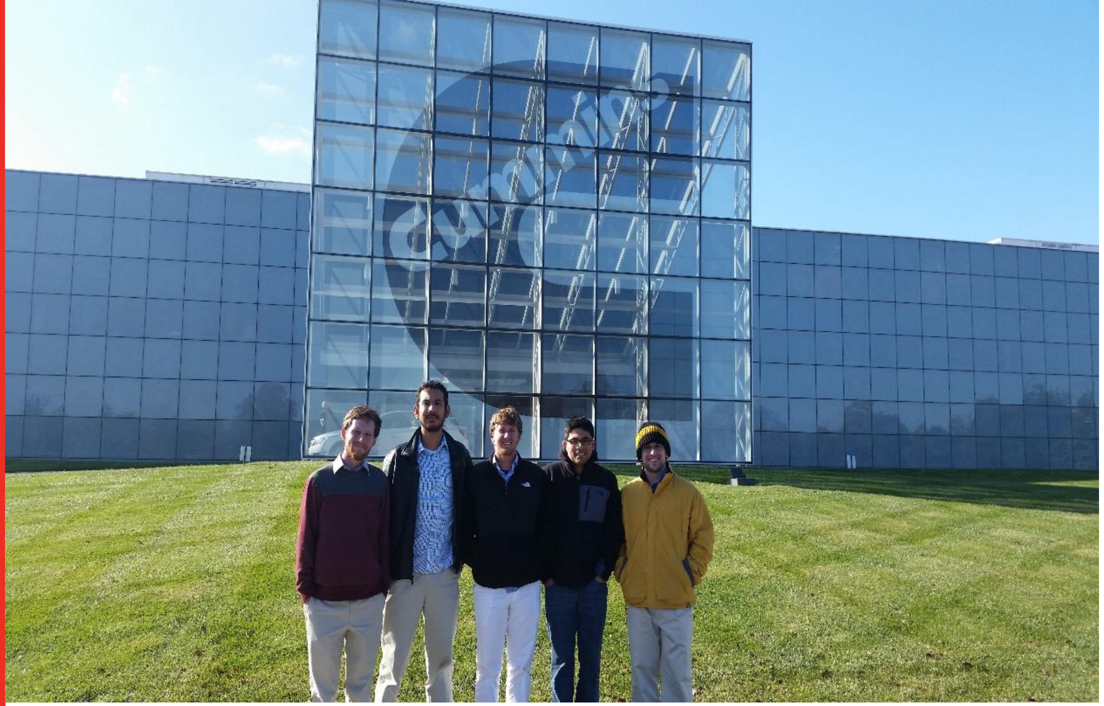


Cummins Energy Savings

Group Number 2

Daniel Baker, Warren Bell, Daniel Carnrike, Kyle Fields, Marvin Fonseca

Cummins Advisor: Dr. England, Dr. Hays

Faculty Advisor: Dr. Ordonez

Instructors: Dr. Gupta, Dr. Shih

4/16/15

Outline

- Background
- Project Scope
- Alternative Methods Investigation
- Organic Rankine Cycle (ORC) Design Overview
- ORC Component Design and Selection
- Simulation Interface and Development
- Conclusion
- Closing Remarks

Background

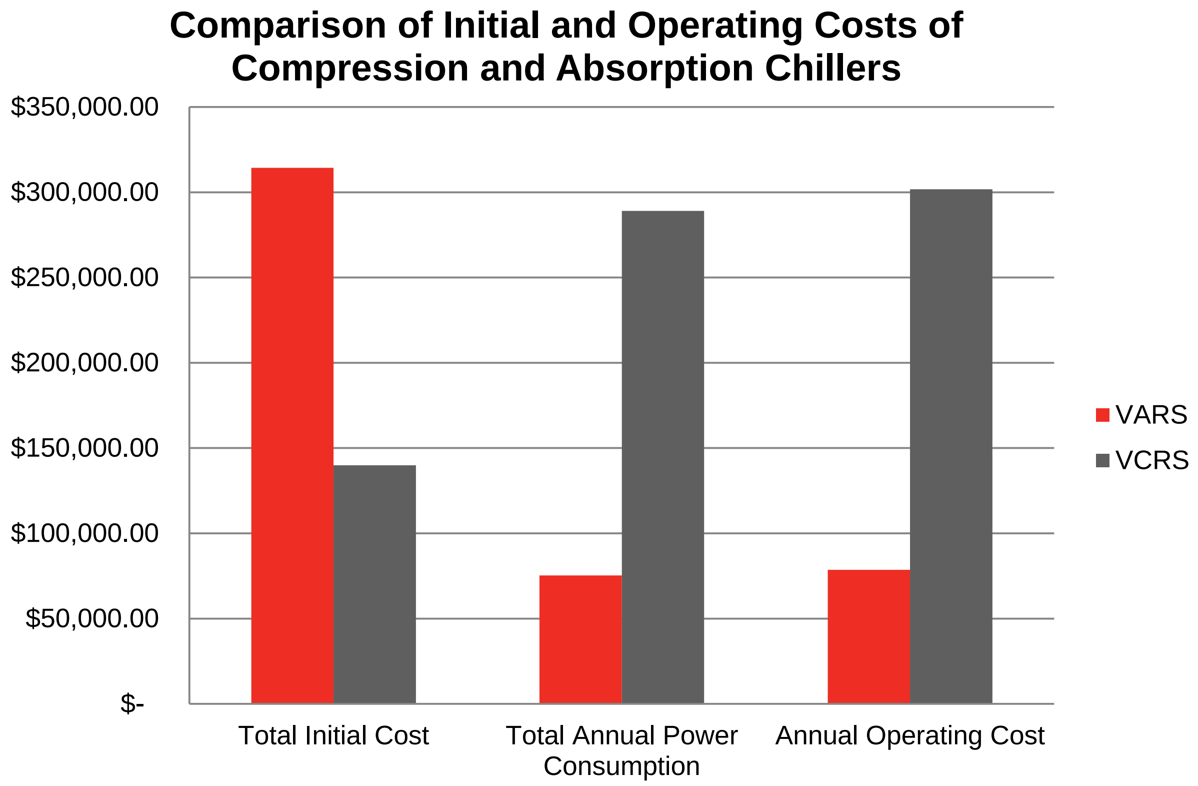
- Cummins aims to reduce their annual energy consumption by 10% at the Cummins Technical Center (CTC).
- Research, Testing, and Development Center
- Cummins uses 20,000 gallons of diesel fuel a year at the facility in engine testing.
- Energy Saving Ideas
  - Chillers
  - Solar Panels
  - Wind Turbines
  - Organic Rankine Cycle
  - Insulation Effects (Already Optimized)

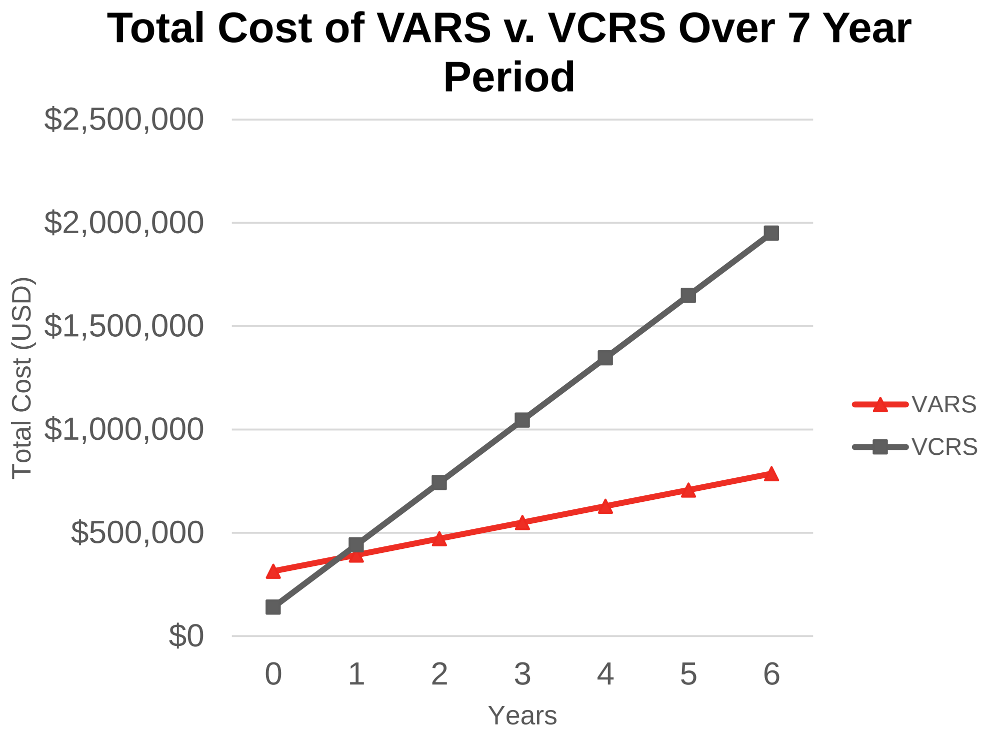
Project Scope

Provide an engine exhaust capture system design and simulation supplemented with other energy saving ideas that will assist in decreasing the overall energy usage at the Cummins Technical Center.

Alternative Methods Investigation

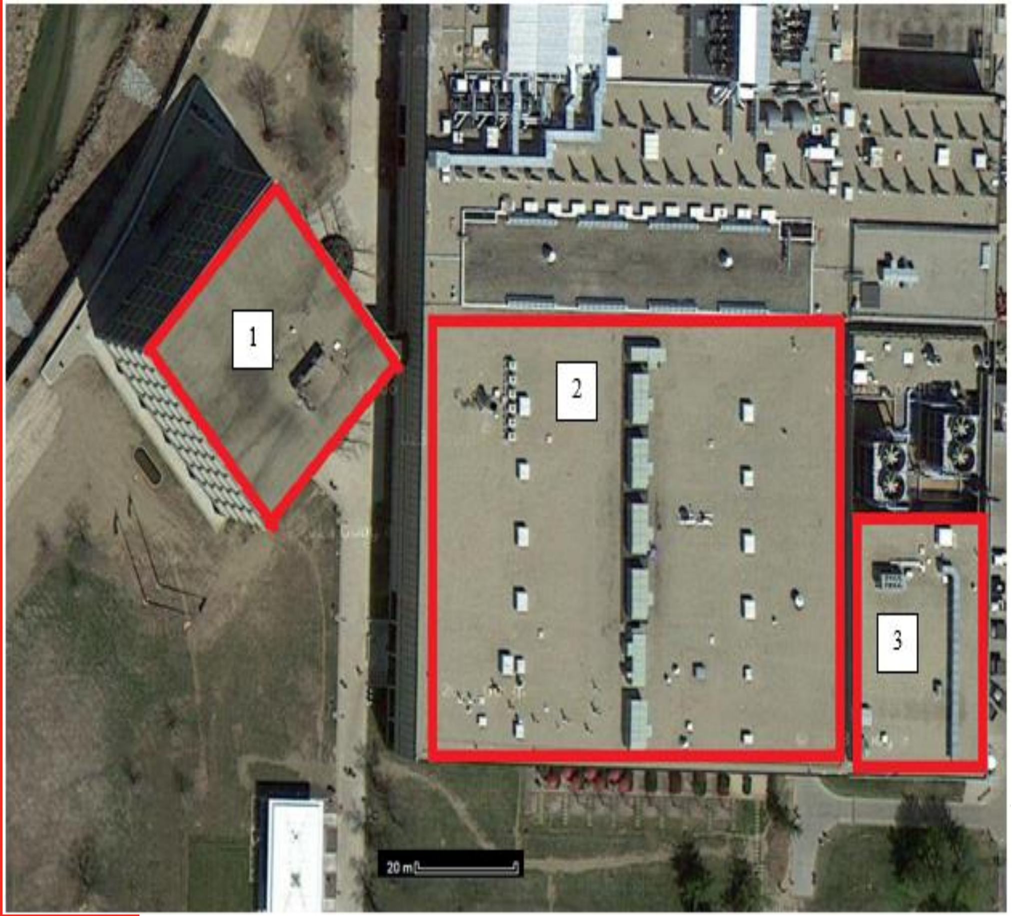
Variable Absorption Refrigeration System (VARS) v. Variable Compression Refrigeration System (VCRS)





Alternative Methods Investigation

Solar Panels



Section	Number of Panels	Annual Energy (kWh)	Annual Money Earned (USD)
Office Building (1)	360	80,483	$6,841.06
CTC Roof (2)	940	208,330	$17,708.05
CTC Roof (3)	115	25,708	$2,185.18
Total	**1,415**	**314,521**	**$26,734.24**

Solar Panel Dimensions: 1m X 1.6m

Total Initial Cost $404,862

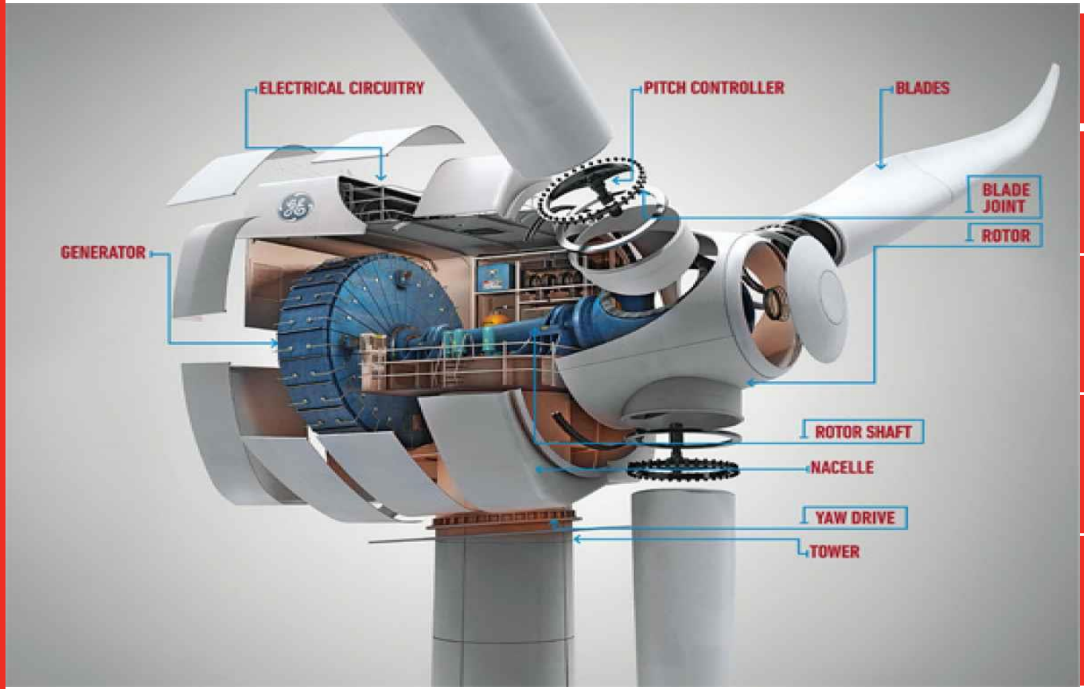
Pay Off Period 18 Years

Solar Panel Lifespan 25 Years

Alternative Methods Investigation

Wind Turbines

Selection



Option	Initial Capital Cost	Mass (kg)	Weight (lbs.)	Weight (tons)
1	$1,283,653.25	433,494	953,688	476
2	$1,299,030.00	489,559	1,077,031	538
3	$1,282,944.32	619,748	1,363,445	681
4	**$1,338,944.32**	**615,124**	**1,353,274**	**676**

Option 1: three-stage drive with a high speed generator
Option 2: single stage drive with medium speed, permanent magnet generator
Option 3: multi path drive with multiple permanent magnet generators

Option 4: direct drive turbine

Alternative Methods Investigation

Wind Turbines

Analysis

Power Generated	**297.72 kW**
Annual Energy Generated	9388.85 GJ/year
Annual Energy Generated	2,608,035 kWh/year
Revenue Annual	$221,682.98/year
25 year ROI ($)	$3,050,701.28
Years to Return	7.94 years

Implementation

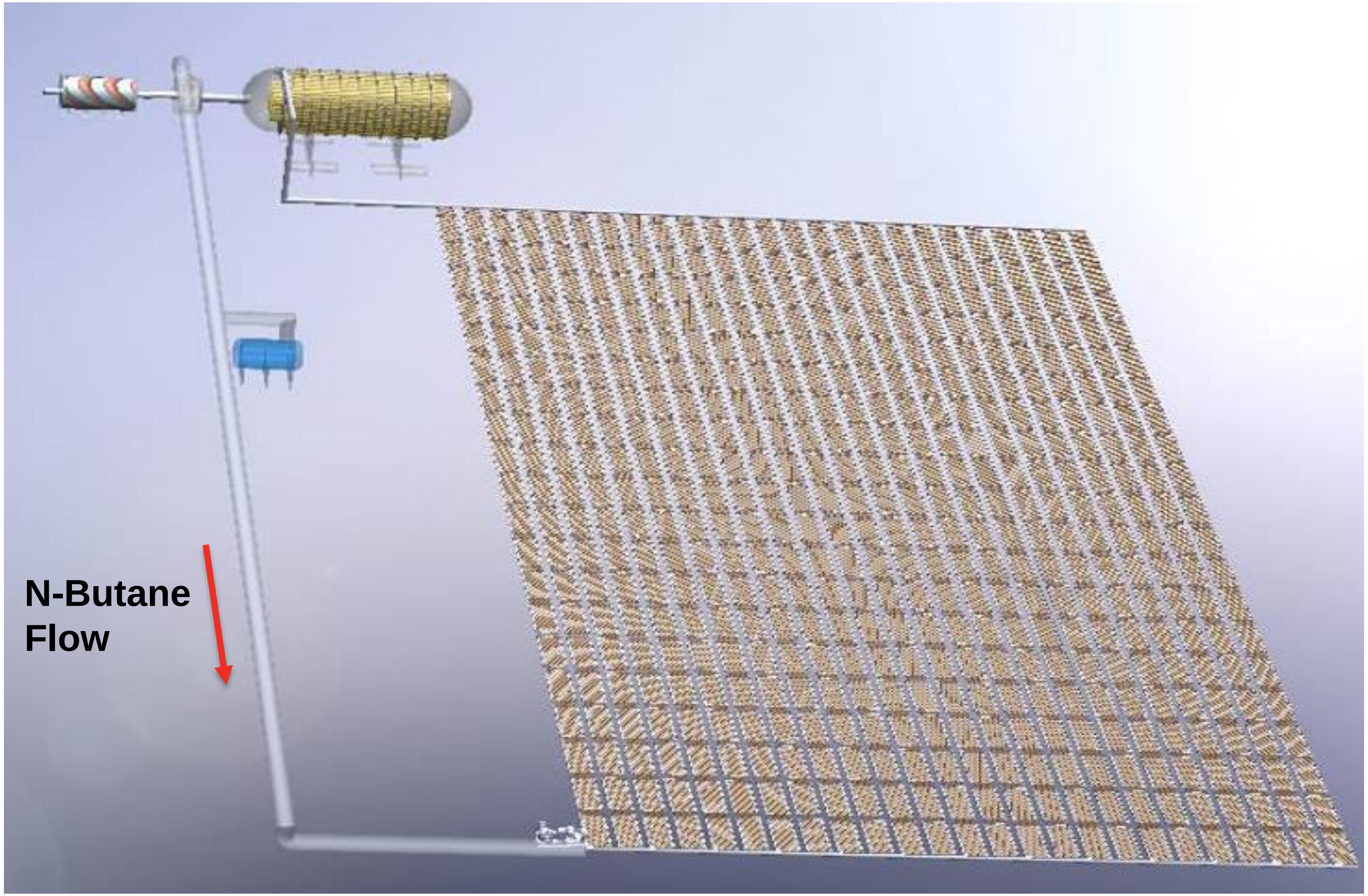
Annual LRC	$6,371.18
Operation and Maintenance	$36,512.49
Shipping	$26,757.09
Installation and Assembly	$51,054.80
Engineering and Permits	$12,269.54
Control, safety, monitoring	$70,000

Summary of Alternative Methods and Exhaust Gas Potential

- Potential Savings in Exhaust Gases
- Discussed at the end of Fall 2014
- Decided Organic Rankine Cycle
- Spring 2015 spent designing, analyzing and developing ORC simulation

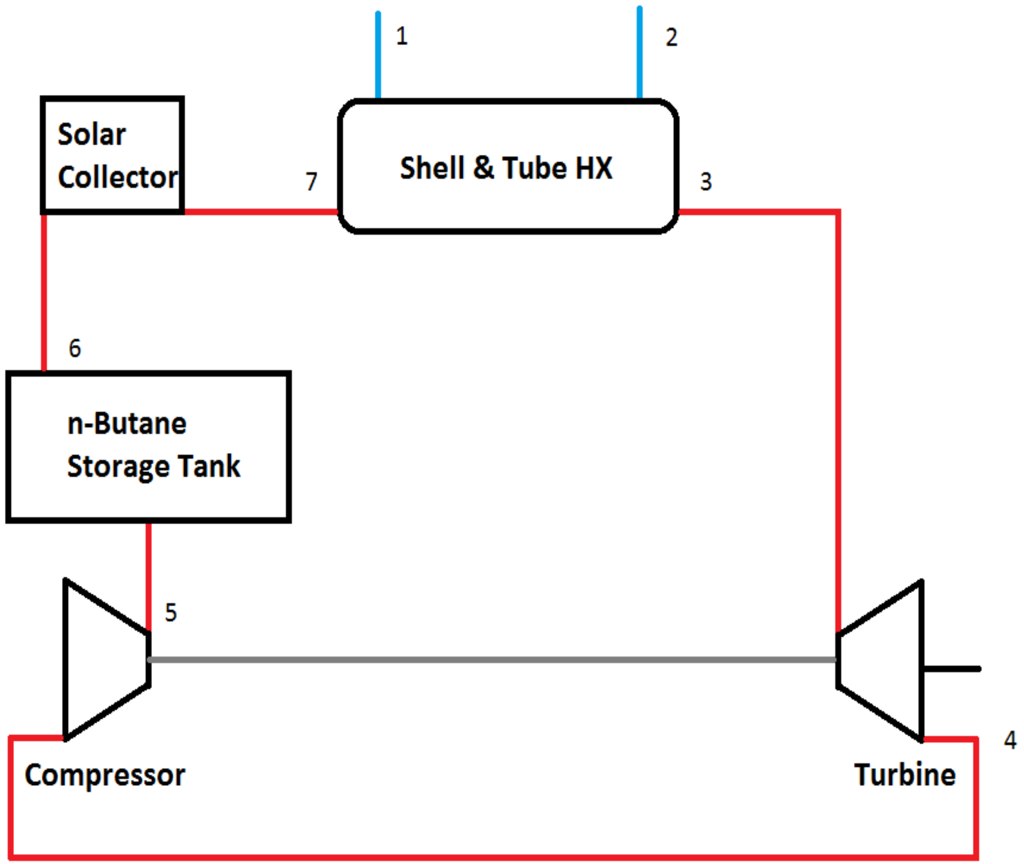
Organic Rankine Cycle (ORC) Design Overview

SolidWorks Rendering of Organic Rankine Cycle



Design Overview

ORC w/ Solar Collectors



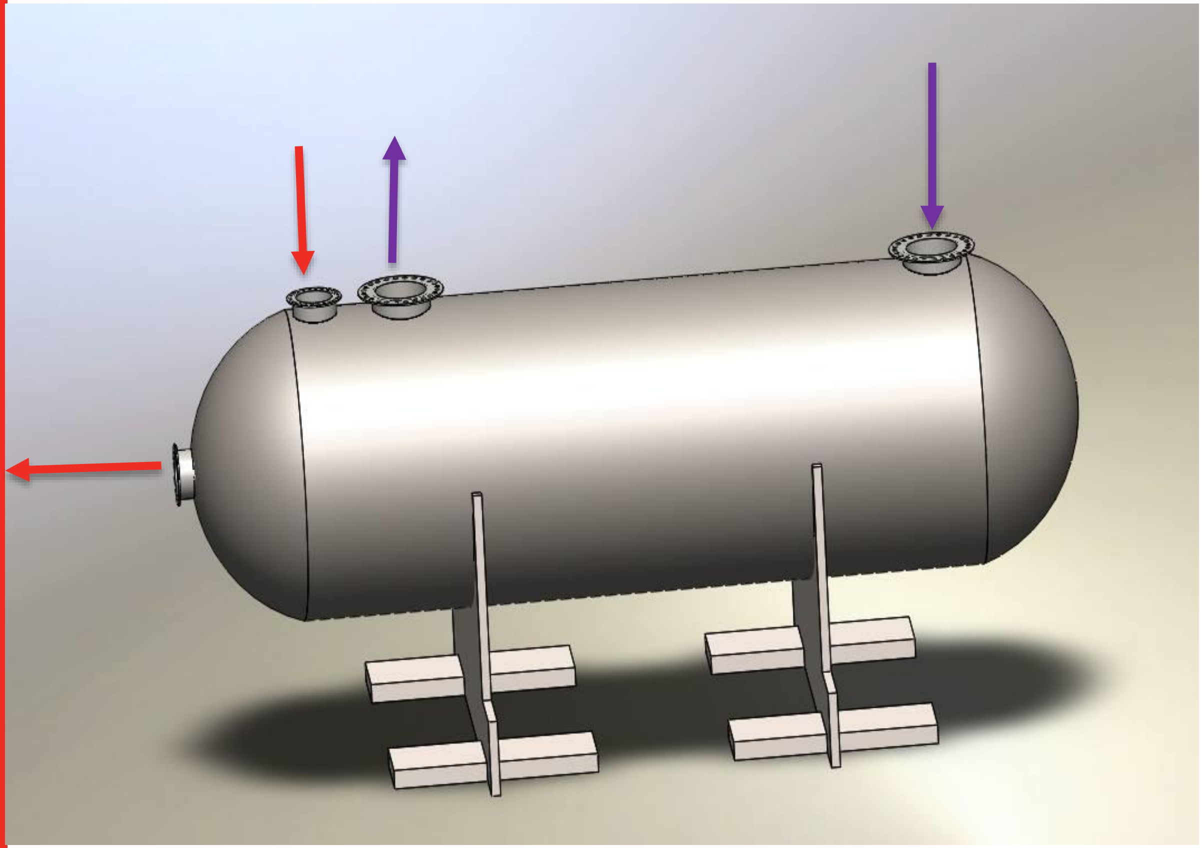
Pressures Calculated using MATLAB

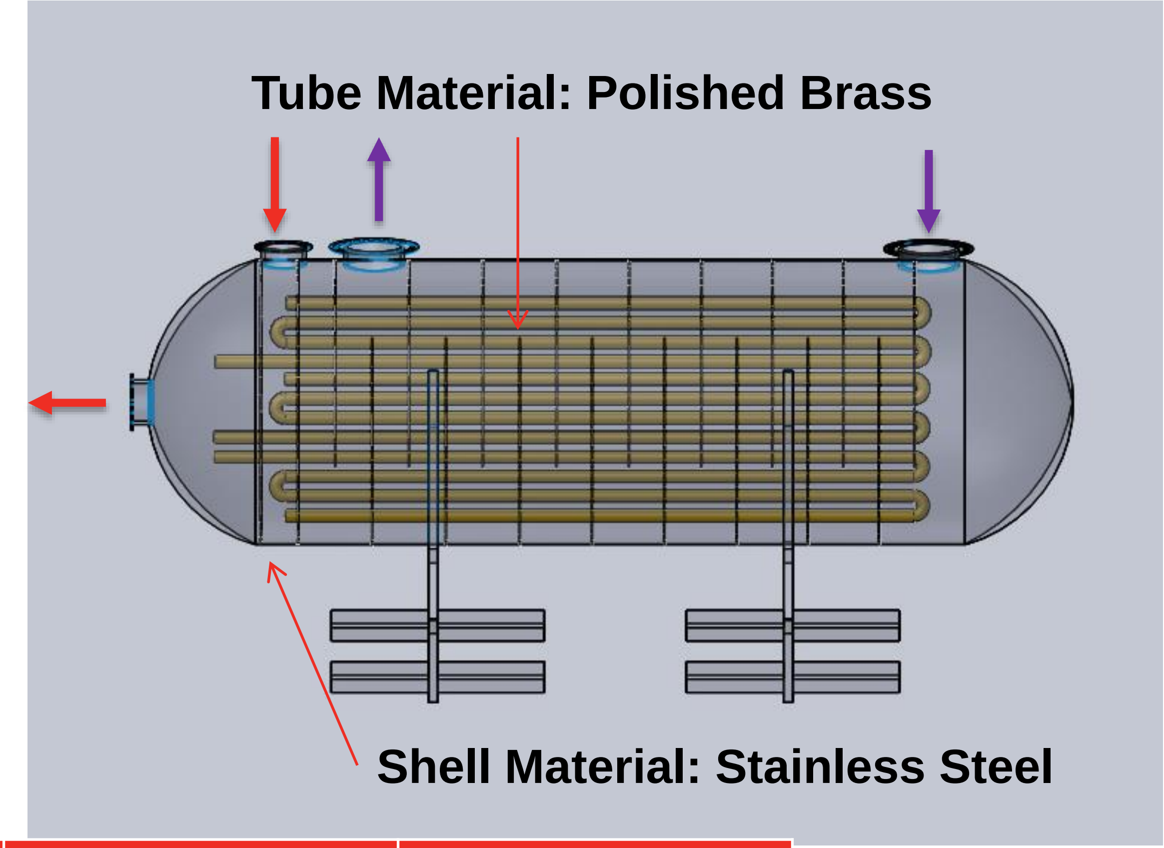
Location	Pressure (MPa)
Heat Exchanger Outlet/Turbine Inlet (3)	1.00
Turbine Outlet/Compressor Inlet (4)	0.5
Compressor Outlet/Tank Inlet (5)	1.10
Tank Outlet/Solar Collector Inlet (6)	1.05
Solar Collector Outlet/Heat Exchanger Inlet (7)	1.04

N-Butane Flow

Exhaust Flow

Heat Exchanger

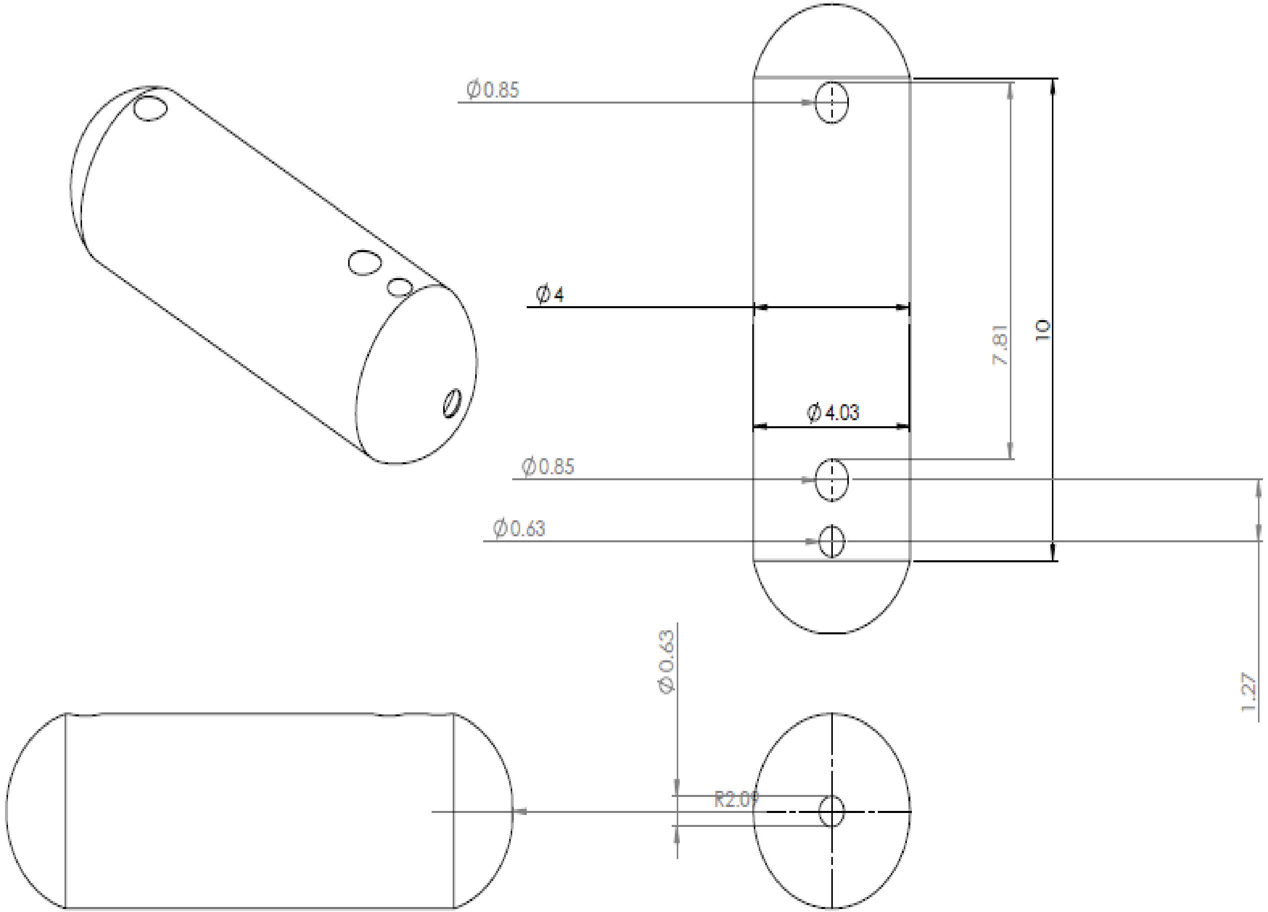




Thermal Efficiency	Pressure Drop n-Butane (kPa)	Weight of System (tons)	Number of Baffles	Baffle Spacing (m)
20%	40	50	20	0.5

Heat Exchanger

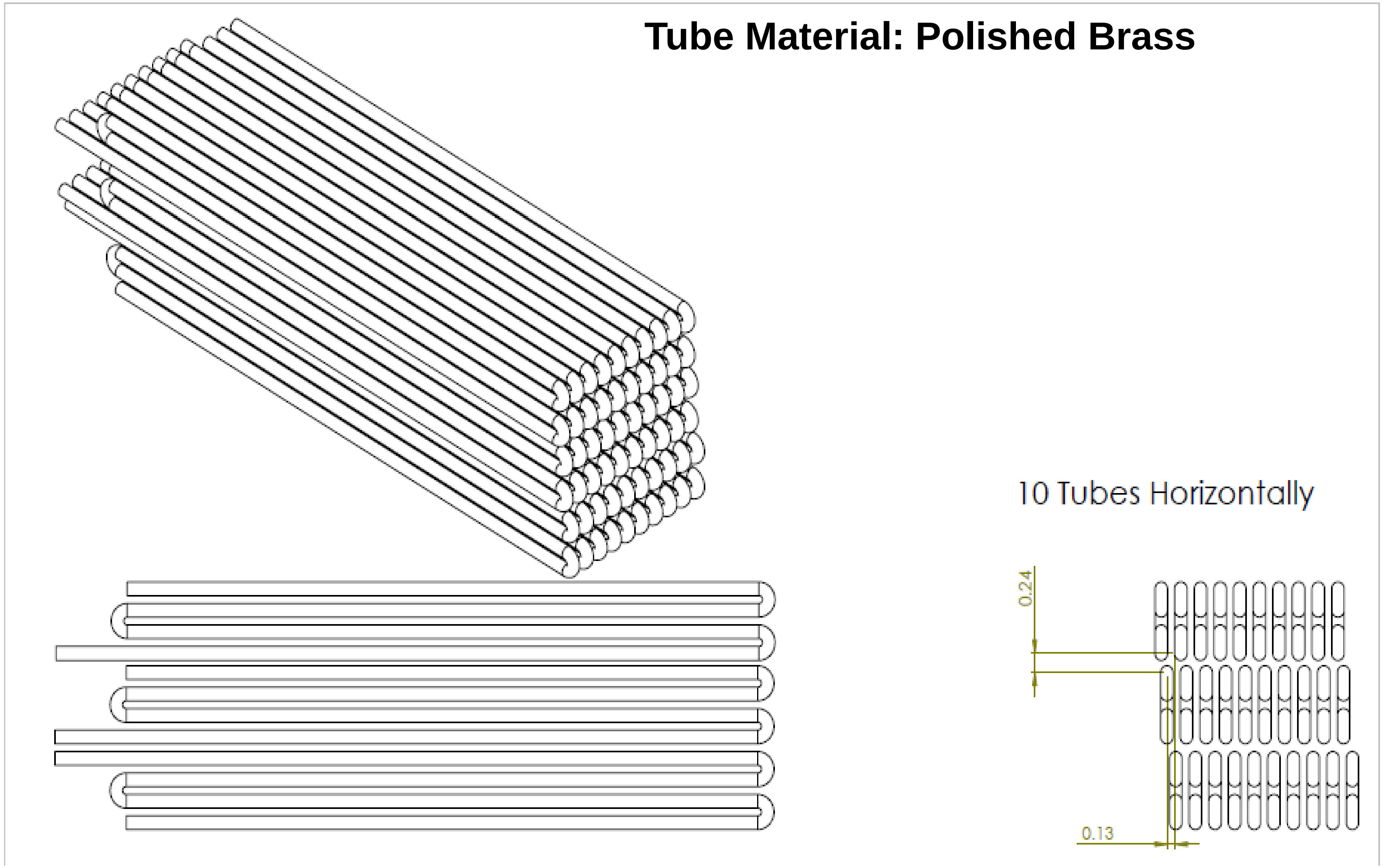
Parameters	Size (m)
n-Butane Inlet and Outlet	0.63
Exhaust Gas Inlet and Outlet	0.85
Shell Inside Diameter	4.0
Shell Outside Diameter	4.03



Shell Material: Stainless Steel

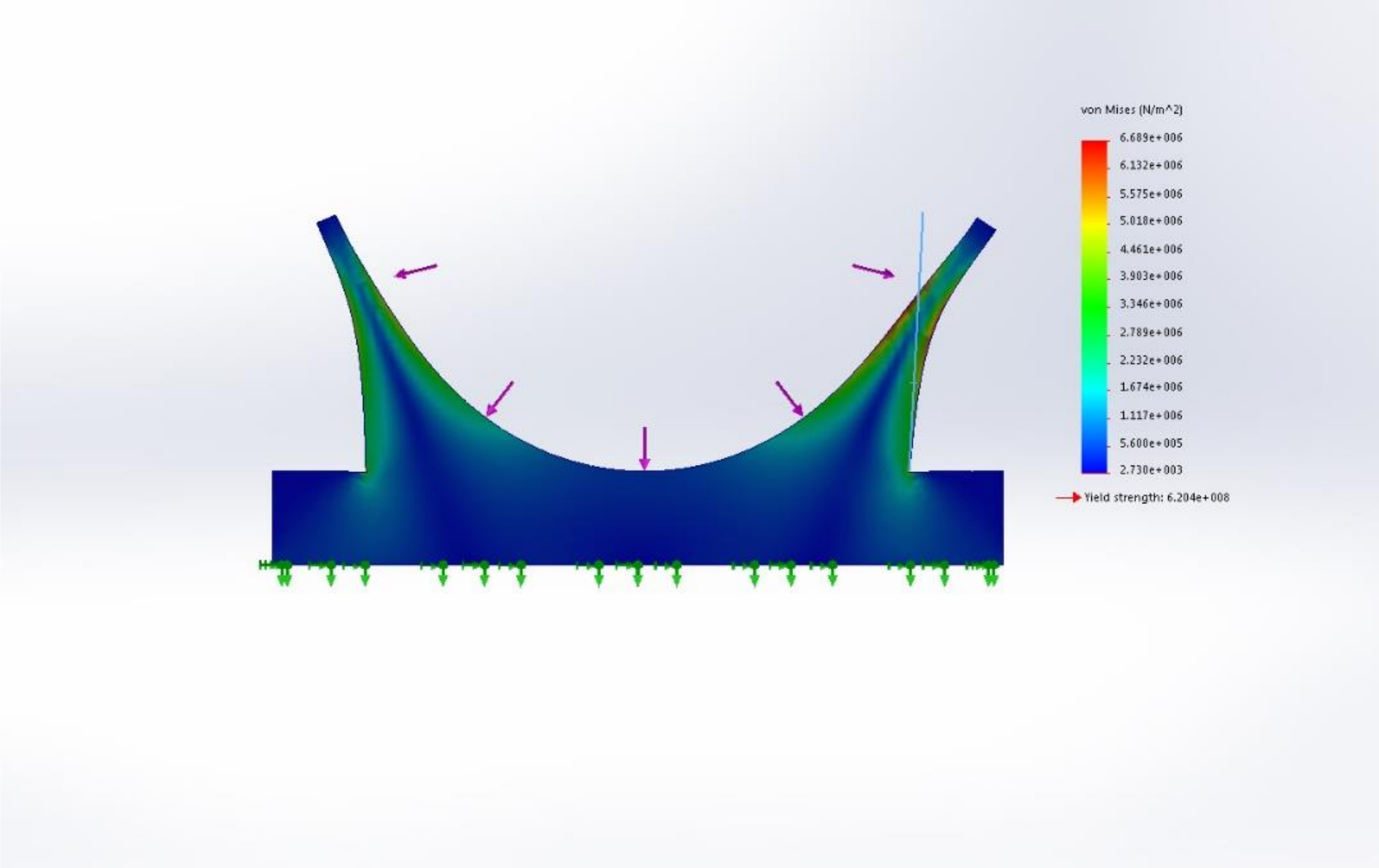
Heat Exchanger

Tube Material: Polished Brass



	Tube Parameters
Tube Inner Diameter (mm)	245
Tube Outer Diameter (mm)	250
Clearance Between Tubes(mm)	25
Number of Passes (per Tube)	4
Number of Tubes	30

Supports for heat exchanger



Turbine

- **Compact steam turbine for output ranges of up to 6 MW**

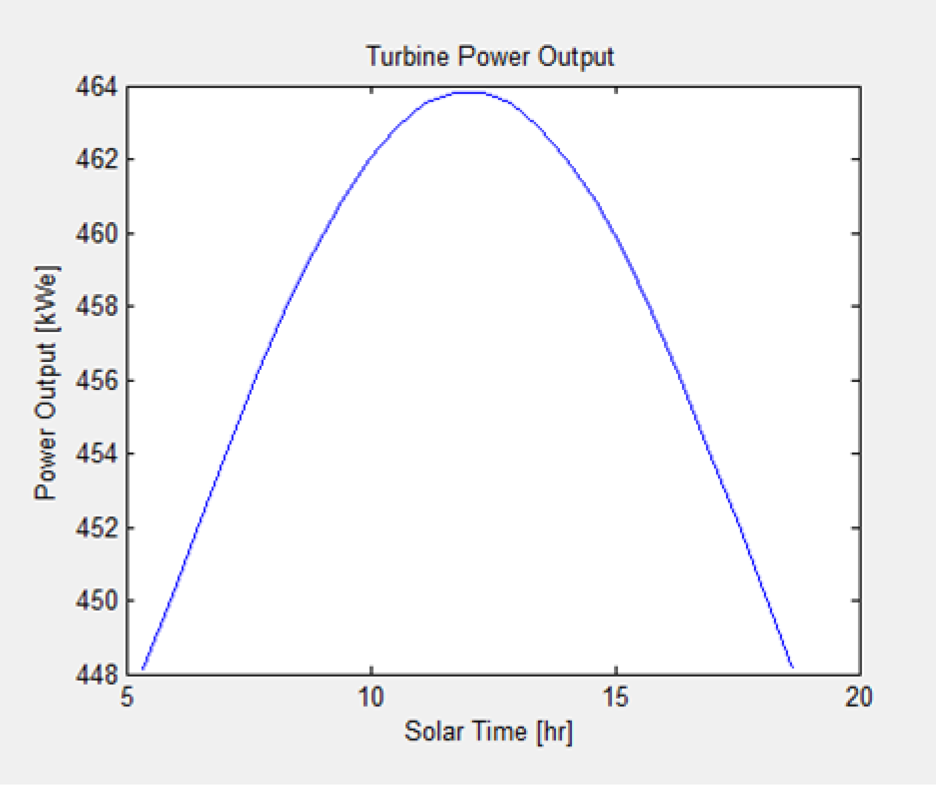
Power output	Up to 6 MW
Speed	According to driven machine
Inlet steam pressure	up to 131 bar (a)
Inlet steam temperature	Dry saturated steam up to 530°C

Typical dimensions of the SST-060 series
Length: 1.5 m / Width: 2.5 m / Height: 2.5 m

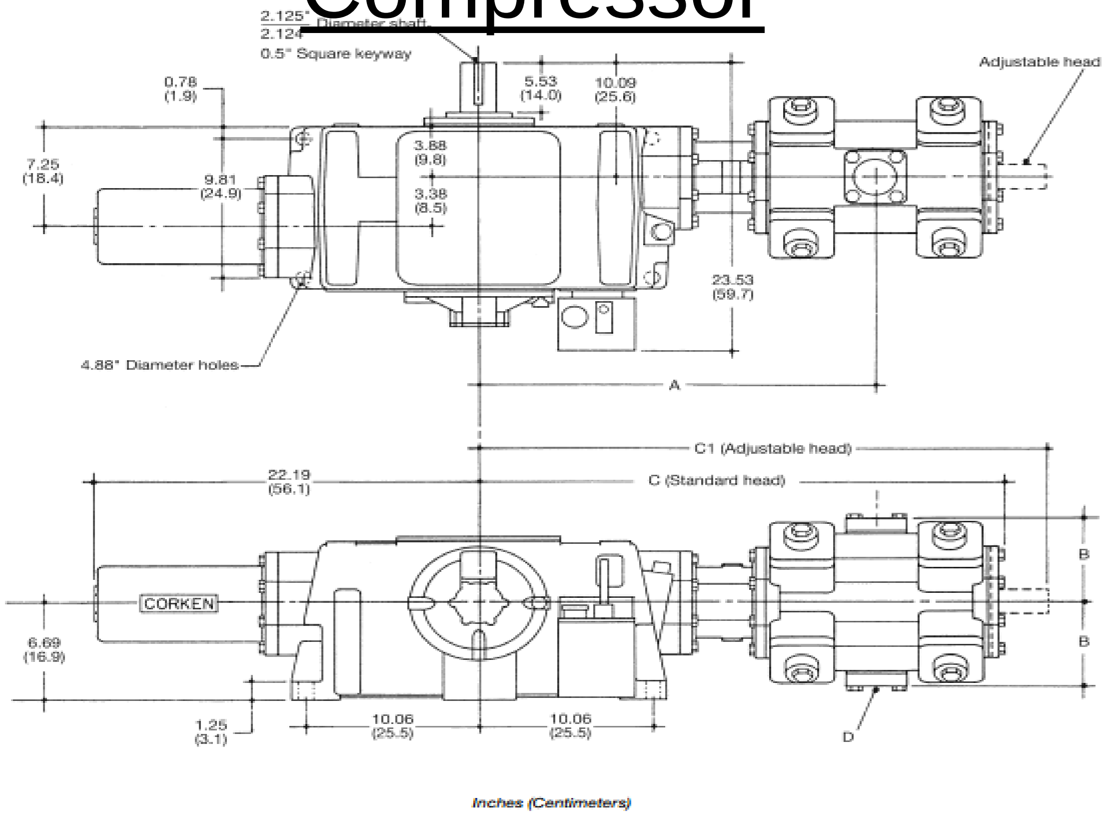
SST-060 Series Siemens Steam Turbines

Turbine

- Variable Turbine Inlet Temperature
- n-butane is an Ideal gas
  - $W_{out} = \dot{m} dh$
  - $dh = c_p \, dT$
  - C_p = 2.2 kJ/kgK [NIST]
- Butane mass flow = 7 kg/s
- Heat input ~ 890 kWt
- 50% Efficient
  - Total Turbine Efficiency(75%) – Compressor Power(25%)
- Average power output of turbine is **440-460 kWe**



Compressor



- Corken Reciprocating Compressor HG601BX
- Motor Speed 1200 rpm
- Maximum Mass Flow Rate: 15.4 kg/m^3
- Maximum Allowable Pressure: 11MPa
- Compressed from 0.5 MPa to 1.1MPa

Solar Collector

AET- 3000 Solar Collectors

Iteration Process

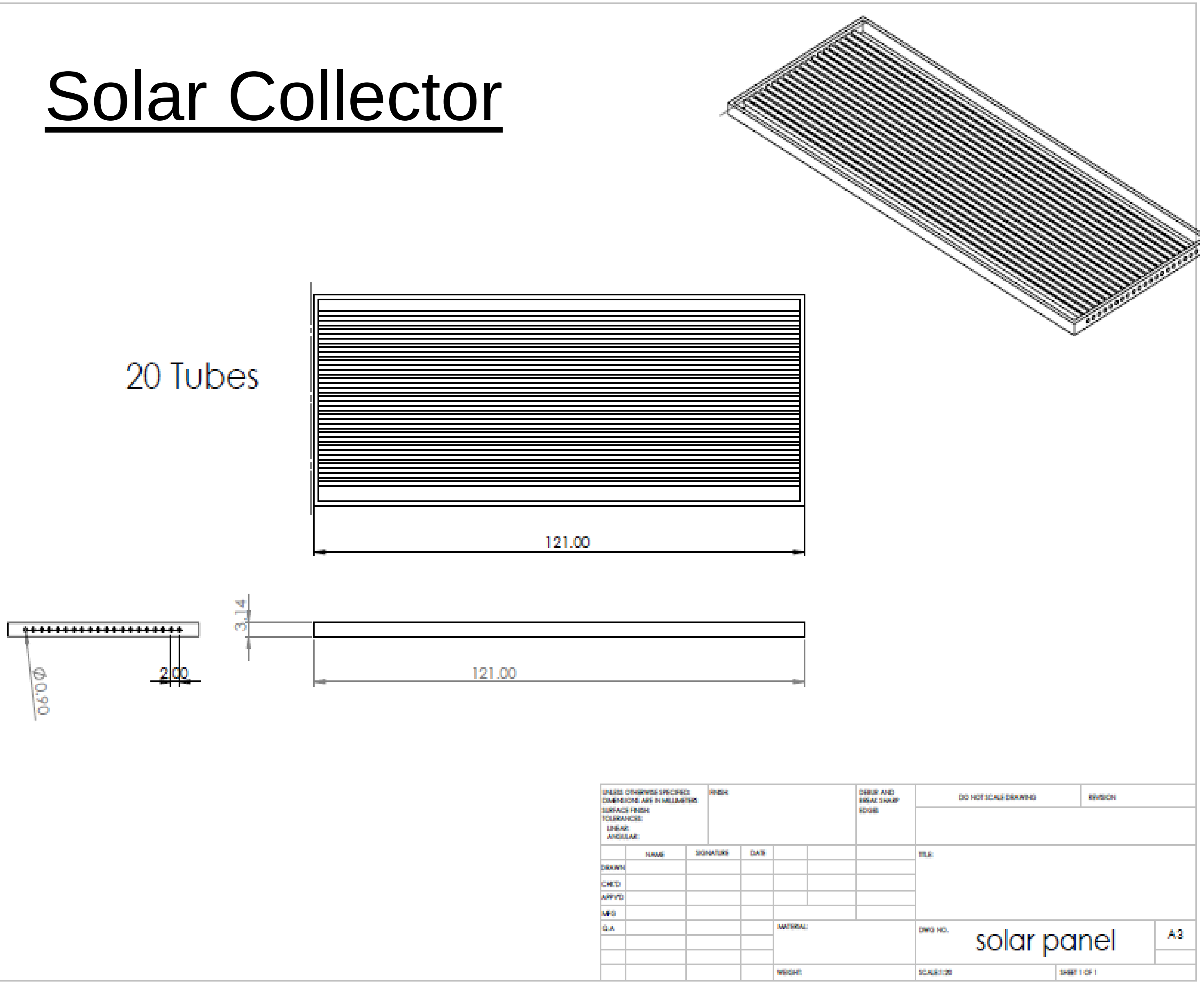
Efficiency

– 26% (February) - 37% (August)

Temperature of n-Butane

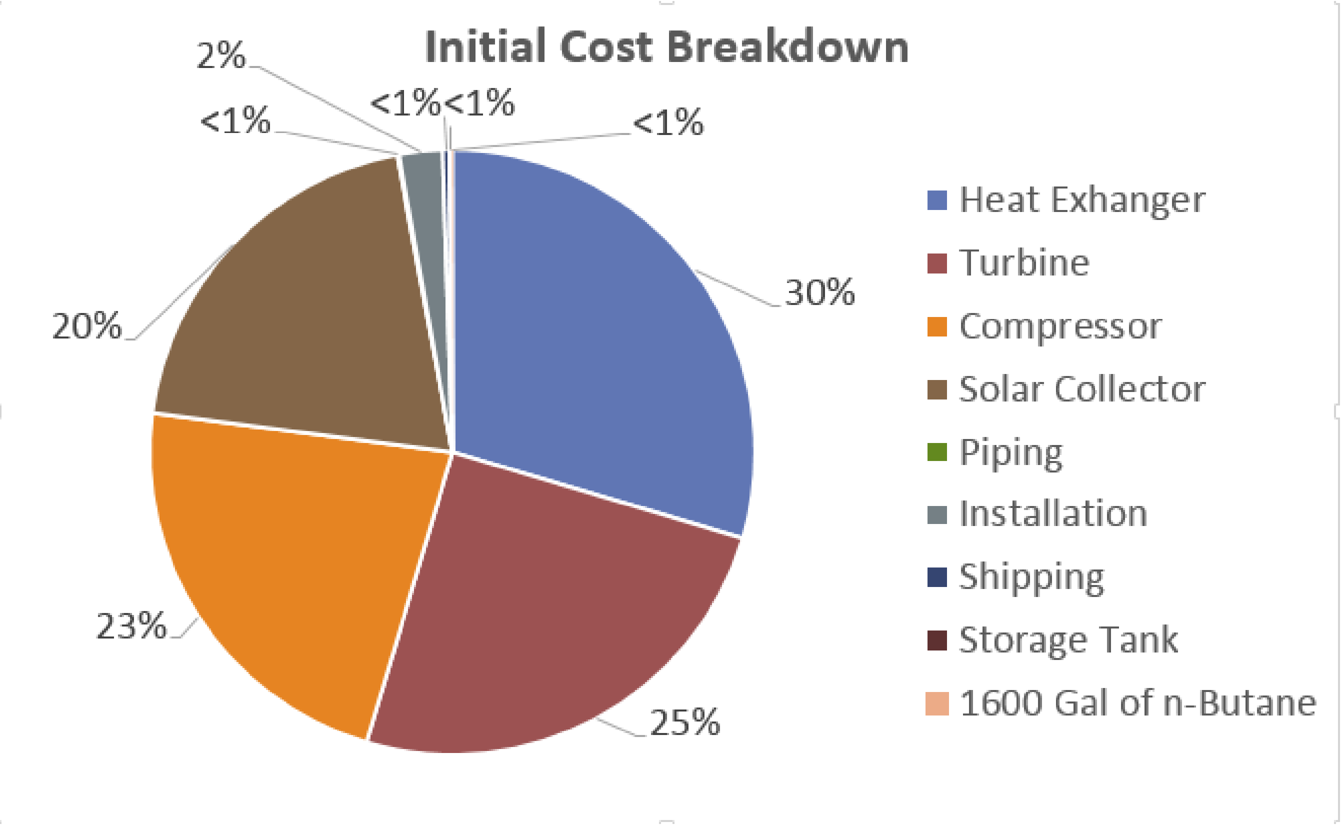
– ~80C - ~130C

Code in Appendix



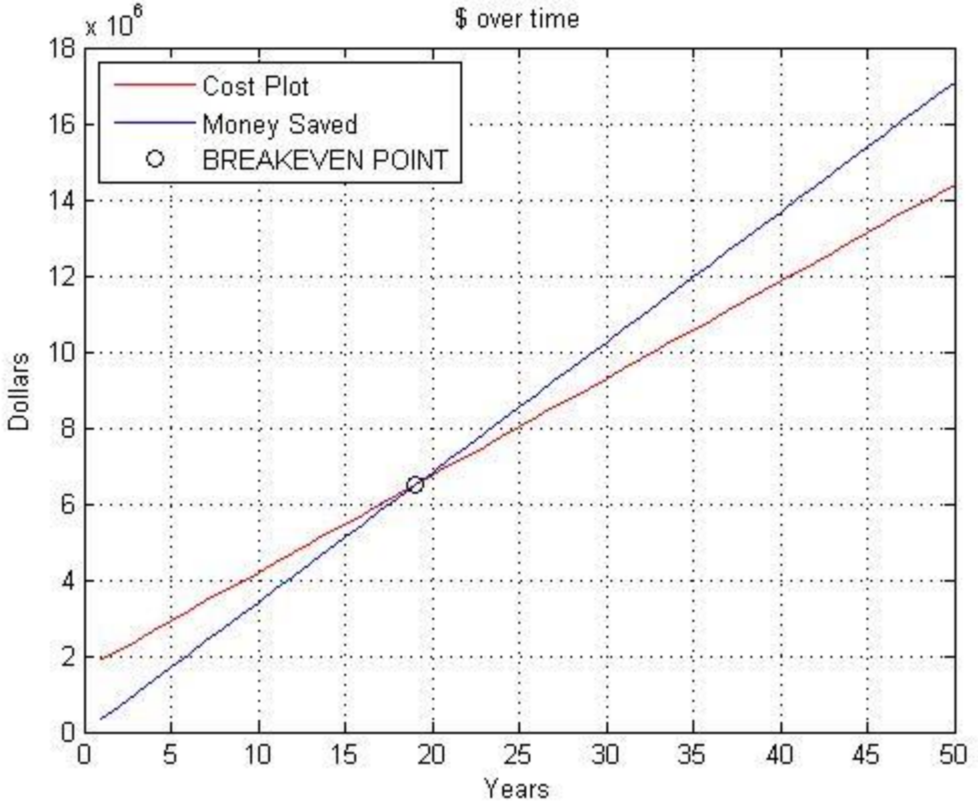
Initial System Cost

Cost	Price
Heat Exchanger	$591,950
Turbine	$500,000
Compressor	$450,000
Storage Tank	$1,965
1600 gal of n-butane	$1,040.00
Solar Collector	$400,000
Piping	$2,000
Shipping	$53,668



Total System Cost = $2,000,623

Pay-Back Time



Total Annual Power Produced = 3,900,000 kWhr

$0.085 kWhr from Duke Energy

Total Annual Savings ~ $330,000

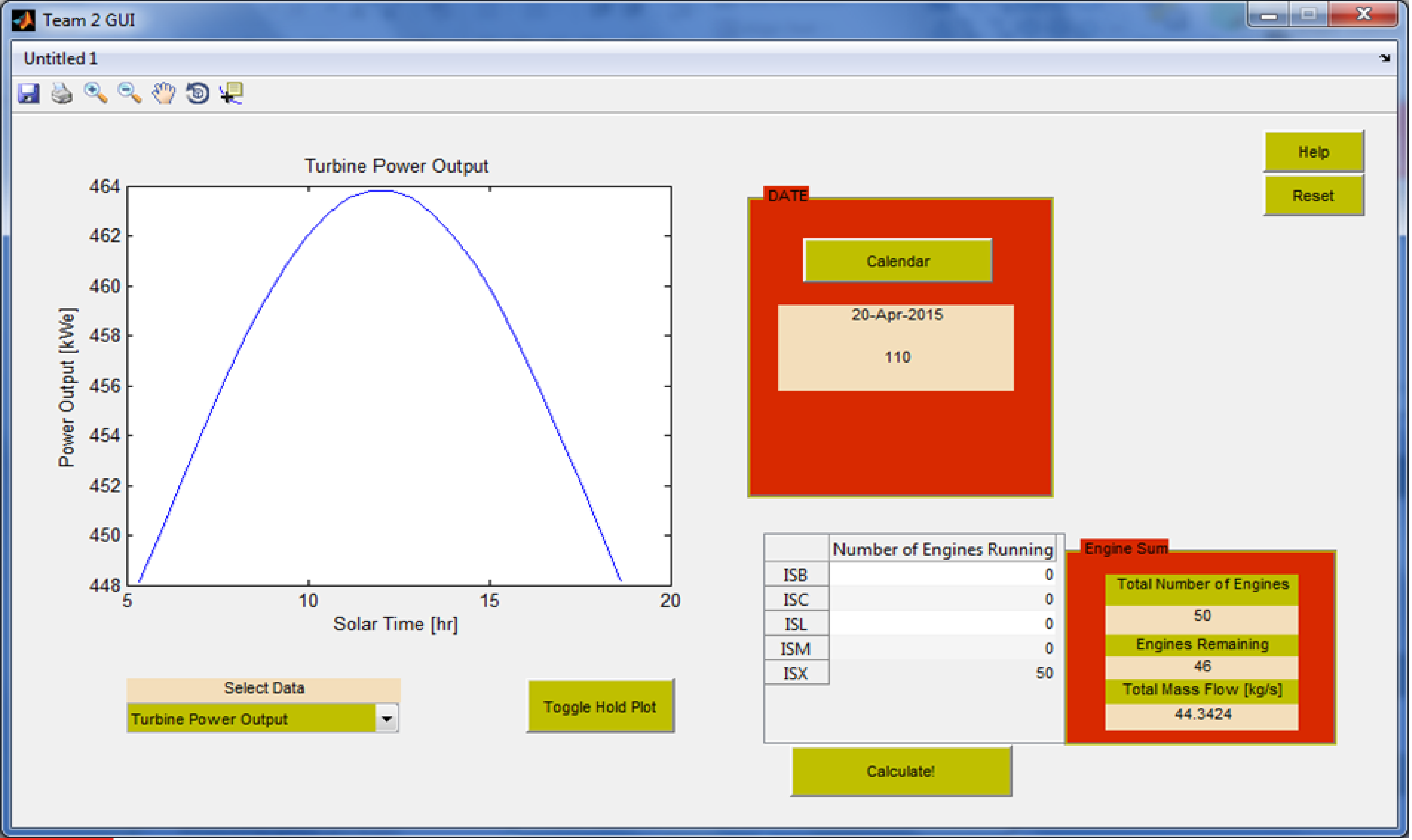
Annual Maintenance Cost = $250,000

Annual Inflation Rate of 2%

Pay-Back Time = 19 Years !!!!

Summary ORC

- Average Annual Savings of ORC is $335,799.91
- Payoff Period of 19 years
- Overall System Efficiency: ~9-11%
- Overall ORC is feasible
- Strongly recommend improving efficiency of system before implementing
  - Could be done in future senior design project
- Reduce the payoff Period by ~5 years



Team 2 GUI
Untitled 1
Turbine Power Output
464
462
460
458
456
454
452
450
448
5
10
15
20
Power Output [kWe]
Solar Time [hr]
Select Data
Turbine Power Output
Toggle Hold Plot
DATE
Calendar
20-Apr-2015
110
Help
Reset
Number of Engines Running
ISB 0
ISC 0
ISL 0
ISM 0
ISX 50
Engine Sum
Total Number of Engines
50
Engines Remaining
46
Total Mass Flow [kg/s]
44.3424
Calculate!

Total Annual Energy Savings

Annual	Initial Cost	Operating Cost	kWh electric	$ generated	Pay Back
ORC	$ 2,000,623.00	$250,000	3,950,587	$335,799.91	19 years
Chillers	$ 325,000.00	$78,630	N/A	$223,095.00	1 years
Wind Turbine	$ 1,338,944.32	$36,512.49	2,608,076	$221,686.50	8 years
Total	$ 3,664,567.32	$365,142.49	6,558,664	$780,581.40	N/A

Total Energy Saved = 4.21% ☺

Project Outcomes

- Lessons Learned
  - Communication
  - Scheduling
  - Time Management
  - Always prepare for the worst
- Overall a great experience

Questions

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```
Collector_area = 2100; %m^2 CTC Roof
Solar_transmittance = 0.92; %AE Collector
Solar_Absorptance = 0.96; %AE Collector
Collector_storage = 0; %J
Global_Conductance = 8; %W/m^2*K
Insolation = Total_Beam * Solar_transmittance;     %correct %W/m^2
G = massflownbutane / Collector_area;
T_f_in = 80 + 273.15;
T_f_out = T_f_in + (50 .* C ./ .126) .* (Insolation ./ max(Insolation));
F_r = (G * cp_nbutane  .*( T_f_out - T_f_in )) ./ (( Solar_Absorptance .* Insolation) - Global_Conductance * ( T_f_in - Temperature_ambient ));
heat_Useful = F_r .* Insolation .* Solar_Absorptance .* ...
    Collector_area - (Global_Conductance .* (T_f_in - Temperature_ambient) .* F_r .* Collector_area);
%Heat_Useful = abs(heat_Useful)
%Heat_lost = (Global_Conductance .* Collector_area .* (T_f_out + 273.15 - Temperature_ambient))
Heat_lost = (Insolation .* Collector_area) - heat_Useful;
Temperaturedifference = heat_Useful ./ (massflownbutane.*cp_nbutane);
t_Collector_out = Temperaturedifference + T_f_in;%K
tcounter = 1;
while tcounter<=48
    if tcounter/2 < time_rise_solar || tcounter/2 > time_set_solar
        t_Collector_out(tcounter) = T_f_in;
    else
        t_Collector_out(tcounter) = t_Collector_out(tcounter);
    end
    tcounter = tcounter + 1;
end
t_Collector_out;
T_Collector_out_C = t_Collector_out - 273.15 %C
TotalTempchange = sum(Temperaturedifference);
Heat_total = heat_Useful + Heat_lost;
Collector_efficiency = heat_Useful ./ Heat_total;
```

Solar Panels

Annual	Initial Cost	Operating Cost	kWh electric	$ generated	Pay Back
Solar Panels	$404,862.00	$2,500	314,521	$26,734.29	18 years

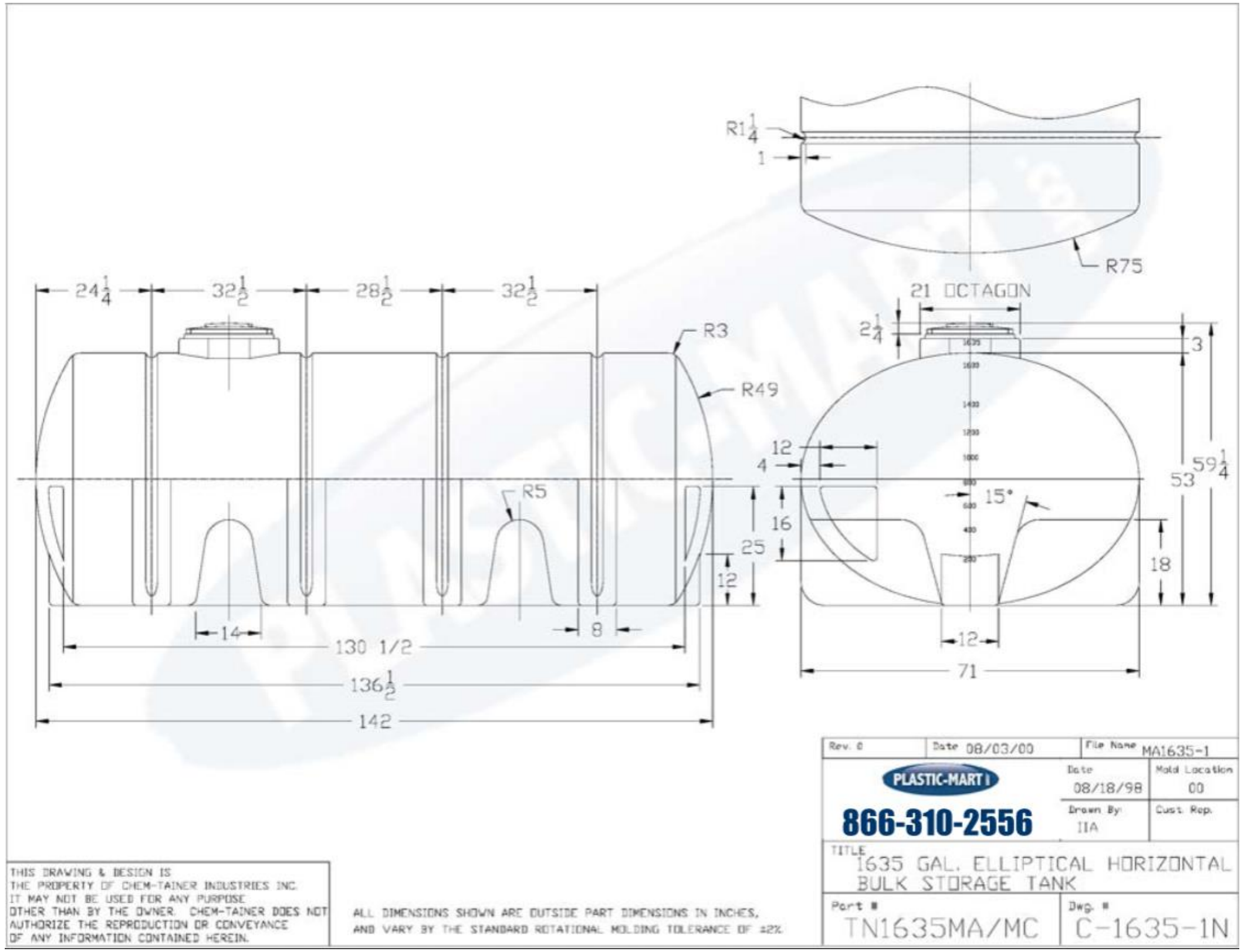
Storage Tank

Details

- Part Number: N-40387
- Mfr. Part Number: 40387
- Capacity: 1635 Gallons
- Dimensions: 142"L x 71"W x 58"H
- Weight: 470 lbs.
- Ships From: CA, GA, MN, OH, OK, TX, UT
- Manufacturer: Norwesco
- Material: Polyethylene
- Price: $1,965.99

Capacity determined by volume of butane needed in heat exchanger.

$V = 6.05\ m^3 = 1598$ gal (Butane in HE)



Working Fluid Selection

	Molecular Weight (g/mol)	Boiling Point (^{O}C)	Wet or Dry	Heat of Vapor @ 1 atm (kJ/kg)
Water	18	100	W	2256
Methanol	32	64	W	1098
2-M-P-H2O	33	93	W	879
Fluorinol 85	88	75	W	442
Toluene	92	110	D	365
R-113	187	48	D	1370
Ammonia	17	-33	D	1370
Isobutane	58	-12	D	367
n - butane	**58**	**-0.4**	**D**	**385**
n - pentane	72	36	D	325

Pipe Material Selection

Material	Therm. Cond. k (W/m*K)	Melting T (F)	Density (kg/m^3)
Black steel	43	2600	7850
304 SS	16	2750	8030
Brass	109	1700	8400
Copper	401	1983	8900

Pipe Insulation Selection

Property	Temperature Range (F)	Conductivity k	Density (lb/ft^3)	Safety
Fiberglass	To 500	0.20-0.31	1.5-3.0	Fire Resistant

Alternative Methods Investigation

Insulation

Material	Thermal Resistance	Types	Green	Fire Resistant
Fiber Glass	2.2 to 2.7	High, Medium, Low Density	20% to 30% Recycled	Yes
Mineral Wool	3.7	Blanket and loose fill	75% post-industrial recycled	Yes
Cellulose	3.2 to 3.8	loose fill or spray	82% to 85% recycled	No
Plastic Fiber	3.8 to 4.3	High, Low Density	----	Yes
Closed Cell Foam	5.6 to 8	Spray, Foam board	-----	No
Closed Cell Foam modified	9	Foil	----	Yes

Alternative Methods Investigation

Insulation

Material	Cost (per ft^2)	Total Material Cost	Total Savings per year
Fiber Glass	0.42	$9,606.66	$18,331.76
Mineral Wool	0.625	$14,295.62	$18,352.97
Cellulose	1.25	$28,591.25	$18,448.09
Plastic Fiber	1.5	$34,309.50	$18,596.58
Closed Cell Foam	2.2	$50,320.60	$18,955.43
Closed Cell Foam modified	2.3	$52,607.90	$19,068.17