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AIChE Home Office 120 Wall Street, FL 23 New York, NY 10005

Dear AIChE,

Enclosed is the design proposal for the 2022 AIChE Design Competition.

This report details the engineering assumptions and techniques used to complete the project, as well as the results and recommendations.

Thank you for this opportunity!

Sincerely,

Andrew Coffey, Trace Francis, April Johnsen, Genna Orr

CHE 4224 Spring 2022

# AIChE Design Project

# April 11, 2022

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#### **Executive Summary**

The goal of this project was to design modular Gas-To-Liquids (GTL) processing plants to be deployed at a network of wellheads, which can convert stranded natural gas resources into liquid material. The reasoning for this project was to reduce greenhouse gas emissions at wellheads by avoiding venting/flaring methane to the atmosphere. The task of the project was to provide the preliminary design package for a Fischer-Tropsch Reaction unit (FTR) and separation facilities, as well as optimizing the deployment of the GTL plant modules into the field. The wellhead network was located around a central plant location where units could be initially deployed from as well as a location to transport product to for further refining. The modules in this design were sized based on feed capacities of 500 MSCF/day, 2,500 MSCF/day, and 5,000 MSCF/day respectively. The central plant had a maximum capacity of 30,000 MSCF/day of natural gas feed, requiring optimization of which wells could be in service at a given time. Permits will be requested at the beginning of 2023, and after approval at six months, the equipment can undergo construction. Production is planned to begin at the start of 2024.

The economic analysis of this project was evaluated over a 20-year period with a 7-year straight line depreciation. The company's hurdle rate was 8%, and an inflation of 3% per year was assumed. After the preliminary design for sixteen well sites, with a starting natural gas feed ranging from 2,870-14,700 MSCF/day, the net present value was determined to be \$2.29B. The total capital investment is estimated to be \$1.33B with a payback period of 3.5 years. This project requires two large units, seven medium units, and twelve small units totaling to 21 module units to be constructed. The project requires the employment of 154 operators. Due to the central plant's capacity and the varied service of wells in any given year, the combined production of these active wells processed on average 21,800 MSCF/day of natural gas each year, producing on average 1.78 MMbbl/year of naphtha and 5.22 MMbbl/year of diesel.

An inherently safer design was implemented after assessing the potential hazards. Since this design not only overcomes the hurdle rate and is designed to reduce major safety risks the final recommendation is to move forward with this project.

### Introduction

AIChE has identified a potential area of growth in the chemical engineering industry. Natural gas is often flared or vented at isolated well sites which leads to higher carbon dioxide (CO<sub>2</sub>) emissions, as opposed to being transported or further processed into usable product. The goal of this project was to investigate ways to convert stranded natural gas resources into liquid petroleum gas (LPG), naphtha, and diesel products through the use of modular GTL plants. This paper details the engineering and supply chain decisions that were made to consider this problem. *Figure 1: Block Flow Diagram* illustrates the generalized process.



#### Figure 1: Block Flow Diagram

The GTL process will utilize steam methane reforming (SMR) to make syngas (CO/H<sub>2</sub> mixture), then the product will be fed to a Fischer-Tropsch Reaction unit (FTR). The reactor will utilize Fischer-Tropsch (FT) synthesis to create higher chain carbon molecules to be sold as LPG, naphtha, and diesel. A separations unit will follow the FTR to purify product streams. A hydro-isomerization unit (HIU) will collect the heavy bottoms product from the main fractionation column to form additional naphtha product, as well as diesel and waxes to further process in a downstream processing plant. The design statement calls for a detailed design of the FTR and separations facilities. Due to the nature of the units being modular and having various sizes, these units were considered at three different operating capacities based on the feed of methane: 5,000 MSCF/day, 2,500 MSCF/day, and 500 MSCF/day. This allowed for a variation of module sizes to be used at any given site based on need.

The GTL plant has four major feeds: methane, steam, carbon dioxide, and oxygen. The flow rates of oxygen, carbon dioxide, and steam depend on the modules maximum methane feed. The first stream is methane which comes directly from the wellhead at 500 psig and 100 °F. Carbon dioxide and high pressure (HP) steam, at those same conditions, are purchased for feeds to the syngas unit. The three feeds are mixed and must be heated before being sent into the syngas unit. The preheater is an electric furnace, heating the combined feed to 1,000 °F. The syngas unit is upstream of the FTR unit immediately following the feed preheater. This process converts methane feedstock into carbon monoxide and hydrogen in a ratio of two moles of hydrogen to one mole of carbon monoxide. This ratio will lead to the desired distribution of alkane products. Carbon monoxide and hydrogen will function as the feed to the Fischer-Tropsch reactor. The syngas unit can operate between a pressure of 300-500 psig and at a temperature of 1,600-1,950 °F. When simulating the syngas unit, the lower bound of the reactor temperature range was the target, as it reduced the amount of duty on the preheater. The two products are formed through three simultaneous reactions: steam reforming, partial oxidation, and the shift reaction. While the steam reforming and the shift reaction will end in equilibrium, the partial oxidation will go to completion. These reactions are listed in *Table 1: Syngas Unit*.

Steam Reforming:	$CH_4 + H_2O \iff CO + 3H_2$
Partial Oxidation:	$CH_4 + \frac{3}{2}O_2 \longrightarrow CO + 2H_2O$
Shift Reaction:	$CO + H_2O \leftrightarrow CO_2 + H_2$

Table 1: Syngas Unit

The steam reforming reaction serves as the primary method for converting methane into carbon monoxide and hydrogen. This is an equilibrium reaction and will not completely consume the methane feed. The partial oxidation reaction helps to convert more of the methane. Finally, the shift reaction functions to balance out the products into the desired 2:1 ratio.

The first part of this project was the design and optimization of the FTR based on the syngas product. Following the FTR design, was the detailed design of the separation units. It was determined that a 3-phase separator would follow the FTR to reduce flow rates to the distillation column by removing water. The distillation column separates the C10 and lighter material from

the C11+ material. C11+ material is sent to the HIU which does not need to be designed for this project. Products from the HIU were calculated given the equations from the design statement.

The second part of the project includes supply chain analysis and the optimized deployment of the modules based on plant capacities and well productions. Given that the well production rates decline over time, unit deployment was designed to provide the maximum product to the central plant.

#### Discussion

When beginning the preliminary stages of the FTR design, it was determined that Aspen HYSYS would be utilized to simulate the processes. The fluid package utilized throughout the simulations was Peng-Robinson. Using the specifications for the feed conditions, material streams were created and fed into an exchanger at a desired outlet temperature of 1,000 °F. The type of steam chosen for the feed was HP steam because of its high temperature allowing for less duty in the syngas preheater. The feed was then fed to an equilibrium reactor which is simulating the syngas reactor. The equations from *Table 1: Syngas Unit* were inserted into the reactor with the partial oxidation reaction having an equilibrium constant set to 1.0 MM to simulate a conversion reaction. An oxygen stream with 99% purity was fed to the reactor as a reactant for the partial oxidation reaction to occur. The reactor was then optimized by varying the inlet flow rates of steam, CO<sub>2</sub>, and oxygen to help meet FTR reactant specifications. Varying the oxygen stream flow rate affected the temperature of the reactor since it was the exothermic reaction, so once a temperature was reached in the range of 1,600-1,950°F, the other two reactant stream (CO<sub>2</sub> and HP steam) flow rates were varied to help reach a product specification of 1.0 mole fraction CO to 2.0 mole fraction H<sub>2</sub>.

Following the reactor was a 2-phase separator which acted to separate excess water from the product stream. The rational for implementing the drum was to reduce the overall flow rate downstream which will allow for a smaller-volume FTR and absorption column. After the separator, an absorption column was used with a water solvent to remove excess CO<sub>2</sub>. Similar to the rational for the separator placement, the column was implemented to help reduce the volume of flow which will eventually lead to the FTR and to also purify the feed stream. The Fischer-Tropsch reactor was designed and costed as a jacketed, non-agitated packed bed reactor. The goal of the reactor was to utilize the 2:1 H<sub>2</sub>/CO feed to create the desired distribution of LPG's, naphtha, and diesel. This was done using the Anderson-Schulz-Flory distribution which is effective from  $390^{\circ}$ F- $450^{\circ}$ F. The higher end of the temperature distribution led to heavier carbon chain material (diesel), which is more valuable. The reactor was then designed to maintain the temperature at roughly  $450^{\circ}$ F. The reaction is highly exothermic which made it necessary to have the reactor jacketed to maintain the temperature of the reactor. This led to the need for a large amount of steam as coolant to maintain that temperature. Pressure drop is also a large factor in the reaction since the vapor flow becomes a two-phase flow, which greatly decreases the conversion of the reactor. The overall pressure drop was reduced by increasing the number of tubes within the reactor while decreasing the tube diameter.

The reactor was modelled using differential equations paired with auxiliary equations. Polymath was considered for modelling the FTR, but it struggled with troubleshooting errors. It was then modelled within MATLAB due to its superior troubleshooting and computational abilities. This was done using a function file which contained all the reactor's differential equations and auxiliary equations. The function file was adjusted depending on the conditions of the reactor and the size of the modular unit's inlet flow. The script file was used to specify the initial conditions and to run the function file. In order to graph the resulting conversion, pressure drop, and temperature changes within the reactor, the function file was used. The script and function file can be seen in the appendix.

Following the FTR is a 3-phase separator which splits water from the hydrocarbon streams to help reduce the size of downstream units. Separators are typically much cheaper compared to other units, so the decision to implement these before larger facilities aims to reduce flow and therefore reducing the size of the more expensive units. The light liquid stream from the separator contains most of the C5-C30 material, which can be separated into the high-value products. This stream was then fed to a distillation column which was operating at atmospheric pressure. The rational for the column was to separate the C11+ material from the C10 and lighter material. The column has a partial condenser to separate tail gas from the naphtha stream. The bottoms products are then fed to the HIU to be separated into diesel and wax products. The

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amount of naphtha in the HIU feed was effectively negligible so it was included into the diesel stream.

### Conclusions

A modular gas plant design is a viable option to produce diesel and naphtha from methane coming from hard-to-reach wellheads. Preliminary design of the units focused on the FTR and separation sections. Supply chain and network analysis were also a large portion of the design. Costing transportation of product trucks as well as module movement is a large expense, but maintenance and repair were the biggest factor to loss of revenue on a yearly basis. Once the preliminary design for all sixteen well sites was completed, it was determined that the project requires two large units, seven medium units, and twelve small units for a total of 21 modules to be built. Due to the central plant's capacity, the number of wells in service at any given year varies. The combined production of these active wells processed on average 21,800 MSCF/day of natural gas each year, producing on average 1.78 MMbbl/year of naphtha and 5.22 MMbbl/year of diesel. After conducting a net present value analysis, the NPV was determined to be \$2.29B. The total capital investment was estimated to be \$1.33B with a payback period of 3.5 years. In addition to being economically attractive, this project is also a relatively safe design as it does not require exotic materials, most of the components are compatible with one another and the overall design is simplified to not include unnecessary equipment. Finally, this design is better for the environment since it is turning methane into products rather than venting to the atmosphere or including continuous flaring.

#### **Recommendations**

Overall, it is recommended to move forward with this project. Given the positive environmental impact it has when compared to traditional methods, as well as the final NPV, the project is attractive in all aspects. When considering the volatility of the oil and gas market, the sensitivity analysis examined the worst-case scenario for oil prices and the project still yielded a positive NPV. When moving forwarded with the project, it is recommended to reexamine product specifications. For this project, the product specifications were left loose and often times unreasonable. In conclusion, verifying product specifications is recommended. Another recommendation is to optimize the number of trucks being used to deploy the modules. It is recommended that the spacing for the modules within the containers is maximized to reduce the total number of containers being deployed.

Since the last three years of production are not profitable, another recommendation is to decommission the units at those wells and salvage material early.

### **Project Premise**

The project was premised on the idea of investigating ways to reduce  $CO_2$  emissions from well sites. When natural gas resources are stranded too far from conventional gathering pipeline systems, it cannot be collected along with crude oil. This results in the gas being burned using an on-site flare. The alternative to these methods of getting rid of natural gas is to implement a modular GTL processing plant among a network of producing wells. This allows for natural gas to be converted into longer-carbon-chain liquids to be transported and further processed at a refinery. Successful design and implementation of a network eliminates the need for methane to be vented or flared at stranded well sites and allows for more non-renewable resources to be utilized in other markets.

## **Heat and Material Balance**

Table 2: Mass Balance for Medium Unit, Table 3: Mole Balance for Medium Unit, and Table 4: Energy Balance for Medium Unit present the mass, mole, and energy balances for the medium unit. The 1% difference in the mass balance is likely due to significant figure errors from entering values back and forth from several platforms (Aspen HYSY, Excel, MATLAB, and PowerPoint). There is a slight loss of heat from the system, but it is shown as 0% because it is negligible.

Medium									
	Stream In (lb/hr)	Stream Out (lb/hr)							
Methane	6594								
Carbon Dioxide	6601								
HP Steam	6950								
Oxygen	6392								
Solvent	3603000								
Process Water Return		3630000							
Naphtha		6538							
Diesel		18880							
Wax		9253							
Sums	3629537	3664671							
Percent Difference %	1%								

#### Table 2: Mass Balance for Medium Unit

Table 3: Mole Balance for Medium Unit

	Medium	
	Stream In (Ibmole/hr)	Stream Out (lbmole/hr)
Methane	411	
Carbon Dioxide	150	
HP Steam	385.8	
Oxygen	200	
Solvent	200000	
Process Water Return		201100
Naphtha		62.43
Diesel		94.66
Wax		26.59
Sums	201146.8	201283.68
Percent Difference %	0%	

Table 4: Energy Balance for Medium Unit

	Medium									
	Heat In (Btu/hr)	Heat Out (Btu/hr)								
Stream										
Methane	13260000									
Carbon Dioxide	25460000									
HP Steam	39120000									
Oxygen	31030									
Feed Preheater	8078000									
Condenser		28220000								
Solvent	2459000000									
FTR Preheater	2671000									
Tower Condenser		1761000								
Tower Reboiler	5530000									
Isom Reboiler	4883000									
Naphtha		5965000								
Process Water Return		2472000000								
Isom Condenser		4025000								
Wax		3249000								
Diesel		12450000								
Sums	24689033030	24775670000								
Percent Difference %	0%									



Figure 2: FTR Unit Process Flow Diagram



Figure 3: PFD for Medium GTL Plant Process (DWG. 1)





Figure 4: PFD for Medium GTL Plant Process (DWG. 2)

#### Table 5: Medium Unit PFD Stream Table

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26 2	28	29	30	31
Medium	Unit	Mathana	Carbon	UD Steam	Syngas Feed	Hot Syngas	99%	Syngas	Condensed	Syngas Product	Absorber	Syngas Product	ETD Food	Water	CO2	Combined	FTR	Separator	Process Water 0	Column	Column	Condensed	Poflux Non	Co	ondensate	Light Reboi	er Reillun	Hydro-Isom	Diesel	Wax S	eparator
	_	wethane	Dioxide	nP Steam	Mixture	Feed	Oxygen	Product	Syngas	Water Removed	Solvent	CO2 Removed	FIR Feed	Removed	Removed	Water	Product	Water Draw	Return	Feed	OVHD	OVHD	Kenux Nap	Dr	rum Vapor	Gases Fee	вопир	Unit Feed	Product F	roduct	Vapor
Vapour Fraction		1.00	1.00	1.00	0.91	1.00	1.00	1.00	0.74	1.00	0.00	1.00	1.00	0.00	0.00	0.00	0.24	0.00	0.00	0.00	1	0.4429	0	0.00	1.00	1.00	0	0.00	0.00	0.00	1.00
Temperature	F	100	100	490	365	1,000	75	1,627	145	145	80	80	449	145	80	80	284	284	82	284	264	154	20	153	153	284	29 504	504	426	758	217
Pressure	psia	500	500	600	500	495	515	495	492	492	495	485	484	492	490	490	495	493	20	493	23	20	153	20	20	493	25 26	i 26	15	20	20
Molar Flow	lbmole/hr	411	150	386	947	947	200	1,608	1,608	1,188	200,000	1,000	1,000	420	200,188	200,608	682	270	201,106	245	139	139	15	62	62	167	84 163	3 121	95	27	229
Mass Flow	lb/hr	6594	6601	6950	20145	20145	6392	26537	26537	18963	3603020	11132	11132	7574	3610851	3618425	46607	4856	3630359	37944	11399	11140	1589	6539	3272	3806 54	43 26109	28134	18880	9253	7078
Liquid Volume Flow	barrel/day	1508	548	477	2533	2533	386	3418	3418	2898	247207	2242	2242	520	247863	248383	4423	333	249681	3503	1181	1181	157	647	377	587 4	78 2399	2479	1690	789	965
Mass Enthalpy	Btu/lb	-2010	-3857	-5629	-3864	-3463	-5	-2630	-3693	-2472	-6826	-1547	-1307	-6751	-6820	-6819	-1463	-6612	-6808	-785	-804	-958	-912	-912	-1073	-1646 -	59 -524	-589	-660	-351	-1381
Component Fraction																															
Hydrogen	lbmole/hr	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.16E+02	6.16E+02	6.16E+02	0.00E+00	6.11E+02	6.11E+02	2.21E-02	4.48E+00	4.50E+00	3.60E+01	2.60E-02	4.05E+01 2	.32E+00	1.67E-02	1.67E-02	5.03E-05 3.14	E-03	2.32E+00 3	.37E+01 7.74E	12 1.35E-11	6.73E-12	0.00E+00 0	00E+00 3	3.60E+01
Water	lbmole/hr	0.00E+00	0.00E+00	3.86E+02	3.86E+02	3.86E+02	0.00E+00	4.29E+02	4.29E+02	9.76E+00	2.00E+05	1.29E+00	1.29E+00	4.19E+02	2.00E+05	2.00E+05	2.95E+02	2.70E+02	2.01E+05 5	.95E+00	4.28E-02	4.28E-02	1.33E-03 8.29	0E-02	5.87E+00 1	.96E+01 3.90E	09 6.75E-09	8.74E-09	0.00E+00 0	00E+00 2	2.55E+01
Carbon Monoxide	lbmole/hr	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.07E+02	3.07E+02	3.07E+02	0.00E+00	3.04E+02	3.04E+02	1.15E-02	2.91E+00	2.92E+00	1.80E+01	1.01E-02	2.09E+01 1	.68E+00	1.21E-02	1.21E-02	6.81E-05 4.25	E-03	1.67E+00 1	.63E+01 2.05E	11 3.57E-11	2.18E-11	0.00E+00 0	00E+00 1	1.80E+01
Nitrogen	lbmole/hr	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E+00	2.00E+00	2.00E+00	2.00E+00	0.00E+00	1.85E+00	1.85E+00	2.00E-04	1.47E-01	1.47E-01	1.81E+00	8.92E-04	1.96E+00 1	1.60E-01	1.15E-03	1.15E-03	5.85E-06 3.65	E-04	1.59E-01 1	.65E+00 1.73E	12 3.01E-12	1.83E-12	0.00E+00 0	00E+00 1	1.81E+00
Oxygen	lbmole/hr	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.98E+02	2.15E-01	2.15E-01	2.15E-01	0.00E+00	2.11E-01	2.11E-01	1.67E-05	4.04E-03	4.05E-03	7.61E-04	8.53E-07	4.81E-03 9	9.49E-05	6.82E-07	6.82E-07	6.41E-09 4.00	)E-07	9.45E-05 6	5.65E-04 3.88E	15 6.74E-15	5.21E-15	0.00E+00 0	00E+00	7.60E-04
Carbon Dioxide	Ibmole/hr	0.00E+00	1.50E+02	0.00E+00	1.50E+02	1.50E+02	0.00E+00	1.73E+02	1.73E+02	1.72E+02	0.00E+00	4.94E-03	4.94E-03	4.58E-01	1.72E+02	1.73E+02	8.60E-03	4.91E-05	1.73E+02 1	1.87E-03	1.34E-05	1.34E-05	3.69E-07 2.30	0E-05	1.84E-03 6	5.68E-03 7.59E	13 1.32E-12	1.51E-12	0.00E+00 0	00E+00	8.53E-03
Methane	Ibmole/hr	4.11E+02	0.00E+00	0.00E+00	4.11E+02	4.11E+02	0.00E+00	8.15E+01	8.15E+01	8.15E+01	0.00E+00	8.14E+01	8.14E+01	3.90E-05	2.89E-03	2.93E-03	8.36E+01	3.25E-03	8.35E+01 1	.24E+01	8.95E-02	8.95E-02	1.20E-03 7.52	2E-02	1.24E+01 7	.11E+01 1.10E	09 1.91E-09	1.71E-09	0.00E+00 0	00E+00 8	3.35E+01
Ethane	Ibmole/hr	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.81E+00	7.81E-06	1.80E+00 5	5.33E-01	3.85E-03	3.85E-03	2.04E-04 1.28	8E-02	5.21E-01 1	.28E+00 1.02E	09 1.77E-09	2.74E-09	0.00E+00 0	00E+00 1	1.80E+00
Propane	Ibmole/hr	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.81E+00	4.57E-07	1.76E+00 8	3.13E-01	5.93E-03	5.93E-03	8.53E-04 5.3	E-02	7.60E-01 9	9.95E-01 1.70E	08 2.93E-08	7.02E-08	0.00E+00 0	00E+00 1	1.76E+00
Butane	Ibmole/hr	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.60E+01	2.46E-07	2.33E+01 1	.60E+01	1.20E-01	1.20E-01	4.27E-02 2.66	E+00	1.33E+01 9	.99E+00 3.71E	06 6.33E-06	2.36E-05	0.00E+00 0	00E+00 2	1.33E+01
Pentane	Ibmole/hr	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.34E+01	5.14E-09	1.72E+01 1	.76E+01	1.37E-01	1.37E-01	9.89E-02 6.17	E+00	1.14E+01 5	.78E+00 3.99E	05 6.73E-05	3.80E-04	0.00E+00 0	00E+00 1	1.72E+01
Hexane	Ibmole/hr	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.10E+01	8.00E-11	1.05E+01 1	.79E+01	1.47E-01	1.47E-01	1.68E-01 1.05	E+01	7.40E+00 3	.13E+00 3.81E	04 6.31E-04	5.36E-03	0.00E+00 0	00E+00 1	1.05E+01
Heptane	Ibmole/hr	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.89E+01	9.16E-13	5.41E+00 1	.72E+01	1.47E-01	1.47E-01	2.15E-01 1.34	E+01	3.75E+00 1	.66E+00 3.13E	03 5.07E-03	6.37E-02	0.00E+00 0	00E+00 5	3.41E+00
Octane	Ibmole/hr	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.70E+01	9.33E-15	2.40E+00 1	.62E+01	1.36E-01	1.36E-01	2.24E-01 1.40	E+01	1.55E+00 8	3.46E-01 2.27E	02 3.55E-02	6.55E-01	0.00E+00 0	00E+00 2	2.40E+00
Nonane	Ibmole/hr	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.53E+01	8.66E-17	9.02E-01 1	.49E+01	9.41E-02	9.41E-02	1.63E-01 1.02	E+01	4.66E-01 4	4.36E-01 0.104	35 0.156665	4.23E+00	0.00E+00 0	00E+00	9.02E-01
Decane	Ibmole/hr	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.38E+01	4.29E-19	2.97E-01 1	.35E+01	3.45E-02	3.45E-02	6.10E-02 3.81	E+00	7.35E-02 2	2.23E-01 0.174	93 0.245255	9.65E+00	0.00E+00 0	00E+00	2.97E-01
n-C11	Ibmole/hr	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.000000	0.00E+00	0.00E+00	1.24E+01	3.32E-21	1.23E-01 1	.23E+01	1.00E-02	1.00E-02	1.79E-02 1.11	E+00	8.91E-03 1	1.14E-01 0.151	84 0.196314	1.11E+01	8.10E+00 0	000000	1.23E-01
n-C12	Ibmole/hr	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.11E+01	1.49E-23	6.15E-02 1	.11E+01	2.8/E-03	2.8/E-03	5.13E-03 3.20	E-01	1.18E-03 E	5.04E-02 0.113	99 0.13204/	1.0/E+01	7.71E+00 0	00E+00	0.15E-02
n-C13	Ibmole/hr	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E+01	1.09E-25	2.98E-02 9	98E+00	5.46E-04	5.46E-04	9.79E-04 6.1	E-02	8.72E-05 2	2.9/E-02 8.30E	02 8.39E-02	9.92E+00	7.09E+00 0	005+00	2.98E-02
0.015	Ibmole/III	0.000000	0.000000	0.000000	0.00E+00	0.000000	0.000000	0.0000000	0.00E+00	0.00E+00	0.000000	0.00E+00	0.000000	0.000000	0.00E+00	0.000+00	9.000000	4.325-20	1.402-02 8	005+00	1.676.05	1.575.05	2.925.05 1.70	E-03	4.25E-00	015 02 4 775	02 3.072-02	0.965+00	6.43E+00 0	005+00	9.035.03
0-016	Ibmole/hr	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.29E+00	2,955-32	4 265-03 7	285+00	2.625-06	2.625-06	4 705-06 2 9	0E-03	3.535.09	1 265-02 2 925	02 3.352-02	7 285+00	5.802+00 0	005+00	4.265-03
n-C17	lbmole/hr	0.00E+00	0.000+00	0.000000	0.00E+00	0.000000	0.000000	0.000000	0.000 +00	0.00E+00	0.000+00	0.00E+00	0.000+00	0.000+00	0.00E+00	0.005+00	6 555+00	7 395-37	2.405-03 6	555400	5 175-07	5.175-07	9.285-07 5.70	05-05	3.915.00 1	ADE-02 2.005	02 1.130-02	6 555+00	4.695+00 0	005+00	+.20E-03
0.019	lbmole/hr	0.000000	0.000000	0.000000	0.005+00	0.005+00	0.000000	0.000000	0.000 +00	0.000+00	0.000000	0.00E+00	0.000+00	0.000+00	0.00E+00	0.005+00	5.905+00	9.365-41	1 255.02 5	905+00	1.005-07	1.005-07	1.805-07 1.1	E-05	3.810-09 2	1 355.02 3.090	02 9 705-02	5 905+00	4.032+00 0	005+00	1 255.02
n-C19	Ibmole/hr	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.30E+00	3.80E-41	7 985-04 5	30F+00	2.27E-08	2.275-08	4.07E-08 2.5/	E-05	5.04E-11 7	7 98F-04 2 20F	02 5.76E-03	5 30E+00	3.80E+00_0	00E+00	7.98E-04
n-C20	lbmole/hr	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4 76E+00	7.02E-44	3 375-04 4	76E+00	1.80F-00	1.80E-09	3 235-09 2.0	F-07	1 10E-12 3	37F-04 1.88F	02 3.555-03	4 76E+00	3.42E+00 0	005+00	3 37E-04
n-C21	lbmole/hr	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.78E+00	1.66E-46	1.86E-04 4	28E+00	3.31E-10	3.31E-10	5.94E-10 3.7	E-08	9.89E-14 1	1.86E-04 1.64E	02 2.32E-03	4.28E+00	0.00E+00 4	06E+00	1.86E-04
n-C22	lhmole/hr	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.85E+00	2.43E-49	1.08E-04 3	85E+00	7.09E-11	7.09E-11	1.27E-10 7.9	E-09	1.13E-14 1	1.08E-04 1.45E	02 1.55E-03	3.85E+00	0.00E+00 3	66E+00	1.08E-04
n-C23	lhmole/hr	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.47E+00	7.26E-52	5 35E-05 3	46E+00	9 20E-12	9 20E-12	1.65E-11 1.0	E-09	5.84E-16	35E-05 1 28E	02 9.695-04	3.46E+00	0.00E+00 3	29E+00	5.35E-05
n-C24	lbmole/hr	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.12E+00	1.47E-54	2.84E-05 3	12E+00	1.50E-12	1.50E-12	2.69E-12 1.6	8E-10	4.33E-17 2	2.84E-05 1.13E	02 6.27E-04	3.12E+00	0.00E+00 2	96E+00	2.84E-05
n-C25	lbmole/hr	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.80E+00	7.25E-57	1.60E-05 2	80E+00	2.94E-13	2.94E-13	5.27E-13 3.29	E-11	4.22E-18 1	1.60E-05 1.01E	02 4.17E-04	2.80E+00	0.00E+00 2	66E+00	1.60E-05
n-C26	Ibmole/hr	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.52E+00	6.37E-60	8.33E-06 2	.52E+00	4.47E-14	4.47E-14	8.02E-14 5.0	E-12	2.82E-19 8	3.33E-06 9.03E	03 2.67E-04	2.52E+00	0.00E+00 2	39E+00	8.33E-06
n-C27	lbmole/hr	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.27E+00	2.99E-62	3.99E-06 2	27E+00	5.18E-15	5.18E-15	9.30E-15 5.8	E-13	1.21E-20 3	3.99E-06 8.08E	03 1.66E-04	2.27E+00	0.00E+00 2	15E+00	3.99E-06
n-C28	lbmole/hr	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.04E+00	3.10E-65	2.50E-06 2	.04E+00	1.45E-15	1.45E-15	2.60E-15 1.62	E-13	2.07E-21 2	2.50E-06 7.25E	03 1.16E-04	2.04E+00	0.00E+00 1	93E+00	2.50E-06
n-C29	Ibmole/hr	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.83E+00	1.16E-67	1.52E-06 1	.83E+00	3.63E-16	3.63E-16	6.51E-16 4.0	/E-14	2.94E-22 1	1.52E-06 6.51E	03 8.04E-05	1.83E+00	0.00E+00 1	74E+00	1.52E-06
n-C30	lbmole/hr	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.83E+00	9.01E-66	4.34E-07 1	.83E+00	6.40E-18	6.40E-18	1.15E-17 7.1	/E-16	7.24E-25 4	4.34E-07 6.48E	03 3.80E-05	1.83E+00	0.00E+00 1	74E+00	4.34E-07
Actual Volume Flow	barrel/day	19807	6307	23783	62616	127992	9244	312719	67376	66847	244975	51321	87036	529	245464	245992	15464	364	668655	4036	193700	85770	167	688	84905	11124 6	06 257030	3300	2141	1234	353282
Mass Density	lb/ft3	1.42	4.47	1.25	1.38	0.673	2.96	0.363	1.68	1.21	62.87	0.927	0.547	61.16	62.88	62.88	12.88	57.09	23.21	40.19	0.252	0.57	40.61	0.16	1.46	0.09 37	.36 0.43421	40.61	37.69	32.05	36.45
Molar Density	lbmole/ft3	0.0887	0.1017	0.0693	0.0646	0.0316	0.0925	0.0220	0.1020	0.0760	3.49	0.0833	0.0491	3.39	3.49	3.49	0.19	3.17	1.29	0.260	0.00307	0.01	0.39 0.0	0311	0.0642	0.00277 0.	95 0.00	0.388	0.19	0.09	0.16

#### Safety and Environmental Summary

Inherently safer consideration should always be addressed in the preliminary design stage since it is often incredibly expensive to incorporate these ideas into an existing plant. The main focus of inherent safety is to avoid hazards rather than attempting to control them by adding additional equipment.

This project includes several inherently safer design considerations. One of the concerns was having a large amount of hazardous material in storage or process equipment that could potentially be released. To minimize this risk, the equipment was sized accordingly based on each modular unit size to ensure that process vessels and piping did not contain excessive amounts of process material that could pose problems in the case of a fire or explosion. Similarly, there is no long-term product storage built at the well sites. Frac tanks on trailers are used to store products until they reach half capacity and are then taken back to the central plant so that products are not being stored onsite for long periods of time. The benefits of these changes are reduced capital cost from smaller equipment and reduced operating cost of buying the mobile storage tanks rather than renting them or building permanent ones on site. Unwanted material was also removed from the process stream. This leads to a lower overall amount of material. It can also lead to a reduction in the size of the equipment used in the process. In this project, an absorption column is used to remove the excess  $CO_2$  while a flash drum removes the water from the system. This leads to an increase in the concentration of the reactants and increased the overall conversion of the reactor. It also reduced the volumetric flow rate of the stream and reduced the size of the reactor and all following equipment.

Another inherently safe factor utilized was substitution. The solvent used in the reactor was water rather than a more exotic solvent. Using water is a much safer than using a potentially toxic or highly flammable solvent. Other solvents are not as readily available, and many times must be regenerated after a certain point which is a significant added expense. For the FTR, medium pressure steam was used as the cooling medium rather than high pressure steam. This is because high pressure steam will cause the reactor to overheat and result in an undesired Anderson-Schulz-Flory probability distribution and the desired products will not be able to be obtained at a temperature over 449 degrees Fahrenheit. Cooling water was also considered but due to the possibility that the water could vaporize, it was determined that the vapor state was the preferred cooling medium. Medium pressure steam is also at a lower temperature which will be less likely to cause an explosion, fire, or material release. Using the medium pressure steam for the reactor also reduces the cost of operation since it is cheaper than the high-pressure steam.

Project safety management is a key management system that needs to be in place at every plant to achieve safe operation. This is done by defining safe operating limits and putting procedures in place to make sure that the process is operating within those limits. In addition to providing general safety information, standard operating procedures for this GTL plant will be clearly defined and written with step-by-step instruction that requires annual certification.

One of the best ways to help make safe practices a habit is to have continuous training programs and yearly, companywide training conferences. People will often pay closer attention when they know they will be quizzed on the material so tests or quizzes after training sessions should be held to confirm that everyone has retained the information provided.

All equipment in the plant needs to be inspected and undergo frequent testing to verify that all processes are operating properly. This should also include a pre-startup safety review and process hazard analysis as each module is redeployed.

Management of change is a significant part of having good safety culture. This system needs to be implemented to require proper documentation for all maintenance, shift changes, contracted work, etc. A mandatory authorization permit for any hazardous activities within the plant should be required as well as the proper training.

To prevent incidents a full-scale emergency planning and response team will be put into effect before start-up. For any incidents that occur, an investigation needs to be held within 48 hours of the occurrence and a written report should be issued and recorded.

After a conducting a chemical reactivity analysis, it was determined that there are potentially hazardous conditions throughout the process since it contains oxygen. Hydrocarbons, especially, those considered to be naphtha, are highly flammable. Oxygen generates heat that creates an exothermic reaction at ambient temperatures. This reaction could be intense, violent, or explosive as shown in the deflagration analysis below. These substances can also create gaseous products that may cause increases in pressure. An increase in pressure may lead to an overpressure event which will be handled with pressure relief devices and rupture disks to prevent any damage to equipment. Reactions from these substances can produce toxic gases such as carbon monoxide, chlorine, hydrogen halide, nitrogen oxides, and acid fumes.

This process also uses a lot of water as the solvent for the reactor. Water when mixed with carbon dioxide and oxygen can be corrosive. The process water return line will need to be monitored and possibly treated to prevent corrosion of the pipes and equipment.



Figure 5: P&ID of Medium Unit Major Fractionator

The modular gas plant is a refinery that deals with volatile carbon chains. If the system were to experience a catastrophic failure, it could lead to flammable liquid or vapors escaping the system and creating health and environmental hazards. Plume dispersion, puff dispersion, and a deflagration were modeled to determine the potential worst-case effects. The Pasquill-Gifford coefficients as well as atmospheric stability classes were used to determine how the plume was spread. The best and worst cases, class A and F, were modelled, and the wells were in a rural setting. It was determined that the worst-case scenario occurs within the large unit. A rupture within the FTR or FTR product line could release a large amount of vapor or flammable liquids. The line is also under pressure at 495 psia and 449 °F. The condition of each model assumes the ambient conditions of the area to assist with specifying variables in the continuity equation.

The plume is modelled using point source dispersion modelling. A modified form of the continuity equation was used to determine the concentration of volatile carbon chains at various distances. *Figure 6: Plume Dispersion Effect* shows how the concentration of the carbon chains that vaporize spread over a distance from 5 meters to 640 meters when escaping at 12 kg/s. A continuous plume is unlikely due to the control systems in place causing a shutdown of the system thus stopping the 12kg/s flow.



Figure 6: Plume Dispersion Effect

In the event the FTR experiences a rupture or of the FTR product line rupturing, a puff model was developed again using the continuity equation. This event assumes that the control system would quickly stop flow upon a sudden pressure drop. The puff model then assumes that all the material within the reactor would be released over a 18 seconds, the amount of time for the reactor volume to move through the reactor. This leads to 216 kg of hydrocarbons being released with 90 kg being vaporized. This 90 kg is composed of the lighter carbons from C1-C12 which are flammable. *Figure 7: Puff Dispersion Case Comparison* shows the dispersion from 5 m to 1,460 m. The average lower flammability limit is 1.63% by volume while the average upper flammability limit is 10.4% by volume. The mixture will only be flammable between these bounds. Since the vapor is a hydrocarbon, it is likely for the mixture to combust at some point upon release due to the many ignition sources located within the GTL plant.



Figure 7: Puff Dispersion Case Comparison

An uncongested vapor cloud deflagration was conducted to determine the potential risks associated with a vapor leak of flammable hydrocarbon gases. The puff model's 90 kg mass was used to determine the equivalent mass of TNT and the resulting damage. The resulting mass of TNT was determined to be 18.6 kg of TNT using an efficiency of 30% for hydrocarbons. *Figure 8: Deflagration Pressures vs Distance* Error! Reference source not found.shows the resulting pressure wave at varying distances. From 0-10 meters, the resulting damage is a total loss of equipment. Beyond that, severe damage is seen all the way to 65 meters, at this point the damage lowers to minor damage to structures and less.



Figure 8: Deflagration Pressures vs Distance

From a safety perspective, there is always risk associated with chemical processes, but there is nothing in this process that is exceptionally unsafe. At this point in the design stage, the only potential for terminating the project is purely economic.

One of the major concerns requiring significant attention in the detailed design stage would be start-up processes. More specifically, since all the units are modular, each unit will have to be taken off the truck and assembled at the well site. The assembly will include a structure that will hold the condenser and condensate receiver up in the air next to the fractionation column in the separation unit. Such a structure may need safety railing and or harnesses for routine maintenance.

Preventing a runaway reaction or loss of containment from the Fischer-Tropsch reactor is a major concern that will require considerable attention and should be adequately addressed with process safety management practices. The most important would be the aforementioned methods like standard operating procedures, management of change procedures, and proper training.

A risk management plan will need to be developed to minimize the frequency and severity of accidents within the plant. A focus on communication with the nearest communities

and adjacent landowners will be necessary to implement a plan to handle emergencies properly. This project also focuses on being environmentally conscious. In many similar processes, methane is vented to the atmosphere, or a flare is used to burn off excess hydrocarbons. In this project the goal was to convert as much methane into products as possible.

Overall, this design is inherently more safe, all of the hazards have been identified and consequences of risk have been addressed and mitigated. A strong safety culture will be realized once the process safety management procedures are put into place and a risk management plan is established.

#### **Equipment Information Summary**

All equipment information can be found in *Table 6: Medium GTL Plant Process Equipment Summary.* This table only summarizes equipment specifications for the medium-sized units, the small and large units can be found in the appendix. Equipment design specifications were determined based on safety of the process and maximizing the NPV. Any specifications marked in *Table 6: Medium GTL Plant Process Equipment Summary* as "N/A" implies that detailed design was not necessary for the scope of the project. The material of construction for all of the equipment and piping is carbon steel since it is the cheapest option that can safely operate given all operating conditions and materials.

All heaters in this design were determined to be electric heaters. After a cost analysis for both feed preheaters (H-101 & H-102) and the column reboiler (H-103), it was determined that fuel gas would cost more than electricity when supplying the duty to run at the desired outlet conditions.

The condensers were all determined to be U-Tube heat exchangers since it is the cheapest option that provided the largest heat transfer area. The syngas condenser (E-101) was not sized since it was within the scope of the syngas unit which did not need to be detailed; however, specifications regarding expected inlet/outlet conditions were provided along with the duties to achieve a calculated area if needed for future reference.

The main fractionation vessel consisted of 7, single-pass sieve trays with a material of construction being carbon steel. The tower has a condenser and reboiler to maintain product specifications and aid in efficient separation and product temperatures. The column was

optimized to maximize the bottoms production in order to produce more C11+ material. The temperature and pressure of the column were determined by examining the relative volatilities of C10 and lighter material compared to C11+ material. Due to the nature of these two product streams, it was a simple separation which allowed for the tower being able to operate at atmospheric pressure, which resulted in lower condenser and reboiler duties. Diesel was a more profitable product compared to naphtha and LPG, so the goal of the design was to produce as much of the heavier products as possible to maximize the project NPV.

A three-phase separator was implemented to provide liquid holdup to remove water and vapor from the main hydrocarbon stream. The purpose of the placement of the vessel was to remove volume from the feed stream to the main fractionation vessel (T-102). This resulted in an overall smaller volume for the distillation column. The orientation of the 3-phase separator was determined to be horizontal as they are cheaper since they don't require as much structuring, and the length and diameter calculated fit within the required dimensions. The condensate receiver following the distillation column is vertical since it contains a higher vapor volume.

A packed bed reactor (PBR) was designed to serve as the FTR (R-102). A PBR was chosen due to the requirement of continuous flow and the use of a catalyst. PBR's are generally versatile and help to increase contact between multiple phases. This reaction leads to the creation of a two-phase liquid/gas flow in contact with a cobalt catalyst. A tubular design was selected to help increase catalyst contact and conversion of the feed into the desired products. Tube numbers ranging from 3-70 were tested, ultimately leading to 42 tubes being the optimum number to increase conversion while balancing catalyst weight and cooling water cost. The reactor was kept at constant temperature to lead to the desired ratio of products. This led to the reactor further being designed as a jacketed reactor to regulate temperature. The reactor was designed to be horizontal to reduce the cost as it requires less structure. This was chosen after a compatibility matrix of the reactants and products was conducted. The conditions of the reactor are also reasonable as the maximum temperature and pressure of carbon steel are 750 °F and 60,000 psi respectively.

Heat Exchangers	E-101	E-102	Heaters	H-101	H-102	H-103		
Туре	U-Tube	U-Tube	Туре	Electric Heater	Electric Heater	Electric Reboiler		
Area (m2)	N/A	11.9	MOC	CS	CS	CS		
Duty (BTU/hr)	28,200,000	1,780,000	Duty (Btu/hr)	8,080,000	2,670,000	5,610,000		
Shell								
Temperature (°C)	886	141						
Pressure (bar)	34.1	1.59						
Phase	Vapor → Liquid	Vapor → Liquid						
MOC	CS	CS						
Tube								
Temperature (°C)	32.2	32.2						
Pressure (bar)	3.45	3.45						
Phase	Liquid	Liquid						
MOC	CS	CS						
Vessels/Towers/	V 404	V 400	V 402	T 404	T 400	T 402	D 404	D 400
Reactors	V-101	V-102	V-103	1-101	1-102	1-103	R-101	R-102
Temperature (°C)	62.8	140	67.2	26.7	221	403	888	254
Pressure (bar)	33.9	34.1	1.59	33.8	5.37	1.38	34.1	33.4
Orientation	N/A	Horizontal	Vertical	Vertical	Vertical	Vertical	Horizontal	Horizontal
MOC	CS	CS	CS	CS	CS	CS	CS	CS
Size								
Height/Length (m)	N/A	7.50	4.74	N/A	5.11	N/A	N/A	3.45
Diameter (m)	N/A	3.09	0.96	N/A	0.914	N/A	N/A	1.00
Internals	N/A	Heavy Liquid Boot	Mist Eliminator	N/A	Sieve Trays	N/A	N/A	42 Tubes

#### **Unit Control and Instrumentation Description**

Controls is an integral part of designing a safer, more reliable design. A full control system was developed for the major fractionator and a preliminary plan was considered for the FTR. The systems were designed considering safety, and access to the operators to monitor the system in the field and in a central control location.

The control systems in place in the major fractionator primarily maintain temperature, pressure, liquid levels, and flow rates. Level controllers are used in the separators and condensate receivers in order to maintain proper separation of phases and components. This is done by using a control valve on a liquid outlet which will adjust the flow of liquid. This will serve to maintain the liquid seal. Temperature controllers are used throughout the system. The temperature controller uses a transmitter and controller to adjust the flow rates of the cooling or heating fluids to the necessary flow rate. This allows the process fluid to maintain the proper temperature. Pressure controllers are used to regulate the flow rate of gasses throughout the system. A pressure indicator records the pressure and sends a signal to a controller which in turn regulates the gas flow line. This system also helps prevent the pressure of the vessels from going above operating conditions.

The control system is depicted in *Figure 5: P&ID of Medium Unit Major Fractionator*. The control system is the same across the sizes of modules, but this description will follow the medium unit's P&ID.

*Table 7: Unit Control and Instrumentation Description* describes the instruments that are not connected to the central control system, and their purpose.

The FTR requires temperature controls to regulate and monitor the temperature due to the exothermic nature of the reaction. The temperature needs to be monitored not only for the safety of the equipment but also for the risk of causing a runaway reaction or creating undesirable products. A backup to the steam cooling system will need to be implemented, as well as a control system. This system should also include pressure relief devices to prevent over pressuring the equipment.

Type of Device	ID	Locations	Description
Pressure Relief	PSV	(V-102)	If overpressure occurs, PSV will allow relief to
Valve		(E-102)	protect the process vessel until overpressure event
		(H-103)	desists.
Rupture Disk	RD	(V-102)	Disk will rupture due to overpressure to prevent
		(T-102)	equipment breakage but may lead to backpressure.
		(H-103)	
Temperature	TI	(V-102)	Monitors temperature at different points throughout
Indicator		(T-102)	the distillation column, and the three-phase separator,
		(E-102)	and overhead condenser. These devices are local
			allowing operators to monitor the tower in person.

Table 7: Unit Control and Instrumentation Description

## **Economics**

This design was evaluated over a 20-year project life with a hurdle rate of 8%. Based on timing for permits, construction is planned to begin in the latter half of 2023, so that the first units can be deployed in the first part of 2024. Units were calculated with a first of a kind (FOAK) cost initially and then a learning rate was applied to the subsequent units. The heat exchangers, FTR, vessels, distillation column, and trays were all calculated using the Turton Appendix A equations for capital costs. The capital cost for the syngas unit, HIU, steam plant, and CO2 recovery unit were cost based on their calculated capacities and scaled for each unit size. The FOAK cost was applied to each size unit since the dimensions will change between units. In *Table 8:Cost of Module by Name* (Total is Sum x 4.8) the total capital cost was multiplied by the supplied multiplier of 4.8 and applied to the total equipment sum. This table also shows the salvage value calculated at the end of the project life.

Based on the unit's positions/usage throughout the well systems over the project life the utilities were calculated based on the capacity of the units deployed (for example a medium unit may be deployed because smalls were unavailable, so the medium runs at a reduced capacity). The utilities reported in *Table 9:Utility Cost per Unit & Usage per Year* are the services used

and the associated usages per year of each unit at full capacity. Some utilities where credited for returning them, those credits were accounted for in the utilities total.

The other operating costs include labor, maintenance (including catalyst recharge), module transportation and product transportation. The number of operators needed for the units employed was calculated to be 154 and the salary estimated at \$80,000 per year. This salary was inflated 3% every year over the project life. Maintenance was calculated to be 10% of the capital cost each year plus the catalyst recharge for all the units every three years. The module transportation was calculated based on the unit capacity and the distance traveled. For example, a unit named Hedy, moved from well 2C to 2B in year ten, and this transportation was approximately 83 miles and cost \$1.4M. Further information of total transportation cost and specific distances traveled can be found in the Appendix. Finally, once the amount of product produced per unit was finalized, the number of product trucks needed per day was determined and priced. Each product truck was priced based on the number of miles driven. The cost for product trucks was \$1.25 per mile, for total product truck costs per well see the Appendix.

Number ID	Name	# OAK	Unit Cost	Salvage
L_1	April	1	(\$40,248,000)	\$4,049,800
L_2	Genna	2	(\$32,199,000)	\$3,244,900
M_1	Hedy	1	(\$25,691,000)	\$2,594,100
M_2	Irene	2	(\$20,553,000)	\$2,080,300
M_3	Katherine	3	(\$18,038,000)	\$1,828,800
M_4	Margaret	4	(\$16,443,000)	\$1,669,300
M_5	Mary	5	(\$15,303,000)	\$1,555,300
M_6	Rachel	6	(\$14,431,000)	\$1,468,100
M_7	Shirley	7	(\$13,732,000)	\$1,398,200
\$_1	Alexa	1	(\$10,536,000)	\$1,078,600
\$_2	Annie	2	(\$8,429,000)	\$867,900
<b>S_</b> 3	Bessie	3	(\$7,398,000)	\$764,800
<b>S_4</b>	Beth	4	(\$6,744,000)	\$699,400
<b>S_</b> 5	Caroline	5	(\$6,276,000)	\$652,600
<b>S_</b> 6	Dijanna	6	(\$5,918,000)	\$616,800
<b>S_7</b>	Dorothy	7	(\$5,632,000)	\$588,200
<b>\$_</b> 8	Ella	8	(\$5,395,000)	\$564,500
<b>S_</b> 9	Evelyn	9	(\$5,194,000)	\$544,400
\$_10	France	10	(\$5,021,000)	\$527,100
S_11	Gertrude	11	(\$4,869,000)	\$511,900
\$_12	Jane	12	(\$4,735,000)	\$498,500
\$_13	June	13	(\$4,614,000)	\$486,400
		Total:	(\$1,331,515,200)	\$28,289,900

Table 8: Cost of Module by Name (Total is Sum x 4.8)

Table 9: Utility Cost per Unit & Usage per Year

Utility	Price/Unit	Large Usage	Medium Usage	Small Usage
Process Water Return (kgal)	- \$0.35/kgal	16680208	8200236	8959728
Electricity (kWh)	\$0.04/kWh	81466782	34854368	7123323
Hydrogen (lb)	\$0.06// <b>1</b> b	3345225	1500150	327177
Cooling Water (kgal)	\$0.15/kgal	26631407	13263693	2650551
Oxygen (Short Ton)	\$100/short ton	44781	22398	4468
MP Steam (klb)	\$2/klb	21672	9747	2152
HP Steam (klb)	\$3/klb	96710	48706	9741
Fuel Gas (MBTU)	\$3/MBTU	171276	76808	16751
CO2 (MSCF)	\$400/MSCF	25845	12923	2579
Direct credits are accounted for in	the price of the utilit	y, credits alone are n	oted as negative.	

The income for this project was solely from the products of naphtha and diesel. The goal was to optimize the amount of diesel as the sale price is \$90/bbl and naphtha was \$75/bbl. The design did not create a viable LPG stream, and since LPG is only \$0.30/lb the focus was not placed on excessive equipment to create and LPG product. Since the design was able to produce a substantial amount of diesel and naphtha, this project was ultimately profitable.

Table 10: Production of LPG, Naphtha, and Diesel by Unit Size

Large		Medium		Small				
LPG (lb)	0	LPG (lb)	0	LPG (lb)	0			
Naptha (bbl)	541076	Naptha (bbl)	200954	Naptha (bbl)	18460			
Diesel (bbl)	1114856	Diesel (bbl)	625172	Diesel (bbl)	120012			

The bottom line of the preliminary design was calculating a rate of return that was greater than 8% and completing an NPV analysis. That final ROR exceeded the hurdle rate substantially coming in at 23%. The project NPV was determined to be \$2.29B with a capital cost of \$1.33B. The average cashflow per year is about \$181M, with the first years being the most profitable and the final years being the least. The cash flow below provides more details, note that in the final three years the maintenance estimates are the same as early on, which is not a completely fair assumption since most units are not in service. The negative values were kept maintaining a conservative estimate of the project.

							C	ash Flow Ta	able for Mod	lular GTL Pl	ants										
End of Year	0	1	2	3	4	5	б	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Net Revenue																					
Income	-	796,000	796,000	814,000	627,000	702,000	803,000	809,000	784,000	826,000	783,000	765,000	753,000	760,000	722,000	526,000	316,000	236,000	127,000	76,000	49,000
Salvage	-	-	-	-	-	-	-	-	-	_	-	-	-	-	-	-	-	-	-	-	28,000
Utilities	-	(79,000)	(79,000)	(77.000)	(51,000)	(72,000)	(78,000)	(74,000)	(36,000)	(40,000)	(42,000)	(62,000)	(68,000)	(73,000)	(69,000)	(58,000)	(27.000)	(16.000)	(2,000)	7.000	5.000
Module Transportation	-	(5 000)	-	(2,000)	(2,000)	(3 000)	(4 000)	(3 000)	(4 000)	(2,000)	(4 000)	(3 000)	(3 000)	(2,000)	(4 000)	(1 000)	(2,000)	(2,000)	(1,000)	(1.000)	-
Product Transportation	-	(1 000)	(1.000)	(1 000)	(1,000)	(1,000)	(1 000)	(1,000)	(1 000)	(1,000)	(1.000)	(2,000)	(2,000)	(2,000)	(2,000)	(2,000)	(2,000)	(2,000)	(1,000)	(1,000)	(1.000)
Maintenence and Repair	_	(134,000)	(134 000)	(134 000)	(134,000)	(134,000)	(134 000)	(134 000)	(134 000)	(134,000)	(134 000)	(134,000)	(134 000)	(134,000)	(134 000)	(134 000)	(134 000)	(134,000)	(134,000)	(134,000)	(134 000)
Labor		(53,000)	(53,000)	(54,000)	(54,000)	(54,000)	(55,000)	(55,000)	(151,000)	(56,000)	(57,000)	(57,000)	(57,000)	(151,000)	(59,000)	(59,000)	(60,000)	(60,000)	(61,000)	(61,000)	(62,000)
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Assets		(101.000)	(101.000)	(101.000)	(101.000)	(101.000)	(101.000)	(101.000)													
Tarabla Incomo	-	(191,000)	(191,000)	250,000	108.000	(191,000)	(191,000)	(191,000)	-	505.000	-	510.000	402.000	402.000	458.000	275.000	-	25.000	(70,000)	(112.000)	(115.000)
	-	550,000	340,000	339,000	198,000	250,000	343,000	335,000	550,000	595,000	548,000	510,000	492,000	493,000	458,000	275,000	95,000	25,000	(70,000)	(113,000)	(115,000)
- Tax 0.2	-	(68,000)	(68,000)	(72,000)	(40,000)	(50,000)	(69,000)	(/1,000)	(112,000)	(119,000)	(110,000)	(102,000)	(99,000)	(99,000)	(92,000)	(55,000)	(19,000)	(5,000)	14,000	23,000	23,000
Net Income	-	269,000	272,000	287,000	159,000	200,000	274,000	284,000	445,000	476,000	439,000	408,000	393,000	395,000	367,000	220,000	76,000	20,000	(56,000)	(91,000)	(92,000)
Depreciation Assets																					-
	-	191,000	191,000	191,000	191,000	191,000	191,000	191,000	-	-	-	-	-	-	-	-	-	-	-	-	-
Capital Cost Assets																					
	(1,332,000)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
									Cash Flow	rs											
Cash Flow	(1,332,000)	459,000	463,000	478,000	349,000	390,000	465,000	474,000	445,000	476,000	439,000	408,000	393,000	395,000	367,000	220,000	76,000	20,000	(56,000)	(91,000)	(92,000)
Discount factor (P/F)	1.0000	1.0800	1.1664	1.2597	1.3605	1.4693	1.5869	1.7138	1.8509	1.9990	2.1589	2.3316	2.5182	2.7196	2.9372	3.1722	3.4259	3.7000	3.9960	4.3157	4.6610
Discount Cash Flow	(1,332,000)	425,000	397,000	380,000	257,000	266,000	294,000	277,000	241,000	239,000	204,000	175,000	157,000	146,000	125,000	70,000	23,000	6,000	(15,000)	(22,000)	(20,000)
NPV at 8% Hurdle Rate	2,293,000	Hurdle Rate:	8% ]	DCFROR:	23%	23% Numbers in cashflow need to be multiplied by 1000 to retrieve the appropriate values.															

Table 11: Cash Flow Table for Modular GTL Plants

### Wellhead Site System Plot

The system for the wells in based around a central plant. The wells in the system all vary in distance from the central plant, these distances are depicted in *Table 12: Well Distances from the Central Plant*. The wells were assumed to be approximately 45° starting from 1A moving toward 2A then to 1B, 2B, 1C and so on around a full 360°. This assumption led to the approximation of each site from each other site as shown in *Table 13*. To better visualize the entire well system, *Figure 9: Wellhead Map* shows an approximation of the wells from the central plant. This map is not exactly to scale, however this visualization helped with optimization for module deployment. The images on each well site are in varying sizes so that the largest producing wells have the largest icons and the least producing have the smallest. The actual starting feed value of methane of each well is depicted and organized from the least productive well to the most as well as the rounded value used throughout the development of this plan in *Table 14*.

Table 12: Well Distances from the Central Plant

Well Name	1A	2A	1B	2B	1C	2C	1D	2D	1E	2E	1F	2F	1G	2G	1H	2H
Miles to		05.0	24		47		70.4	10			1	10	50	07		26
<b>Central Plant</b>	62	85.8	21	84.7	1/	2.4	/3.4	42	6.2	98.8	91	13	59	8/	89.3	36

Table 13:Well Distances from Other Wells in the System

Well Name	1A	1B	10	1D	1E	1F	1G	1H	2A	2B	2C	2D	2E	2F	2G	2H
1A		49.4	64.3	125.2	68.2	141.8	85.6	63.2	37.1	83.7	63.0	102.1	157.9	68.0	85.3	31.9
1B			15.0	76.3	25.8	112.0	75.3	91.7	66.9	65.8	20.2	53.7	118.5	33.4	97.0	34.0
1C				62.5	18.1	103.7	76.0	102.0	80.8	69.3	14.8	38.8	106.5	29.4	102.9	45.3
1D					69.2	116.9	122.4	162.7	132.5	88.3	71.2	38.1	98.0	79.3	157.3	107.5
1E						86.7	59.3	93.8	91.6	87.3	5.7	36.3	93.1	12.1	89.6	41.8
1F							64.6	127.5	173.4	172.3	91.9	84.4	37.8	79.1	98.9	109.9
1G								63.3	121.3	141.0	61.2	84.5	93.7	47.3	39.6	56.1
1H									97.3	144.7	91.5	129.1	156.5	85.2	34.5	57.7
2A										65.3	85.8	119.3	184.6	95.4	122.2	65.5
2B											83.0	94.5	169.6	97.7	158.6	92.0
2C												40.3	98.8	14.8	89.4	37.7
2D													75.2	44.0	120.4	78.0
2E														90.1	131.6	126.8
2F															78.3	38.3
2G																66.6
2H																



Figure 9: Wellhead Map

Well Name	Original	Rounded				
wenname	Production	Estimated Feed				
2F	2874	2900				
1B	2989	3000				
1E	3290	3300				
2D	3840	3800				
1A	4494	4500				
2G	6076	6100				
2H	6468	6500				
1H	7081	7100				
1D	7447	7400				
2E	7939	7900				
1C	8365	8400				
2C	8742	8700				
2A	9182	9200				
1G	11155	11200				
2B	12258	12300				
1F	14737	14700				

Table 14: Well Starting Methane Feed Values

# **Unit Deployment and Redeployment Logistics**

The central plant can only process the product equivalent of 30,000 MSCF of natural gas feed each day. Each well starts with the feed depicted in *Table 14: Well Starting Methane Feed Values* and produces that same amount for 2 years then steadily decreases by 35% each year. The graph in *Figure 10: Well 1A Methane Supply* depicts the decline of Well 1A to represent the decrease. In order to optimize the wells in service at any given time, the startup of the wells was varied over the project life.


### Figure 10: Well 1A Methane Supply

Since the production of each well decreases over time, there was less of a need for larger modular units later in the project. There were occasions where a well may be taken out of service in the middle of its useful production life, to optimize the use of methane while still meeting the central plant's capacity. *Figure 13: Well Feed Value (MSCF/day) and Years in Service* shows what wells were determined to be in service each year. *Figure 11: Optimized Service Years of Wells in System over the Project Life* shows further information such as the feed for each year, showing the total of the methane as well as the number of wells in service each year. This table represents the method that was used to optimize the utilization of each well, each array of the feed and its decline was shuffled though out the years to find the best time to bring the well into service. It was important to try to get as close to the central plant's 30,000 MSCF/day capacity while also minimizing the number of wells in service at a time, as that translates to total minimum number of modular units.



Figure 11: Optimized Service Years of Wells in System over the Project Life

The unit sizes were based on feed of methane with three sizes, 500 MSCF/day, 2,500 MSCF/day, and 5,000 MSCF/day. Based on the optimized service of the wells, modules had to be assigned to active wells each year of the project. This was accomplished by displaying the map of the wells next to its total production and the calculated number of units needed to meet the feed of the well. An example of two years of the well sites with their modules is displayed in *Figure 14: Example of Year 1 and Year 10 Module Distribution*. When refining the total number of modules, the turndown of the unit was considered and it was determined that the units could not turn down more than approximately 60%, so when a well only had, for example 100 MSCF/day remaining, that production was lost.

The final number of units needed of each size was determined to be twelve small, seven medium, and two larges. In *Table 15:Module Fleet Inventory Deployment Plan* the full fleet of modules is displayed as well as their location. Due to the cost of moving the modules, unused units would remain at the site they were last used while they waited to be deployed to the next site.

Well Name										Ye	ar									
weinwahle	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1A														2900	2900	1900	1200	800	500	300
1B												3000	3000	1900	1300	800	500	300		
10												3300	3300	2100	1400	900	500	400	200	200
1D														3800	3800	2500	1600	1000	700	400
1E			4500	4500	2900		1900	1000	800	500	300									
1F			6000	6000	3900							2500	1700	1000	500	500	300			
1G													6500	6500	4200	2700	1800	1200	800	500
1H									7000	7000	4600	3000	1900	1300	800	500	300			
2A					7400	7400	4800				3000	2000	1300	900	500	400				
2B										7900	7900	5000	3400	2200	1400		900	500	400	300
2C				8400	8400	5400	3500	2300	1500	1000	500	400	300							
2D	8500	8500	5500								3500	2400	1600	1000	500	400	300			
2E	9000	9000	6000	3900	2500	1500											1000	500	500	300
2F	11000	11000	7300				4500	3000	2000				1300	800	500	400				
2G								12300	12300	8000	5000	3400	2200	1400	900	500	400	300		
2H						14500	14500	9500	6000	4000	2500	1700	1000	500	500	300				
# Wells in Service	3	3	5	4	5	4	5	5	6	6	8	10	12	13	13	12	11	8	6	6
Total Methane Supply (MSCF/day)	28500	28500	29300	22800	25100	28800	29200	28100	29600	28400	27300	26700	27500	26300	19200	11800	8800	5000	3100	2000

Figure 13: Well Feed Value (MSCF/day) and Years in Service



Figure 14: Example of Year 1 and Year 10 Module Distribution

Table 15: Module Fleet Inventory Deployment Plan

Number ID	Name	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15	Year 16	Year 17	Year 18	Year 19	Year 20
L_1	April	Constuction	2D	2D	2D	2C	2C	2H	2H	2H	2H	2B	2B	2B	2B	1D						
L_2	Genna	Constuction	2F	2F	2F	2F	2A	2A	2H	2G	2G	2G	2G	2G	1G							
M_1	Hedy	Constuction	2D	2D	1E	1E	1E	2C	2C	2C	2C	2B	2B	1B	1B	1B	1B	1B	1D	1D	1D	1D
M_2	Irene	Constuction	2E	2E	1F	1F	1F	2H	2A	2G	2G	2G	2A	2A	2A	1A						
M_3	Katherine	Constuction	2F	2F	1F	1F	1F	2H	2F	2F	1H											
M_4	Margaret	Constuction	2E	2E	2E	2E	2E	2H	2H	2H	1H	1H	1H	1F	1F	1G	1G	2E	2E	2E	2E	2E
M_5	Mary	Constuction	2E	2E	2E	2C	2C	2C	1E	2G	2G	2G	2D	2D	2D	2B						
M_6	Rachel	Constuction	2F	2F	2F	2F	2A	2A	2A	2G	2G	1H	1H	1C								
M_7	Shirley	Constuction	CP	CP	CP	CP	CP	CP	CP	CP	2F	2H	2H	2H	2G	2G	2G	2G	1G	1G	1G	1G
S_1	Alexa	Constuction	2D	2D	2D	2C	2C	2C	2C	2C	2H	2H	2H	1C	1C	1A	1A	1B	1C	1C	1C	1C
S_2	Annie	Constuction	2D	2D	2D	2C	2C	2H	2H	2H	1H	2G	2G	2G	1G	1F	1H	1H	1H	1H	1H	1H
S_3	Bessie	Constuction	CP	CP	1E	1E	1E	1E	2H	2H	1H	1H	2A	2A	2H	2H	1H	1H	1H	1H	1G	1G
S_4	Beth	Constuction	2E	2E	2E	2E	2E	2E	2F	1E	1E	2B	2B	2B	2H	2H	2H	2H	2B	2B	2B	2B
S_5	Caroline	Constuction	2E	2E	2E	2E	2E	2E	2F	1E	1E	1E	1E	1E	2F	2F	1F	1C	2E	2E	2E	2E
S_6	Dijanna	Constuction	2E	2E	1E	1E	1E	2H	2H	2H	1H	1H	1H	1B	1B	2A	2A	1B	1B	1B	1B	1B
S_7	Dorothy	Constuction	CP	CP	1E	1E	1E	2H	2H	2H	2H	1H	1H	1H	2F	2F	2F	2F	2B	1A	1A	1A
S_8	Ella	Constuction	2F	2F	1F	1F	1F	2E	2C	2C	2H	2H	2D	2D	2F	2D	2D	2D	2D	2D	1D	1D
S_9	Evelyn	Constuction	2F	2F	1F	1F	1F	1F	2F	2F	2F	2C	2C	1C	1C	2A	2A	2A	2A	1A	1A	1A
S_10	France	Constuction	CP	CP	CP	CP	1F	1F	1F	1F	1F	2H	2D	2D	1G	1E	2G	2G	2G	2G	1A	1A
S_11	Gertrude	Constuction	CP	CP	1E	1E	1E	2H	2H	2H	1H	1H	1H	1H	1G	2D	2G	1F	1F	1D	1G	1G
S_12	Jane	Constuction	CP	CP	2D	2E	2E	2E	2F	2F	2F	2C	2C	2C	2C	2C	2C	1C	2E	1D	1D	1D
	Un	its were named to	make it e	asier for	identifica	ation, all	units are	named a	fter fema	le scienti	est of gre	at renow	m.				CP:	Central I	Plant	No	t In Serv	rice

Based on the deployed modules the product truck development plan was created. This plan was designed by finding the maximum number of product trucks needed every five years, as they are contracted in five-year increments. Using the total production per day, the number of trucks was determined and then priced based on the requirement to return to the central plant to off load product. It was estimated that any given driver could work a maximum of 11 hours in a day and that the average speed of travel was 65 mph. It was also assumed to take about 45 minutes to load and unload a truck. This information helped model the number of trips required per day to any given site. The number of trips were then applied to how many trips a specific could truck make in a day based on the distance to the central plant and the allowable number of work hours. The total number of contracted product trucks are displayed in *Table 16: Total Product Trucks Contracted*.

Table 16: Total Product Trucks Contra	ctea	tec
Table 16: Total Product Trucks Contra	cte	te

Years:	1-5	6-10	11-15	16-20
Trucks Contracted	16	20	30	27

## **Summary of NPV and Sensitivity Analysis**

The costs for the project have the potential to suddenly change as it is hard to predict future trends in inflation and demand. Variable analysis was conducted to determine the potential effects in changes to costs. Tornado charts were assembled to compare the effects of each new cost. *Figure 15: Single Variable Analysis Tornado Chart* shows the relative impact of varying costs for capital, labor, total feed, and total utilities as well as varying income from naphtha and diesel. Income was found to have the most profound effects on the profitability of the project. The price of oil can vary greatly over time and can be affected by many factors. The price low point was chosen to be a 45% reduction from original prices while the high point was a 45% increase in price. This is based upon trends in the last 20 years. Ultimately, income is the most important factor for the success of the project in a field that experience upturns and downturns frequently. The next major factor is the capital cost of the system. All the equipment is modular. This leads to an increase in the cost as it is specialized for being capable of being disassembled and moved relatively quickly. The cost of this equipment is difficult to estimate. A 4.8 multiplier

was used to initially estimate the cost of equipment. A lower bound of 1.7 was selected as it is the Lang factor for a prefabricated modular plant. The upward bound was chosen to be 7.9 as it was the opposite direction of the Lang factor. This multiplier greatly affects the profit of the project as a multiplier of 7.9 would reduce the NPV by \$1B.



Figure 15: Single Variable Analysis Tornado Chart

Assuming the capital cost and income are fixed, labor was then compared to the cost of the feeds and utilities. *Figure 16: Labor Cost Comparison with Feed and Utilities* show the relative weight of varying the combined utilities and feed by  $\pm$  10%. This number was chosen to estimate the potential increase or decrease in utilities on top of inflation. The labor cost was varied by adjusting the average operator pay from \$50k/year to \$130k/year. The salary depends heavily on the experience of the operators and the location of the site. Ultimately, it was found that the increase in utilities and feed would cause less of an effect on the total NPV. Labor was found to have a similar effect. The increase in cost of utilities and feed will not lead to the project being economically unattractive even with the large of amount of water, steam, and other auxiliary feeds and utilities.



Figure 16: Labor Cost Comparison with Feed and Utilities

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Appendix

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
Large L	Jnit [	Methane	Carbon	HP Steam	Syngas Feed	Hot Syngas	99% Oxygen	Syngas	Condensed	Syngas Product	Absorber	Syngas Product	FTR Feed	Water	CO2 Removed	Combined	FTR Product	Water Mix	Process Water	Column	Column	Condensed	Reflux	Naphtha	Condensate	Light Gases	Reboiler	Boilup	Hydro-Isom	Diesel	Wax 1	Separator
			Dioxide		Mixture	Feed	184	Product	Syngas	Water Removed	Solvent	CO2 Removed		Removed		Water			Return	Feed	OVHD	OVHD			Drum Vapor		Feed		Unit Feed	Product	Product	Vapor
Vapour Fraction		1.000	1.000	1.000	0.913	1.000	1.000	1.000	0.740	1.000	0.000	1.000	1.000	0.000	0.000	0.000	0.209	0.000	0.003	0.000	1.000	0.318	0.000	0.000	1.000	1.000	0.000	1.000	0.000	0.000	0.000	1.000
Temperature	F	100.0	100.0	490.0	364.1	1000.0	75.0	1628.0	145.0	145.0	80.0	80.0	449.0	145.0	80.6	80.8	284.0	284.0	82.9	284.0	284.9	144.2	144.2	144.2	144.2	220.9	437.0	516.9	516.9	417.90	712.40	283.96
Pressure	psia	500.0	500.0	600.0	500.0	495.0	514.7	495.0	489.0	489.0	495.0	485.0	484.0	489.0	490.0	489.0	495.0	493.0	20.0	493.0	23.0	20.0	20.0	20.0	20.0	20.0	26.5	28.0	28.0	14.70	20.00	493.00
Molar Flow	Ibmole/hr	822	300	765	1887	1887	400	3210	3210	2375	200000	2014	2014	834	200361	201195	1367	553	202127	528	293	293	32	168	93	380	642	375	267	178	89	286
Mass Flow	lb/hr	13187	13203	13782	40172	40172	12784	52956	52956	37904	3603020	22684	22684	15052	3618239	3633291	100276	9953	3653350	84358	25318	25320	3384	17792	4141	10106	123397	60972	62425	33790	20640	5965
Liquid Volume Flow	barrel/day	3016	1095	946	5057	5057	1/2	6825	6825	5792	247207	4526	4526	1033	248473	249506	9404	683	251659	7750	2561	2588	332	1755	499	1470	11087	5579	5496	3042	2455	971
Mass Enthalpy	Btu/lb	-2010.3	-3857.0	-5628.7	-3858.6	-3457.3	-4.9	-2623.8	-3686.5	-2469.5	-6826.1	-1575.7	-1338.2	-6751.1	-6813.4	-6813.1	-1420.2	-6612.5	-6798.0	-781.9	-782.0	-969.7	-915.9	-915.9	-1244.8	-1562.6	-653.4	-514.2	-578.3	-670.6	-398.3	-1783.2
Component Fraction																																
Hydrogen	Ibmole/hr	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.23E+03	1.23E+03	1.23E+03	0.00E+00	1.23E+03	1.23E+03	4.36E-02	4.26E+00	4.30E+00	6.10E+01	5.15E-02	6.53E+01	4.77E+00	1.63E-02	1.63E-02	6.58E-05	1.11E-02	4.76E+00	6.09E+01	1.73E-09	2.95E-09	3.63E-09	0.00E+00	0.00E+00	5.61E+01
Water	Ibmole/hr	0.00E+00	0.00E+00	7.65E+02	7.65E+02	7.65E+02	0.00E+00	8.53E+02	8.53E+02	1.96E+01	2.00E+05	2.60E+00	2.60E+00	8.33E+02	2.00E+05	2.01E+05	5.99E+02	5.52E+02	2.01E+05	1.2/E+01	4.36E-02	4.36E-02	1.92E-03	3.23E-01	1.24E+01	4.59E+01	2.21E-07	3.76E-07	1.16E-06	0.00E+00	0.00E+00	3.35E+01
Carbon Monoxide	Ibmole/hr	0.0000000	0.00E+00	0.000000	0.00E+00	0.00E+00	0.00E+00	0.15E+U2	6.15E+02	0.15E+U2	0.000000	0.12E+02	0.12E+02	2.285-02	2.776+00	2.79E+00	3.25E+01	2.13E-02	3.532+01	3.672+00	0.000000	0.000000	9.805-05	1.05E-02	3.000+00	3.25E+01	3.42E-09	5.84E-09	8.71E-09	0.000000	0.000+00	2.886+01
Nitrogen	Ibmole/hr	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.00E+00	4.00E+00	4.00E+00	4.00E+00	0.00E+00	3.86E+00	3.86E+00	3.95E-04	1.38E-01	1.38E-01	0.00E+00	0.00E+00	1.38E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Oxygen	Ibmole/hr	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.96E+02	4.2/E-01	4.2/E-01	4.2/E-01	0.00E+00	4.23E-01	4.23E-01	3.28E-05	3.80E-03	3.84E-03	0.00E+00	0.00E+00	3.84E-03	0.00E+00	0.00E+00	0.00E+00	0.000000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.000000	0.0000000
Carbon Dioxide	Ibmole/hr	0.00E+00	3.00E+02	0.00E+00	3.00E+02	3.00E+02	0.00E+00	3.44E+02	3.44E+02	3.43E+02	0.00E+00	6.48E+00	6.48E+00	9.01E-01	3.3/E+02	3.38E+02	0.00E+00	0.00E+00	3.38E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Methane	Ibmole/hr	8.22E+02	0.00E+00	0.00E+00	8.22E+02	8.22E+02	0.00E+00	1.63E+02	1.63E+02	1.03E+02	0.00E+00	1.63E+02	1.63E+02	7.71E-05	2.78E-03	2.85E-03	1.69E+02	7.59E-03	1.69E+02	3.03E+01	1.03E-01	1.03E-01	1.946-03	3.2/E-01	3.00E+01	1.69E+02	1.21E-07	2.06E-07	4.44E-07	0.00E+00	0.000+00	1.39E+02
Ethane	Ibmole/hr	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.6/E+00	1.7/E-05	3.61E+00	1.26E+00	4.33E-03	4.33E-03	3.28E-04	5.51E-02	1.21E+00	3.61E+00	4.80E-08	8.14E-08	3.00E-07	0.00E+00	0.00E+00	2.41E+00
Propane	Ibmole/hr	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.37E+00	1.20E-00	4.11E+00	2.22E+00	1.055.03	1.055.03	1.5/E-03	2.03E-01	2.105+00	4.11E+00	4.885-07	8.23E-07	4.02E-00	0.00E+00	0.000+00	2.15E+00
Butane	Ibmole/hr	0.0000000	0.00E+00	0.000000	0.000000	0.002+00	0.000000	0.000000	0.0000000	0.000+00	0.000000	0.000000	0.002+000	0.000000	0.000+00	0.000+00	4.372+00	4.322-08	3.34E+00	2.93E+00	1.05E-02	1.05E-02	4.946-03	8.30E-01	2.100+00	3.546+00	3.702-00	0.302-00	5.42E-05	0.000000	0.000000	1.446+00
Pentane	Ibmole/hr	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.2/E+01	1.1/E-08	3.08E+01	4.19E+01	1.5/E-01	1.5/E-01	1.31E-01	2.20E+01	2.00E+01	3.08E+01	2.8/E-04	4.75E-04	6.11E-03	0.00E+00	0.00E+00	1.082+01
nexane	Ibmole/hr	0.0000000	0.00E+00	0.000000	0.00E+00	0.00E+00	0.00E+00	0.000000	0.0000000	0.00E+00	0.000000	0.000000	0.000000	0.000000	0.00E+00	0.000000	4.748+01	1.79E-10	1.62E+01	4.1/E+01	1.62E-01	1.622-01	1.805-01	3.12E+01	1.05E+01	1.62E+01	1.486-03	2.412-03	4.60E-02	0.000000	0.000+00	3.096+00
Heptane	Ibmole/hr	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.26E+01	2.02E-12	7.49E+00	3.9/E+01	1.5/E-01	1.5/E-01	2.08E-01	3.49E+01	4.53E+00	7.49E+00	6.75E-03	1.08E-02	3.00E-01	0.00E+00	0.00E+00	2.968+00
Uctane	Ibmole/hr	0.0000000	0.00E+00	0.000000	0.00E+00	0.00E+00	0.00E+00	0.000000	0.0000000	0.000+00	0.000000	0.000000	0.000000	0.000+00	0.000+00	0.000000	3.846+01	2.03E-14	3.1/E+00	3.09E+01	1.416-01	1.412-01	1.995-01	3.346+01	1.69E+00	3.172+00	2.796-02	4.326-02	1.75E+00	0.000000	0.000+00	1.486+00
Nonane	Ibmole/hr	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.45E+01	1.88E-10	1.2/E+00	3.3/E+01	1.06E-01	1.06E-01	1.52E-01	2.50E+01	5.19E-01	1.27E+00	8.82E-02	1.31E-01	7.04E+00	0.00E+00	0.00E+00	7.55E-01
Decane n.C11	Ibmole/hr	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.1/E+01	7.155.31	4.985-01	3.13E+01	1 735.02	1.735-02	7.576-02	4.255+00	1.00E-01	4.986-01	1.572-01	1.065-01	2.245+01	0.00E+00	0.000+00	3.92E-01
0.012	Ibmole/III	0.000000	0.000000	0.005+00	0.000000	0.005+00	0.000000	0.005+00	0.000000	0.000+00	0.000+00	0.00000	0.002+00	0.000000	0.000+00	0.005+00	2.795+01	2 245 22	1.075.01	2.776401	6.135.02	6.135.02	2.335-02	4.236100	2,385,02	1.075.01	1.315-01	1.435.01	2.346701	2.426101	0.00000	1.940-01
n-C12	Ibmole/hr	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.585+01	3.316-23	5.015-02	2.576+01	1 955-03	1.955-03	3.386-03	4.575-01	2.28E-03	5.01E-02	9,725-02	0.055-02	2.426+01	2.4/6+01	0.000+00	4.095-02
0.014	Ibmole/III	0.005+00	0.005+00	0.005+00	0.005+00	0.005+00	0.005+00	0.005+00	0.000000	0.000+00	0.005+00	0.005+00	0.002+00	0.000000	0.005+00	0.005+00	2.2001	0.395.39	3.010-02	2.235+01	E 135 04	E 13E 04	7.515.04	4.375-01	2.000-04	3.335.02	6.725-02	5.032-02	2.210+01	2.246701	0.00000	4.306-02
0-C15	Ibmole/hr	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.000+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.005+01	3.585-20	1.395-02	1.00E+01	3.12E-04	3.12E-04	7.51E-04	4.03E-02	2.30E-05	1.33E-02	5.235-02	3.00E-02	1.905+01	1.01E+01	0.000+00	1.395-02
0.015	Ibmole/hr	0.000000	0.00E+00	0.000+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.000000	0.000000	0.000000	0.000000	0.00E+00	0.000000	1.900+01	2.586-30	1.385-02	1.902+01	2.002-04	2.002-04	2.945-04	4.935-02	5.10E-00	1.386-02	5.23E-02	3.902-02	1.896+01	1.910+01	0.000+00	1.386-02
n-C10	Ibmole/hr	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.04E+01	1 595 36	7.01E-03	1.04E+01	0.10E-05	0.102-05	3.105.05	1.52E-02	0.75E-07	7.01E-03	4.00E-02	1.575.02	1.04E+01	1.05E+01	0.000+00	7.01E-03
n-C19	lbmole/hr	0.00E+00	0.00E+00	0.000+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.000+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.482+01	1.385-30	3.925-03	1.486+01	7 135-05	7 135-05	1.05E-05	1.76E-03	2.17E-08	3.926-03	3.210-02	1.01E-02	1.460+01	1.496+01	0.000+00	3.926-03
0.010	lbmole/hr	0.005+00	0.005+00	0.005+00	0.005+00	0.005+00	0.005+00	0.005+00	0.005+00	0.000+00	0.005+00	0.005+00	0.005+00	0.000000	0.005+00	0.005+00	1.105+01	0.155.40	1 205-02	1.105+01	7.132-00	2.645.06	3.975.06	£ 505.04	4 555.00	1 305.03	2.000-02	6 715.02	1.350+01	1.346101	0.000000	1 205-02
n-C19	lbmole/hr	0.00E+00	0.00E+00	0.000+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.000+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.075+01	0.13E-43	5.405-04	1.075+01	5.285-07	5.285-07	7.745-07	1.30E-04	4.53E-09	5.40E-04	1.925-02	4 21E-03	1.075+01	1.085+01	0.000+00	5.405-04
0.021	lbmole/hr	0.005+00	0.005+00	0.005+00	0.005+00	0.005+00	0.005+00	0.005+00	0.005+00	0.000+00	0.005+00	0.005+00	0.005+00	0.000000	0.005+00	0.005+00	0.655+00	2 545-45	3.402-04	0.665+00	1 735.07	1 725-07	2.525-07	4.345.05	2.336-10	3.402-04	1.522-02	3 795-03	0.665+00	0.005+00	1.375+01	3.400-04
0.022	lbmole/hr	0.00E+00	0.00E+00	0.000+00	0.00E+00	0.00E+00	0.000+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.000+00	0.00E+00	0.00E+00	0.000+00	0.000+00	9.605+00	5.19E-40	1.705-04	9.60E+00	6 165-08	6 165-08	0.025-08	1.526-05	5.07E-11	1 705-04	1.676-02	1.975-03	8.605+00	0.00E+00	1.376+01	1.705-04
0.022	Ibmole/III	0.000000	0.000000	0.005+00	0.005+00	0.005+00	0.000000	0.005+00	0.000000	0.000+00	0.000+00	0.005+00	0.002+00	0.000000	0.005+00	0.005+00	7.915.00	1 555 51	9.305.05	2.092400	1.635.08	1.635.08	3.375.08	2.005.05	7.005.12	9.305.05	1.405-02	1.105.03	7.915+00	0.005+00	1.115-01	9.305.05
n-C24	Ibmole/hr	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.025+00	2 146-54	8.39E-05	7.035+00	4.905-00	4.805-00	7.195-00	1.215-06	7.09E-13	8.39E-05	1.296-02	7.775-04	7.810+00	0.00E+00	0.045+00	8.39E-05
0.025	lbmole/hr	0.00E+00	0.00E+00	0.005+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.000+00	0.00E+00	0.00E+00	0.000+00	0.000+00	6 325+00	1.546-56	2.48E-05	6 32E+00	1.665-09	1.665-09	2.435-09	4.005-07	1.57E-14	2.48E-05	1.025-02	5 22E-04	6.325+00	0.00E+00	9.94E+00	2.485-05
0.025	lbmole/hr	0.005+00	0.005+00	0.005+00	0.00E+00	0.005+00	0.000+00	0.005+00	0.00E+00	0.00E+00	0.005+00	0.005+00	0.005+00	0.00E+00	0.000+00	0.005+00	5.685+00	1.346-50	1 285-05	5.685+00	4.805-10	4.805-10	7.04E-10	1 195-07	1.0/E-14	1 285-05	9.065-02	3.226-04	5.685+00	0.000000	8.055+00	1.285-05
0.027	lbmole/hr	0.00E+00	0.00E+00	0.005+00	0.00E+00	0.00E+00	0.0000+00	0.000+00	0.00E+00	0.00E+00	0.00E+00	0.000+00	0.000+000	0.00E+00	0.000+00	0.000+00	5.11E+00	6 35E-62	6.09E-06	5.11E+00	1.18E-10	1.185-10	1.735-10	2 905-08	1.346-15	6.09E-05	8.00E-03	2 13E-04	5.11E+00	0.000000	7 225+00	6.00E-06
0.029	Ibmole/In	0.005+00	0.005+00	0.005.00	0.005+00	0.005+00	0.005+00	0.005+00	0.005+00	0.000+000	0.005+00	0.005+00	0.005+00	0.000000	0.005+00	0.005+00	4.605.000	6 505 65	3,805,05	4.605+00	4.075.11	4.075.11	7 205 11	1 335 08	4 335 17	3 905 06	7 355 03	1 505 04	4.605+00	0.005+00	6.505+00	3 905 05
0.029	lbmole/hr	0.00E+00	0.00E+00	0.000+00	0.00E+00	0.00E+00	0.00E+00	0.000+00	0.00E+00	0.00E+00	0.00E+00	0.00000	0.00E+00	0.00E+00	0.000+00	0.000+00	4.14E+00	2.46E-67	2 295-06	4.000+00	1.965-11	1.965-11	7.25E-11	A 84E-00	9.55E-17	2 295-06	6.51E-03	1.05E-04	4.000+00	0.00E+00	5.86E+00	2.205-06
0-C30	lbmole/hr	0.00E+00	0.00E+00	0.005+00	0.0002+00	0.000+000	0.000+00	0.000+00	0.000000	0.000+00	0.000+00	0.000+00	0.0000	0.0002400	0.000+00	0.000+00	3 72E+00	1.715-65	5.84E-07	3 72E+00	1 385-12	1 385-12	2.03E-12	3.405-10	8 82E-20	5.84E-07	5.825-02	4 59E-05	3 72E+00	0.00E+00	5.25E+00	5 84E-07
Actual Volume Flow	harrel/day	39614	12615	47160	124723	255108	18499	624384	135492	134440	244975	103349	175314	1052	245915	246966	28764	745	1036112	8909	419288	12960	353	1854	127407	590527	14190	555142	7432	3818	3724	19714
Mass Density	lb/ft3	1 42	4 47	1 25	1 38	0.67	2 96	0.36	155452	1 21	62 87	0.94	0.55	61 16	62.89	62.89	14 90	57.09	15.07	40.49	415200	0.84	41.02	41 02	0.14	0.07	37.17	0.47	35.90	37.83	37.88	1 32
Molar Density	lbmole//tt2	0.090	0.102	0.050	0.055	0.033	0.003	0.30	0.101	0.075	3,400	0.093	0.049	3 200	3,493	3 493	0.202	3 160	0.834	0.253	0.003	0.010	0.387	0.397	0.003	0.003	0.103	0.003	0.154	0.200	0.103	0.064
molar Density	iomore/jt3	0.089	0.102	0.009	0.005	0.032	0.092	0.022	0.101	0.076	5.490	0.085	0.049	5.390	3.483	3.462	0.205	5.109	0.034	0.235	0.003	0.010	0.307	0.567	0.003	0.003	0.193	0.003	0.154	0.200	0.102	0.004

Table 1: Large Unit PFD Stream Table

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
Small U	Jnit	Methane	Carbon Dioxide	HP Steam	Syngas Feed Mixture	Hot Syngas Feed	99% Oxygen	Syngas Product	Condensed Syngas	Syngas Product Water Removed	Absorber Solvent	Syngas Product CO2 Removed	FTR Feed	Water Co Removed Rem	02 Cor oved V	ombined Water	FTR Product	Water Mix	Process Water Return	Column Feed	Column OVHD	Condensed OVHD	Reflux N	laphtha	Condensate Drum Vapor	Light Gases	Reboiler Feed	Boilup	Hydro-Isom Die Unit Feed Pro	sel V duct P	Vax roduct	Separator V/apor
Vapour Fraction		1.00	1.00	1.00	0.91	1.00	1.00	1.00	0.74	1.00	0.00	1.00	1.00	0.00	0.00	0.00	0.23	0.00	0.00	0.00	1.00	0.01	0.00	1.00	1.00	1.00	0.00	1.00	0.00	0.00	0.00	) 00
Temperature	F	500.0	500.0	600.0	500.0	495.0	514.7	495.0	489.0	489.0	495.0	485.0	484.0	489.0	490.0	489.0	495.0	4.5	4.5	4.5	300.9	183.9	183.9	20.0	4.5	4.5	430.7	510.1	20.0	425.7	774.0	25.0
Pressure	psia	100.0	100.0	490.0	364.7	1000.0	75.0	1627.2	145.0	145.0	80.0	80.0	449.0	145.0	80.0	80.1	284.0	131.0	81.6	131.0	23.0	20.0	20.0	183.9	131.0	131.0	26.0	26.0	183.9	14.7	20.0	510.1
Molar Flow	lbmole/hr	82.0	29.9	77.0	188.9	188.9	39.9	320.8	320.8	237.1	200000.0	193.2	193.2	83.7 200	043.9 2	200127.7	133.0	11.9	200230.0	30.7	6.0	6.0	0.7	0.1	90.4	90.4	76.5	51.1	5.3	18.36	6.992	25 36
Mass Flow	lb/hr	1315.5	1317.2	1386.6	4019.4	4019.4	1275.2	5294.5	5294.5	3783.7	3603020.1	. 2140.8	2140.8	1510.9 3604	662.9 36	606173.8	9748.3	214.6	3609144.6	6781.2	675.4	676.1	74.0	3.6	2752.6	2756.2	14418.7	8238.9	597.8	3640	2539	6179 81
Liquid Volume Flow	barrel/day	300.9	109.3	95.1	505.3	505.3	77.0	682.0	682.0	578.2	247206.8	433.7	433.7	103.7 247	351.4 2	247455.1	916.3	14.7	247771.2	600.6	65.4	65.8	7.2	0.4	301.0	301.4	1297.7	754.6	58.2	326	216	542.03
Mass Enthalpy	Btu/lb	-2010.3	-3857.0	-5628.7	-3863.8	-3462.8	-4.9	-2630.0	-3693.3	-2472.3	-6826.1	-1549.5	-1308.2	-6751.1 -6	824.7	-6824.6	-1411.0	-6774.9	-6821.3	-831.2	-692.7	-888.5	-885.3	-1499.6	-2421.3	-2420.1	-659.6	-519.2	-885.3	-660.7	-335.5	-573 6
Component Fraction																																
Hydrogen	lbmole/hr	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.23E+02	1.23E+02	1.23E+02	0.00E+00	1.18E+02	1.18E+02	4.38E-03 4.6	E+00 4	4.65E+00	6.01E+00	6.07E-07	1.07E+01	5.97E-04	1.00E-04	1.00E-04	1.10E-05 5	5.39E-04	6.01E+00	6.01E+00	2.24E-14	3.34E-14	5.81E-05 0.	00E+00	0.00E+00	3 47E-15
Water	lbmole/hr	0.00E+00	0.00E+00	7.70E+01	7.70E+01	7.70E+01	0.00E+00	8.56E+01	8.56E+01	1.96E+00	2.00E+05	2.49E-01	2.49E-01	8.36E+01 2.0	E+05 2	2.00E+05	5.76E+01	1.19E+01	2.00E+05	5.37E-02	9.50E-03	9.50E-03	4.91E-03 2	2.77E-02	4.56E+01	4.56E+01	3.60E-10	5.36E-10	2.60E-02 0.	00E+00	0.00E+00	1.43E-1.0
Carbon Monoxide	lbmole/hr	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.12E+01	6.12E+01	6.12E+01	0.00E+00	5.82E+01	5.82E+01	2.28E-03 3.0	E+00 3	3.04E+00	3.00E+00	3.41E-07	6.04E+00	6.70E-04	1.13E-04	1.13E-04	1.99E-05 5	5.64E-04	3.00E+00	3.00E+00	8.72E-14	5.97E-14	1.06E-04 0.	00E+00	0.00E+00	1.655-14
Nitrogen	lbmole/hr	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.99E-01	3.99E-01	3.99E-01	3.99E-01	0.00E+00	2.45E-01	2.45E-01	3.96E-05 1.5	4E-01 1	1.54E-01	3.53E-01	1.30E-07	5.07E-01	6.79E-05	1.15E-05	1.15E-05	1.91E-06 5	5.78E-05	3.53E-01	3.53E-01	7.99E-15	1.19E-14	1.01E-05 0.	00E+00	0.00E+00	1.50E-1.5
Oxygen	lbmole/hr	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.95E+01	4.28E-02	4.28E-02	4.28E-02	0.00E+00	3.86E-02	3.86E-02	3.31E-06 4.2	1E-03 4	4.21E-03	7.61E-04	1.79E-10	4.97E-03	2.64E-07	4.50E-08	4.50E-08	1.17E-08 2	2.02E-07	7.61E-04	7.61E-04	1.15E-16	1.72E-16	6.21E-08 0.	00E+00	0.00E+00	2.74E-17
Carbon Dioxide	lbmole/hr	0.00E+00	2.99E+01	0.00E+00	2.99E+01	2.99E+01	0.00E+00	3.45E+01	3.45E+01	3.44E+01	0.00E+00	1.26E-10	1.26E-10	9.08E-02 3.4	E+01 3	3.45E+01	8.60E-03	9.56E-08	3.45E+01	9.78E-06	1.71E-06	1.71E-06	8.37E-07 5	5.35E-06	8.59E-03	8.60E-03	4.01E-14	1.30E-13	4.44E-06 0.	00E+00	0.00E+00	1.41E-14
Methane	lbmole/hr	8.20E+01	0.00E+00	0.00E+00	8.20E+01	8.20E+01	0.00E+00	1.63E+01	1.63E+01	1.63E+01	0.00E+00	1.63E+01	1.63E+01	7.74E-06 2.9	9E-03	3.00E-03	1.62E+01	1.89E-08	1.62E+01	7.38E-03	1.27E-03	1.27E-03	4.18E-04 5	5.16E-03	1.62E+01	1.62E+01	7.00E-12	1.04E-11	2.22E-03 0.	00E+00	0.00E+00	1.92E-1.2
Ethane	lbmole/hr	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00 0.0	E+00 0	0.00E+00	3.53E-01	1.60E-11	3.52E-01	6.58E-04	1.17E-04	1.17E-04	7.55E-05 2	2.58E-04	3.52E-01	3.52E-01	1.29E-11	1.91E-11	4.00E-04 0.	00E+00	0.00E+00	6 07E-12
Propane	lbmole/hr	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00 0.0	E+00 0	0.00E+00	3.53E-01	2.45E-13	3.51E-01	1.96E-03	3.57E-04	3.57E-04	2.97E-04 3	3.85E-04	3.51E-01	3.51E-01	4.00E-10	5.92E-10	1.57E-03 0.	00E+00	0.00E+00	2:89E-10
Butane	lbmole/hr	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00 0.0	E+00 0	0.00E+00	5.07E+00	3.19E-14	4.99E+00	8.39E-02	1.55E-02	1.55E-02	1.45E-02 7	7.13E-03	4.99E+00	4.99E+00	1.82E-07	2.68E-07	7.68E-02 0.	00E+00	0.00E+00	2!:02E-07
Pentane	lbmole/hr	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00 0.0	E+00 0	0.00E+00	4.56E+00	1.39E-16	4.36E+00	2.12E-01	3.94E-02	3.94E-02	3.86E-02 7	7.59E-03	4.35E+00	4.36E+00	4.29E-06	6.29E-06	2.05E-01 0.	00E+00	0.00E+00	7'.15E-06
Hexane	lbmole/hr	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00 0.0	E+00 0	0.00E+00	4.10E+00	3.99E-19	3.61E+00	4.99E-01	9.29E-02	9.29E-02	9.27E-02 7	7.47E-03	3.60E+00	3.61E+00	9.06E-05	1.31E-04	4.92E-01 0.	00E+00	0.00E+00	2!:24E-04
Heptane	lbmole/hr	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00 0.0	E+00 0	0.00E+00	3.69E+00	6.70E-22	2.67E+00	1.02E+00	1.89E-01	1.89E-01	1.91E-01 6	6.51E-03	2.67E+00	2.67E+00	1.52E-03	2.16E-03	1.01E+00 0.	00E+00	0.00E+00	5i-44E-03
Octane	lbmole/hr	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00 0.0	E+00 0	0.00E+00	3.32E+00	7.98E-25	1.61E+00	1.71E+00	3.00E-01	3.00E-01	3.03E-01 4	4.42E-03	1.61E+00	1.61E+00	1.89E-02	2.64E-02	1.61E+00 0.	00E+00	0.00E+00	91 69E-02
Nonane	lbmole/hr	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00 0.0	E+00 0	0.00E+00	2.98E+00	6.53E-28	7.79E-01	2.21E+00	2.55E-01	2.55E-01	2.58E-01 1	1.66E-03	7.77E-01	7.79E-01	1.16E-01	1.57E-01	1.37E+00 0.	00E+00	0.00E+00	8137E-01
Decane	lbmole/hr	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00 0.0	E+00 0	0.00E+00	2.68E+00	1.66E-31	3.15E-01	2.37E+00	7.35E-02	7.35E-02	7.43E-02 2	2.15E-04	3.15E-01	3.15E-01	1.96E-01	2.54E-01	3.94E-01 0.	00E+00	0.00E+00	197E+00
n-C11	lbmole/hr	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00 0.0	E+00 0	0.00E+00	2.41E+00	7.89E-35	1.13E-01	2.30E+00	1.59E-02	1.59E-02	1.61E-02 2	2.06E-05	1.13E-01	1.13E-01	1.62E-01	1.99E-01	8.54E-02 2.	51E+00	0.00E+00	221E+00
n-C12	lbmole/hr	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00 0.0	E+00 0	0.00E+00	2.17E+00	1.49E-38	4.31E-02	2.13E+00	4.71E-03	4.71E-03	4.76E-03 2	2.95E-06	4.31E-02	4.31E-02	1.16E-01	1.32E-01	2.52E-02 2.	39E+00	0.00E+00	210E+010
n-C13	lbmole/hr	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00 0.0	E+00 0	0.00E+00	1.95E+00	6.13E-42	1.33E-02	1.94E+00	1.28E-03	1.28E-03	1.30E-03 3	3.37E-07	1.33E-02	1.33E-02	8.13E-02	8.38E-02	6.87E-03 2.	19E+00	0.00E+00	193E+00
n-C14	lbmole/hr	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00 0.0	E+00 0	0.00E+00	1.76E+00	9.56E-46	3.88E-03	1.75E+00	2.60E-04	2.60E-04	2.63E-04 2	2.72E-08	3.88E-03	3.88E-03	5.69E-02	5.09E-02	1.39E-03 1.	99E+00	0.00E+00	175E+00
n-C15	lbmole/hr	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00 0.0	E+00 0	0.00E+00	1.58E+00	7.80E-50	1.61E-03	1.58E+00	7.09E-05	7.09E-05	7.18E-05 4	4.03E-09	1.61E-03	1.61E-03	4.32E-02	3.38E-02	3.80E-04 1.	79E+00	0.00E+00	158E+00
n-C16	lbmole/hr	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00 0.0	E+00 0	0.00E+00	1.42E+00	5.83E-54	5.53E-04	1.42E+00	1.50E-05	1.50E-05	1.52E-05 4	4.02E-10	5.53E-04	5.53E-04	3.34E-02	2.22E-02	8.04E-05 1.	51E+00	0.00E+00	142E+00
n-C17	lbmole/hr	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00 0.0	E+00 0	0.00E+00	1.28E+00	1.11E-59	2.33E-04	1.28E+00	3.39E-06	3.39E-06	3.42E-06 5	5.09E-11	2.33E-04	2.33E-04	2.60E-02	1.39E-02	1.82E-05 1.	45E+00	0.00E+00	128E+00
n-C18	lbmole/hr	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00 0.0	E+00 0	0.00E+00	1.15E+00	5.89E-66	9.25E-05	1.15E+00	7.52E-07	7.52E-07	7.61E-07 6	6.15E-12	9.25E-05	9.25E-05	2.10E-02	8.95E-03	4.03E-06 1.	30E+00	0.00E+00	115E+00
n-C19	lbmole/hr	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00 0.0	E+00 0	0.00E+00	1.03E+00	7.32E-73	3.99E-05	1.03E+00	1.90E-07	1.90E-07	1.93E-07 9	9.19E-13	3.99E-05	3.99E-05	1.75E-02	5.89E-03	1.02E-06 1.	17E+00	0.00E+00	103E+010
n-C20	lbmole/hr	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00 0.0	E+00 0	0.00E+00	9.29E-01	8.08E-71	9.08E-06	9.29E-01	1.99E-08	1.99E-08	2.02E-08 3	3.01E-14	9.08E-06	9.08E-06	1.46E-02	3.64E-03	1.07E-07 1.	05E+00	0.00E+00	9 29E-01
n-C21	lbmole/hr	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00 0.0	E+00 0	0.00E+00	8.36E-01	5.46E-75	3.45E-06	8.36E-01	4.21E-09	4.21E-09	4.26E-09 3	3.28E-15	3.45E-06	3.45E-06	1.25E-02	2.39E-03	2.26E-08 0.	00E+00	2.37E-01	8:36E-01
n-C22	lbmole/hr	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00 0.0	E+00 0	0.00E+00	7.52E-01	1.72E-79	1.42E-06	7.52E-01	1.02E-09	1.02E-09	1.03E-09 4	4.40E-16	1.42E-06	1.42E-06	1.09E-02	1.60E-03	5.47E-09 0.	00E+00	2.13E-01	7 52E-01
n-C23	lbmole/hr	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00 0.0	E+00 0	0.00E+00	6.76E-01	1.73E-83	4.35E-07	6.76E-01	1.59E-10	1.59E-10	1.61E-10 2	2.95E-17	4.35E-07	4.35E-07	9.51E-03	1.00E-03	8.52E-10 0.	00E+00	1.92E-01	6 76E-01
n-C24	lbmole/hr	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00 0.0	E+00 0	0.00E+00	6.08E-01	9.27E-88	1.51E-07	6.08E-01	3.04E-11	3.04E-11	3.07E-11 2	2.72E-18	1.51E-07	1.51E-07	8.39E-03	6.53E-04	1.63E-10 0.	00E+00	1.73E-01	6 08E-01
n-C25	lbmole/hr	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00 0.0	E+00 0	0.00E+00	5.47E-01	2.03E-91	5.87E-08	5.47E-01	6.81E-12	6.81E-12	6.88E-12 3	3.20E-19	5.87E-08	5.87E-08	7.44E-03	4.35E-04	3.65E-11 0.	00E+00	1.55E-01	5-47E-01
n-C26	lbmole/hr	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00 0.0	E+00 0	0.00E+00	4.92E-01	2.90E-96	1.94E-08	4.92E-01	1.22E-12	1.22E-12	1.24E-12 2	2.70E-20	1.94E-08	1.94E-08	6.62E-03	2.80E-04	6.56E-12 0.	00E+00	1.40E-01	4 92E-01
n-C27	lbmole/hr	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00 0.0	E+00 0	0.00E+00	4.42E-01	6.33E-100	5.46E-09	4.42E-01	1.74E-13	1.74E-13	1.76E-13 1	1.55E-21	5.46E-09	5.46E-09	5.90E-03	1.75E-04	9.32E-13 0.	00E+00	1.25E-01	4-42E-01
n-C28	Ibmole/hr	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00 0.0	E+00 0	0.00E+00	3.98E-01	1.48E-101	2.57E-09	3.98E-01	5.35E-14	5.35E-14	5.41E-14 2	2.99E-22	2.57E-09	2.57E-09	5.28E-03	1.22E-04	2.87E-13 0.	00E+00	1.13E-01	3 98E-01
n-C29	lbmole/hr	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00 0.0	E+00 0	0.00E+00	3.58E-01	1.33E-101	1.14E-09	3.58E-01	1.50E-14	1.50E-14	1.52E-14 4	4.95E-23	1.14E-09	1.14E-09	4.74E-03	8.51E-05	8.04E-14 0.	00E+00	1.01E-01	3 585-01
n-C30	Ibmole/hr	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00 0.0	E+00 0	0.00E+00	1.95E+00	7.26E-101	7.96E-10	1.95E+00	2.05E-15	2.05E-15	2.08E-15 1	1.12E-24	7.96E-10	7.96E-10	2.57E-02	2.20E-04	1.10E-14 0.	00E+00	5.54E+00	195E+00
Actual Volume Flow	barrel/day	3952	1259	4745	12493	25536	1844	62389	13525	13419	244975	9913	16811	106 2	5089	245195	2921	15	730585	624	9960	172	8	101	542756	543235	1656	81398	63	411	339	717
Mass Density	lb/ft3	1.42	4.47	1.25	1.38	0.67	2.96	0.36	1.67	1.21	62.87	0.92	0.54	61.16	62.87	62.87	14.27	61.45	21.12	46.46	0.29	16.82	40.46	0.15	0.02	0.02	37.22	0.43	40.44	37.86	32.05	35.84
Molar Density	lbmole/ft3	0.089	0.102	0.069	0.065	0.032	0.092	0.022	0.101	0.076	3.490	0.083	0.049	3.390	3.489	3.489	0.195	3.411	1.172	0.211	0.003	0.150	0.359	0.003	0.001	0.001	0.197	0.003	0.359	0.191	0.088	0 151

 Table 2: Small Unit PFD Stream Tables



Figure 1: Large GTL Module P&ID



Figure 2: Small GTL Module P&ID

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| M_6<br>M_7<br>S_1<br>S_2<br>S_3<br>S_4<br>S_5<br>S_6<br>S_7<br>S_6<br>S_7<br>S_8<br>S_9<br>S_10                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | Margaret<br>Mary<br>Rachel<br>Shirley<br>Alexa<br>Annie<br>Bessie<br>Beth<br>Caroline<br>Dijanna<br>Dorothy<br>Ella<br>Evelyn<br>France                                                                                                           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   -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         - | \$       -         \$       638,821         \$       432,817         \$       -         \$       97,500         \$       96,603         \$       86,563         \$       -         \$       -         \$       -         \$       86,563         \$       -         \$       -         \$       56,603         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -                                                                                                                 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 -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -</td><td>\$    </td><td>5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5</td><td>\$         -           \$         -           \$         702,801           \$         -           \$         702,801           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         74,151           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         100,325           \$         -           \$         -           \$         -           \$         -           \$         -</td><td>\$         572,588           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         296,744           \$         22,506           \$         -           \$         22,506           \$         -           \$         138,050           \$         159,706           \$         -           \$         146,550           \$         -           \$         -</td><td>S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S        </td><td>\$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$      128,025  <td>\$</td></td></t<></tr> <tr><th>M_6<br/>M_7<br/>S_1<br/>S_2<br/>S_3<br/>S_4<br/>S_5<br/>S_6<br/>S_7<br/>S_6<br/>S_7<br/>S_8<br/>S_9<br/>S_10<br/>S_11<br/>S_11</th><td>Margaret<br/>Mary<br/>Rachel<br/>Shirley<br/>Alexa<br/>Annie<br/>Bessie<br/>Beth<br/>Caroline<br/>Dijanna<br/>Dorothy<br/>Ella<br/>Evelyn<br/>France<br/>Gertrude</td><td>\$       37,300         \$       741,000         \$       741,000         \$       97,500         \$       -         \$       63,000         \$       -         \$       63,000         \$       -         \$       148,200         \$       148,200         \$       148,200         \$       19,500         \$       -         \$       19,500         \$       -         \$       -</td><td>S       -         S       -         S       -         S       -         S       -         S       -         S       -         S       -         S       -         S       -         S       -         S       -         S       -         S       -         S       -         S       -         S       -         S       -         S       -         S       -         S       -         S       -         S       -         S       -         S       -         S       -         S       -         S       -         S       -         S       -         S       -         S       -         S       -         S       -         S       -</td><td>S         593,596           S         -           S         -           S         -           S         -           S         -           S         -           S         -           S         -           S         -           S         -           S         -           S         -           S         -           S         -           S         9,300           S         118,719           S         -           S         9,300</td><td>\$       -         \$       -         \$       -         \$       741,219         \$       -         \$       60,508         \$       60,508         \$       60,508         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -</td><td>\$       -         \$       -         \$       -         \$       715,771         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -</td><td>\$         824,466           \$         824,466           \$         951,274           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         56,603           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         62,693           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -</td><td>\$       491,202         \$       287,065         \$       -         \$       42,961         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       62,693         \$       135,117         \$       -         \$       -         \$       135,117         \$       -         \$       -         \$       135,117         \$       -         \$       -         \$       135,117         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$</td><td>\$       916,432         \$       -         \$       671,670         \$       916,432         \$       -         \$       916,432         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -</td><td>\$       -         \$       638,821         \$       432,817         \$       -         \$       97,500         \$       56,603         \$       86,563         \$       86,563         \$       -         \$       -         \$       56,603         \$       86,563         \$       -         \$       56,603         \$       -         \$       56,603         \$       -         \$       56,603         \$       -         \$       56,603         \$       -         \$       56,603         \$       -         \$       56,603         \$       -         \$       56,603         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -     <!--</td--><td>\$         022,032           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         258,512           \$         287,065           \$         -           \$         287,065           \$         -           \$         51,702           \$         -           \$         -           \$         130,891           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         22,192           \$         164,893           \$         -</td><td>\$          \$       916,432         \$          \$      
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          \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -</td><td>\$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         59,349           \$         98,240           \$         138,050           \$         138,050           \$         18,109           \$         -           \$         127,764           \$         65,949           \$         -           \$         126,762           \$         94,921</td><td>\$     -     4       \$     278,239     4       \$     -     4       \$     709,061     4       \$     709,061     4       \$     -     4       \$     90,051     4       \$     96,433     4       \$     96,853     4       \$     96,853     4       \$     96,853     4       \$     96,853     4       \$     96,853     4       \$     96,853     4       \$     96,853     4       \$     96,853     4       \$     96,853     4       \$     96,853     4       \$     96,853     4       \$     100,325     4       \$     65,949     4       \$     121,252     4       \$     126,762     4</td><td>5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       191,246         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -</td><td>\$         -           \$         -           \$         702,801           \$         702,801           \$         -           \$         702,801           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         74,151           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         100,325           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -</td><td>\$         572,588           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         296,744           \$         22,506           \$         -           \$         22,506           \$         -           \$         138,050           \$         159,706           \$         -           \$         146,550           \$         -           \$         -           \$         -</td><td>S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S       <tr tr=""> <tr tr="">          S        </tr></tr></td><td>S     -       S     -       S     -       S     -       S     -       S     -       S     -       S     -       S     -       S     -       S     -       S     -       S     -       S     -       S     -       S     -       S     -       S     -       S     -       S     -       S     -       S     -       S     -       S     -       S     -       S     -       S     -       S     -       S     -       S     -       S     -       S     -       S     -       S     -       S     -       S     -       S     -       S     -       S     -       S     -       S     128,025       S     128,069</td><td>\$</td></td></tr> <tr><th>M_6<br/>M_7<br/>S_1<br/>S_2<br/>S_3<br/>S_4<br/>S_5<br/>S_6<br/>S_7<br/>S_8<br/>S_7<br/>S_8<br/>S_9<br/>S_10<br/>S_11<br/>S_12<br/>S_12</th><th>Margaret<br/>Mary<br/>Rachel<br/>Shirley<br/>Alexa<br/>Annie<br/>Bessie<br/>Beth<br/>Caroline<br/>Dijanna<br/>Dorothy<br/>Ella<br/>Evelyn<br/>France<br/>Gertrude<br/>Jane</th><th>\$ 37,300         \$ 741,000         \$ 741,000         \$ 97,500         \$ 07,500         \$ 07,500         \$ 10,500         \$ 03,000         \$ 03,000         \$ 03,000         \$ 03,000         \$ 03,000         \$ 03,000         \$ 03,000         \$ 03,000         \$ 03,000         \$ 148,200         \$ 148,200         \$ 148,200         \$ 19,500         \$ 19,500         \$ - 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          S         -           S         -           S         -           S         -           S         -           S         -           S         -           S         -           S         -           S         -           S         -           S         -           S         -           S         -           S         -           S         9,300           S         118,719           S         -           S         9,300           S         63,000</th><th>\$       -         \$       -         \$       741,219         \$       -         \$       760,508         \$       60,508         \$       60,508         \$       60,508         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       - 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          \$         -           \$         -           \$         258,512           \$         287,065           \$         287,065           \$         287,065           \$         51,702           \$         51,702           \$         -           \$         51,702           \$         -           \$         130,891           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         22,192           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         22,192</th><th>\$            \$         916,432           \$            \$         903,136           \$         903,136           \$            \$         903,136           \$            \$            \$            \$            \$            \$            \$            \$            \$            \$            \$            \$            \$            \$            \$            \$            \$            \$            \$            \$            \$            \$            \$            \$            \$            \$        </th><th>\$         493,434           \$         -           \$         956,228           \$         -           \$         956,236           \$         -           \$         765,236           \$         -           \$         67,972           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -</th><th>\$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         99,507           \$         59,349           \$         98,240           \$         138,050           \$         138,050           \$         127,764           \$         65,949           \$         -           \$         126,762           \$         94,921           \$         94,921           \$         -</th><th>\$     -     4       \$     278,239     5       \$     484,264     5       \$     709,061     5       \$     709,061     5       \$     -     5       \$     96,433     5       \$     96,853     5       \$     96,853     5       \$     -     5       \$     -     5       \$     -     5       \$     -     5       \$     -     5       \$     -     5       \$     -     5       \$     65,949     5       \$     126,762     5       \$     -     5</th><th>5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       191,246         5       86,563         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       - 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          \$         -           \$         -           <td< th=""><th>\$         572,588           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         22,506           \$         -           \$         22,506           \$         -           \$         138,050           \$         -           \$         159,706           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -</th><th>S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S       <tr td="">            S</tr></th><th>\$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     128,025       \$     183,669       \$     -</th><th>\$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       - 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      \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$      128,025 <td>\$</td>                                                                                                                         | \$                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | M_6<br>M_7<br>S_1<br>S_2<br>S_3<br>S_4<br>S_5<br>S_6<br>S_7<br>S_6<br>S_7<br>S_8<br>S_9<br>S_10<br>S_11<br>S_11 | Margaret<br>Mary<br>Rachel<br>Shirley<br>Alexa<br>Annie<br>Bessie<br>Beth<br>Caroline<br>Dijanna<br>Dorothy<br>Ella<br>Evelyn<br>France<br>Gertrude | \$       37,300         \$       741,000         \$       741,000         \$       97,500         \$       -         \$       63,000         \$       -         \$       63,000         \$       -         \$       148,200         \$       148,200         \$       148,200         \$       19,500         \$       -         \$       19,500         \$       -         \$       - | S       -         S       -         S       -         S       -         S       -         S       -         S       -         S       -         S       -         S       -         S       -         S       -         S       -         S       -         S       -         S       -         S       -         S       -         S       -         S       -         S       -         S       -         S       -         S       -         S       -         S       -         S       -         S       -         S       -         S       -         S       -         S       -         S       -         S       -         S       - | S         593,596           S         -           S         -           S         -           S         -           S         - 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        \$       -         \$       -         \$       -         \$       -         \$ | \$       916,432         \$       -         \$       671,670         \$       916,432         \$       -         \$       916,432         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       - | \$       -         \$       638,821         \$       432,817         \$       -         \$       97,500         \$       56,603         \$       86,563         \$       86,563         \$       -         \$       -         \$       56,603         \$       86,563         \$       - 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    -           \$         258,512           \$         287,065           \$         -           \$         287,065           \$         -           \$         51,702           \$         -           \$         -           \$         130,891           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         22,192           \$         164,893           \$         -</td> <td>\$          \$       916,432         \$          \$       903,136         \$          \$       903,136         \$          \$       903,136         \$          \$          \$          \$          \$          \$          \$          \$          \$          \$          \$          \$          \$          \$          \$          \$          \$          \$          \$          \$          \$          \$          \$          \$          \$          \$          \$      </td> <td>\$         493,434           \$         -           \$         956,228           \$         -           \$         956,236           \$         -           \$         765,236           \$         -           \$         67,972           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -</td> <td>\$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         59,349           \$         98,240           \$         138,050           \$         138,050           \$         18,109           \$         -           \$         127,764           \$         65,949           \$         -           \$         126,762           \$         94,921</td> <td>\$     -     4       \$     278,239     4       \$     -     4       \$     709,061     4       \$     709,061     4       \$     -     4       \$     90,051     4       \$     96,433     4       \$     96,853     4       \$     96,853     4       \$     96,853     4       \$     96,853     4       \$     96,853     4       \$     96,853     4       \$     96,853     4       \$     96,853     4       \$     96,853     4       \$     96,853     4       \$     96,853     4       \$     100,325     4       \$     65,949     4       \$     121,252     4       \$     126,762     4</td> <td>5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       191,246         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -</td> <td>\$         -           \$         -           \$         702,801           \$         702,801           \$         -           \$         702,801           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         74,151           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         100,325           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -</td> <td>\$         572,588           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         296,744           \$         22,506           \$         -           \$         22,506           \$         -           \$         138,050           \$         159,706           \$         -           \$         146,550           \$         -           \$         -           \$         -</td> <td>S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S       <tr tr=""> <tr tr="">          S        </tr></tr></td> <td>S     -       S     -       S     -       S     -       S     -       S     -       S     -       S     -       S     -       S     -       S     -       S     -       S     -       S     -       S     -       S     -       S     -       S     -       S     -       S     -       S     -       S     -       S     -       S     -       S     -       S     -       S     -       S     -       S     -       S     -       S     -       S     -       S     -       S     -       S     -       S     -       S     -       S     -       S     -       S     -       S     128,025       S     128,069</td> <td>\$</td> | \$         022,032           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         258,512           \$         287,065           \$         -           \$         287,065           \$         -           \$         51,702           \$         -           \$         -           \$         130,891           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         22,192           \$         164,893           \$         - | \$          \$       916,432         \$          \$       903,136         \$          \$       903,136         \$          \$       903,136         \$          \$          \$          \$          \$          \$          \$          \$          \$          \$          \$          \$          \$          \$          \$          \$          \$          \$          \$          \$          \$          \$          \$          \$          \$          \$          \$ | \$         493,434           \$         -           \$         956,228           \$         -           \$         956,236           \$         -           \$         765,236           \$         -           \$         67,972           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         - | \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         59,349           \$         98,240           \$         138,050           \$         138,050           \$         18,109           \$         -           \$         127,764           \$         65,949           \$         -           \$         126,762           \$         94,921 | \$     -     4       \$     278,239     4       \$     -     4       \$     709,061     4       \$     709,061     4       \$     -     4       \$     90,051     4       \$     96,433     4       \$     96,853     4       \$     96,853     4       \$     96,853     4       \$     96,853     4       \$     96,853     4       \$     96,853     4       \$     96,853     4       \$     96,853     4       \$     96,853     4       \$     96,853     4       \$     96,853     4       \$     100,325     4       \$     65,949     4       \$     121,252     4       \$     126,762     4 | 5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       191,246         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       - | \$         -           \$         -           \$         702,801           \$         702,801           \$         -           \$         702,801           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         74,151           \$         - 
         \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         100,325           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         - | \$         572,588           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         296,744           \$         22,506           \$         -           \$         22,506           \$         -           \$         138,050           \$         159,706           \$         -           \$         146,550           \$         -           \$         -           \$         - | S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S <tr tr=""> <tr tr="">          S        </tr></tr> | S     -       S     -       S     -       S     -       S     -       S     -       S     -       S     -       S     -       S     -       S     -       S     -       S     -       S     -       S     -       S     -       S     -       S     -       S     -       S     -       S     -       S     -       S     -       S     -       S     -       S     -       S     -       S     -       S     -       S     -       S     -       S     -       S     -       S     -       S     -       S     -       S     -       S     -       S     -       S     -       S     128,025       S     128,069 | \$ | M_6<br>M_7<br>S_1<br>S_2<br>S_3<br>S_4<br>S_5<br>S_6<br>S_7<br>S_8<br>S_7<br>S_8<br>S_9<br>S_10<br>S_11<br>S_12<br>S_12 | Margaret<br>Mary<br>Rachel<br>Shirley<br>Alexa<br>Annie<br>Bessie<br>Beth<br>Caroline<br>Dijanna<br>Dorothy<br>Ella<br>Evelyn<br>France<br>Gertrude<br>Jane | \$ 37,300         \$ 741,000         \$ 741,000         \$ 97,500         \$ 07,500         \$ 07,500         \$ 10,500         \$ 03,000         \$ 03,000         \$ 03,000         \$ 03,000         \$ 03,000         \$ 03,000         \$ 03,000         \$ 03,000         \$ 03,000         \$ 148,200         \$ 148,200         \$ 148,200         \$ 19,500         \$ 19,500         \$ -         \$ -         \$ -         \$ -         \$ -         \$ -         \$ -         \$ -         \$ -         \$ -         \$ -         \$ -         \$ -         \$ -         \$ -         \$ -         \$ -         \$ -         \$ -         \$ -         \$ -         \$ -         \$ -         \$ -         \$ -         \$ -         \$ -         \$ -         \$ -         \$ - </th <th>S       -         S       -         S       -         S       -         S       -         S       -         S       -         S       -         S       -         S       -         S       -         S       -         S       -         S       -         S       -         S       -         S       -         S       -         S       -         S       -         S       -         S       -         S       -         S       -         S       -         S       -         S       -         S       -         S       -         S       -         S       -         S       -         S       -         S       -</th> <th>S         593,596           S         -           S         -           S         -           S         -           S         -           S         -           S         -           S         -           S         -           S         -           S         -           S         -           S         -           S         -           S         -           S         -           S         9,300           S         118,719           S         -           S         9,300           S         63,000</th> <th>\$       -         \$       -         \$       741,219         \$       -         \$       760,508         \$       60,508         \$       60,508         \$       60,508         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -</th> <th>\$       -         \$       -         \$       -         \$       715,771         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -</th> <th>\$         824,466           \$         951,274           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         56,603           \$         -           \$         56,603           \$         -           \$         56,603           \$         -           \$         56,603           \$         -           \$         -           \$         62,693           \$         56,715           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -      <tr tbox<="" td=""> </tr></th> <th>\$       491,202         \$       287,065         \$       -         \$       42,961         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       62,693         \$       135,117         \$       62,693         \$       135,117         \$       -         \$       135,117         \$       -         \$       148,244         \$       118,719         \$       -         \$       -         \$       -         \$       -         \$       118,719         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -</th> <th>\$       916,432         \$       -         \$       671,670         \$       916,432         \$       -         \$       916,432         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -</th> <th>\$       -         \$       638,821         \$       432,817         \$       -         \$       -         \$       97,500         \$       56,603         \$       86,563         \$       -         \$       -         \$       56,603         \$       -         \$       -         \$       56,603         \$       -         \$       56,603         \$       -         \$       56,603         \$       -         \$       56,603         \$       -         \$       56,603         \$       -         \$       56,603         \$       -         \$       86,563         \$       -         \$       86,563         \$       -         \$       86,563</th> <th>\$         022,032           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         258,512           \$         287,065           \$         287,065           \$         287,065           \$         51,702           \$         51,702           \$         -           \$         51,702           \$         -           \$         130,891           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         22,192           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         22,192</th> <th>\$            \$         916,432           \$            \$         903,136           \$         903,136           \$            \$         903,136           \$            \$            \$            \$            \$            \$            \$            \$            \$            \$            \$            \$            \$            \$            \$            \$            \$            \$            \$            \$            \$            \$            \$            \$            \$            \$        </th> <th>\$         493,434           \$         -           \$         956,228           \$         -           \$         956,236          
\$         -           \$         765,236           \$         -           \$         67,972           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -</th> <th>\$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         99,507           \$         59,349           \$         98,240           \$         138,050           \$         138,050           \$         127,764           \$         65,949           \$         -           \$         126,762           \$         94,921           \$         94,921           \$         -</th> <th>\$     -     4       \$     278,239     5       \$     484,264     5       \$     709,061     5       \$     709,061     5       \$     -     5       \$     96,433     5       \$     96,853     5       \$     96,853     5       \$     -     5       \$     -     5       \$     -     5       \$     -     5       \$     -     5       \$     -     5       \$     -     5       \$     65,949     5       \$     126,762     5       \$     -     5</th> <th>5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       191,246         5       86,563         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       134,334         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -</th> <th>\$         -           \$         -           \$         702,801           \$         702,801           \$         -           \$         702,801           \$         -           \$         -           \$         -           \$         -           \$         -           \$         74,151           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         100,325           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           <td< th=""><th>\$         572,588           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         22,506           \$         -           \$         22,506           \$         -           \$         138,050           \$         -           \$         159,706           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -</th><th>S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S       <tr td="">            S</tr></th><th>\$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     128,025       \$     183,669       \$     -</th><th>\$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       - 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          S         -           S         -           S         -           S         -           S         -           S         9,300           S         118,719           S         -           S         9,300           S         63,000 | \$       -         \$       -         \$       741,219         \$       -         \$       760,508         \$       60,508         \$       60,508         \$       60,508         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       - | \$       -         \$       -         \$       -         \$       715,771         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       - | \$         824,466           \$         951,274           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         56,603           \$         -           \$         56,603           \$         -           \$         56,603           \$         -           \$         56,603           \$         -           \$         -           \$         62,693           \$         56,715           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         - <tr tbox<="" td=""> </tr> | \$       491,202         \$       287,065         \$       -         \$       42,961         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       62,693         \$       135,117         \$       62,693         \$       135,117         \$       -         \$       135,117         \$       -         \$       148,244         \$       118,719         \$       -         \$       -         \$       -         \$       -         \$       118,719         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       - | \$       916,432         \$       -         \$       671,670         \$       916,432         \$       -         \$       916,432         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$ 
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          \$         -           \$         -           \$         -           \$         -           \$         -           \$         258,512           \$         287,065           \$         287,065           \$         287,065           \$         51,702           \$         51,702           \$         -           \$         51,702           \$         -           \$         130,891           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         22,192           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         22,192 | \$            \$         916,432           \$            \$         903,136           \$         903,136           \$            \$         903,136           \$            \$            \$            \$            \$            \$            \$            \$            \$            \$            \$            \$            \$            \$            \$            \$            \$            \$            \$            \$            \$            \$            \$            \$            \$            \$ | \$         493,434           \$         -           \$         956,228           \$         -           \$         956,236           \$         -           \$         765,236           \$         -           \$         67,972           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         - | \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         99,507           \$         59,349           \$         98,240           \$         138,050           \$         138,050           \$         127,764           \$         65,949           \$         -           \$         126,762           \$         94,921           \$         94,921           \$         - | \$     -     4       \$     278,239     5       \$     484,264     5       \$     709,061     5       \$     709,061     5       \$     -     5       \$     96,433     5       \$     96,853     5       \$     96,853     5       \$     -     5       \$     -     5       \$     -     5       \$     -     5       \$     -     5       \$     -     5       \$     -     5       \$     65,949     5       \$     126,762     5       \$     -     5 | 5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       191,246         5       86,563         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       134,334         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       - | \$         -           \$         -           \$         702,801           \$         702,801           \$         -           \$         702,801           \$         -           \$         -           \$         -           \$         -           \$         -           \$         74,151           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         100,325           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         - <td< th=""><th>\$         572,588           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         22,506           \$         -           \$         22,506           \$         -           \$         138,050           \$         -           \$         159,706           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -</th><th>S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S       <tr td="">            S</tr></th><th>\$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     128,025       \$     183,669       \$     -</th><th>\$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       - 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      \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     128,025       \$     183,669       \$     - | \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -     
   \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       - |
| \$         493,434           \$         -           \$         956,228           \$         -           \$         956,236           \$         -           \$         765,236           \$         -           \$         67,972           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         - | \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         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| M_6<br>M_7<br>S_1<br>S_2<br>S_3<br>S_4<br>S_5<br>S_6<br>S_7<br>S_8<br>S_7<br>S_8<br>S_9<br>S_10<br>S_11<br>S_12<br>S_12                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | Margaret<br>Mary<br>Rachel<br>Shirley<br>Alexa<br>Annie<br>Bessie<br>Beth<br>Caroline<br>Dijanna<br>Dorothy<br>Ella<br>Evelyn<br>France<br>Gertrude<br>Jane                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | \$ 37,300         \$ 741,000         \$ 741,000         \$ 97,500         \$ 07,500         \$ 07,500         \$ 10,500         \$ 03,000         \$ 03,000         \$ 03,000         \$ 03,000         \$ 03,000         \$ 03,000         \$ 03,000         \$ 03,000         \$ 03,000         \$ 148,200         \$ 148,200         \$ 148,200         \$ 19,500         \$ 19,500         \$ -         \$ -         \$ -         \$ -         \$ -         \$ -         \$ -         \$ -         \$ -         \$ -         \$ -         \$ -         \$ -         \$ -         \$ -         \$ -         \$ -         \$ -         \$ -         \$ -         \$ -         \$ -         \$ -         \$ -         \$ -         \$ -         \$ -         \$ -         \$ -         \$ - </th <th>S       -         S       -         S       -         S       -         S       -         S       -         S       -         S       -         S       -         S       -         S       -         S       -         S       -         S       -         S       -         S       -         S       -         S       -         S       -         S       -         S       -         S       -         S       -         S       -         S       -         S       -         S       -         S       -         S       -         S       -         S       -         S       -         S       -         S       -</th> <th>S         593,596           S         -           S         -           S         -           S         -           S         -           S         -           S         -           S         -           S         -           S         -           S         -           S         -           S         -           S         -           S         -           S         -           S         9,300           S         118,719           S         -           S         9,300           S         63,000</th> <th>\$       -         \$       -         \$       741,219         \$       -         \$       760,508         \$       60,508         \$       60,508         \$       60,508         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -</th> <th>\$       -         \$       -         \$       -         \$       715,771         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -</th> <th>\$         824,466           \$         951,274           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         56,603           \$         -           \$         56,603           \$         -           \$         56,603           \$         -           \$         56,603           \$         -           \$         -           \$         62,693           \$         56,715           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -      <tr tbox<="" td=""> </tr></th> <th>\$       491,202         \$       287,065         \$       -         \$       42,961         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       62,693         \$       135,117         \$       62,693         \$       135,117         \$       -         \$       135,117         \$       -         \$       148,244         \$       118,719         \$       -         \$       -         \$       -         \$       -         \$       118,719         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -</th> <th>\$       916,432         \$       -         \$       671,670         \$       916,432         \$       -         \$       916,432         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -</th> <th>\$       -         \$       638,821         \$       432,817         \$       -         \$       -         \$       97,500         \$       56,603         \$       86,563         \$       -         \$       -         \$       56,603         \$       -         \$       -         \$       56,603         \$       -         \$       56,603         \$       -         \$       56,603         \$       -         \$       56,603         \$       -         \$       56,603         \$       -         \$       56,603         \$       -         \$       86,563         \$       -         \$       86,563         \$       -         \$       86,563</th> <th>\$         022,032           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         258,512           \$         287,065           \$         287,065           \$         287,065           \$         51,702           \$         51,702           \$         -           \$         51,702           \$         -           \$         130,891           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         22,192           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         22,192</th> <th>\$            \$         916,432           \$            \$         903,136           \$         903,136           \$            \$         903,136           \$            \$            \$            \$            \$            \$            \$            \$            \$            \$            \$            \$            \$            \$            \$            \$            \$            \$            \$            \$            \$            \$            \$            \$            \$            \$        </th> <th>\$         493,434           \$         -           \$         956,228           \$         -           \$         956,236           \$         -           \$         765,236           \$         -           \$         67,972           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -</th> <th>\$         -           \$         -           \$         -           \$         -           \$         -         
 \$         -           \$         -           \$         -           \$         99,507           \$         59,349           \$         98,240           \$         138,050           \$         138,050           \$         127,764           \$         65,949           \$         -           \$         126,762           \$         94,921           \$         94,921           \$         -</th> <th>\$     -     4       \$     278,239     5       \$     484,264     5       \$     709,061     5       \$     709,061     5       \$     -     5       \$     96,433     5       \$     96,853     5       \$     96,853     5       \$     -     5       \$     -     5       \$     -     5       \$     -     5       \$     -     5       \$     -     5       \$     -     5       \$     65,949     5       \$     126,762     5       \$     -     5</th> <th>5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       191,246         5       86,563         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       134,334         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -         5       -</th> <th>\$         -           \$         -           \$         702,801           \$         702,801           \$         -           \$         702,801           \$         -           \$         -           \$         -           \$         -           \$         -           \$         74,151           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         100,325           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           <td< th=""><th>\$         572,588           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         22,506           \$         -           \$         22,506           \$         -           \$         138,050           \$         -           \$         159,706           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -</th><th>S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S       <tr td="">            S</tr></th><th>\$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     - 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        \$       760,508         \$       60,508         \$       60,508         \$       60,508         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       - | \$       -         \$       -         \$       -         \$       715,771         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -                                                                             | \$         824,466           \$         951,274           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         56,603           \$         -           \$         56,603           \$         -           \$         56,603           \$         -           \$         56,603           \$         -           \$         -           \$         62,693           \$         56,715           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         - 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          \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         99,507           \$         59,349           \$         98,240           \$         138,050           \$         138,050           \$         127,764           \$         65,949           \$         -           \$         126,762           \$         94,921           \$         94,921           \$         -                                                                                                                                                                                                                                                      | \$     -     4       \$     278,239     5       \$     484,264     5       \$     709,061     5       \$     709,061     5       \$     -     5       \$     96,433     5       \$     96,853     5       \$     96,853     5       \$     -     5       \$     -     5       \$     - 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          \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         100,325           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         - <td< th=""><th>\$         572,588           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         22,506           \$         -           \$         22,506           \$         -           \$         138,050           \$         -           \$         159,706           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -</th><th>S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S            S       <tr td="">            S</tr></th><th>\$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     -       \$     - 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  \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -         \$       -</th></td<> | \$         572,588           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         -           \$         22,506           \$         -           \$         22,506           \$         -           \$         138,050   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Table 3: Transportation Cost per Year

### c:\_:. Cal

							C	olumr	n Sizing	3									
	Dedecanizer																		
Number of Stages	ber of es are services and the services are																		
4	2	20	27.9	0.122	4.651E+06	1.300E+07	0.49	9 7	7 3	4.50	2.25	14.86	236.31	15.90	1.3716	0.686	4.53	6.69	1.48
4	2	20	27.9	0.122	1.779E+06	5.607E+06	0.49	9 7	7 3	3.00	2.50	15.10	106.75	7.07	0.9144	0.762	5.11	3.36	0.66
4	2	20	27.9	0.122	3.430E+05	1.189E+06	0.49	) 7	7 3	1.50	2.00	15.31	27.05	1.77	0.4572	0.610	4.15	0.68	0.16

Table 4: Distillation Column Sizing for Each Unit Size

			Co	osting											
	Dedecanizer														
Cp0, Tower	Cp0, Tower Cp0, Trays Fp, Tower Fp, Trays Fq, Trays CBM, Trays CBM, Tower CBM, Total (2001) CBM, Total (2022)														
8672.49	1207.78	1.19		1.00	\$7,976	\$38,303	\$46,279	\$85,098							
5760.09	844.43	0.96	1.00	1.00	\$5,668	\$23,027	\$28,696	\$52,765							
2647.28	773.45	0.73		1.00	\$5,261	\$9,474	\$14,736	\$27,096							

Table 5: Distillation Column Costing for Each Unit Size

Heat Exchangers	E-101	E-102	Heaters	H-101	H-102	H-103		
Туре	U-Tube	U-Tube	Туре	Electric Heater	Electric Heater	Electric Reboiler		
Area (m2)	N/A	31.1	MOC	CS	CS	CS		
Duty (BTU/hr)	56,300,000	4,650,000	Duty (Btu/hr)	16,100,000	6,710,000	13,000,000		
Shell			• • •					
Temperature (°C)	886	141						
Pressure (bar)	34.1	1.59						
Phase	Vapor → Liquid	Vapor → Liquid						
MOC	CS	CS						
Tube								
Temperature (°C)	32.2	32.2						
Pressure (bar)	3.45	3.45						
Phase	Liquid	Liquid						
MOC	CS	CS						
Vessels/Towers/	V 101	V 100	V 102	T 101	T 100	T 102	B 101	B 100
Reactors	V-101	V-102	v-105	1-101	1-102	1-105	R-101	R-102
Temperature (°C)	62.8	140	67.2	26.7	221	403	888	254
Pressure (bar)	33.9	34.1	1.59	33.8	5.37	1.38	34.1	33.4
Orientation	N/A	Horizontal	Vertical	Vertical	Vertical	Vertical	Horizontal	Horizontal
MOC	CS	CS	CS	CS	CS	CS	CS	CS
Size								
Height/Length (m)	N/A	11.5	2.79	N/A	4.53	N/A	N/A	2.87
Diameter (m)	N/A	1.89	1.73	N/A	1.37	N/A	N/A	1.524
Internals	N/A	Heavy Liquid Boot	Mist Eliminator	N/A	Sieve Trays	N/A	N/A	42 Tubes

# Table 6: Large GTL Plant Process Equipment Summary

Heat Exchangers	E-101	E-102	Heaters	H-101	H-102	H-103		
Туре	U-Tube	U-Tube	Туре	Electric Heater	Electric Heater	Electric Reboiler		
Area (m2)	N/A	2.29	MOC	CS	CS	CS		
Duty (BTU/hr)	5,630,000	343,000	Duty (Btu/hr)	1,610,000	545,000	1,190,000		
Shell								
Temperature (°C)	886	141						
Pressure (bar)	34.1	1.59						
Phase	Vapor → Liquid	Vapor $\rightarrow$ Liquid						
MOC	CS	CS						
Tube								
Temperature (°C)	32.2	32.2						
Pressure (bar)	3.45	3.45						
Phase	Liquid	Liquid						
MOC	CS	CS						
Vessels/Towers/	V 101	V 400	V 402	T 101	T 100	T 102	D 101	D 100
Reactors	V-101	V-102	V-103	1-101	1-102	1-105	R-101	R-102
Temperature (°C)	62.8	140	67.2	26.7	221	403	888	254
Pressure (bar)	33.9	34.1	1.59	33.8	5.37	1.38	34.1	33.4
Orientation	N/A	Horizontal	Vertical	Vertical	Vertical	Vertical	Horizontal	Horizontal
MOC	CS	CS	CS	CS	CS	CS	CS	CS
Size								
Height/Length (m)	N/A	5.27	1.30	N/A	4.15	N/A	N/A	1.78
Diameter (m)	N/A	0.86	0.91	N/A	0.457	N/A	N/A	0.75
Internals	N/A	Heavy Liquid Boot	Mist Eliminator	N/A	Sieve Trays	N/A	N/A	42 Tubes

Table 7: Small GTL Plant Process Equipment Summary



Figure 3: Income Effects on NPV



Figure 4: Variable Effects on NPV

		FOAI	K Plant Cost	LARGE					
		Costing	Heuristics fr	om Turton					
Equipment Type	Equipment Description	Name/Tag	мос	E quipment Cost Attribute	Units	Pressure (barg)	Diameter (m)		Final Cost
HEX	Shell & Tube (U-Tube)	Condenser	CS & CS					\$	134,000
HEX	Shell & Tube (U-Tube)	Reboiler	CS & CS					\$	347,000
FTR	Jacketed Nonagitated (simi	lar to price of "process u	nits" CS	5.20	m	35.90	1.52	\$	226,000
Seperator	Horizontial	Three Phase Seperator	CS	32.57	m	33.12	1.89	\$	452,000
Seperator	Vertical		CS	6.69	m	5.37	1.37	\$	71,000
Receiver			CS			2001 Cost:	21770.05	\$	41,000
Trays	Seive		CS			2001 Cost:	7976	\$	15,000
						Tur	ton Total	s	1,286,000
		Proj	ect Prompt C	Costing					
	Base Cost	Base Capacity	Units	Faatan		Consoit	Units		Cost
Syngas Unit	21,620,000		12.2 kg/s	0.67		5.1	kg/s	\$	11,991,000
HI Unit	8,290,000		1.13 kg/s	0.55		7.9	kg/s	S	24,116,000
CO2 Recovery	5,300,000		5.54 kg/s	0.55		1.7	kg/s	\$	2,735,000
Steam Plant	Unit Cost:		300 Usage:	400	Hp			s	120,000
			_		_	Pac	ket Total	\$	38,962,000
				Τα	otal Co	ost for La	rge Unit	\$	40,248,000

# Table 7: FOAK Plant Cost for Large Unit

		FOAK	Plant Cost N	<b>IE DIUM</b>					
Costing Heuristics from Turton									
Equipm ent Type	Equipment Description	Name/Tag	мос	E quipment Cost Attribute	Units	Pressure (barg)	Diameter (m)		Final Cost
HEX	Shell & Tube (U-Tube)	Condenser	CS & CS					\$	105,000
HEX	Shell & Tube (U-Tube)	Reboiler	CS & CS					\$	257,000
FTR	Jacketed Nonagitated (simi	lar to price of "process u	nits" CS	2.80	m <sup>3</sup>	35.90	1.00	\$	163,000
Seperator	Horizontial	Three Phase Seperator	CS	12.35	m <sup>3</sup>			\$	50,000
Seperator	Vertical		CS	3.36	m <sup>3</sup>	5.37	0.91	\$	43,000
Condensate Receiver			CS			2001 Cost:	14847.186	\$	28,000
Trays	Seive		CS			2001 Cost:	5668	\$	11,000
						Tut	ton Total	S	657,000
		Proj	ect Prompt C	Costing					
	Base Cost	Base Capacity	Units	Scaling Factor		Operating Capacity	Units		Cost
Syngas Unit	21,620,000		12.2 kg/s	0.67		2.5	kg/s	\$	7,552,000
HI Unit	8,290,000		1.13 kg/s	0.55		3.5	kg/s	\$	15,553,000
CO2 Recovery	5,300,000		5.54 kg/s	0.55		0.83	kg/s	S	1,868,000
Steam Plant	Unit Cost:		300 Usage:	202	Hp			S	61,000
						Pac	ket Total	\$	25,034,000
				Tota	Cost	for Mediu	ım Unit	\$	25,691,000

Table 8: FOAK Plant Cost for Medium Unit

		FC	)AK Plant SM	IALL					
	Costing Heuristics from Turton								
Equipm ent Type	Equipment Description	Name/Tag	мос	Equipment Cost Attribute	Units	Pressure (barg)	Diameter (m)		Final Cost
HEX	Shell & Tube (U-Tube)	Condenser	CS & CS					\$	95,000
HEX	Shell & Tube (U-Tube)	Reboiler	CS & CS					\$	193,000
FTR	Jacketed Nonagitated (simi	ilar to price of "process v	inits" CS	0.80	m <sup>3</sup>	35.90	0.75	\$	84,000
Seperator	Horizontial	Three Phase Seperator	CS CS	3.09	$m^3$			\$	24,000
Seperator Condensate	Vertical		CS	0.68	m <sup>3</sup>	5.37	0.46	\$	18,000
Receiver			CS			2001 Cost:	8247.97	\$	16,000
Trays	Seive		CS			2001 Cost:	5261	\$	10,000
-						Tur	rton Total	S	440,000
		Pro	ject Prompt (	Costing					
	Base Cost	Base Capacity	Units	Scaling Factor		Operating Capacity	Units		Cost
Syngas Unit	21,620,000		12.2 kg/s	0.67		0.51	kg/s	S	2,565,000
HI Unit	8,290,000	1	1.13 kg/s	0.55		0.78	kg/s	\$	6,755,000
CO2 Recovery	5,300,000	)	5.54 kg/s	0.55		0.17	kg/s	S	770,000
Steam Plant	Unit Cost:	1	300 Usage:	20	Hр			S	6,000
						Pac	cket Total	\$	10,096,000
				Тс	otal C	ost for Sm	all Unit	\$	10,536,000

## Table 9: FOAK Plant Cost for Small Unit

Heat Exchanger Design				Heat Exchanger Utilities						
	Dedecanizer									
				Condenser						
Condenser Duty (BTU/hr)	Ao (m²)	Ср,0	Cbm,2022	Mass Flow Rate (Ib/hr)	kGal/yr	S.F.	Adj. kgal/yr	Costs (\$/yr)		
4.651E+06	31.1	1.797E+04	\$134,479	2.323E+05	2.440E+05		1.952E+05	\$97,600		
1.779E+06	11.9	1.404E+04	\$105,104	8.886E+04	9.333E+04	80%	7.466E+04	\$37,332		
3.430E+05	2.3	1.276E+04	\$95,498	1.713E+04	1.799E+04		1.440E+04	\$7,198		
				Reboiler						
Reboiler Duty (BTU/hr)	Ao (m^2)	Cp,o	Cbm,2022	kWh/h	kWh/yr	S.F.	Adj. kWh/yr	Costs (\$/yr)		
1.300E+07	157.0	2.800E+04	\$346,608	3811.4	3.339E+07		2.671E+07	\$1,068,402		
5.607E+06	67.7	2.078E+04	\$257,145	1643.3	1.440E+07	80%	1.152E+07	\$460,658		
1.189E+06	14.3	1.559E+04	\$192,964	348.4	3.052E+06		2.442E+06	\$97,671		

Table 10: Condenser/Reboiler Sizing and Pricing for Each Unit

		Syngas F	Preheater (ele	ctricity)					
Preheater Duty (BTU/hr)	kWh/h	kWh/yr	S.F.	Adj. kWh/yr	Costs (\$/yr)				
1.612E+07	4724.3	4.138E+07		3.311E+07	\$1,324,31				
8.078E+06	2367.4	2.074E+07	80%	1.659E+07	\$663,63				
1.612E+06	472.4	4.138E+06		3.311E+06	\$132,43				
Preheater (fuel gas)									
Preheater Duty (BTU/hr)	MBtu/hr	MBtu/yr	S.F.	Adj. MBtu/yr	Costs (\$/yr)				
1.612E+07	16120.0	1.412E+08		1.130E+08	\$338,906,88				
8.078E+06	8078.0	7.076E+07	80%	5.661E+07	\$169,831,87				
1.612E+06	1612.0	1.412E+07		1.130E+07	\$33,890,68				
		Syi	ngas Condens	er					
Syngas Condenser Duty (BTU/hr)	Mass Flow Rate (Ib/br)	kGal/yr	S.F.	Adj. kgal/yr	Costs (\$/yr)				
5.627E+07	2.811E+06	2.952E+06		2.362E+06	\$1,180,89				
2.822E+07	1.410E+06	1.481E+06	80%	1.184E+06	\$592,23				
5.630E+06	2.812E+05	2.954E+05		2.363E+05	\$118,15				
	FTR Preheater								
Preheater Duty (BTU/hr)	kWh/h	kWh/yr	S.F.	Adj. kWh/yr	Costs (\$/yr)				
6.710E+06	1966.5	1.723E+07		1.378E+07	\$551,25				
2.671E+06	782.8	6.857E+06	80%	5.486E+06	\$219,43				
5.449E+05	159.7	1.399E+06	1	1.119E+06	\$44,76				

Table 11: Heater Costing for each Unit

Dedecanizer HEX Details										
	Conder	nser (U-Tube)	Reboiler (Thermosyphon)							
	Temp. (°F)	Press. (psi)	Press. (psi)							
Tc,in	90		50	437	26.5					
Tc,out	110		47	516.9	28					
Th,in	284.9		23	490	600					
Th,out	144.2		20	490	598.5					
Cp/hfg	1.001	BTU/Ibm*°F		1203.85	Btu/Ib					
Uo	150	Btu/(F*ft^2*h	ir)	200	Btu/(F*ft^2*hr)					
F		0.9		1						
ΔT,Im		103.03		38.49						
Area (ft <sup>2</sup> )	25	ft2		154	ft2					

Table 12: Condenser/Reboiler Specifications (Steam on reboiler can be negated)

HEX Specifications								
ube	Thermosyphon (Fixed Tube)							
4.1884	К1	4.3247						
-0.25	К2	-0.303						
0.1974	К3	0.1634						
0.0388	C1	0.03881						
-0.113	C2	-0.11272						
0.0818	СЗ	0.08183						
1.35	Fm	1.35						
1.63	B1	1.63						
1.66	B2	1.66						
Tube								
3.8062								
0.8924								
-0.167								
0								
0								
0								
1								
1.63								
1.66								
	EX Sp Jbe 4.1884 -0.25 0.1974 0.0388 -0.113 0.0818 1.35 1.63 1.66 Tube 3.8062 0.8924 -0.167 0 0 0 1.63 1.63 1.63 1.63 1.63 1.66	EX SUSUSITICAT           Ibe         Thermosyphe           4.1884         K1           -0.25         K2           0.1974         K3           0.0388         C1           -0.113         C2           0.0388         C1           -0.113         C2           0.0818         C3           1.63         B1           1.64         B2           Tube            3.8062            0.8924            -0.167            0.0            0.0            1.63         K           1.64         K           1.65         K           1.66         K						

Table 13: Additional Heat Exchanger Sizing Information

Tower/Ti Fa	ray Material ctors		Design Pressures			
Fm, CS	1		Dedecanizer			
FBM, CS	1		P, reb (psi)	P, reb adj.	P,reb (bar)	
$\eta_{Large}$	60.57%		27.9	77.9	5.37	
ŊH <sub>e</sub> den	59.59%					
η <sub>s=20</sub>	58.80%		P	ressure Dro	ops	
			∆P Condens	6	psi	
Colur	nn Costing Fac	tors	∆P Reboiler	1.5	psi	
	Tower	Trays (Sieve)	∆P Stage	0.1	psi	
k1	3.4947	2.9949				
k2	0.4485	0.4465				
k3	0.1074	0.3961		Pressur	e Factor	s
B1	2.25		Cond	enser	Reboiler	
В2	1.82		Fp, debut	1.09	Fp, debut	2.28
Additional	Tower Spacing					
Top Spacing	Bottom Spacing					
(m)	(m)		Conve	ersions		
1.2192	1.8288		psi→bar	0.0689476		
			Gal→lbs	8.34		
CEPC	I Factors		ft→m	0.3048		
CEPCI, 2001	397		ft^2→m^2	0.092903		
CEPCI, 2021	730		psig→psia	14.3		
			$BTU \rightarrow kWh$	0.00029307		
			°F → °C			

Table 14: Additional Distillation Column Sizing Information

Feed Conditions							
Variable	Value	Units					
P <sub>Gauge</sub>	8.3	psig					
P <sub>Absolute</sub>	23.0	psia					
Mist Elimin	ator?	Yes					
$\rho_V$	0.1389	lb					
$\rho_L$	41.02	ft <sup>3</sup>					
$\mu_V$	0.01035						
$\mu_L$	0.3151	Ср					
$W_V$	4141	lb					
$W_L$	21174	hr					
Atmospher	ric Pressure w	ith Respect					
	to Elevation						
Elev (ft)	0	ft					
Elev (m)	0	m					
P <sub>atmospheric</sub>	101325	Pa					
Patmospheric	14.7	psi					

Table 15: Large Condensate Receiver Feed Conditions

2.	2-Phase Separator Sizing							
Variable	Equation	Value	Units					
Q <sub>V</sub>	$Q_V = \frac{W_V}{(3,600)(\rho_V)}$	8	$\frac{ft^3}{s}$					
$Q_L$	$Q_L = \frac{W_L}{(60)(\rho_L)}$	8.60	$\frac{ft^3}{min}$					
U <sub>T</sub>	$U_T = K \left(\frac{\rho_L - \rho_V}{\rho_V}\right)^{1/2}$	6.16	$\frac{ft}{s}$					
$U_V$	$U_T = 0.75 U_T$	4.62	ft/s					
$V_H$	$V_H = (T_H)(Q_L)$	86.031204	ft <sup>3</sup>					
$V_S$	$V_S = (T_S)(Q_L)$	43.015602	ft³					
L/D	From Table 4	1	5					
	$D = \left(\frac{4(V_H + V_S)}{(\pi)(0.6)(L/D)}\right)^{1/3}$	5.67						
D			ft					
A <sub>T</sub>	$A_T = \frac{\pi}{4}D^2$	25.3	ft²					
H <sub>LLL</sub>	$H_{LLL} = 0.5D + 7$	9.83	in					
$A_{LLL}$	From Table 5	2.2	$ft^2$					
$H_V$		2	ft					
$A_V$	From Table 5	8.91	$ft^2$					
L	$L = \frac{V_H + V_S}{A_T - A_V - A_{LLL}}$	9.14	ft					
φ	$\varphi = \frac{H_V}{U_V}$	0.433	s					
U <sub>VA</sub>	$U_{VA} = \frac{Q_V}{A_V}$	0.9	$\frac{ft}{s}$					
$L_{Min}$	$L_{Min} = U_{VA}\varphi$	0.4	ft					
L <sub>Actual</sub>	9.1		ft					
Volume	$V = (I_1, \ldots, I_n)(A_n)$	231	ft <sup>3</sup>					
volume	Actual (AT)	6.54	m <sup>3</sup>					

Table 16: Large Condensate Receiver Sizing

Feed Conditions							
Variable	Value	Units					
P <sub>Gauge</sub>	8.3	psig					
P <sub>Absolute</sub>	23.0	psia					
Mist Elimin	ator?	Yes					
$\rho_V$	0.1539	lb					
$\rho_L$	40.47	ft³					
$\mu_V$	0.009254						
$\mu_L$	0.2864	Ср					
$W_V$	15.94	lb					
$W_L$	3570.6	hr					
Atmospher	ric Pressure w	ith Respect					
	to Elevation						
Elev (ft)	0	ft					
Elev (m)	0	m					
P <sub>atmospheric</sub>	101325	Pa					
Patmospheric	14.7	psi					

Table	17: Medium	Condensate	Receiver	Feed	Conditions
+					

2-	Phase Separat	tor Siz	ing
Variable	Equation	Value	Units
Q <sub>V</sub>	$Q_V = \frac{W_V}{(3,600)(\rho_V)}$	0	$\frac{ft^3}{s}$
$Q_L$	$Q_L = \frac{W_L}{(60)(\rho_L)}$	1.47	$\frac{ft^3}{min}$
U <sub>T</sub>	$U_T = K \left(\frac{\rho_L - \rho_V}{\rho_V}\right)^{1/2}$	5.81	$\frac{ft}{s}$
U <sub>V</sub>	$U_{T} = 0.75 U_{T}$	4.36	ft/s
$V_H$	$V_H = (T_H)(Q_L)$	14.70472	ft <sup>3</sup>
$V_S$	$V_S = (T_S)(Q_L)$	7.3523598	ft <sup>3</sup>
L/D	From Table 4	1	.5
D	$D = \left(\frac{4(V_H + V_S)}{(\pi)(0.6)(L/D)}\right)^{1/3}$	3.15	ft
A <sub>T</sub>	$A_T = \frac{\pi}{4}D^2$	7.8	ft²
H <sub>LLL</sub>	$H_{LLL} = 0.5D + 7$	9.00	in
$A_{LLL}$	From Table 5	1.4	ft²
$H_V$		2	ft
$A_V$	From Table 5	4.95	ft <sup>2</sup>
L	$L = \frac{V_H + V_S}{A_T - A_V - A_{LLL}}$	15.56	ft
φ	$\varphi = \frac{H_V}{U_V}$	0.459	s
U <sub>VA</sub>	$U_{VA} = \frac{Q_V}{A_V}$	0.0	$\frac{ft}{s}$
$L_{Min}$	$L_{Min} = U_{VA}\varphi$	0.0	ft
$L_{Actual}$	15.6		ft
Volumo	$V = (I \rightarrow )(A \rightarrow )$	121	$ft^3$
volume	V = ( <sup>L</sup> Actual)( <sup>A</sup> T)	3.4309	$m^3$

Table 18: Medium Condensate Receiver Sizing

Feed Conditions			
Variable	Value	Units	
P <sub>Gauge</sub>	8.3	psig	
PAbsolute	23.0	psia	
Mist Elimin	ator?	Yes	
$\rho_V$	0.1542	lb	
$\rho_L$	40.46	ft <sup>3</sup>	
$\mu_V$	0.009189	_	
$\mu_L$	0.2855	Ср	
$W_V$	3.636	lb	
$W_L$	671.82	hr	
Atmospher	ric Pressure w	ith Respect	
	to Elevation		
Elev (ft)	0	ft	
Elev (m)	0	m	
Patmospheric	101325	Pa	
P <sub>atmospheric</sub>	14.7	psi	

2-Phase Separator Sizing				
Variable	Equation	Value	Units	
Q <sub>V</sub>	$Q_V = \frac{W_V}{(3,600)(\rho_V)}$	0.0065	$\frac{ft^3}{s}$	
$Q_L$	$Q_L = \frac{W_L}{(60)(\rho_L)}$	0.28	$\frac{ft^3}{min}$	
U <sub>T</sub>	$U_T = K \left( \frac{\rho_L - \rho_V}{\rho_V} \right)^{1/2}$	5.81	$\frac{ft}{s}$	
$U_V$	$U_{T} = 0.75U_{T}$	4.36	ft/s	
$V_H$	$V_H = (T_H)(Q_L)$	2.7674246	ft <sup>3</sup>	
$V_S$	$V_S = (T_S)(Q_L)$	1.3837123	ft <sup>3</sup>	
L/D	From Table 4	1	.5	
D	$D = \left(\frac{4(V_H + V_S)}{(\pi)(0.6)(L/D)}\right)^{1/3}$	3.00	ft	
A <sub>T</sub>	$A_T = \frac{\pi}{4} D^2$	7.1	$ft^2$	
$H_{LLL}$	$H_{LLL} = 0.5D + 7$	9.00	in	
$A_{LLL}$	From Table 5	1.4	ft <sup>2</sup>	
$H_V$		2	ft	
$A_V$	From Table 5	4.71	$ft^2$	
L	$L = \frac{V_H + V_S}{A_T - A_V - A_{LLL}}$	4.26	ft	
φ	$\varphi = \frac{H_V}{U_V}$	0.459	s	
U <sub>VA</sub>	$U_{VA} = \frac{Q_V}{A_V}$	0.0	$\frac{ft}{s}$	
$L_{Min}$	$L_{Min} = U_{VA}\varphi$	0.0	ft	
$L_{Actual}$	4.3		ft	
Volumo	$V = (I_{1},, )(A_{-})$	30	$ft^3$	
volume	- (LActual)(AT)	0.8532	$m^3$	

Table 20: Small Condensate Receiver Sizing

	Large	Unit			0.502	( )-0.226
Dedecanizer		$\eta_{section}$	$\eta_{section} = 0.503(\mu_L \alpha)$			
	μ	K (light)	K (heavy)	500107		
Tray 1	0.2533	0.2713	0.1455			
Tray 2	0.3548	0.4530	0.2539		α	1.6111
Tray 3	0.2544	1.0445	0.6450		η <sub>zLage</sub>	60.57%
Tray 4	0.2285	1.6734	1.0921			
Avg.	0.2728	0.8605	0.5341			
	Mediu	m Unit				
	Dedeo	anizer			α	1.6283
	μ	K (light)	K (heavy)		η, <sub>Medium</sub>	59.59%
Tray 1	0.2739	0.2205	0.1142			
Tray 2	0.3926	0.3790	0.2069			
Tray 3	0.2642	0.9271	0.5650			
Tray 4	0.2296	1.4945567	0.9693002			
Avg.	0.2901	0.7552933	0.4638618			
	Smal	l Unit				
	Dedeo	anizer				
	μ	K (light)	K (heavy)		α	1.6400
Tray 1	0.2740	0.2104	0.1084		η <sub>small</sub>	58.80%
Tray 2	0.4256	0.3771	0.2047			
Tray 3	0.2803	0.9202	0.5563			
Tray 4	0.2422	1.5059	0.9682			
Avg.	0.3055	0.7534	0.4594			

Table 21: O'Connell Correlation for Tray Efficiency

Feed Conditions			
Variable	Value	Units	
Pgauge	480.3	psig	
P <sub>absolute</sub>	495.0	psia	
Mist Elimin	ator?	Yes	
$\rho_V$	0.02122	lh	
$\rho_L$	46.11	£+3	
$\rho_H$	61.42	<i>j</i> ι -	
ṁ <sub>ν</sub>	26710	11	
$\dot{m}_{LL}$	71200	10	
ήτ <sub>HL</sub>	2366	hr	
$\mu_V$	1.01E-02	lb	
$\mu_L$	1.417	<i>tD</i>	
$\mu_H$	0.4953	jt * S	

Table 22: Large 3-Phase Separator Feed Conditions

3	3-Phase Separato	or Sizin	g
Variable	Equation	Value	Units
0	$a = W_{V}$	249.64	$ft^3$
ev	$Q_V = \frac{1}{3,600\rho_V}$	343.64	S
2	$a = W_{LL}$	25.74	$ft^3$
<i>e</i> 11	$Q_{LL} = \frac{1}{60\rho_L}$	25.74	min
0	0	0.64	$ft^3$
CRL.	$Q_{HL} = \frac{1}{60\rho_H}$	0.04	min
"	$\mu_{\mu} = \nu \left( \rho_{L} - \rho_{V} \right)^{1/2}$	14 54	ft
07	$b_T = R \left( -\rho_V \right)$	14.04	8
$U_V$	$U_V = 0.75 U_T$	10.90	ft/s
$V_{H}$	$V_H = T_H Q_L$	263.8	$ft^3$
$V_S$	$V_S = T_S Q_L$	131.9	ft"
L/D			3.5
_	$(4(V_{\mu}+V_{c}))^{1/3}$	6.21	
U	$D = \left(\frac{1}{0.6\pi(L/D)}\right)$		n in
	(0.0.1(0,0))	_	ļ
4-	$A_{\pi} = \frac{\pi D^2}{2}$	30.32	ft <sup>2</sup>
nT	4		, - , -
H <sub>V</sub>	Larger of 0.2D or 2.0	2	ft
A.,	$A_{\mu} = u^* A_{\tau}$	8.43	$ft^2$
	Set as minimum from figure		,- ц
	Set as minimum from figure		n
HLLB	Set as minimum from figure	0.5	ft
ALLY	$A_{LLV} = y * A_T$	3.16	$ft^2$
	$V_H + V_S$		
L	$L = \frac{n}{A_T - A_V - A_{UV}}$	21.12	ft
+	A - U (U	0.192	-
φ 77	$\phi = H_V / U_V$	0.103	S ft/a
1	$V_{AV} = Q_V / A_V$	41.3	10/2
L-min	$L_{min} = O_{VA} \Phi$	1.0	n 6
Lactual		21.1	rt Ci
$U_{HL}$	$U_{\mu\mu} = \frac{k_S(\rho_R - \rho_L)}{k_S(\rho_R - \rho_L)}$	1.76	72
	$\mu_L$		s
tur	$t_{HL} = \frac{12(H_{LLB} + D - H_V)}{T}$	32.12	-
	U <sub>RL</sub>	02.12	<b>1</b>
<u>_</u>	$(A_T - A_V)L$	17.07	
0 <sub>LL</sub>	$\theta_{LL} = \frac{Q_{LL}}{Q_{LL}}$	17.97	s
	t <sub>111</sub> 011	37.76	
Ladjurtod	$L = \frac{1}{(A_{\tau} - A_{v})}$	0	ft
LIU			6.08
$H_{HLL}$	$H_{HLL} = D - H_V$	4.21	ft
A <sub>NLL</sub>	$A_{NLL} = A_{LLV} + V_H/L$	10.14	ft²
H <sub>NLL</sub>	From Table 3	21.89	ft
H <sub>HL</sub>	Guess	2	ft
U.,,	$U_{LH} = \frac{k_S(\rho_H - \rho_L)}{k_S(\rho_H - \rho_L)}$	5.04	ft
	μ <sub>H</sub>	0.04	8
UP	$U_{P} = 0.75U_{LH}$	3.78	ft/s
	4 - 120		
DB	$D_B = \left(\frac{4 * 12Q_{BL}}{2}\right)$	1.61	ft
	$\sqrt{\pi U_P}$		
	12H <sub>R</sub>	0.00	_
t <sub>LH</sub>	$U_{LH} = U_{LH}$	2.38	s
	$\pi D_n^2 H_{\mu\mu}$		
$\theta_{HL}$	$\theta_{HL} = \frac{1}{40} \frac{1}{100}$	5.59266	s
	7%HL		613
V <sub>Verrel</sub>		1145	/t <sup>-3</sup>
V <sub>Boot</sub>	5.10 / ft <sup>3</sup>		
V		1150	ft"
- 18441		32.6	$m^3$

Table 23: Large 3-Phase Separator Sizing

Feed Conditions			
Variable	Value	Units	
Pgauge	480.3	psig	
Pabsolute	495.0	psia	
Mist Elimin	ator?	Yes	
$\rho_V$	0.0217	lh	
$\rho_L$	46.22	£+3	
$\rho_H$	61.5	,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,	
ṁ <sub>V</sub>	13930		
π̀ <sub>LL</sub>	31340	<u>10</u>	
ήτ <sub>HL</sub>	1332	hr	
$\mu_V$	1.01E-02	lb	
$\mu_L$	1.472	10 ft = 5	
$\mu_H$	0.5088	Jt * S	

Table 24: Medium 3-Phase Separator Feed Conditions

3	<b>3-Phase Separato</b>	or Sizin	g
Variable	Equation	Value	Units
0	$w_{y}$	170.00	$ft^3$
$Q_V$	$Q_V = \frac{1}{3,600\rho_V}$	178.32	8
0	$a = W_{LL}$	11.20	$ft^3$
QIT.	$Q_{LL} = \frac{1}{60\rho_L}$	11.30	min
0,,,	$o_{HL} = \frac{W_{HL}}{W_{HL}}$	0.36	$ft^3$
CHL.	60 <i>ρ</i> <sub>H</sub>	0.00	min
U <sub>7</sub>	$U_T = K \left(\frac{\rho_L - \rho_V}{\rho_L}\right)^{1/2}$	14.39	ft
	$\rho_{\gamma}$ /	10.90	S ft/c
V.	$V_{\nu} = T_{\nu}O_{\nu}$	116.6	ft <sup>3</sup>
V <sub>R</sub> V <sub>c</sub>	$V_{e} = T_{e}O_{e}$	58.3	$ft^3$
L/D	-33 41		3.5
	1/3	4.73	
D	$D = \left(\frac{4(V_H + V_s)}{2(s_1 + V_s)}\right)^{1/2}$		ft
	$(0.6\pi(L/D))$		1
	$1 - \pi D^2$	17.60	<b>6</b> •2
AT	$A_{T} = -\frac{1}{4}$	11.00	<i>J</i> .
H <sub>V</sub>	Larger of 0.2D or 2.0	2	ft
Δ	A= u*A.	7.07	ft <sup>2</sup>
н	Set as minimum from figure	1	,- њ
Π <u>ιι</u> γ	Set as minimum from figure		н 6
H <sub>LLB</sub>	Set as minimum from figure	0.5	nt .
ALLY	$A_{LLV} = y * A_T$	2.71	ft²
	$V_H + V_S$	22.27	
L	$L = \frac{1}{A_T - A_V - A_{LLV}}$	22.31	IC I
ф	$\Phi = H_V / U_V$	0.185	s
UVA	$U_{AV} = Q_V / A_V$	25.2	ft/s
L <sub>min</sub>	$L_{min} = U_{VA} \Phi$	4.7	ft
Lactual		22.4	ft
	$k_S(\rho_R - \rho_L)$	1.00	ft
OHL	$D_{HL} \equiv \frac{\mu_L}{\mu_L}$	1.63	s
•	$t_{} = \frac{12(H_{LLB} + D - H_V)}{12(H_{LLB} + D - H_V)}$	00.00	
°HL	• <sub><i>HL</i></sub> = <i>U</i> <sub><i>HL</i></sub>	22.93	s
-	$(A_{x} = A_{y})L$		
$\theta_{LL}$	$\theta_{LL} = \frac{(AT - AT)^2}{Q_{LL}}$	20.84	s
	tur, 0, ,	24.61	
Ladjurtod	$L = \frac{-m_{e} + m_{e}}{(A_{T} - A_{V})}$	24.01	ft
			E 20
L/D		0.70	5.20
H <sub>HLL</sub>	$H_{HLL} = D - H_V$	2.73	ft F+2
A <sub>NLL</sub>	$A_{NLL} = A_{LLV} + V_H/L$	10.52	/ <sup>1-</sup>
n <sub>NLL</sub>	From Table 3	10.53	n 6
n <sub>HL</sub>	Buess		r( 6+
$U_{LH}$	$U_{LH} = \frac{\kappa_{S}(\rho_{H} - \rho_{L})}{\mu_{H}}$	4.90	<u>/ 1</u>
11	11 0.7511	2.67	° f+/a
Up	0 <sub>P</sub> = 0.730 <sub>LH</sub>	3.01	10/0
n	4 * 12Q <sub>HL</sub>	1 22	
DB	$D_B = \pi U_P$	1.23	I.C.
	12H <sub>12</sub>		
$t_{LH}$	$t_{LH} = \frac{n}{U_{LH}}$	2.45	s
	πD <sup>2</sup> H		
$\theta_{HL}$	$\theta_{HL} = \frac{\pi \omega_p n_{HL}}{40.00}$	5.53043	s
	TGHL	499	643
V <sub>Verrel</sub>		433	f t-3
V <sub>Boot</sub>	2.95 / t <sup>a</sup>		
VTetel		436	Jt
		12.3	m <sup>.,</sup>

Table 25: Medium 3-Phase Separator Sizing

Feed Conditions			
Variable	Value	Units	
Pgauge	480.3	psig	
Pabsolute	495.0	psia	
Mist Elimin	ator?	Yes	
$\rho_V$	0.02168	lh	
$\rho_L$	46.46	£+3	
$\rho_H$	61.45	<i>J1</i> -	
ṁ <sub>V</sub>	2753	11.	
<i>ṁ</i> LL	6781	10	
π̀ <sub>HL</sub>	214.6	hr	
$\mu_V$	1.00E-02	115	
$\mu_L$	1.673	<u></u>	
$\mu_H$	0.5011	Jt * S	

Table 26: Small 3-Phase Separator Feed Conditions

3	<b>B-Phase Separato</b>	or Sizin	g
Variable	Equation	Value	Units
0	$a = W_{V}$	25.27	$ft^3$
80	$Q_V = \frac{1}{3,600\rho_V}$	35.27	S
0	$a = W_{ll}$	2.42	$ft^3$
QШ	$Q_{LL} = \frac{1}{60\rho_L}$	2.43	min
0	$Q_{m} = \frac{W_{HL}}{W_{HL}}$	0.06	$ft^3$
<b>6</b> <i>H</i> L	<i>ωn.</i> 60 <i>ρ<sub>H</sub></i>	0.00	min
U.	$U_{T} = K \left( \frac{\rho_{L} - \rho_{V}}{\rho_{L}} \right)^{1/2}$	14.44	ft
	μ ( ρ <sub>ν</sub> )	10.00	S Stale
<i>U<sub>V</sub></i>	$U_V = 0.75 U_T$	10.83	Jt/S 6+3
V <sub>R</sub>	$V_H = I_H Q_L$ $V_L = T_L Q_L$	24.3	ft <sup></sup> ft <sup>3</sup>
VS L/D	$v_S = I_S Q_L$	12.0	35
2/2		2.83	0.0
П	$D = \left(\frac{4(V_H + V_s)}{1/3}\right)^{1/3}$	2.00	ft
-	$D = \left( 0.6\pi (L/D) \right)$		
	$\pi D^2$		
$A_T$	$A_T = -4$	6.29	ft <sup>z</sup>
Н.,	Larger of 0.2D or 2.0	2	fe
,		4.75	r. 2
Α <sub>γ</sub>	$A_{\rm V} = 9 A_{\rm T}$	4.15	<i>J</i> t-
HLLY	Set as minimum from figure	1	ft
H <sub>llb</sub>	Set as minimum from figure	0.5	ft
ALLY	$A_{LLV} = y * A_T$	1.99	$ft^2$
	$V_H + V_s$		
L	$L = \frac{L}{A_T - A_V - A_{UV}}$	-82.86	ft
*	φ = H /Π	0 185	<i>c</i>
Ψ	$\Psi = H_V / \delta_V$ $H_{vv} = O_v / A_v$	7.4	s ft/s
L.	$U_{AV} = Q_V / A_V$	1.4	/ - / - 2 ft
D <sub>mm</sub>	$\sigma_{min} = \sigma_{VA} \phi$	14	6
Lactual	k (a = a )	1.4	ft
$U_{HL}$	$U_{HL} = \frac{\kappa_S(p_H - p_L)}{n_s}$	1.46	1 2
	$\mu_L$ 12( $H_{UP} + D - H_V$ )	<b>•</b>	-
$t_{HL}$	$t_{HL} = U U U U U U U U U U U U U U U U U U U$	10.92	s
$\theta_{LL}$	$\theta_{II} = \frac{(A_T - A_V)L}{(A_T - A_V)L}$	0.87	s
	Qui		
Laura	$L = \frac{\tau_{HL}Q_{LL}}{(A - b)}$	17.29	ft
- 44100 (24	$(A_{\gamma} - A_{V})$		
L/D			6.11
H <sub>HLL</sub>	$H_{HLL} = D - H_V$	0.83	ft
$A_{NLL}$	$A_{NLL} = A_{LLV} + V_H/L$	3.43	ft²
H <sub>NLL</sub>	From Table 3	1.54	ft
$H_{HL}$	Guess	2	ft
Urn	$U_{LH} = \frac{k_S(\rho_H - \rho_L)}{k_S(\rho_H - \rho_L)}$	4.88	ft
- 1.01	<sup>µ</sup> H		S
Up	$U_{P} = 0.75U_{LH}$	3.66	ft/s
	4 + 120		
DB	$D_B = \left  \frac{1 + 2 D_{QHL}}{\pi U_0} \right $	0.49	ft
	V nop		
t <sub>LH</sub>	$t_{LH} = \frac{12H_H}{H}$	2.46	s
	U <sub>LH</sub>		
θ	$\theta_{HL} = \frac{\pi D_p^2 H_{HL}}{2}$	4 79235	5
- HL	$4Q_{HL}$	4.10200	-
Vyerrel		109	$ft^3$
VBaat		0.48	ft <sup>3</sup>
u		109	ft <sup>3</sup>
V Tatal		3.1	$m^3$

Table 27: Small 3-Phase Separator Sizing

## Function File Code

function f = FTRFunctionFinal(W,Y) X = Y(1);z = Y(2);T = Y(3);Ta = Y(4);Dt = 20; % cmTube = 42;db = 0.8; %gm/cm^3 mc = 395000; %g/hr Vt = W/db; Vtft = Vt\*3.53\*10^-5; Vtotal=Vtft\*Tube %ft^3 F1o = 60922/Tube; %CO F2o = 122434/Tube; %H2 F3o = 259/Tube; %H2O F4o = 0; %C Chain F5o = 16254/Tube; %CH4 F6o = 42/Tube; %02

F7o = 636/Tube; %CO2

```
Fi = F5o+F6o+F7o;
```

Fto = F1o+F2o+F3o+F4o+Fi;

S1 = 1;

S2 = 2;

- S3 = 1;
- S4 = 1;

02 = F20/F10;

O3 = F30/F10;

04 = F40/F10;

 $F1 = F10^{*}(1-X);$ 

- F2 = F1o\*(02-(S2/S1)\*X);
- F3 = F1o\*(03+(S3/S1)\*X);
- F4 = F1o\*(04+(S4/S3)\*X);
- Ft = F1+F2+F3+F4+Fi;

To = 505;

```
T1 = exp((-4492)*((1/T)-(1/473)));
```

- T2 = exp(8237\*((1/T)-(1/473)));
- Pto = 32;

P1o = Pto\*0.331;

P2o = Pto\*0.6251;

P3o = Pto\*0.0013;

P4o = Pto\*0;

Pio = (Fi/Fto)\*Pto;

- $P1 = Pto^{*}(F1/Ft)^{*}(T/To)^{*}z;$
- $P2 = Pto^{*}(F2/Ft)^{*}(T/To)^{*}z;$
- P3 = Pto\*(F3/Ft)\*(T/To)\*z;
- $P4 = Pto^{*}(F4/Ft)^{*}(T/To)^{*}z;$
- Pi = Pto\*(Fi/Ft)\*(T/To)\*z;
- Pt = P1+P2+P3+P4+Pi;

k = 0.173;

k2 = 4.512;

Cp1 = 0.0282; %BTU/g\*K

- Cp2 = 0.0275;
- Cp3 = 0.0549;
- Cp4 = 0.0438;
- Cp5 = 0.0438;
- Cp6 = 0.0295;
- Cp7 = 0.0423;
- Cpc = 0.0459;

Hrx = -154.444; %BTU/gmole CO

Do = 0.00885; %gm/cm^3

 $D = Do^{*}(Pt/Pto)^{*}(T/To)^{*}(Ft/Fto);$
por = 0.4;

dc = db/(1-por);

u = 57804; %cm/hr

 $G = u^*D;$ 

```
Ua = abs((0.385*((G)^(0.8)))/(Dt^(0.2)));
```

a = 0.00000305; %differ from excel

```
r1 = (-k*T1*P2*P1)/((1+k2+T2*P1)^2);
```

dXdW = -r1/F10;

dzdW = ((-a)/(2\*z))\*(T/To)\*(Ft/Fto)\*1.5;

dTdW = (r1\*Hrx-(Ua\*(T-Ta)/dc))/(F1\*Cp1+F2\*Cp2+F3\*Cp3+F4\*Cp4+F5o\*Cp5+F6o\*Cp6+F7o\*Cp7);

dTadW = ((Ua/dc)\*(T-Ta))/(mc\*Cpc);

```
f = [dXdW;dzdW;dTdW;dTadW];
```

end

```
Script Code
```

clc

Wspan = [0,100000]; %Range for independent variable or catalyst weight % list values for dependent variables in order 1Conversion 2Pressure Drop %Guy-Lussac for temp and pressure y0 = [0,1,505,451]; % Initial Values for 0, 1, 473, 298

 $\ensuremath{\texttt{\%FTRNoP}}$  sees only conversion, Reactor Temp and Coolant Temp

```
[W, y] = ode78(@FTRFunctionFinal,Wspan,y0);
```

```
%Plotting this stuff
```

%Conversion

plot(W,y(:,1));

%legend('Catalyst Weight','Conversion')

```
ylabel('Conversion');
```

xlabel('Catalyst Weight');

figure;

%Pressure Drop

%plot(W,y(:,2));

```
%legend('Catalyst Weight','Conversion')
```

```
%ylabel('Pressure Drop');
```

```
%xlabel('Catalyst Weight');
```

%figure;

%CHANGED THE ARRAY POSTIONS

```
%Reactor Temperature
```

```
plot(W,y(:,3));
```

```
%legend('Catalyst Weight','Conversion')
```

```
ylabel('Reactor Temperature');
```

```
xlabel('Catalyst Weight');
```

```
%figure;
```

%Coolant Temperature

```
%plot(W,y(:,4));
```

```
%legend('Catalyst Weight','Conversion')
```

```
%ylabel('Coolant Temperature');
```

```
%xlabel('Catalyst Weight');
```