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Process Design II, Spring 2013

OxyBurn

CLEAN AIR POWER

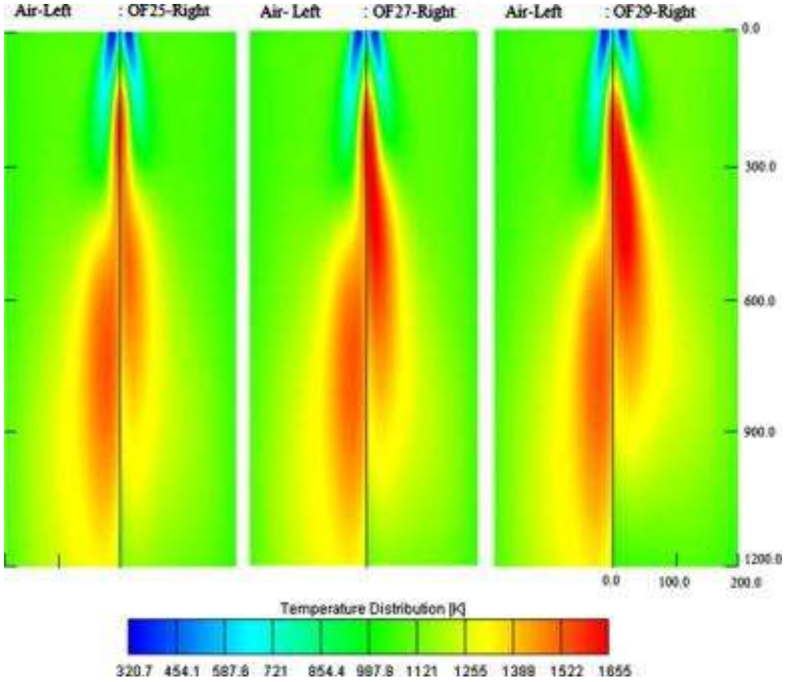
ASU with Oxy-fuel Combustion for Zero Emission Energy

Objective

- Generate 1-2MW electricity
- Develop an air separation process
- Capture CO_2
- Create zero emissions, zero pollution

Oxy-Fuel Combustion

Using concentrated oxygen for a pure combustion



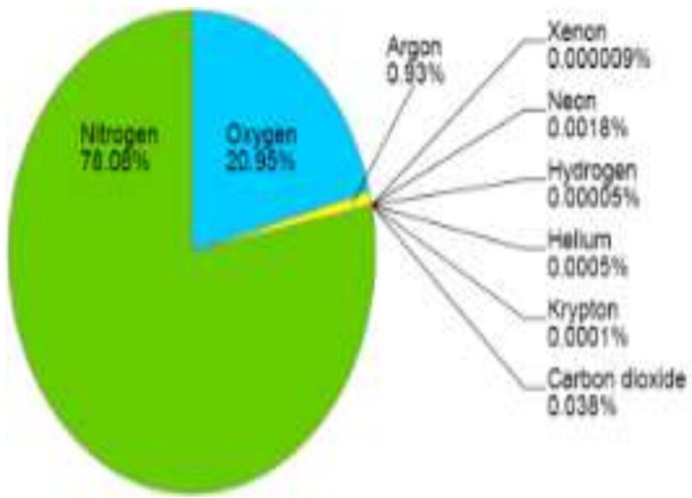
Flame temperature profiles for different O_2 concentrations

<u>Benefits</u>

+ Higher fuel efficiency
+ Improved process control
+ Clean CO_2 product
+ Zero emission energy

Air Separation

- Separates and purifies air's constituents
- First ASU, 1902
- Used in adjunct to many processes
- Cryogenic distillation is established and dependable
  - Many new technologies are under research



Air Separation

Cryogenic Process

- Produce Larger amount
- High purity of Oxygen
- Need more energy

Non-Cryogenic Process

- Produce Lower amount
- High purity of Oxygen
- Need Lower energy

Air Separation(Non-Cryogenic)

	Pros	Cons
Adsorbent	-Small Scale Production -Moderate Oxygen Purity	-High Operating Cost -Limit in Production
Membrane	-Economical process -Less equipment	-Uneconomical for high Purity & low volume -Higher temperature

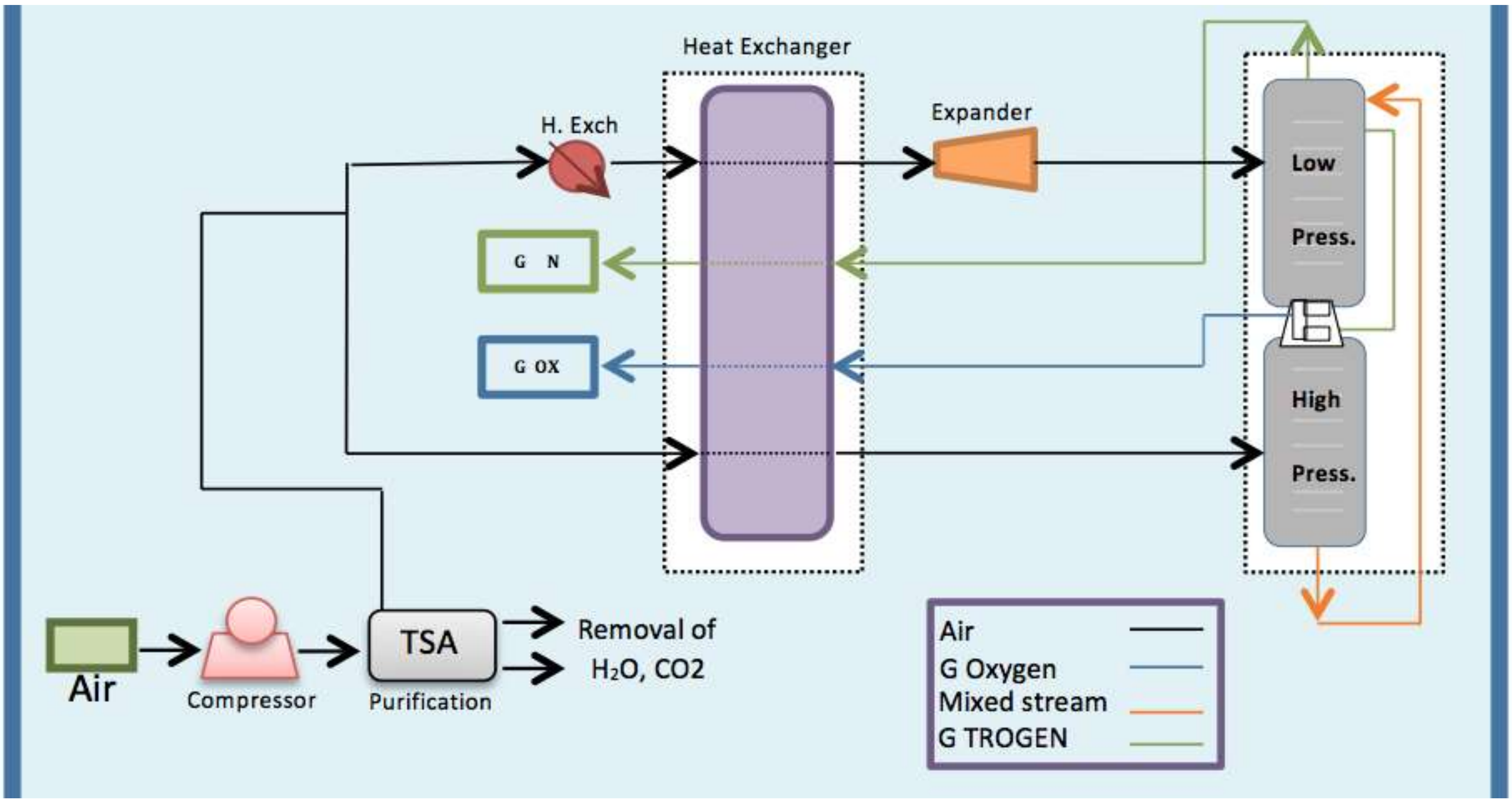
Cryogenics

- Cryogenic Distillation
- Features
- Applications

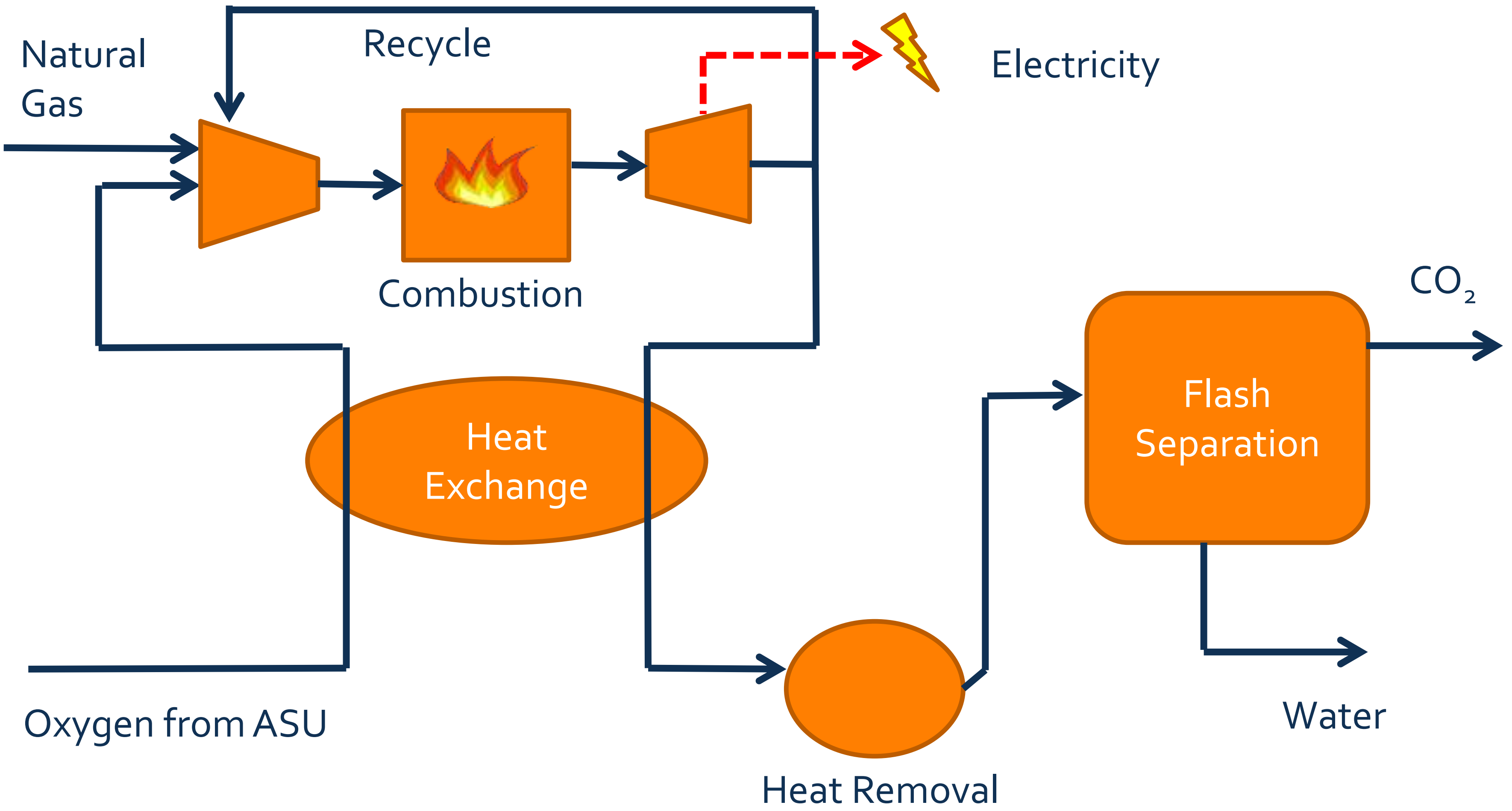
Cryogenic liquefaction process

- **What is Cryogenic liquefaction process ?**
  - Differences of the boiling point of the air components.
- **Filtering & Compressing.**
  - Ambient air is sucked through a filter and compressed to approximately 100 psi.
- **Purification.**
  - Removal of (H_2O,CO_2).
- **Rectification (Separation).**
  - Two- column rectification system , **high-pressure** and **low-pressure column**.
  - Liquid oxygen produced as bottom product from (HPC).
  - Nitrogen is formed at the top of the (LPC).
  - Oxygen gas produced due to heat exchange.

Cryogenic Air Separation



Combustion Process

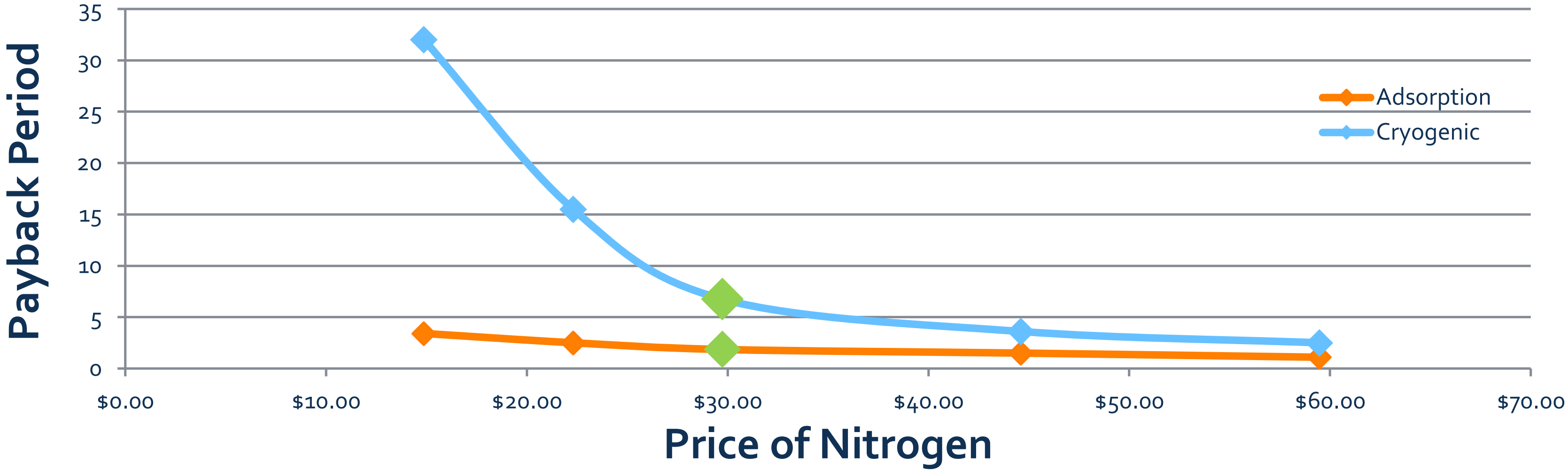


Economic Overview

- Capital Costs
  - Sensitivity analysis
  - Operating Cost (Feed, Operating Hours, etc.)
  - ASU and Power Plant
  - IRR, NPV, PBP
- State and Federal Incentives

Sensitivity Analysis

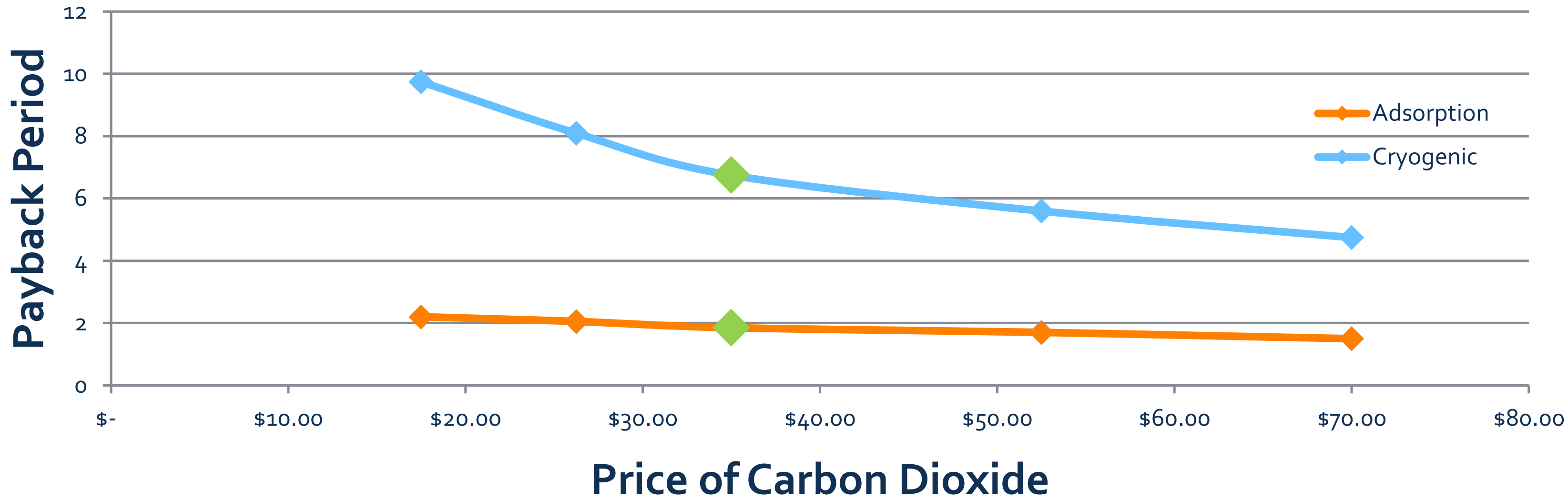
Payback Period vs. Selling Price N2



Nitrogen ($/ton)	Payback Period (years) (Cryogenic)	Payback Period (years) (adsorption)
$14.87	**32**	**3.4**
$22.30	**15.5**	**2.5**
$29.74	**6.75**	**1.85**
$44.61	**3.6**	**1.5**
$59.48	**2.5**	**1.1**

Sensitivity Analysis

Payback Period vs. Selling Price CO_2



Carbon Dioxide ($/ton)	Payback Period (years) (Cryogenic)	Payback Period (years) (adsorption)
$14.87	9.75	3.4
$22.30	8.1	2.5
$29.74	6.75	1.85
$44.61	5.6	1.5
$59.48	4.75	1.1

Adsorption vs. Cryogenic

Overall Economics

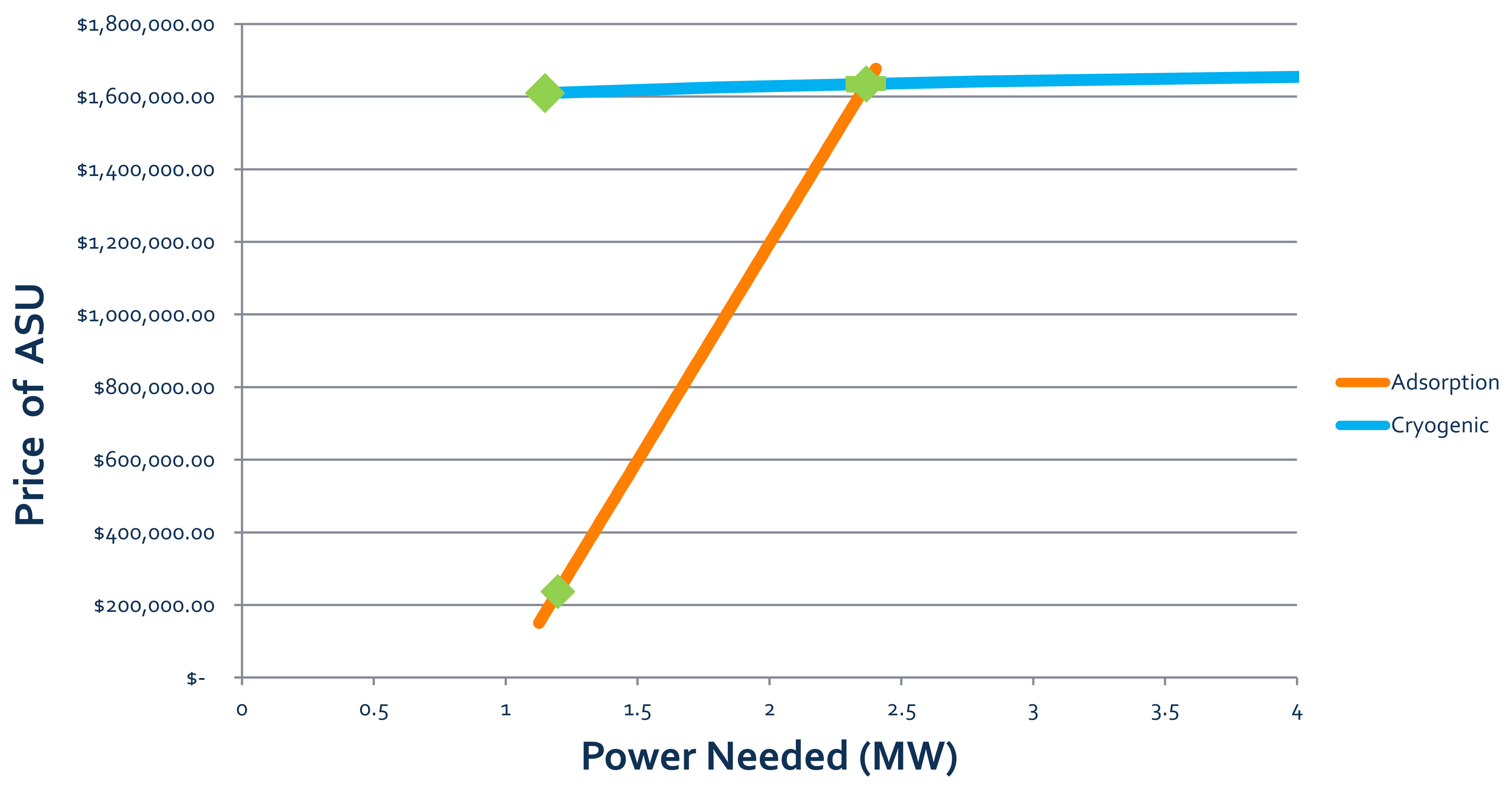
Cryogenic

- Capital Costs:
  - ***ASU: $2.5 Million***
  - Power Plant: **$1.18 Million**
  - Storage: **$.75 Million**
- ***Operating Costs (8000 hr/yr): $1.35 Million***
- Total Capital Investment: **$4.75 Million**
- NPV 30 (30 years): **$5.8 Million**
- IRR (30 year base): **11%**
- ***Payback Period: 6.75years***

Adsorption

- Capital Costs:
  - ***ASU: $.52 Million***
  - Power Plant: **$1.18 Million**
  - Storage: **$.75 Million**
- ***Operating Costs (8000 hr/yr): $.71 Million***
- Total Capital Investment: **$3 Million**
- NPV 30 (30 years): **$19 Million**
- IRR (30 year base): **36%**
- ***Payback Period: 1.85years***

Point where Cryogenic over Adsorption



OSHA and EPA

- Capture of CO_2
  - Control the rate and order of chemical addition
  - Provide robust cooling
  - Segregate incompatible materials to prevent mixing
  - Credits for collecting Carbon Dioxide
- High amount of water waste

OxyFuel Economic Issues

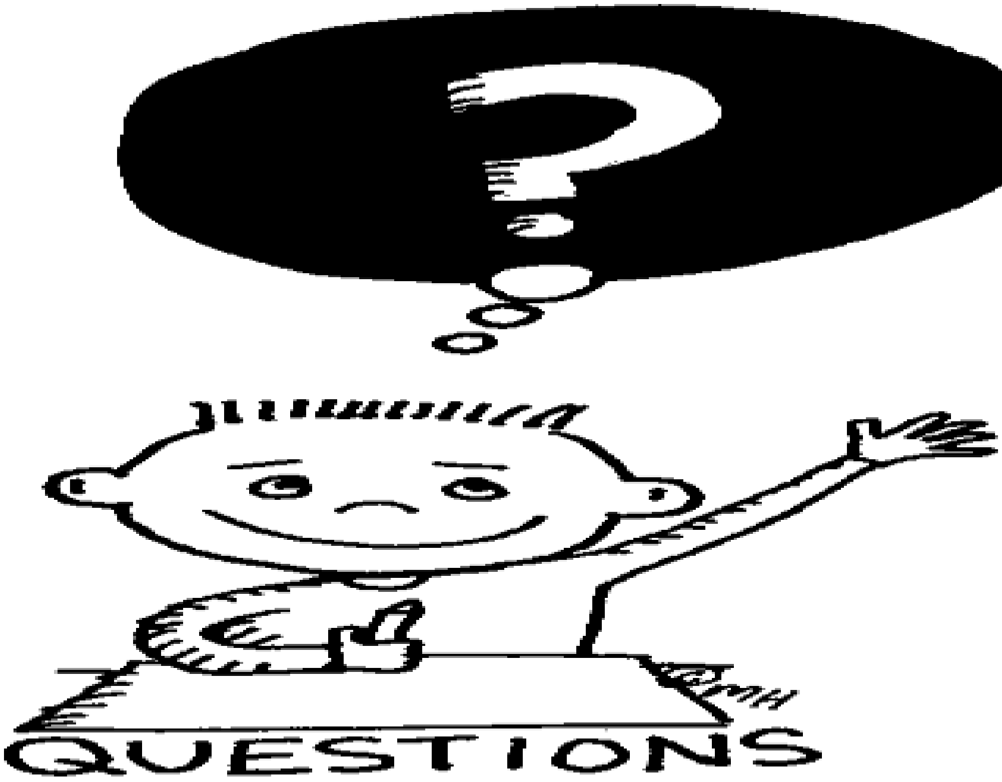
- Determining the exact needs of the Wind Tunnel to pick best process

- Questionable product market

Conclusion & Recommendation

- Using the Adsorption is a more economical process up to **2.5 MW.**
- If **more** than **2.5 MW** need go with Cryogenic Process.
- Each process can be profitable
  - Even with the questionable prices of products
  - There will be success without incentives.
- Research for UW Wind Tunnel, either route is suitable for the needs of the project.

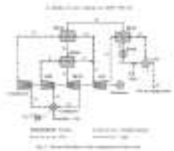
Questions

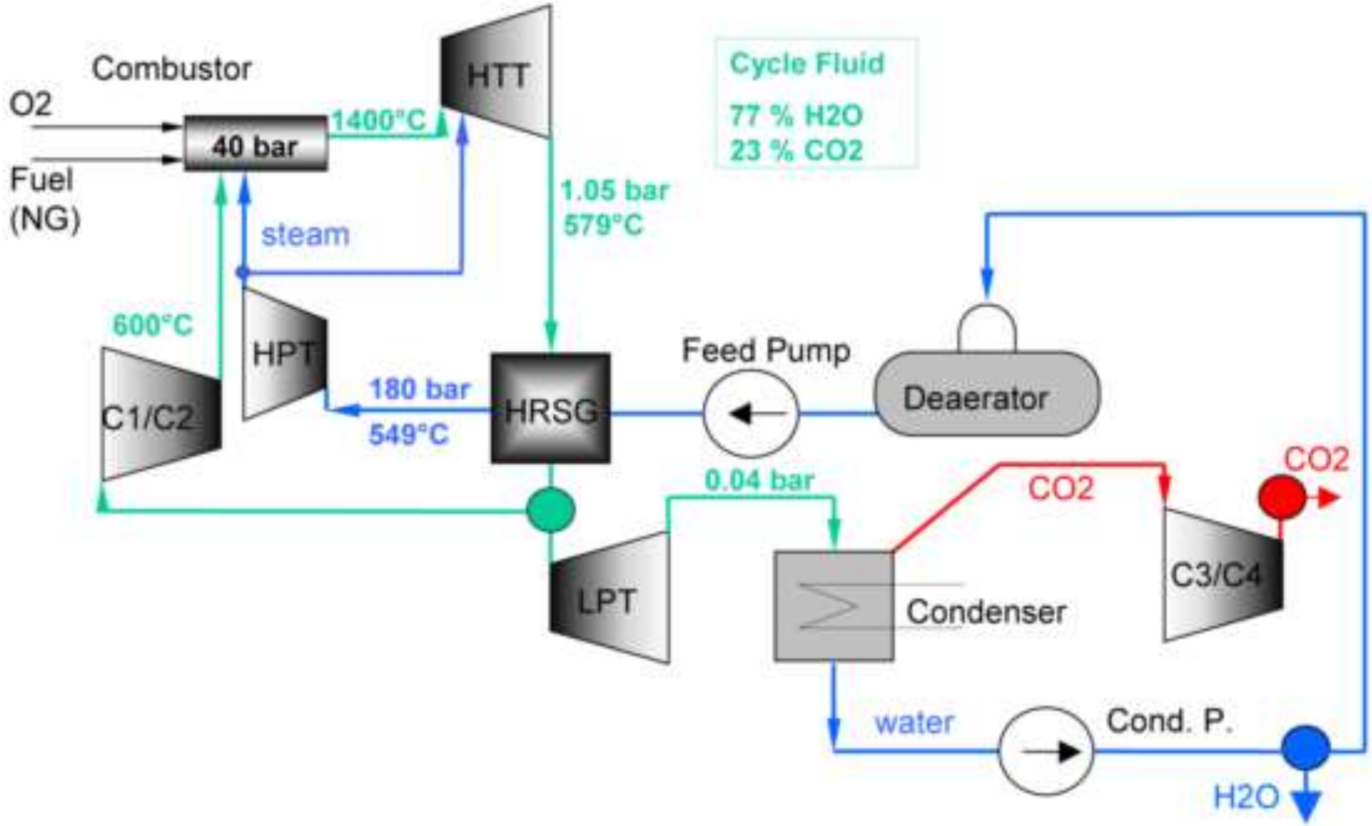


Combined Cycle

- Increase efficiency to about 52.6%
- Increase income from power by about $200,00 per year
- Increase capital by about $2 million
- The break even occurs at about 10 years (w/o T.V.M.)
- It can be added in the future & the system designed to allow expansion
- Highly recommended for larger system

Graz Cycle





Principle flow scheme of basic S-Graz Cycle power plant

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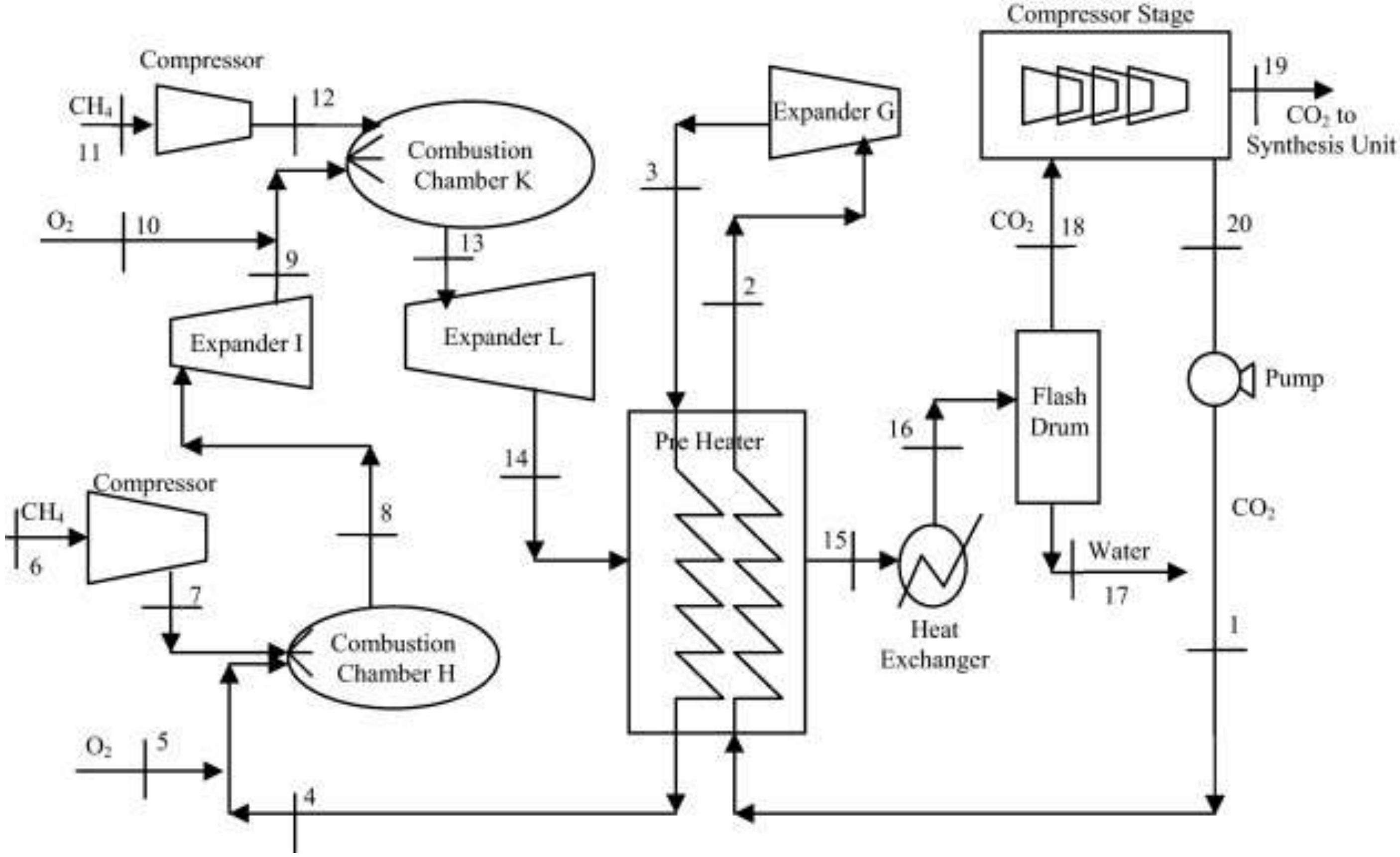

Turbine Performance

- Performance
- Output 6,000 shp (4,470 kW)
- SFC .443 lb/shp-hr
- Heat rate 8,140 Btu/shp-hr
- 10,916 Btu/kWs-hr
- 11,520 kJ/kWs-hr
- Exhaust gas flow 35.9 lb/sec (16.3 kg/sec)
- Exhaust gas temperature 1,049°F (565°C)
- Power turbine speed 7000 rpm
- Dimensions*
- Base plate width 93 in (2.36 m)
- Base plate length 281 in (7.14 m)
- Enclosure height 94 in (2.39 m)
- Base plate weight 60,000 lbs (27,273 kg)
- Duct flow areas Inlet 12 sq ft (1.12 sq m)
- Exhaust 7 sq ft (0.65 sq m)
- Performance*
- Output 4,200 kW
- Heat rate 11,603 Btu/kW-hr

Balances

Tom White

CH4 + 2O2 -> 2H2O + CO2		
Energy Production		
Energy Production	1150.0	kW
Heat of Combustion CH4	0.2475	kW hr/mol CH4
Methane`		
CH4 mol rate	4646.5	mol CH4 / hr
CH4 mass rate	163.9	**lbs CH4/hr**
SCFH CH4	3880.0	SCF CH4/ hr
Oxygen* `		
O2 mol rate	9292.9	mol O2/hr
O2 mass rate	655.6	**lbs O2/hr**
SCFH O2	7759.9	SCF O2/hr
Carbon Dioxide`		
CO_2 mol rate	4646.5	mol CO2/ hr
CO2 mass rate	450.7	**lbs CO2/hr**
Water (from Combustion)`		
H2O mol rate	9292.9	mol H2O /hr
H2O mass rate	368.8	**lbs H2O/ hr**
Air (dry) *		
Dry air mol rate	44362.7	mol Air/ hr
Dry air mass rate	2793.9	**lbs Air/hr**
Nitrogen*		
N2 mol rate	34640.2	mol N2/ hr
N2 mass rate	2138.3	**lbs N2/hr**

Conservation to Check Work		
`	**Combustion Balance**	
	0.0	
*	**Air balance**	
	0.0	
	Overall Balance	
	0.0	

Air Composition	
N2	0.78084
O2	0.209476
Other	0.009684

Molar mass		
Methane	16	g/mol
Oxygen	32	g/mol
Nitrogen	28	g/mol
Water	18	g/mol
CO2	44	g/mol
Air MW	28.566752	g/mol

STP conditions & Constants		
T	15	°C
	288.15	K
P	1	atm
R	8.20575E-05	m^3 atm/ K mol
	0.002897918	ft^3 atm/K mol

Conversion Factors		
1 g=	0.0022046	lbs
1 kJ=	0.000277778	kW hr

Notes:

*These balances do not take into account argon and other dry air components.
*The molar flow rates of N2 and O2 are correct for their respective molecular flow rate, not the total stream flow rate.
*Can use the stream purities to find total flow aproximations.
* The MW of dry air uses O2 and CO2 only so the value is less then the usual 28.97
*Heat of combustion found from NIST. Uses pure methane's ΔcH°gas (49.5 MJ/kg)
*Z=1

Turbine

- General Electric
  - LM 500
  - Designed for marine power
  - Thermal efficiency: 31%
  - Smaller version of industry leading turbines (LM2500)

LM500 Gas Turbine-Generator Set

LM500 on Marine Base

Material Balance for Power Plant

OxyBurn

$$CH_4 + 2O_2 \longrightarrow 2H_2O + CO_2 + \text{Energy}$$

		Units
Power Generated	1.15	MW (MJ/s)
Mass Flow Rate of CH_4	12516	SCF/hr
Mass Flow Rate of O_2	2114	lb/hr
H2O	1190	lb/hr
CO_2 Product Stream (liquid)	1450	lb/hr