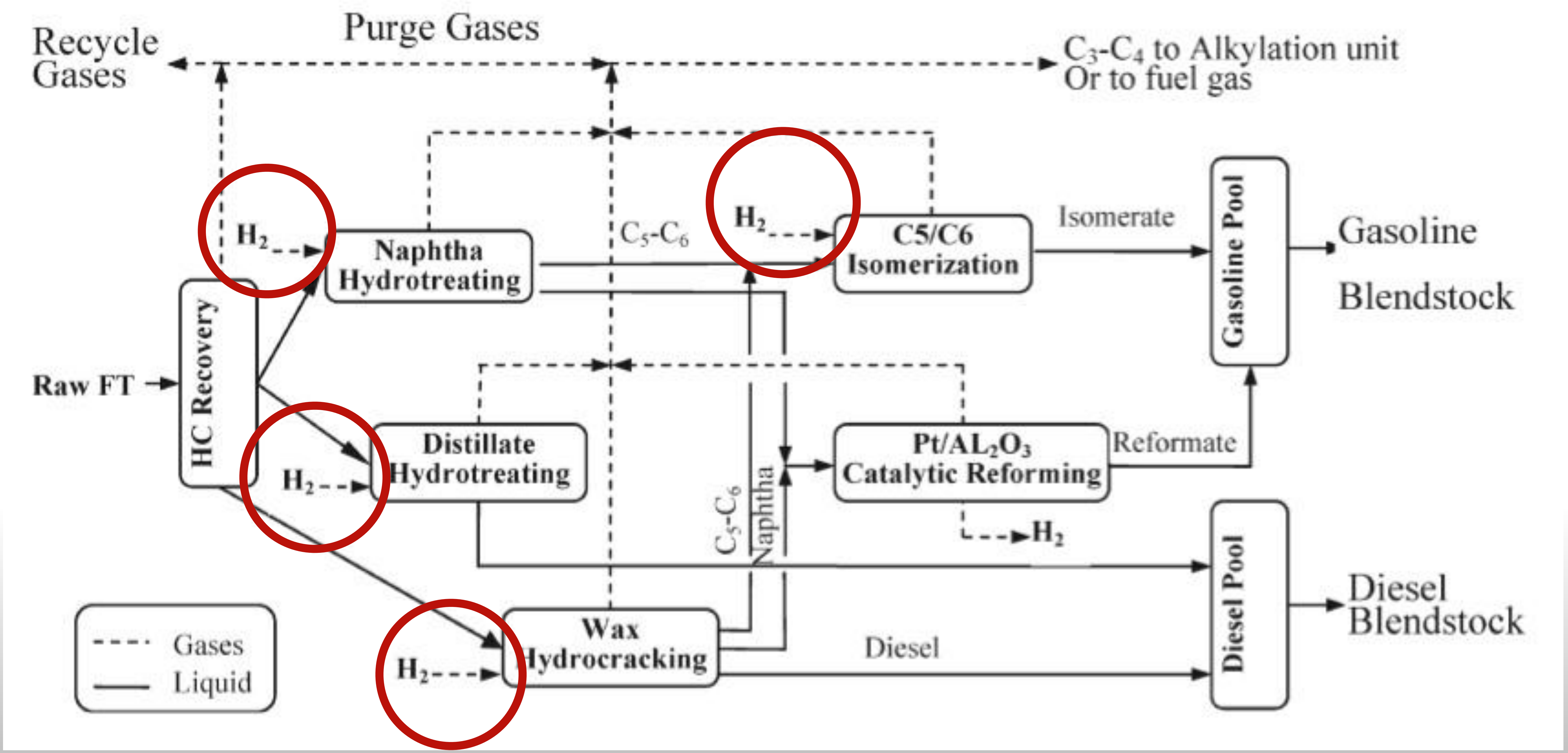
# Distillation




| Fraction | Boiling Point (° C) |
|---|---|
| Light Gases | < 40 |
| Light Naptha | 30-90 |
| Heavy Naptha | 90-200 |
| Distillate | 200-300 |
| Heavy Wax | 300-350 |

# Refining

## Hydrogen Inputs



# Biofuels Process Overview

Steam, Heated Air

Photo of switchgrass by Stephen Ausmus (USDA), public domain image.

Gasification

Acid Gas Removal

Fischer-Tropsch Reactor

Distillation & Refining


Image by MIT OpenCourseWare.

Hydrogen

Heat

# Final Products

| Product Classification | Mass Flow (kg/s) | Mass Flow (barrels/day) |
|---|---|---|
| Light Gas | 2.02 | --- |
| Diesel | 2.87 | 1874 |
| Gasoline | 6.33 | 4780 |
| Total Diesel and Gasoline | 11.22 | 6654 |

- Expected revenue from: > $1.7 million/day
- Assuming 15 gal/tank, this amount of gasoline and diesel can fill over 18,500 cars/day
- Compare to U.S. 2011 demand of 9.12 million barrels/day



http://pascagoula.chevron.com/Files/pascagoula/Misc/2010%20Fact%20Sheet.pdf

# Carbon Sequestration

## $CO_2$ management


- Options:
  - Recycle
  - Sell
  - Underground storage
  - Deep ocean dissolution
- $CO_2$ liquifies at 300kg/m$^3$
- Compress to 20 MPa with in-line integrally geared compressor and DDHF multistage barrel pump

# Looking Forward


Public domain image

# Future Work and Economics

- Potential improvements
  - scale up
  - use oxygen from $H_2$ plant in gasification step
  - recycle flue gas, $H_2S$, $CO_2$ wastes

- Jobs generated: farmers, drivers, plant workers
- Total daily profit: $1.4 million/day
- Total profit selling only electricity: $0.83 million/day

# Concluding Thoughts

# Implications

- This facility design can feasibly produce green electricity, biodiesel, and biogasoline
- Minimal carbon emissions
- Nuclear reactor produces 1000 MWe to grid and powers hydrogen and biofuel plants
- Biofuels produces enough alternative fuels for 18,500 cars/day

# Acknowledgments


- Dr. Short
- Tyrell Arment
- Koroush Shirvan
- Professor Golay
- Professor Forsberg
- Professor Driscoll
- Professor Todreas

# Questions & Discussion

22.033 / 22.33 Nuclear Systems Design Project
Fall 2011