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Sunlight to Convert Carbon Dioxide into Transportation Fuels

Scott Danielsen
University of Pennsylvania

Elizabeth Glover
University of Pennsylvania

Kate McCarty
University of Pennsylvania

Luisa Valle
University of Pennsylvania

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Abstract
The proposed plant to convert sunlight and carbon dioxide to transportation fuels will utilize a Counter-Rotating Ring Receiver Reactor Recuperator (CR5) to convert carbon dioxide into carbon monoxide gas and oxygen gas. The CR5 is a solar chemical heat engine that provides an environment for the continuous reduction/oxidation of iron oxide, which allows for the reaction of carbon dioxide to carbon monoxide and oxygen. The plant will contain 150 CR5s each attached to its own parabolic mirror dish in order to collect sunlight. A carbon dioxide feed of approximately 25,070 kg/hr will be used to produce 9,520 kg/hr carbon monoxide. The devices will then feed a mixture of carbon dioxide and carbon monoxide gas to both a water gas shift reactor and a Fischer-Tropsch reactor. The Fischer- Tropsch reactor will use the carbon monoxide along with hydrogen gas produced from the water gas shift reactor to produce a range of hydrocarbon products following an Anderson- Schulz-Flory distribution centered around octane. The FT oil products (naphtha, gasoline, diesel, heavy ends) will be sold while the light-end products will be used to meet the utility requirements of the plant itself.

The plant will be located in the western part of Texas in the Mojave Desert in order to take advantage of the high solar flux in this region. Due to the necessity of sunlight to provide energy for the CR5 reaction, the production of carbon monoxide will only take place during daylight hours and 2 hours worth of carbon monoxide production along with an excess of 10% of this amount will be stored in floating roof storage tanks. The storage of some extra carbon monoxide will keep the startup and shutdown production of petrol product constant as the sun rises and sets. The water gas shift reactions and Fischer- Tropsch reactors will operate for as long as carbon monoxide is available and will shut down once the carbon monoxide is depleted.

Assuming a discount rate of 13%, the project yields a -$5.5 billion NPV over a 30 year time period. Based on this negative net present value, the plant proves to be economically unattractive. This result is primarily driven by high operating costs due to the high stress put on expensive catalysts that require frequent replacement as well as daily startup/shutdown costs.

The largest negative economic factors in the plant projections are related to operating expenses. Specifically, the daily startup and shutdown costs associated with the CR5, WGS and FT reactors are significant. A related factor is the replacement cost of catalysts due to the high amounts of stress associated with daily shutdown, which requires 1 the catalysts to be replaced every 5 years. Storage tanks for continuous operation were considered, which would require 134 storage tanks total. This option is potentially more economically attractive; however, continuous operation was still discounted because the cost of maintenance, piping equipment costs, and other logistical challenges associated with housing the storage tanks. In addition, this option still produces a negative NPV after 30 years.

Finally, the compressor operation requires significant electricity, factoring into the economic unattractiveness of the operation of this plant. These variables all lead to a negative net present value and negative cash on hand throughout thirty years of operation. Consequently, unless technological advancements can be made to change the fundamental operations of the sunlight to transportation fuel plant, the investment is not recommended.

Disciplines
Biochemical and Biomolecular Engineering | Chemical Engineering | Engineering

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Scott Danielsen

Elizabeth Glover

Kate McCarty

Luísa Valle

Advisor:
Prof. Talid Sinno

Project Originator:
Dr. Matthew Targett

April 15, 2014

Prof. Leonard Fabiano
Prof. Talid Sinno
Dr. Matthew Targett
Department of Chemical and Biomolecular Engineering
University of Pennsylvania
Philadelphia, PA 19104

April 15th, 2014

Prof. Fabiano, Prof. Sinno, and Dr. Targett,

The following report consists of our CBE 459 Process System Senior Design Project, "Sunlight to Convert Carbon Dioxide into Transportation Fuels," proposed by Dr. Matthew Targett. The plant design utilizes a propriety Counter Rotating Ring Receiver Reactor Recuperator (CR5) heat engine reactor to split carbon dioxide into carbon monoxide to be used as a feed for a plant utilizing water gas shift and Fischer-Tropsch technologies to produce transportation fuels.

This report focuses primarily on a preliminary plant design and associated profitability analysis. A net present value analysis has been performed in order to determine the viability of this project. This analysis yielded a -$5.5 million NPV over thirty years, using the most likely outcome of several factors.

Based on the analysis presented in the report, we recommend that further design work be undertaken to further refine the design components and investment figures. More work needs to be done by Sandia National Laboratory and other researchers on the CR5, in understanding the technology, improving efficiency, and lowering the projected costs.

Sincerely,

_____	_____
Scott Danielsen	Elizabeth Glover
_____	_____
Katherine McCarty	Luísa Valle

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Section 1 – Abstract

The proposed plant to convert sunlight and carbon dioxide to transportation fuels will utilize a Counter-Rotating Ring Receiver Reactor Recuperator (CR5) to convert carbon dioxide into carbon monoxide gas and oxygen gas. The CR5 is a solar chemical heat engine that provides an environment for the continuous reduction/oxidation of iron oxide, which allows for the reaction of carbon dioxide to carbon monoxide and oxygen. The plant will contain 150 CR5s each attached to its own parabolic mirror dish in order to collect sunlight. A carbon dioxide feed of approximately 25,070 kg/hr will be used to produce 9,520 kg/hr carbon monoxide. The devices will then feed a mixture of carbon dioxide and carbon monoxide gas to both a water gas shift reactor and a Fischer-Tropsch reactor. The Fischer-Tropsch reactor will use the carbon monoxide along with hydrogen gas produced from the water gas shift reactor to produce a range of hydrocarbon products following an Anderson-Schulz-Flory distribution centered around octane. The FT oil products (naphtha, gasoline, diesel, heavy ends) will be sold while the light-end products will be used to meet the utility requirements of the plant itself.

The plant will be located in the western part of Texas in the Mojave Desert in order to take advantage of the high solar flux in this region. Due to the necessity of sunlight to provide energy for the CR5 reaction, the production of carbon monoxide will only take place during daylight hours and 2 hours worth of carbon monoxide production along with an excess of 10% of this amount will be stored in floating roof storage tanks. The storage of some extra carbon monoxide will keep the startup and shutdown production of petrol product constant as the sun rises and sets. The water gas shift reactions and Fischer-Tropsch reactors will operate for as long as carbon monoxide is available and will shut down once the carbon monoxide is depleted.

Assuming a discount rate of 13%, the project yields a -$5.5 billion NPV over a 30 year time period. Based on this negative net present value, the plant proves to be economically unattractive. This result is primarily driven by high operating costs due to the high stress put on expensive catalysts that require frequent replacement as well as daily startup/shutdown costs.

The largest negative economic factors in the plant projections are related to operating expenses. Specifically, the daily startup and shutdown costs associated with the CR5, WGS and FT reactors are significant. A related factor is the replacement cost of catalysts due to the high amounts of stress associated with daily shutdown, which requires

the catalysts to be replaced every 5 years. Storage tanks for continuous operation were considered, which would require 134 storage tanks total. This option is potentially more economically attractive; however, continuous operation was still discounted because the cost of maintenance, piping equipment costs, and other logistical challenges associated with housing the storage tanks. In addition, this option still produces a negative NPV after 30 years.

Finally, the compressor operation requires significant electricity, factoring into the economic unattractiveness of the operation of this plant. These variables all lead to a negative net present value and negative cash on hand throughout thirty years of operation. Consequently, unless technological advancements can be made to change the fundamental operations of the sunlight to transportation fuel plant, the investment is not recommended.

Section 2 – Introduction & Project Charter

As the world population grows and technology expands, there is a huge push to harness new sources of energy. One area of intense research is the energy supplied by the Sun. Annual global energy consumption is supplied via solar radiation to the Earth every 70 minutes.

Solar energy can also be used to power reversed combustion, which provides the raw material for making transportation fuels. Research by Sandia National Laboratory indicates that reverse combustion can be carried out using a parabolic mirrored dish to concentrate solar energy onto a CR5. The CR5 was developed by Dr. Richard Diver and is a proprietary machine still in development. The CR5 is a solar chemical heat engine that provides an environment for the continuous reduction/oxidation of iron oxide. A schematic of the CR5 is shown in Figure 2.1. The CR5 is composed of two chambers, with rings made out of an iron oxide material that, when heated to temperatures around 2,000°C can reduce carbon dioxide. The rings then proceed to rotate to the reduction chamber where the iron oxide material releases an oxygen atom to create oxygen gas. This enables the iron oxide to return to the oxidation chamber ready to accept oxygen from a CO_2 molecule. Both of these reactions are highly endothermic:

$$Fe_3O_4 \rightarrow 3FeO + \frac{1}{2}O_2 \qquad Reduction$$

$$3FeO + CO_2 \rightarrow Fe_3O_4 + CO \qquad Oxidation$$

$$CO_2 \rightarrow CO + \frac{1}{2}O_2 \qquad Overall$$

Each CR5 unit has incoming streams of 18,970 kg/hr of CO_2 and sunlight in order to produce 9,520 kg/hr of CO and 5,440 kg/hr of O_2 based on an average of 10 sunlight hours per day. Each device is comprised of 102 counter-rotating rings, measuring 36 inches in diameter. (Kim, 2011) The rings have 25.4 mm high fins with reactive iron oxide on each fin in order to maximize surface area. Ring spacing is approximately 6.4mm; there each CR5 will be approximately 0.65m deep. (Diver, 2008) Each CR5 is connected to an $88m^2$ parabolic mirrored dish that acts as a solar concentrator.

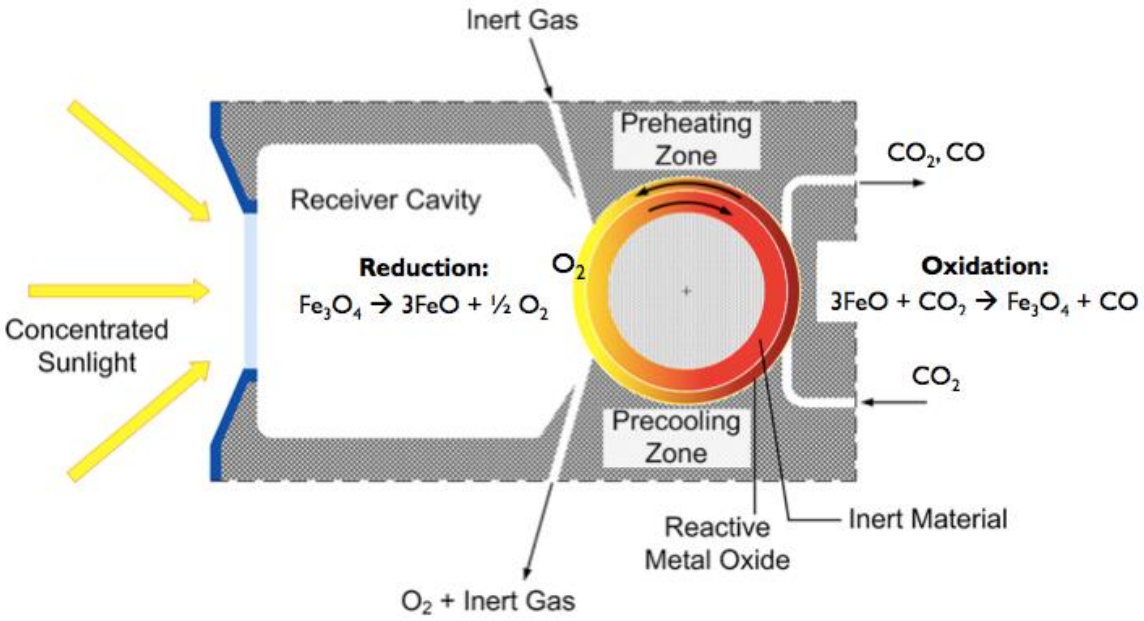

Figure 2.1. CR5 Schematic. Image adapted from J. Lapp, J. H. Davidson, & W. Lipinski.

The CR5 has one chamber for the reduction reaction where the parabolic dish concentrates solar flux in order to provide enough heat energy to drive the endothermic reduction reaction while producing oxygen gas as a byproduct. (Kim, 2011) This chamber operates at 2300 K. (Diver, 2008) The counter-rotating motion of the CR5 allows heat transfer between rings, thus making the CR5 more efficient because hot rings rotating out of the reduction chamber are cooled surrounding counter-rotating rings coming from the oxidation chamber, where the iron oxide is oxidized and carbon monoxide is produced. This chamber operates at 600 K. (Diver, 2008) Both chambers operate at 0.2 atm; therefore, a vacuum is required to create suitable operating conditions. (Diver, 2008)

The counter rotating rings rotate at 0.75 rpm (Diver, 2008.) Each CR5 operates at approximately 25% efficiency (Kim, 2011). The oxygen output from each CR5 is purged while a portion of the carbon monoxide produced by each CR5 is fed to the water gas shift reactor and the remainder is fed to the Fischer-Tropsch reactor. The sunlight to transportation fuels plant will utilize 150 CR5s.

A portion of the carbon monoxide produced by the CR5s is then fed to water gas shift reactors where it is combined with water vapor to produce hydrogen gas. The remaining carbon monoxide along with hydrogen gas from the water gas shift reactions is then fed to Fischer-Tropsch reactors in order to produce a distribution of hydrocarbons including octane and other transportation fuels, which are sold for a profit.

The sunlight to transportation fuels plant will convert 18,970 kg/hr of carbon dioxide and produce 4.3 MM barrels of liquid transportation fuels per year. The plant will be located in the western part of Texas in order to take advantage of the high incidence of solar radiation year round as well as the CO_2 pipelines running through the area, as this will be the source of CO_2 for the plant. In addition, the plant will be co-located with an oil refinery, which will purchase the fuel products directly from the plant and have the necessary equipment for refinement and processing. The product mix produced by the plant will represent a higher quality product than crude oil.

The CR5 reactors are able to run during the day when sunlight is available while the Fischer-Tropsch and water gas shift reactions will run when CO product from the CR5 reactors is available. Storage tanks will be used to hold two hours of CR5 output, in order to create a constant flow rate into the FT and WGS reactors. Additional storage tanks will hold a week's worth of FT fuel that will be sold. In addition, massive amounts of piping must be incorporated into the plant design in order to transport the products of each CR5 reactor to water gas shift reactors and the Fischer-Tropsch reactor.

Section 3 – Technology-Readiness Assessment (Innovation Map)

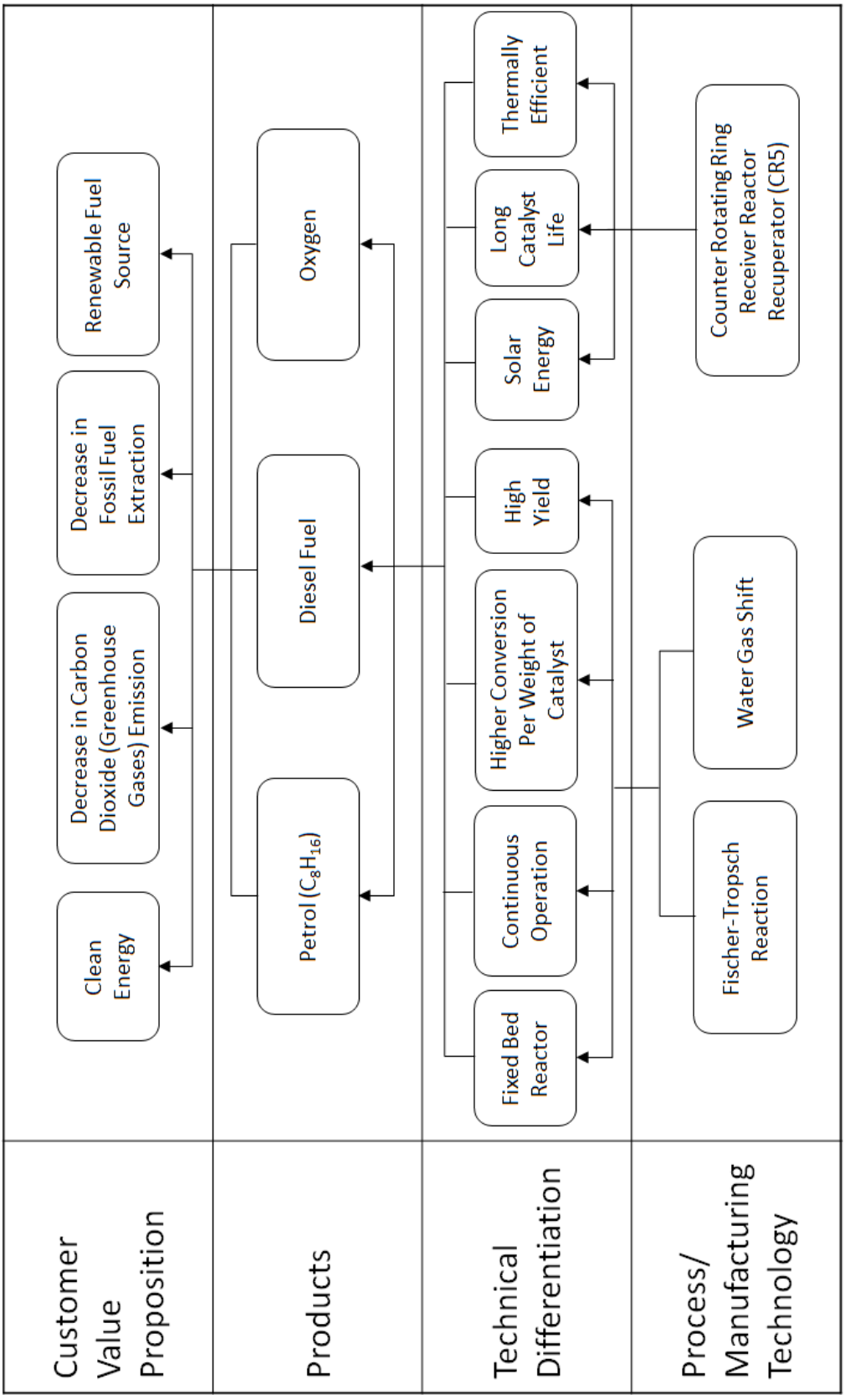

Figure 3.1. Innovation Map.

Section 4 – Market and Competitive Analysis & Customer Requirements

The global demand for crude oil products is massive and continues to grow. In 2013, global petroleum and other liquids consumption averaged 90.4MM barrels per day (bbl/d), a 1.34% increase from 2012, with a 2.1% increase in the United States. This number is expected to grow by 1.2MM bbl/d in 2014 and 1.4MM bbl/d in 2015 (EIA, 2014). Currently, crude oil production involves drilling deep into the Earth, expending energy while releasing carbon dioxide into the atmosphere, which is harmful to the environment. The sunlight to transportation fuels plant would intake carbon dioxide to make oil while releasing oxygen gas and distribution of hydrocarbons as byproducts. Therefore, a sunlight to transportation fuels plant provides and environmentally friendly way to produce high demand products.

Other companies such as Torresol Energy and Brightsource Energy are exploring concentrated solar power in order to produce electricity. Torresol energy is using heliostats, or flat mirrors, with a molten-salt heat storage system in order to produce 19.9MW of electricity. This type of electricity production has made Torresol 1.5-3 times more efficient than other sources of renewable energy. Brightsource energy uses proprietary software to control thousands of heliostats to track the sun during the day and use solar energy to turn turbines to produce electricity. Both plants use energy storage systems to facilitate the production of electricity while the sun is down to avoid startup and shutdown costs.

4.1 Market Analysis (Indirect Competitors)

Three primary forms of energy are used at large scale in the United States: crude oil, natural gas and coal. Crude oil requires refining to create petroleum and petroleum products. These products, including diesel, jet fuel and gasoline, are used as transportation fuels as well as sources of energy for plants and operations. Burning natural gas is a common source of heat for homes, cooking and some natural gas-fueled vehicles. Coal is used to power plants.

Crude oil production in the United States has seen the highest growth in the geographic regions of the Bakken formation in North Dakota/Montana, the Eagle Ford formation in South Texas, and the Gulf of Mexico. The U.S. Energy Information Administration (EIA) indicates increased production in the coming years, as well as expansion of processing by U.S. refineries. This increase in crude oil production primarily

reflects U.S. international policy of decreasing dependence on the Middle East, the former leader in crude oil. In response to higher energy requirements within the United States, the natural gas consumption has also seen increases.

In addition to crude oil and natural gas, coal is a third source of energy, although coal is not used in transportation. The United States coal consumption is on the rise, while exports are projected to remain flat (EIA, 2014).

These three sources of energy hinge greatly on natural resources. As energy consumption within the United States as well as globally, the government and the energy industry are looking to alternative sources of energy.

4.2 Competitive Analysis

Alternative sources of energy can be considered direct competitors to the sunlight to transportation fuel plant. These sources include wind power electricity generation, solar electricity generation, and liquid biofuels. Electricity generation technology affecting transportation fuel demand hinges on significant strides in the electrical vehicle market. Additionally, biofuels are currently not a supported form of fuel in the mass vehicle market. Consequently, these forms of energy are not currently at competition with the sunlight to transportation fuel plant products. It is, though, important to note that the electrical vehicle market is potentially at the verge of high growth, which would have a negative impact on the demand for transportation fuels.

Companies other are in the process of developing concentration solar power (CSP) technology, to harness solar power and generate electricity. These include Abengoa, BrightSource and Torresol Energy. Abengoa's research primarily concentrates on the electricity generation and biofuel production (Abengoa, 2014). BrightSource provides electricity generation and solar enhanced oil recovery for global oil reserves (BrightSource, 2014). Torresol Energy uses central-power technology for solar electricity generation (Torresol Energy, 2014).

Section 5 – Process Flow Diagram

5.1 Process Block Overview

The process flow diagram (Figure 5.2.1) is divided into four sections as an accurate representation of the thrusts of the plant operation. The process can be envisioned as a section containing the array of CR5s and parabolic mirror dishes (Section: CR5), the water gas shift reactor section (Section: WGS), the Fischer-Tropsch reactor section (Section: FT), and the interface between the CR5 array and the rest of the process (Section: Global). Aspen Plus process flow diagrams for each section are shown in Figures 5.3.1 (Section: Global), 5.4.1 (Section: CR5), 5.5.1 (Section: WGS), and 5.6.1 (Section: FT). Table 5.7.1 shows the stream directory for the entire process, detailing the streams entering and exiting each block. Aspen reports and results (input summary, block reports, utilities reports, convergence report, flowsheet balance, & stream results table) shown in Appendix B.

5.2 Aspen Process Flow Diagram

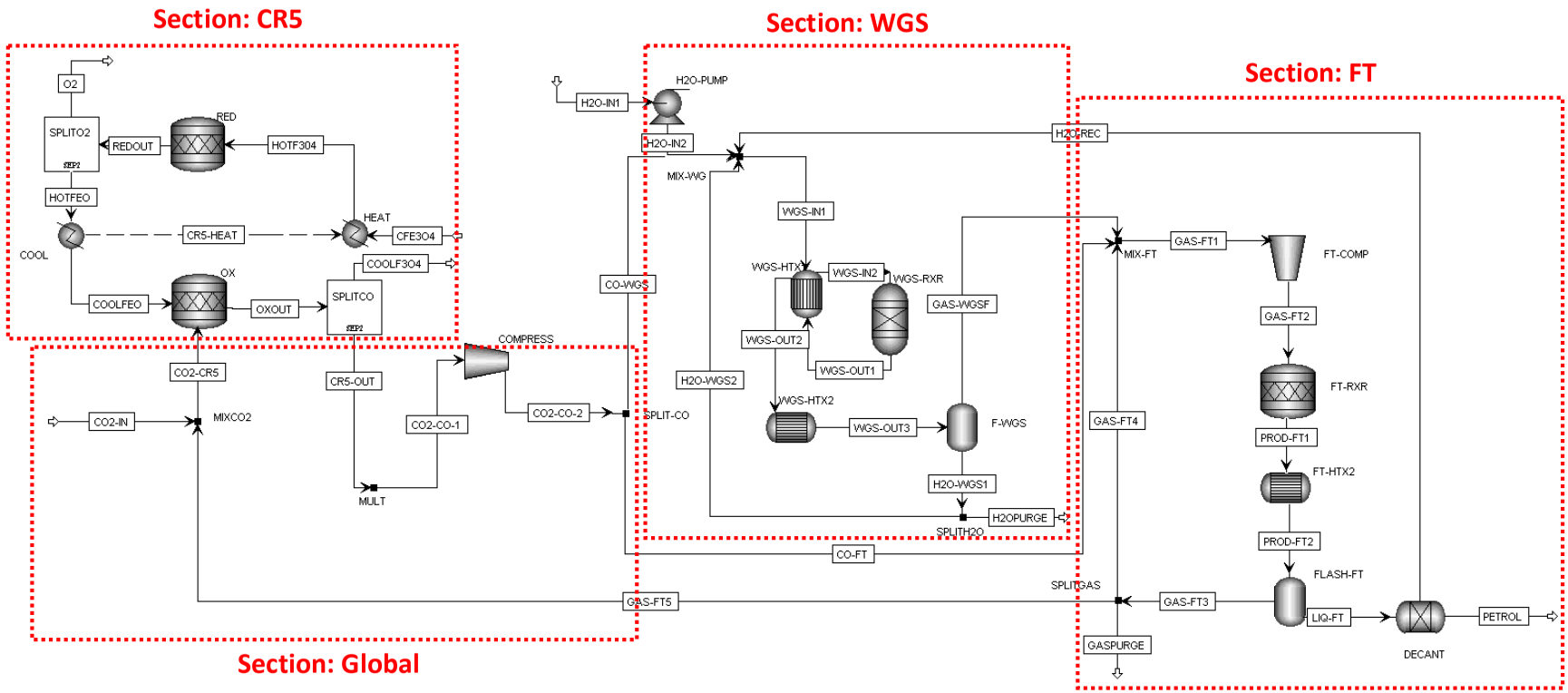

Figure 5.2.1. Aspen Process Flow Diagram.

5.3 Global Section

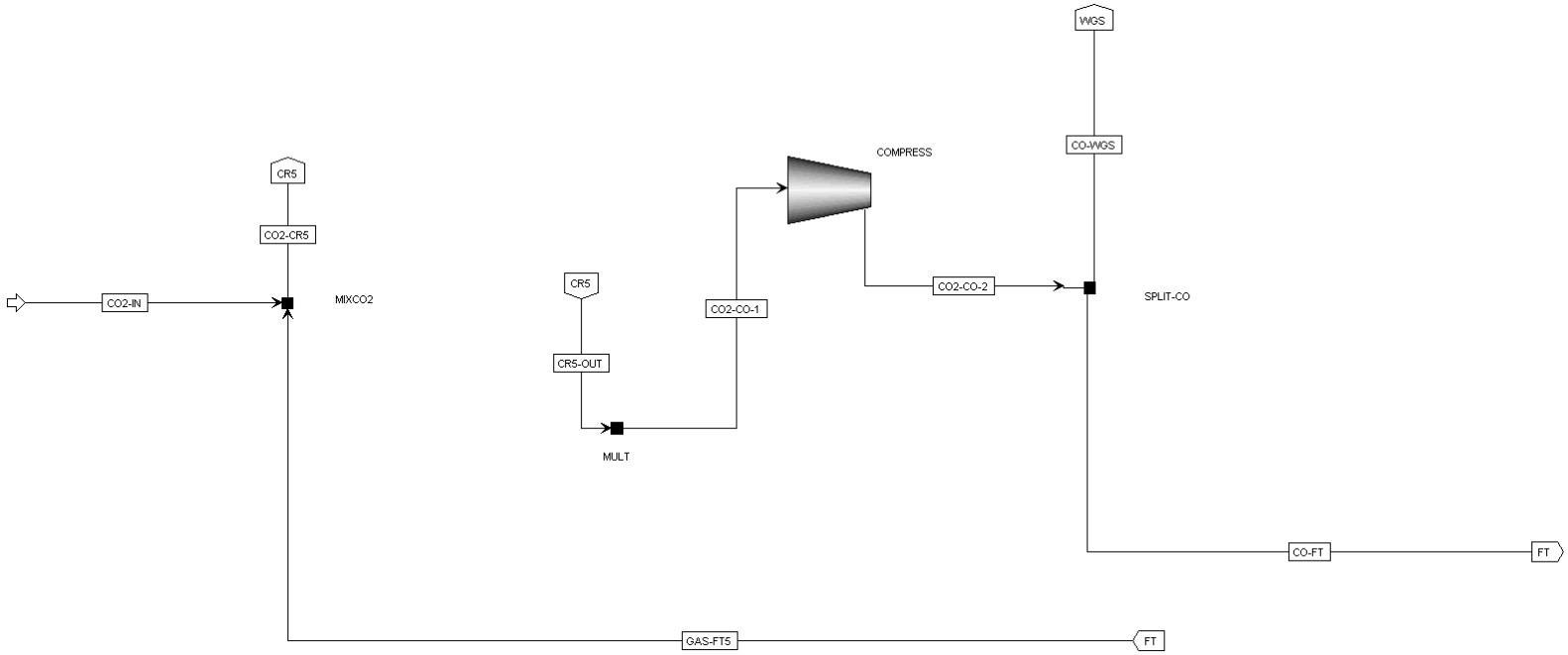

Figure 5.3.1. Aspen Process Flow Diagram for Global Section.

5.4 CR5 Section

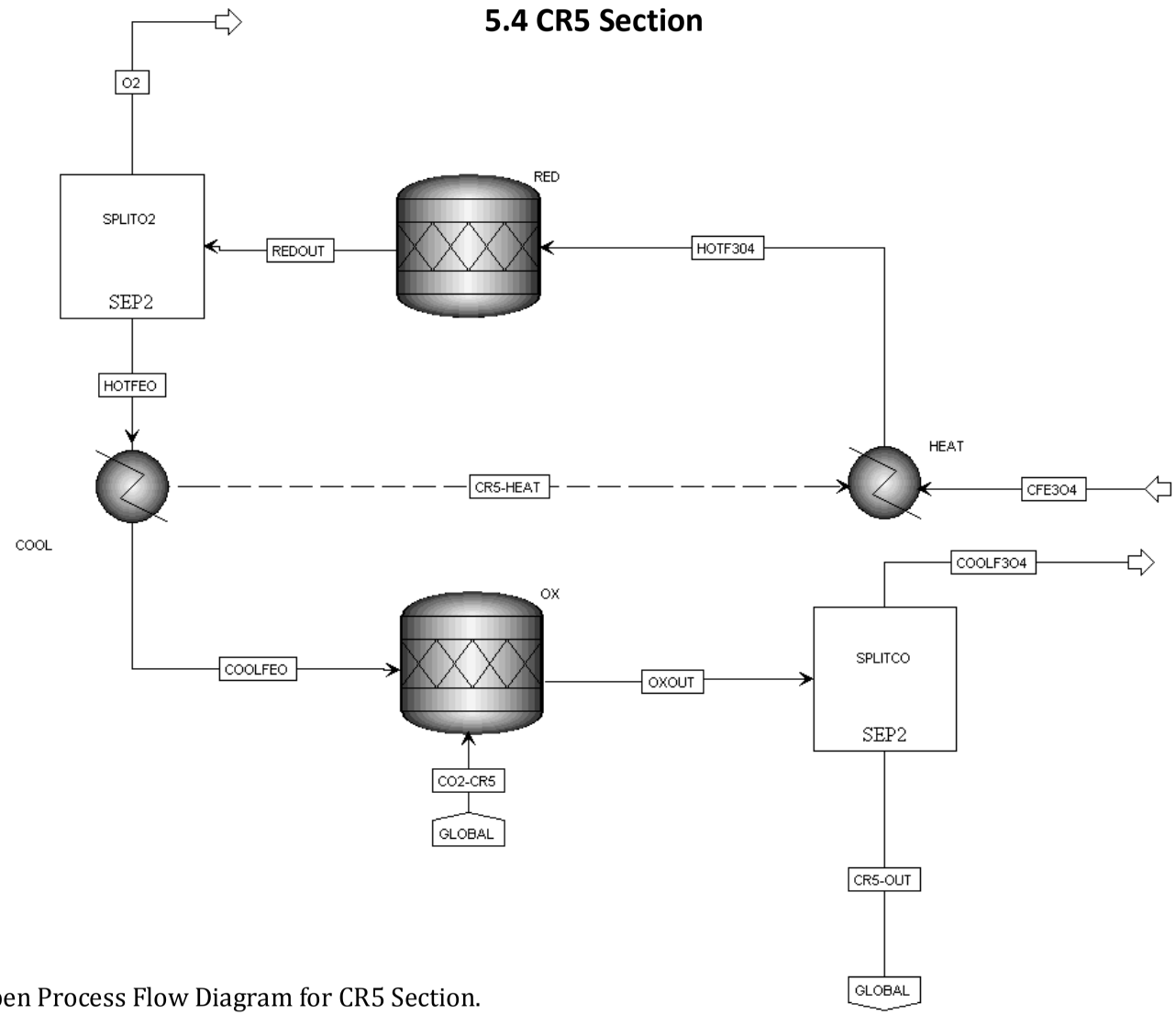

Figure 5.4.1. Aspen Process Flow Diagram for CR5 Section.

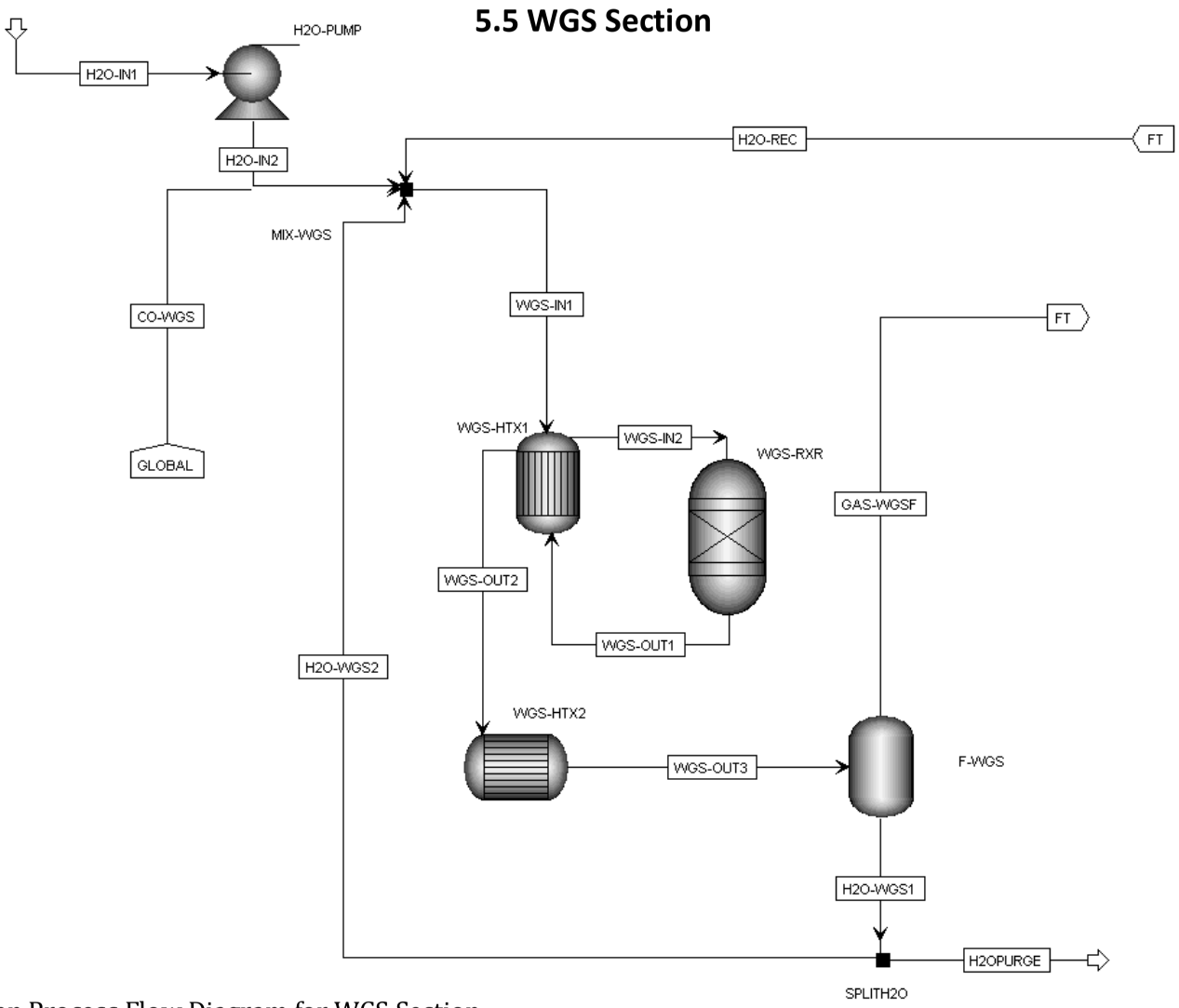

Figure 5.5.1. Aspen Process Flow Diagram for WGS Section.

5.6 FT Section

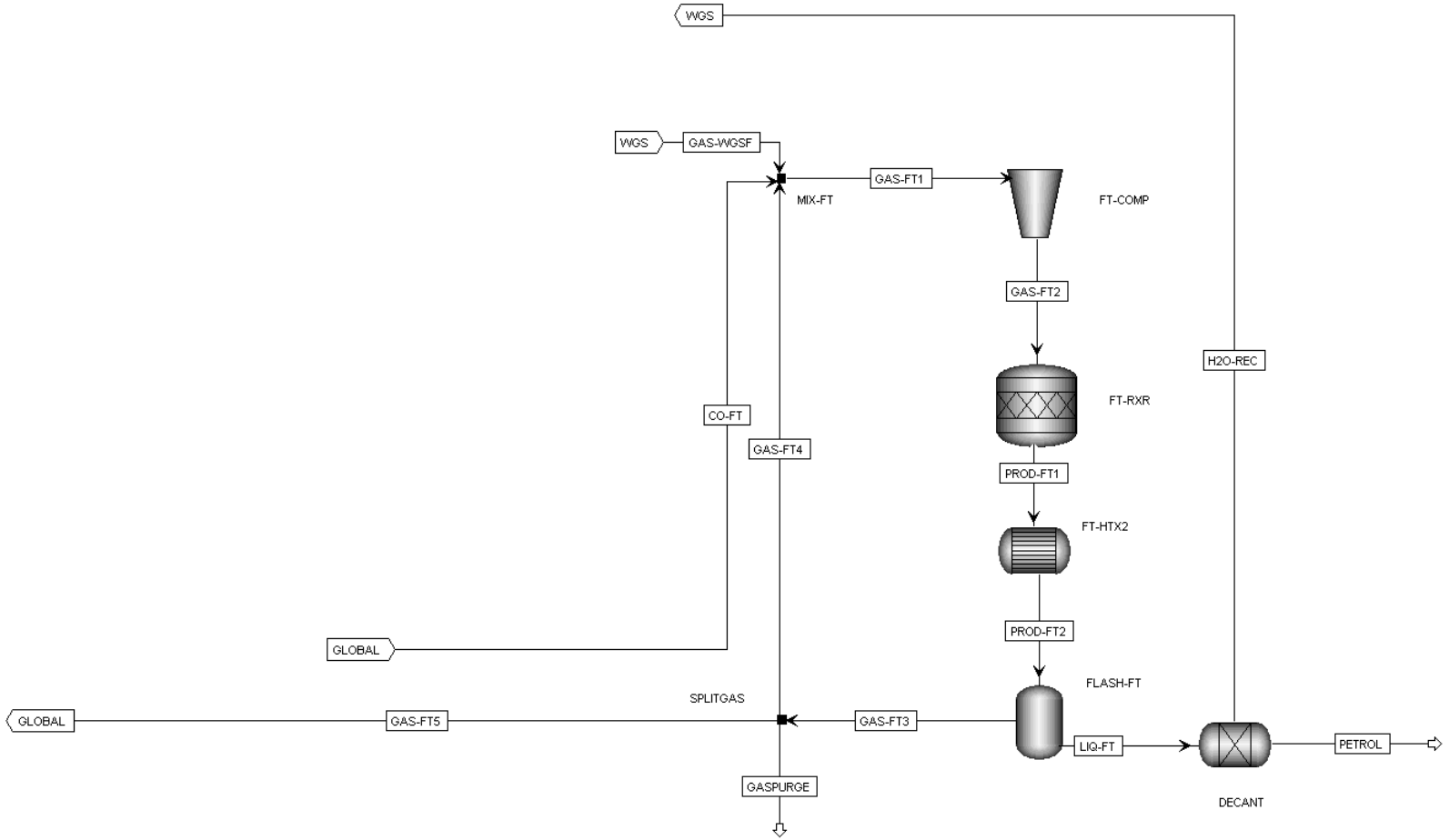

Figure 5.6.1. Aspen Process Flow Diagram for FT Section.

5.7 Streams

Table 5.7.1. Stream Directory.

Stream	Leaving		Entering	
	Block Type	Block Name	Block Type	Block Name
Section: Global				
CO2-IN			Mixer	MIXCO2
CO2-CO-1	Multiplier	MULT	Compressor	COMPRESS
CO2-CO-2	Compressor	COMPRESS	Splitter	SPLIT-CO
CO-WGS	Splitter	SPLIT-CO	Mixer	MIX-WG
CO-FT	Splitter	SPLIT-CO	Mixer	MIX-FT
Section: CR5				
CO2-CR5	Mixer	MIXCO2	Reactor	CR5-OX
CFE3O4			Heater	HEAT
HOTF3O4	Boiler	HEAT	Reactor	RED
REDOUT	Reactor	RED	Separator	SPLITO2
O2	Separator	SPLITO2		
HOTFEO	Separator	SPLITO2	Heater	COOL
COOLFEO	Heater	COOL	Reactor	OX
OXOUT	Reactor	OX	Separator	SPLITCO
COOLF3O4	Separator	SPLITCO		
CR5-OUT	Separator	SPLITCO	Multiplier	MULT
Section: WGS				
H2O-IN1			Pump	H2O-PUMP
H2O-IN2	Pump	H2O-PUMP	Mixer	MIX-WG
H2O-WGS2	Splitter	SPLITH2O	Mixer	MIX-WG
WGS-IN1	Mixer	MIX-FT	Heat Exchanger	WGS-HTX1
WGS-IN2	Heat Exchanger	WGS-HTX1	Reactor	WGS-RXR
WGS-OUT1	Reactor	WGS-RXR	Heat Exchanger	WGS-HTX1
WGS-OUT2	Heat Exchanger	WGS-HTX1	Heat Exchanger	WGS-HTX2
WGS-OUT3	Heat Exchanger	WGS-HTX2	Separator	F-WGS
GAS-WGSF	Separator	F-WGS	Mixer	MIX-FT
H2O-WGS1	Separator	F-WGS	Splitter	SPLITH2O
H2OPURGE	Splitter	SPLITH2O		
Fischer-Tropsch Reaction				
GAS-FT1	Mixer	MIX-FT	Compressor	FT-COMP
GAS-FT2	Compressor	FT-COMP	Reactor	FT-RXR
PROD-FT1	Reactor	FT-RXR	Heat Exchanger	FT-HTX2
PROD-FT2	Heat Exchanger	FT-HTX2	Separator	FLASH-FT
GAS-FT3	Separator	FLASH-FT	Splitter	SPLITGAS
GAS-FT4	Splitter	SPLITGAS	Mixer	MIX-FT
GAS-FT5	Splitter	SPLITGAS	Mixer	MIX-CO2
GASPURGE	Splitter	SPLITGAS		
LIQ-FT	Separator	FLASH-FT	Separator	DECANT
H2O-REC	Separator	DECANT	Mixer	MIX-WG
PETROL	Separator	DECANT		

Section 6 – Process Description

Design and calculations for the process equipment discussed in the process description below are shown in Section 7. Utility requirements are shown in Section 8 and alternative process considerations are discussed in Sections 9 and 12. Process equipment costing and other financial analysis is shown in Sections 10 and 11.

6.1 Overview

The production of liquid transportation fuels is accomplished in several sections: an array of CR5s and a plant containing water gas shift and Fischer-Tropsch blocks. The overall Aspen process flow diagram is shown in Figure 5.2.1, the Section: Global process flow diagram is shown in Figure 5.3.1, the Section: CR5 process flow diagram is shown in Figure 5.4.1, the Section: WGS process flow diagram is shown in Figure 5.5.1, and the Section: FT process flow diagram is shown in Figure 5.6.1. Aspen reports and results (input summary, block reports, utilities reports, convergence report, flowsheet balance, & stream results table) shown in Appendix B. The stream composition evolution is shown as a function of mass fraction in Figure 6.1.1 and as a function of mass flows in Figure 6.1.2.

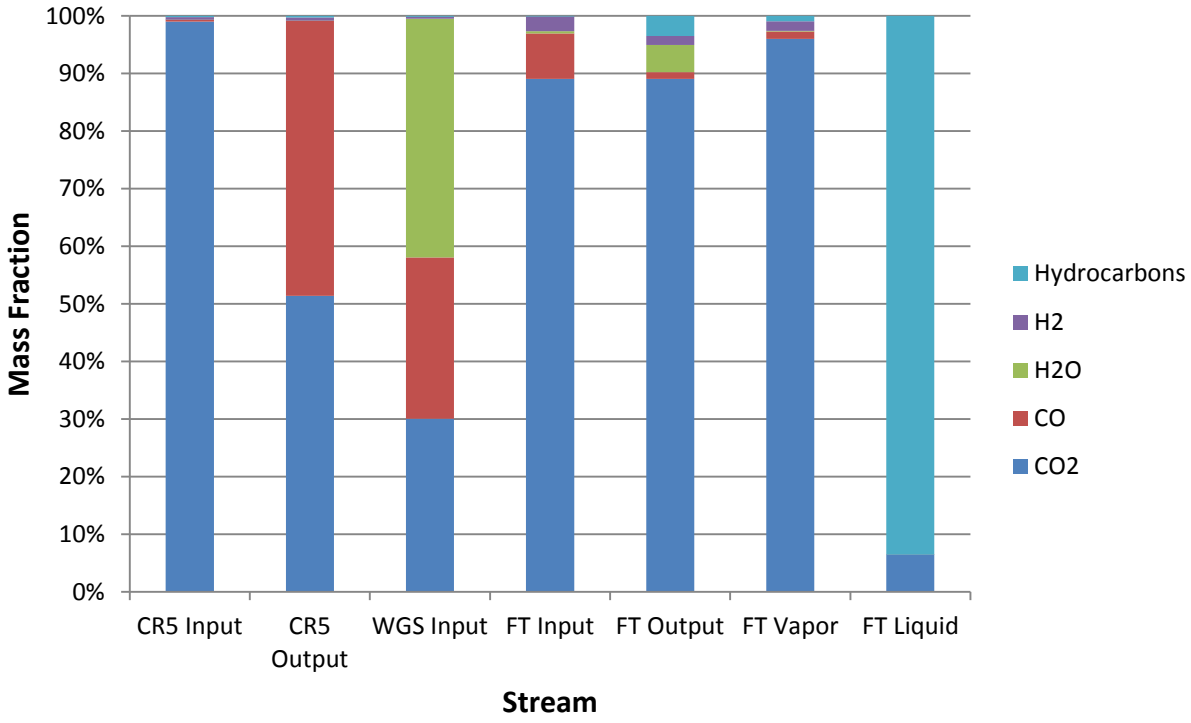

Figure 6.1.1. Component Mass Fractions throughout Process.

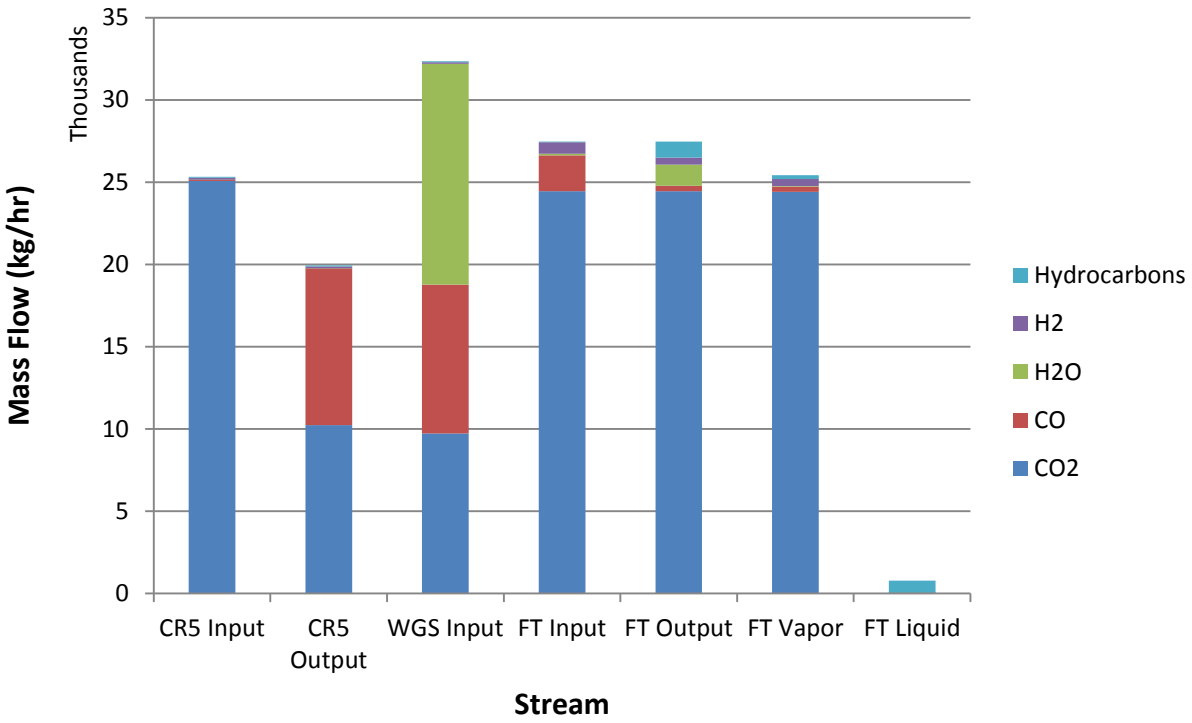

Figure 6.1.2. Component Mass Flows throughout Process.

6.2 CR5 & Global Sections

The Section: Global process flow diagram is shown in Figure 5.3.1, the Section: CR5 process flow diagram is shown in Figure 5.4.1, and the stream directory is contained in Table 5.7.1. Inlet CO_2 (CO2-IN) combines with recycled syngas (primarily CO_2) from the FT section (GAS-FT5) in MIXCO2 prior to entering the CR5 unit. The CR5 unit was modeled in Aspen by breaking apart its major functions: reduction, oxidation, heat transfer, and separation schemes. While the CR5 in reality is a single block process, this approach allowed for the simulation of the reactions, heat, and stream compositions to feed to the rest of the plant. A torn stream (COOLF3O4 & CFE3O4) allows for simulation of the Fe_3O_4/FeO living in the CR5 system. The outlets from the CR5 system are the oxygen product (O2) and CO_2-CO mixture (CR5-OUT). A comparison of the composition of the inlet and outlet from the CR5 is shown in Figure 6.2.1.

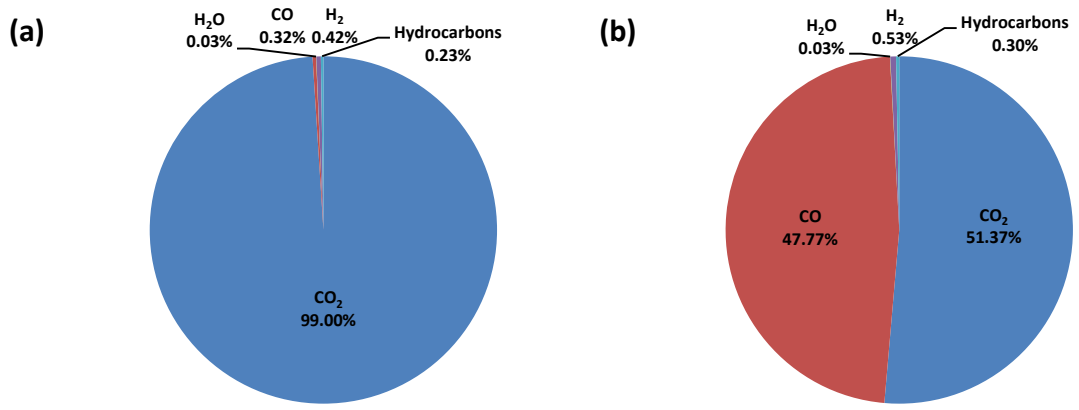

Figure 6.2.1. Component Mass Fractions in (a) Inlet to CR5: CO2-CR5 and (b) Outlet from CR5: CR5-OUT.

CR5-OUT goes through a multiplier block, which allowed for the investigation of the effects of number of CR5s on overall production. *[**Note: Streams and other reports from Aspen present in Section 5, Section 6, Appendix B, and Appendix C show results on a per-CR5 basis, while equipment descriptions (Section 7) and costing (Section 8, Section 10, Section 11, and Appendix D) are on a total basis for 150 CR5s].*

CO2-CO1 is then compressed by a compressor (COMPRESS) from the vacuum pressure of the CR5 (0.2 atm) up to 10 bar before being split to feeds for the WGS and FT sections, CO-WGS & CO-FT.

6.3 Water Gas Shift Section

The Section: WGS process flow diagram is shown in Figure 5.5.1 and the stream directory is contained in Table 5.7.1. Inlet water (H2O-IN1) is then pumped by H2O-PUMP to the WGS reactor pressure of 10 bar. This water (H2O-IN2) is then mixed with CO-WGS, the H_2O recycle from WGS (H2O-WGS2), and the H2O recycle from FT (H2O-REC) in MIX-WGS. WGS-IN1 is then fed to the heat exchanger (WGS-HTX1) where the stream is heated to 300°C by the effluent from the reactor (WGS-OUT1) at 487°C. The WGS reactor (WGS-RXR) is exothermic and run adiabatically, giving to the temperature rise. The reactor shifts some of the carbon monoxide and water to produce hydrogen gas. This product stream needs further cooling after WGS-HTX1 and is sent to WGS-HTX2 where it is cooled from 152°C to 50°C using cooling water. WGS-OUT3 is then separated using a flash vessel (F-WGS) with water being recycled (H2O-WGS2) after a small purge (H2OPURGE). A comparison of the composition of the inlet to WGS (WGS-IN1) and inlet to FT (GAS-FT1)

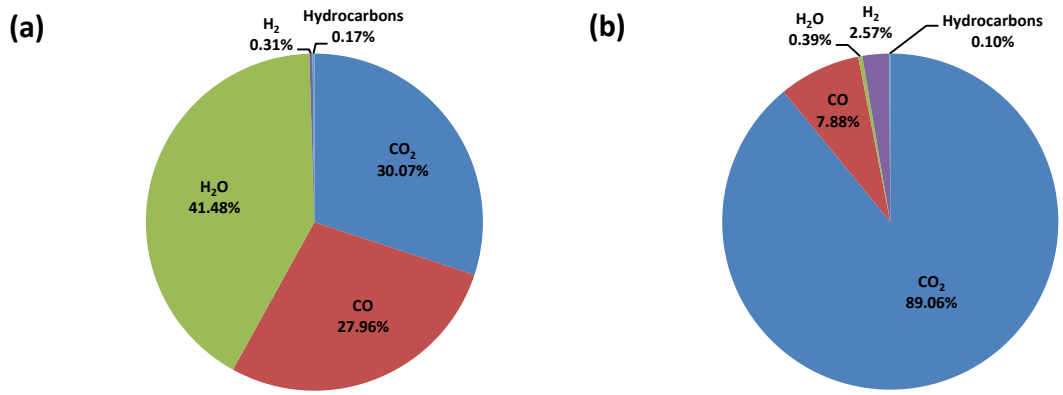

Figure 6.3.1. Component Mass Fractions in (a) Inlet to WGS: WGS-IN1 and (b) Inlet to FT: GAS-FT1.

6.4 Fischer-Tropsch Section

The Section: FT process flow diagram is shown in Figure 5.6.1 and the stream directory is contained in Table 5.7.1. The syngas produced from the WGS (GAS-FT1) is then mixed with a syngas recycle (GAS-FT4) and the CO from the CR5s (CO-FT) to achieve the ideal 2.1:1 H_2:CO ratio for optimal Fischer-Tropsch product yields via mixer, MIX-FT. This gas (GAS-FT1) is then compressed to 20 bar for the Fischer-Tropsch reaction occurring in FT-RXR. The Fischer-Tropsch reaction is highly exothermic, converting syngas (GAS-FT2) to hydrocarbon products and water (PROD-FT1). Cooling water utilities are thus necessary to keep the reactor at a designated temperature of 200°C. The FT products (PROD-FT1) are then further cooled by cooling water utilities in heat exchanger FT-HTX2 to 50°C in anticipation of flash separation in FLASH-FT. This separation separates the liquid products, higher molecular weight hydrocarbons and water, from the gaseous light end hydrocarbons and unreacted syngas. The liquid hydrocarbons (PETROL) are decanted (DECANT) from the water product (H2O-REC) to form the water recycle and liquid transportation fuels product. The gaseous products (GAS-FT3) are then split into a purge (GASPURGE) and recycles back to the FT (GAS-FT4) and the CR5s (GAS-FT5). A comparison of the composition of the FT outlet (PROD-FT2) to the compositions of the vapor (GAS-FT3) and liquid (PETROL) product streams is shown in Figure 6.4.1. Figure 6.4.1 further shows the overall petroleum cuts included within the liquid transportation fuel component of the product.

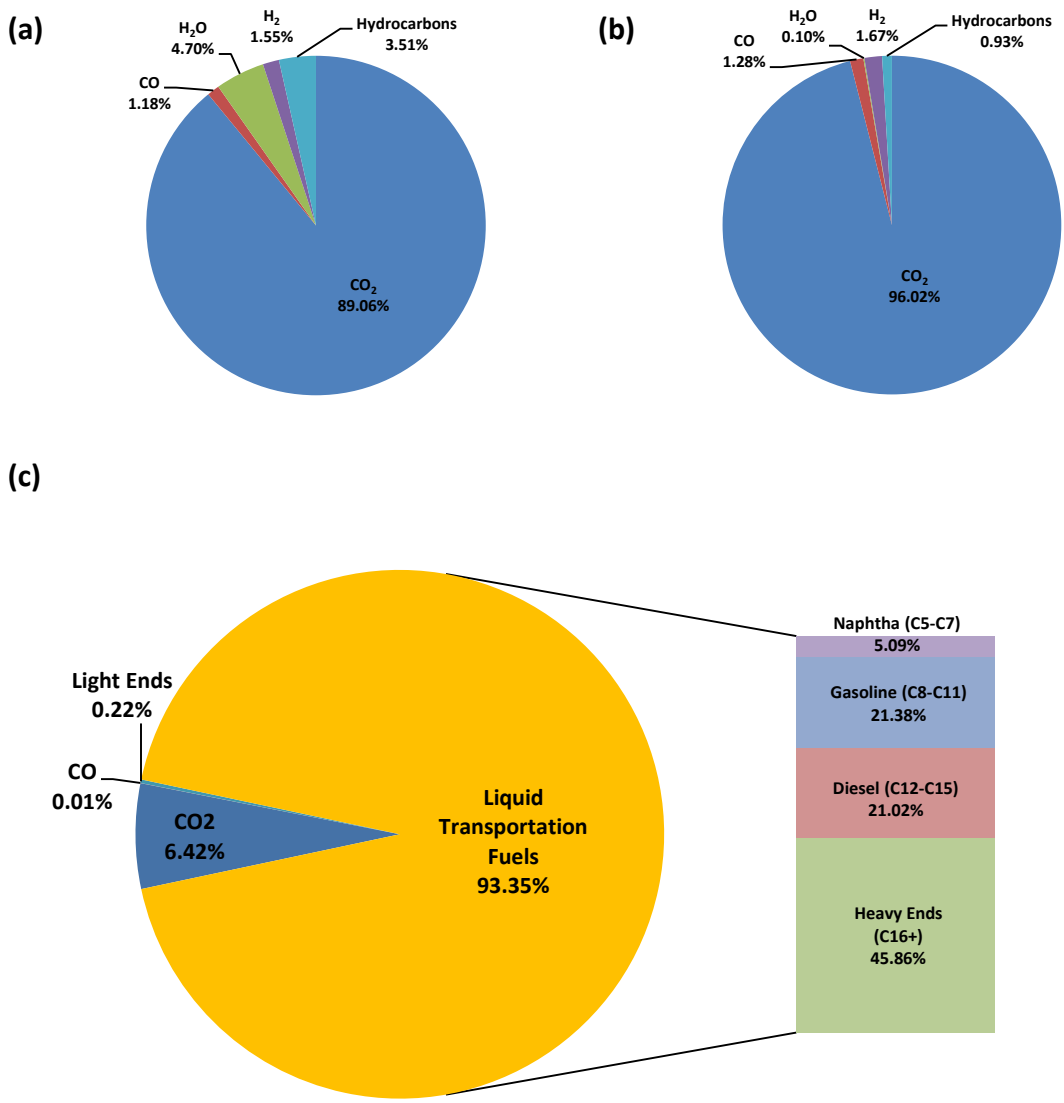

Figure 6.4.1. Component Mass Fractions in (a) Total Product from FT: PROD-FT2, (b) Gas Product from FT: GAS-FT3, and (c) Liquid Product from FT: PETROL.

Section 7 – Equipment List and Descriptions

7.1 CR5

The CR5 is a solar chemical heat engine that provides an environment for the continuous reduction/oxidation of iron oxide, which allows for the reaction of carbon dioxide to carbon monoxide and oxygen. The CR5 unit was modeled in Aspen by breaking apart its major functions: reduction, oxidation, heat transfer, and separation schemes. While the CR5 in reality is a single block process, this approach allowed for the simulation of the reactions, heat, and stream compositions to feed to the rest of the plant. A torn stream (COOLF3O4 & CFE3O4) allows for simulation of the Fe_3O_4/FeO living in the CR5 system. The outlets from the CR5 system are the oxygen product (O2) and CO_2-CO mixture (CR5-OUT).

Inputs (CO2-CR5) into each reactor are 25,070 kg/hr of carbon dioxide and small amounts of hydrocarbons and carbon monoxide, which enter at a temperature of 241°C and 0.2 bar. The CR5 produces outputs (O2) comprised of 5,440 kg/hr O_2 exiting at 2030°C & 0.2 bar and (CR5-OUT) comprised of 10,238 kg/hr CO_2 and 9,520 kg/hr carbon monoxide, which exit at 327°C & 1 bar.

The CR5 unit costing, as discussed in Section 10.1 indicates a price per parabolic disk of $25,000 and a price per CR5 of $2,300, for a total of $27,300. The breakdown of these costs can be seen in Table 10.1.1. 150 CR5s are utilized in this plant.

The equipment specification sheet is shown in Table 7.1.1.

Table 7.1.1. CR5 Specification Sheet.

CR5				
Identification:	Item		CR5	
	Item No.		CR5	
	Number Required		150	
Function:	To convert a feed of carbon dioxide (CO2) into carbon monoxide (CO) and oxygen gas (O2)			
Operation:	Semi-Continuous			
Performance of Unit				
	Oxidation Chamber		*Reduction Chamber*	
	Outlet		*Inlet*	*Outlet*
Stream Name	O2		CO2-CR5	CR5-OUT
Phase	Vapor		Mixed	Vapor
Molar Flow Rate (kmol/hr)	170.00		626.80	626.80
Mass Flow Rate (kg/hr)	5439.80		25322.96	19931.00
Carbon Monoxide	0.00		81.17	9520.73
Carbon Dioxide	0.00		25069.96	10238.57
Hydrogen Gas	0.00		106.31	106.31
Water	0.00		6.48	6.48
Oxygen	5439.80		0.00	0.00
Temperature (C)	2026.85		241.26	326.85
Pressure (bar)	0.2		0.2	1.00
Design Data:	Utility:		Sunlight	
	Catalyst:		Iron Oxide	
	Diameter:		0.91	m
	Parabolic Dish Surface Area per CR5:		88.00	m
	Number of Rings per CR5:		102	
	Number of Chambers per CR5:		2	
	Chambers	Reduction	Temperature:	2300 K
			Pressure:	0.2 bar
		Oxidation	Temperature:	600 K
			Pressure:	0.2 bar
	Hours of operation:		10	hr
	Solar insulation:		0.69	kW/m2
	Solar to chemical energy conversion efficiency:		20	%
	Solar collection efficiency:		50	%
CR5 Price:				$2,314
Parabolic Dish Price:				$25,054
Price per Unit:				$27,367
Total Cost (150 Units):				$4,105,050

7.2 WGS-RXR

The water gas shift reactor, shown in the Aspen process flow diagram as WGS-RXR in Section: WGS in Figures 5.2.1 and 5.5.1, is a fixed bed catalyst reactor that relies on equilibrium conditions in order to drive the reaction towards the desired outputs. Inputs (WGS-IN2) into each reactor are of 452,240 kg/hr of carbon monoxide and 670,820 kg/hr water vapor, which enter at a temperature of 300°C and 1 bar, giving outputs (WGS-OUT1) of 1,075,210 kg/hr CO_2 and 32,910 kg/hr hydrogen gas, which exit at 487°C and 10 bar.

For ease of maintenance and catalyst replenishment, it was assumed there would be 3 equal sized reactors in parallel. Each reactor has a total volume of 235,580 m^3. Each WGS reactor is assumed to operate at a yield of 96%. There is a combination of catalysts used to increase the efficiency of the WGS reaction by speeding up the kinetics of the reaction. Each reactor will have a catalyst with composition of 73% Fe_2O_3, 15% Al_2O_3, 8% Cr_2O_3, and 4% CuO, a commercial catalyst commonly used for water gas shift.

The f.o.b. pricing for the reactor vessel is given by:

$$C = (4.57 \times 10^4) V^{0.67}$$

where V is the volume of the reactor.

Based off costing calculations shown in Section 10.2 the total cost per WGS reactor is $8,300,000. Given the fact that the plant requires 3 reactors, the total cost for these reactors is $24,900,000. The catalyst, based on a weight-averaged cost model, is a total of $1,030,000,000. The costing of the catalyst is further discussed in Table 10.2.1 in Section 10.2. The high cost associated with the catalyst is primarily due to the high volume of catalyst required, necessary for the large volumetric flow rates associated with this reactor (WGS-RXR).

The equipment specification sheet is shown in Table 7.2.1.

Table 7.2.1. Water Gas Shift Reactor Specification Sheet.

Water-Gas Shift Reactor			
Identification:	Item		Fixed-Bed Reactor
	Item No.		WGS-RXR
	Number Required		3
Function:	To convert a feed of carbon monoxide (CO) and water vapor (H2O) into carbon dioxide (CO2) and hydrogen gas (H2)		
Operation:	Semi-Continuous		
Performance of Unit			
	Inlet	*Outlet*	
Stream Name	WGS-IN2	WGS-OUT1	
Phase	Vapor	Vapor	
Molar Flow Rate (kmol/hr)	66992.75	67380.09	
Mass Flow Rate (kg/hr)	1617250.00	1617300.00	
Carbon Monoxide	452236.50	82819.60	
Carbon Dioxide	486334.75	1075210.50	
Hydrogen Gas	5050.37	32909.33	
Water	670823.50	426370.00	
Temperature (C)	300.00	486.60	
Pressure (bar)	1.00	10.00	
Design Data:	Material:		Carbon Steel
	Vessel Weight:		905517364 kg
	Vessel Dimensions:	Diameter	53.13 m
		Length	106.26 m
	Residence Time:		1 sec
	Void Fraction		0.375
	Catalyst Volume:		1472.22 m^2
	Catalyst:		73.0% Iron (III) Oxide (Fe_2O_3), 15.0% Alumina (Al_2O_3), 8.0% Chromium Oxide(Cr_2O_3), 4.0% Copper (II) Oxide (CuO)
Price of Catalyst per m^3:			$234,108.60
Cost of Catalyst:			$344,660,143.45
Bare Module Cost Per Unit:			$8,302,688.52
Total Bare Module Cost:			$24,908,065.57

7.3 FT-RXR

The Fischer-Tropsch reactor, shown in the Aspen process flow diagram as FT-RXR in Section: FT in Figures 5.2.1 and 5.6.1, is also a fixed bed catalyst reactor. The Fischer-Tropsch reactor will have an inlet stream (GAS-FT2) of 108,240 kg/hr CO and 35,300 kg/hr H_2. These streams will enter at 525°C and 20 bar.

Fischer-Tropsch product distribution is represented by the Anderson-Schulz-Flory Distribution:

$$\frac{W_n}{n} = (1-\alpha)^2 \alpha^{n-1}$$

where W_n is the weight fraction of hydrocarbons containing n carbons and α is the chain growth probability (probability that a molecule will continue reacting to form a longer chain).

The catalyst used in the Fischer-Tropsch reactor was chosen based off multiple sources in literature to provide an alpha value of 0.89. This specific value for alpha was chosen to center the mass distribution on octane, maximizing the sellable products while minimizing lower value high molecular weight waxes. This expected Anderson Schulz Flory Distribution is shown in Figure 7.3.1 and in Table 7.3.1.

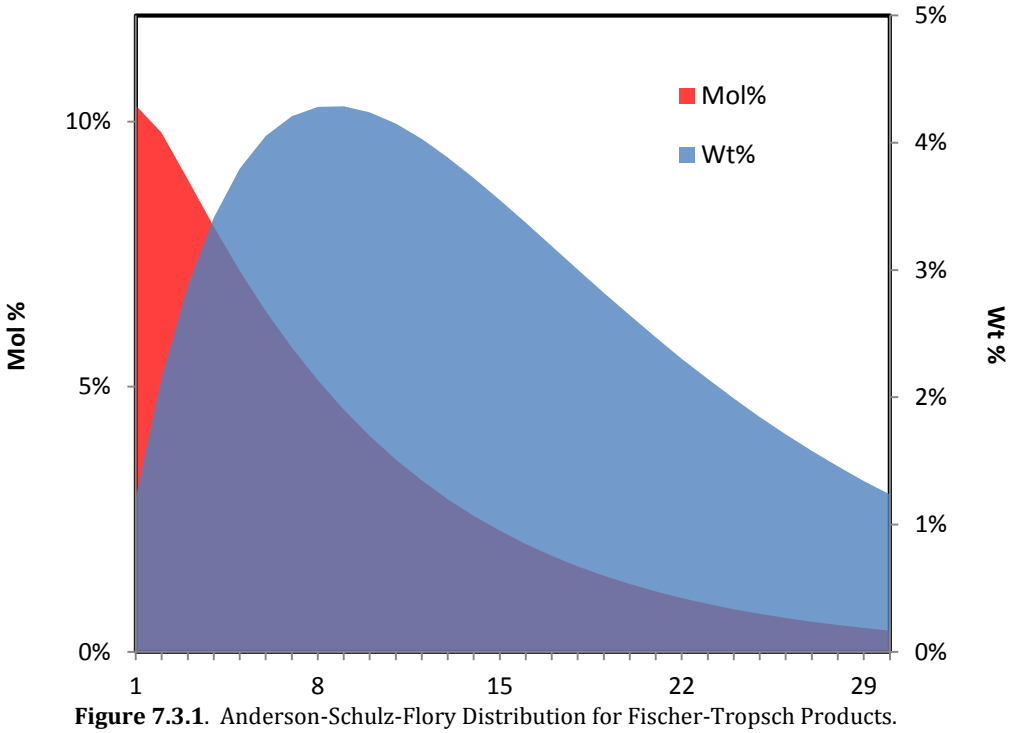

Figure 7.3.1. Anderson-Schulz-Flory Distribution for Fischer-Tropsch Products.

Table 7.3.1. Anderson-Schulz-Flory Distribution for Fischer-Tropsch Products.

#C	MW	Mass Fraction	Mole Fraction
1	16	0.0121	0.103084
2	30	0.021538	0.097861
3	44	0.028753	0.089075
4	58	0.03412	0.080188
5	72	0.037959	0.071863
6	86	0.04054	0.064256
7	100	0.042094	0.057378
8	114	0.042816	0.051195
9	128	0.042869	0.045652
10	142	0.042393	0.040694
11	156	0.041503	0.036264
12	170	0.040296	0.03231
13	184	0.038852	0.028782
14	198	0.037238	0.025636
15	212	0.035509	0.022831
16	226	0.03371	0.020332
17	240	0.031877	0.018105
18	254	0.030039	0.01612
19	268	0.02822	0.014353
20	282	0.026438	0.012779
21	296	0.024706	0.011377
22	310	0.023036	0.010129
23	324	0.021434	0.009017
24	338	0.019905	0.008027
25	352	0.018454	0.007146
26	366	0.017081	0.006361
27	380	0.015787	0.005663
28	394	0.01457	0.005041
29	408	0.013431	0.004487
30	422	0.012366	0.003994

The catalyst is a Cobalt-Rhenium catalyst in a ratio of 21:1 with 30% weight loading of Cobalt and 4.5% weight loading of Rhenium. Each catalyst particle will be between 150-250 microns. The support for the catalyst will be made of aluminum oxide with an active metal dispersion of 5.4%.

The total outlet (PROD-FT1) flow rate will be 1,373,100 kg/hr. By mass fraction, the outlet stream from the Fischer-Tropsch reactor will be 5.1% naphtha (C5-C7), 21.4% gasoline (C8-C11), 21.0% diesel (C12-C15), and 45.9% heavy ends (C16+). This leaves 0.2% of light ends (C1-C4), 6.4% carbon dioxide. The remaining 10.9% of the product stream by

mass is made up of carbon monoxide, hydrogen gas, and water vapor. The product stream (PROD-FT1) leaves the FT reactor at 200°C and 20 bar.

The cost of the cooling water to keep isothermal conditions is $790/hr. For ease of maintenance and catalyst replenishment, it was assumed there would be 3 equal sized reactors in parallel. Each reactor has a total volume of 98,960 m^3.

The f.o.b. pricing for the reactor vessel is given by:

$$C = (4.57 \times 10^4) V^{0.67}$$

where V is the volume of the reactor.

As can be seen in Section 10.3, the cost of each FT reactor is $4,600,000, resulting in a total cost of $14,000,000 for all three FT reactors. The catalyst, based on a weight-averaged cost model, is a total of $1,300,000,000. The Rhenium is the driving factor in this high cost for catalyst, constituting 76% of the total catalyst cost, even though it is only 4.5% of the composition by weight. The costing of the catalyst is further discussed in Table 10.3.1 in Section 10.3.

The equipment specification sheet is shown in Table 7.3.2.

Figure 7.3.2. Fischer-Tropsch Reactor Specification Sheet

Fischer-Tropsch Reactor				
Identification:	Item		Fixed-Bed Reactor	
	Item No.		FT-RXR	
	Number Required		3	
Function:	Using Fischer-Tropsch hydrocabon synthesis to convert a feed of carbon monoxide (CO) and hydrogen gas (H2) into a distrubution of liquid hydrocarbons			
Operation:	Semi-Continuous			
Performance of Unit				
	Inlet		*Outlet*	
Stream Name	GAS-FT2		PROD-FT1	
Phase	Vapor		Mixed	
Molar Flow Rate (kmol/hr)	49487.35		128753.34	
Mass Flow Rate (kg/hr)	1373100.00		1373100.00	
Carbon Monoxide	108244.70		16236.71	
Carbon Dioxide	1222844.50		1222844.50	
Hydrogen Gas	35301.61		21262.67	
Water	5391.24		64567.50	
C1	82.67		735.29	
C2	146.70		1307.85	
C3	194.26		1743.46	
C4	225.07		2064.60	
C5	232.30		2278.09	
C6	203.69		2389.14	
C7	137.21		2406.73	
C8	65.42		2373.57	
C9	26.07		2336.65	
C10	9.62		2294.82	
C11	3.65		2240.66	
C12	1.21		2173.18	
C13	0.36		2095.46	
C14	0.13		2007.61	
C15	0.04		1915.10	
C16	0.02		1816.68	
C17	0.00		1716.95	
C18	0.00		1620.54	
C19	0.00		1519.41	
C20	0.00		1425.09	
C21	0.00		1332.23	
C22	0.00		1238.58	
C23	0.00		1156.36	
C24	0.00		1072.89	
C25	0.00		995.03	
C26	0.00		919.00	
C27	0.00		852.14	
C28	0.00		783.98	
C29	0.00		721.63	
C30	0.00		666.42	
Temperature (C)	5255.39		200.00	
Pressure (bar)	20.00		20.00	
Design Data:	Material:		Carbon Steel	
	Vessel Weight:		905517364	kg
	Vessel Dimensions:	Diameter	39.79	m
		Length	79.58	m
	Residence Time:		1	sec
	Void Fraction		0.375	
	Catalyst:		30 % wt Co, 4.5% wt Re, supported on Al_2O_3; metal dispersion 5.4%; 177-250 microns diameter	
	Catalyst Volume:		618.00	m^3
Price of Catalyst per m^3:				$702,989.99
Cost of Catalyst:				$434,447,814
Bare Module Cost Per Unit:				$4,641,571
Total Bare Module Cost:				$13,924,713.81

7.4 H2O-PUMP

There will be a centrifugal pump, shown in the Aspen process flow diagram as H2O-PUMP in Section: WGS in Figures 5.2.1 and 5.5.1, in place to transport the water for the input to the water gas shift reactor. The size factor, S, for the pump was calculated using

$$S = Q(H)^{0.5}$$

where Q is the flow rate through the pumps in gallons per minute, and H is the pump head in feet. The base cost C_B of the pump was calculated using:

$$C_B = \exp\{9.7171 - 0.6019[\ln(S)] + 0.0519[\ln(S)]^2\}$$

where C_B cost includes the base plate and driver coupling but not the electric motor. Hence the total cost of the pump, without the electric motor, is equal to:

$$C_P = F_T F_M C_B$$

where F_T is the type factor and F_M is the material factor. The electric motor with explosion-proof enclosure can be priced using:

$$C_P = F_T C_B$$

where C_B can be calculated using:

$$C_B = \exp\{5.8259 + 0.13141[\ln(P_C)] + 0.053255[\ln(P_C)]^2 + 0.0286828[\ln(P_C)]^3 - 0.0035549[\ln(P_C)]^3\}$$

where P_C is the horsepower consumption. This sizing and costing of the pump is shown in Table 7.4.1 and the equipment specification sheet is shown in Table 7.4.2.

Table 7.4.1. H2O-PUMP Sizing & Costing Table.

Pump Sizing & Costing	
Equipment Category	Pumps
Subtype	Centrifugal Pumps
Construction Material	Cast Iron
Pump Type	3600 RPM, HSC, 650 - 3200 ft, 100 - 1500 gpm, 1450 Hp
Flow Rate, Q (gpm)	1.21955333
Head, H (ft)	3018.37
Equipment Base f.o.b. Cost	$3,307.19
Material Factor	1.00
Pump Type Factor	8.90
Bare-Module Factor	3.3
CE Index	500
Equipment Bare-Module Cost	$37,040.51

The pump will transport 621,530 kg/hr of H_20. The total bare module cost of the centrifugal pump is $17,100. The pump will be coupled with an electrical motor and the total bare module cost of the electric motors is $154,090. The pump has an efficiency of 29.6%. The temperature and pressure of the incoming water (H2O-IN1) is 25°C and 1 bar respectively, and the temperature and pressure of the outlet stream (H2O-IN2) are 25.5°C and 10 bar. The power consumption of the pump is 528.5 kW. This pump develops a head of 13,810 m-kgf/kg.

Table 7.4.2. H2O-PUMP Equipment Specification Sheet.

Pump			
Identification:	Item	Pump	
	Item No.	H2O-PUMP	
	Number Required	15	
Function:	Pump used to circulate the water into the Water-Gas Shift		
Operation:	Semi-Continuous		
Performance of Unit			
	Inlet	*Outlet*	
Stream Name	H2O-IN1	H2O-IN2	
Phase	Liquid	Liquid	
Molar Flow Rate (kmol/hr)	2300.00	2300.00	
Mass Flow Rate (kg/hr)	41435.14	41435.14	
Water	41435.14	41435.14	
Temperature (C)	25.00	25.53	
Pressure (bar)	1.00	10.00	
Design Data:	Utility Used	Electricity	
	Power Consumption	35.236	kW
	Head	920.35	m
	Pump Efficiency	29.57	%
Centrifugal Pump			
Bare Module Cost:			$37,040.51
Electric Motors			
Bare Module Cost:			$10,272.52
Total Bare Module Cost:			$47,313.03

7.5 COMPRESS

There will be an isentropic centrifugal compressor, shown in the Aspen process flow diagram as COMPRESS in Section: Global in Figures 5.2.1 and 5.3.1, in place to compress the output gas of the CR5 (CO2-CO-1) for the desired input (CO2-CO-2) to the water-gas shift reactor pressure. The f.o.b. pricing for the compressor is given by:

$$C_P = F_D F_M C_B$$

where F_D is equal to 1.15 since the process uses an electric motor. The base cost, C_B, for a centrifugal compressor is:

$$C_B = \exp\{7.5800 + 0.80[\ln(P_C)]\}$$

where P_C is the horsepower consumption. The equation is valid when P_C is between 200 to 30,000 Hp.

The sizing and costing of the flash drum for water gas shift (F-WGS) is shown in Table 7.5.1.

Table 7.5.1. COMPRESS Sizing & Costing Table.

Compressor Sizing & Costing	
Equipment Category	Fans, Blowers, Compressors
Subtype 1	Compressors
Subtype 2	Centrifugal Compressor
Construction Material	Cast Iron/Carbon-Steel
Drive	Electric Motor Drive
Consumed Power, Hp	28,520
Applicable Range	200 - 30,000 Hp
Equipment Base f.o.b. Cost	$6,118,268.30
Material Factor	1.00
Drive Factor	1.00
Equipment Bare-Module Cost	$116,247,097.70

The process will require 19 compressors. The equipment will compress 4,950 kg/hr of outlet gas from the CR5s (CO2-CO-1) from a pressure of 1 bar to 10 bar. The compression will increase the temperature of the stream from 327°C to 850°C. The compressor is composed of carbon steel and uses electricity. Each compressor consumes a total 28,250 kW of power. The isentropic efficiency of the equipment is of 72%, and the mechanical efficiency is of 100%. The bare module cost per unit is of $6,120,000 and the total bare module cost for 19 compressors is $116,300,000.

The equipment specification sheet is shown in Table 7.5.2.

Table 7.5.2. COMPRESS Equipment Specification Sheet.

Compressor			
Identification:	Item	Isentropic Centrifugal Compressor	
	Item No.	COMPRESS	
	Number Required	19	
Function:	Compress the output gas of the CR5 to the desired Water-Gas Shift reactor pressure		
Operation:	Semi-Continuous		
Performance of Unit			
	INLET	OUTLET	
Stream Name	CO2-CO-1	CO2-CO-2	
Phase	Vapor	Vapor	
Molar Flow Rate (kmol/hr)	4948.50	4948.50	
Mass Flow Rate (kg/hr)	157351.58	157351.58	
Carbon Monoxide	75163.97	75163.97	
Carbon Dioxide	80831.29	80831.29	
Hydrogen Gas	839.40	839.40	
Water	51.14	51.14	
Temperature (C)	326.85	849.59	
Pressure (bar)	1.00	10.00	
Design Data:	Utility Used	Electricity	
	Material	Carbon Steel	
	Power Consumption (HP)	28520.05	kW
	Isentropic Efficiency	72	%
	Mechanical Efficiency	100	%
Bare Module Cost Per Unit:		$6,118,268.30	
Total Bare Module Cost:		$116,247,097.70	

7.6 FT-COMP

There will be an isentropic centrifugal compressor, shown in the Aspen process flow diagram as FT-COMP in Section: FT in Figures 5.2.1 and 5.6.1, in place to compress the combined gas stream (GAS-FT1) to the desired input pressure of the Fischer-Tropsch reactor. The f.o.b. pricing for the compressor is given by:

$$C_P = F_D F_M C_B$$

where F_D is equal to 1.15 since the process uses an electric motor. The base cost, C_B, for a centrifugal compressor is:

$$C_B = \exp\{7.5800 + 0.80[\ln(P_C)]\}$$

where P_C is the horsepower consumption. The equation is valid when P_C is between 200 to 30,000 Hp.

The sizing and costing of the compressor (FT-COMP) is shown in Table 7.6.1.

Table 7.6.1. FT-COMP Sizing & Costing Table.

Compressor Sizing & Costing	
Equipment Category	Fans, Blowers, Compressors
Subtype 1	Compressors
Subtype 2	Centrifugal Compressor
Construction Material	Cast Iron/Carbon-Steel
Drive	Electric Motor Drive
Consumed Power, Hp	29,179
Applicable Range	200 - 30,000 Hp
Equipment Base f.o.b. Cost	$6,118,268.30
Material Factor	1.00
Drive Factor	1.00
Total Bare Module Cost	$159,074,975.80

The process will require 26 compressors. The equipment will compress 5,710 kg/hr syngas (GAS-FT1) from a pressure of 1 bar to 20 bar. The compression will increase the temperature of the stream (GAS-FT1) from 52°C to 525°C. The compressor is composed of carbon steel and uses electricity. Each device consumes a total 29,180 kW of power. The isentropic efficiency of the equipment is of 72%, and the mechanical efficiency is of 100%. The bare module cost per unit is of $6,120,000 and the total bare module cost for 26 compressors is $159,000,000.

The equipment specification sheet is shown in Table 7.6.2.

Table 7.6.2. FT-COMP Equipment Specification Sheet.

Compressor			
Identification:	Item	Isentropic Centrifugal Compressor	
	Item No.	FT-COMP	
	Number Required	26	
Function:	Compress the output gas of the Water-Gas Shift section to the desired Fischer-Tropsch reactor pressure		
Operation:	Semi-Continuous		
Performance of Unit			
	INLET	OUTLET	
Stream Name	GAS-FT1	GAS-FT2	
Phase	Vapor	Vapor	
Molar Flow Rate (kmol/hr)	5710.08	5710.08	
Mass Flow Rate (kg/hr)	158434.62	158434.62	
Carbon Monoxide	12489.77	12489.77	
Carbon Dioxide	141097.44	141097.44	
Hydrogen Gas	4073.26	4073.26	
Water	622.07	622.07	
Temperature (C)	51.60	525.86	
Pressure (bar)	1.00	20.00	
Design Data:	Utility Used	Electricity	
	Material	Carbon Steel	
	Power Consumption (HP)	29178.81	kW
	Isentropic Efficiency	72	%
	Mechanical Efficiency	100	%
Bare Module Cost Per Unit:		$6,118,268.30	
Total Bare Module Cost:		$159,074,975.80	

7.7 F-WGS

A flash drum, shown in the Aspen process flow diagram as F-WGS in Section: WGS in Figures 5.2.1 and 5.5.1, is used to separate the Water-Gas Shift products into liquid water (H2O-WGS1) for recycle and product gases (GAS-WGSF) for the Fischer-Tropsch process. The flash drum (vertical pressure vessel) sized by first calculating the volume of the vessel, using:

$$V = 2\left(\frac{F_L}{\rho_L}\right)\tau$$

where F_L is the flow rate of the liquid, ρ_L is the density of the liquid phase, and τ is the residence time. The relation between length of the vessel (L) and diameter of the vessel (D) chosen was of:

$$L = 4D$$

The diameter of the vessel can be found using:

$$D = \left(\frac{V}{\pi}\right)^{1/3}$$

The f.o.b. pricing for the vertical pressure vessel is given by:

$$C_P = F_M C_V + C_{PL}$$

where C_V is the purchase cost of the empty vessel, C_{PL} is the cost for platforms and ladders, and F_M is the material factor. The purchase cost of the empty vessel is calculated by:

$$C_V = \exp\{7.0132 - 0.18255[\ln(W)] + 0.02297[\ln(W)]^2\}$$

where weight, W, is given by:

$$W = \pi(D_i + t_s)(L + 0.8D_i)t_s\rho$$

where t_S is the shell thickness. The added cost of platforms and ladders can be found using:

$$C_{PL} = 361.8(D_i)^{0.73960} + (L)^{0.70684}$$

where D_i is the vessel inner diameter and L is the length of the shell.

The sizing and costing of the flash drum for water gas shift (F-WGS) is shown in Table 7.7.1 below.

Table 7.7.1. F-WGS Sizing & Costing Table.

Flash Drum Sizing & Costing	
Vessel Type	Vertical
Vessel Material (Cost)	Carbon Steel
Material Factor	1
Height/Length (ft)	37.00
Diameter (ft)	9.25
Operating Pressure (psig)	72.52
Design Pressure (psig)	96
Material (Stress)	Carbon Steel (SA-285 Grade C)
Design Temperature (F)	-20 to 650
Maximum Allowable Stress (psig)	13750
Minimum Wall Thickness	
Inside Diameter Range (ft)	8 - 10
Minimum Thickness (in.)	0.44
Weld Efficiency	
Wall Thickness Range (in.)	< 1.25
Efficiency	0.85
Estimated Wall Thickness (in.)	0.47
Corrosion Allowance (in.)	0.13
Vessel Wall Thickness (in)	0.60
Vessel Weight (lbs)	31643
Vessel Cost	$86,793.00
Platforms & Ladders Cost	$24,071.03
Total f.o.b. Purchase Cost	$110,864.03
Bare-Module Factor	4.16
Total Bare-Module Cost	$461,194.36

A V-L equilibrium vertical pressure vessel is composed of a carbon steel material. The vessel has a diameter of 3 m, a length of 11 m, a wall thickness of 0.15 m and a residence time of 5 min. The plant will require 3 flash drums, and each vessel will have a flow rate of 39,400 L/min. The flash vessel will have an inlet (WGS-OUT3) flow of 1,617,000 kg/hr, with a temperature of 50°C and a pressure of 10 bar. The liquid (H2O-WGS1) flow rate of the vessel will have a flow rate of 421,000 kg/hr, at a temperature of 25°C and a pressure of 5 bar. The vapor (GAS-WGSF) flow rate of the vessel will have a flow rate of

1,196,000 kg/hr, at a temperature of 25°C and a pressure of 5 bar. The bare module cost per unit of the flash vessel is of $461,000 and the total bare module cost is of $1,383,000.

The equipment specification sheet is shown in Table 7.7.2.

Table 7.7.2. F-WGS Equipment Specification Sheet.

Flash Vessel				
Identification:	Item		Vertical Pressure Vessel	
	Item No.		F-WGS	
	Number Required		3	
Function:	Separate the Water-Gas Shift products into liquid water for recycle and product gases for the Fischer-Tropsch process.			
Operation:	Semi-Continuous			
Performance of Unit				
	Inlet		*Outlet*	
Stream Name	WGS-OUT3		H20-WGS1	GAS-WGSF
Phase	Liquid		Liquid	Vapor
Molar Flow Rate (kmol/hr)	67380.00		23375.97	44004.13
Mass Flow Rate (kg/hr)	1617310.00		421124.54	1196185.50
Carbon Monoxide	82819.60		0.00	82819.60
Carbon Dioxide	1075210.50		0.00	1075210.50
Hydrogen Gas	32909.33		0.00	32909.33
Water	426370.00		421124.54	5245.48
Temperature (C)	50.00		25.00	25.00
Pressure (bar)	10.00		5.00	5.00
Design Data:	Flash Type:	V-L Equilibrium	Diameter:	2.82 m
	Column Material:	Carbon Steel	Length:	11.28 m
	Total Flow:	118285.92 L/min	Thickness:	0.15 m
	Per Vessel:	39428.64 L/min	Residence Time:	5 min
Bare Module Cost Per Unit:				$461,194.36
Total Bare Module Cost:				$1,383,583.08

7.8 FLASH-FT

A flash drum, shown in the Aspen process flow diagram as FLASH-FT in Section: FT in Figures 5.2.1 and 5.6.1, is used to separate the Fischer-Tropsch products into product gases for recycle and liquid hydrocarbons for decanting. The flash drum (vertical pressure vessel) sized by first calculating the volume of the vessel, using:

$$V = 2\left(\frac{F_L}{\rho_L}\right)\tau$$

where F_L is the flow rate of the liquid, ρ_L is the density of the liquid phase and τ is the residence time. The relation between length of the vessel (L) and diameter of the vessel (D) chosen was of:

$$L = 4D$$

The diameter of the vessel can be found using:

$$D = \left(\frac{V}{\pi}\right)^{1/3}$$

The f.o.b. pricing for the vertical pressure vessel is given by:

$$C_P = F_M C_V + C_{PL}$$

where C_V is the purchase cost of the empty vessel, C_{PL} is the cost for platforms and ladders, and F_M is the material factor. The purchase cost of the empty vessel is calculated by:

$$C_V = \exp\{7.0132 - 0.18255[\ln(W)] + 0.02297[\ln(W)]^2\}$$

where weight, W, is given by:

$$W = \pi(D_i + t_s)(L + 0.8D_i)t_s\rho$$

where t_S is the shell thickness. The added cost of platforms and ladders can be found using:

$$C_{PL} = 361.8(D_i)^{0.73960} + (L)^{0.70684}$$

where D_i is the vessel inner diameter and L is the length of the shell.

The sizing and costing of the flash drum for Fischer-Tropsch (FLASH-FT) is shown in Table 7.8.1 below.

Table 7.8.1. FLASH-FT Sizing & Costing Table.

Flash Drum Sizing & Costing	
Vessel Type	Vertical
Vessel Material (Cost)	Carbon Steel
Material Factor	1
Height/Length (ft)	24.18
Diameter (ft)	6.05
Operating Pressure (psig)	217.56
Design Pressure (psig)	266
Material (Stress)	Carbon Steel (SA-285 Grade C)
Design Temperature (F)	-20 to 650
Maximum Allowable Stress (psig)	13750
Minimum Wall Thickness	
Inside Diameter Range (ft)	6 - 8
Minimum Thickness (in.)	0.375
Weld Efficiency	
Wall Thickness Range (in.)	< 1.25
Efficiency	0.85
Estimated Wall Thickness (in.)	0.8484
Corrosion Allowance (in.)	0.125
Vessel Wall Thickness (in)	0.973
Vessel Weight (lbs)	22217
Vessel Cost	$68,957.13
Platforms & Ladders Cost	$13,017.78
Total f.o.b. Purchase Cost	$81,974.92
Bare-Module Factor	4.16
Total Bare-Module Cost	$341,015.65

A V-L equilibrium vertical pressure vessel is composed of a carbon steel material. The vessel has a diameter of 1.9 m, a length of 7.4 m, a wall thickness of 0.26 m and a residence time of 5 min. The plant will require 3 flash drums, and each vessel will have a flow rate of 16,000 L/min. The flash vessel will have an inlet (PROD-FT2) flow of 1,373,100 kg/hr, with a temperature of 30°C and a pressure of 20 bar. The liquid (LIQ-FT) flow rate of the vessel will have a flow rate of 102,000 kg/hr, at a temperature of 25°C and a pressure of 15 bar. The vapor (GAS-FT3) flow rate of the vessel will have a flow rate of 127,000 kg/hr, at a temperature of 25°C and a pressure of 15 bar. The bare module cost per unit of the flash vessel is of $341,000 and the total bare module cost is of $1,020,000.

The equipment specification sheet is shown in Table 7.8.2.

Table 7.8.2. Vertical Pressure Vessel Equipment Specification Sheet.

Flash Vessel				
Identification:	Item	Vertical Pressure Vessel		
	Item No.	FLASH-FT		
	Number Required	3		
Function:	Separate the Fischer-Tropsch products into product gases for recycle and liquid hydrocarbons for decanting.			
Operation:	Semi-Continuous			
Performance of Unit				
	Inlet		*Outlet*	
Stream Name	PROD-FT2		LIQ-FT	GAS-FT3
Phase	Mixed		Liquid	Vapor
Molar Flow Rate (kmol/hr)	42917.78		3758.12	39159.66
Mass Flow Rate (kg/hr)	1373100.00		102163.94	1270936.07
Carbon Monoxide	16236.71		3.31	16233.40
Carbon Dioxide	1222844.50		2497.03	1220347.50
Hydrogen Gas	21262.67		1.51	21261.16
Water	64567.50		63271.90	1295.57
C1	735.29		0.40	734.89
C2	1307.85		3.70	1304.15
C3	1743.46		16.51	1726.95
C4	2064.60		63.82	2000.77
C5	2278.09		213.03	2065.06
C6	2389.14		578.43	1810.71
C7	2406.73		1187.08	1219.65
C8	2373.57		1792.05	581.52
C9	2336.65		2104.97	231.68
C10	2294.82		2209.33	85.49
C11	2240.66		2208.24	32.42
C12	2173.18		2162.41	10.77
C13	2095.46		2092.30	3.17
C14	2007.61		2006.46	1.15
C15	1915.10		1914.72	0.38
C16	1816.68		1816.54	0.14
C17	1716.95		1716.91	0.04
C18	1620.54		1620.53	0.01
C19	1519.41		1519.40	0.00
C20	1425.09		1425.09	0.00
C21	1332.23		1332.23	0.00
C22	1238.58		1238.58	0.00
C23	1156.36		1156.36	0.00
C24	1072.89		1072.89	0.00
C25	995.03		995.03	0.00
C26	919.00		919.00	0.00
C27	852.14		852.14	0.00
C28	783.98		783.98	0.00
C29	721.63		721.63	0.00
C30	666.42		666.42	0.00
Temperature (C)	30.00		25.00	25.00
Pressure (bar)	20.00		15.00	15.00
Design Data:	Flash Type:	V-L Equilibrium	Diameter:	1.84 m
	Column Material:	Carbon Steel	Length:	7.37 m
	Total Flow:	47232.99 L/min	Thickness:	0.26 m
	Per Vessel:	15744.33 L/min	Residence Time:	5 min
Bare Module Cost Per Unit:			$341,015.65	
Total Bare Module Cost:			$1,023,046.95	

7.9 WGS-HTX1

A heat exchanger, shown in the Aspen process flow diagram as WGS-HTX1 in Section: WGS in Figures 5.2.1 and 5.5.1, is needed to recover energy from the WGS reactor outlet (WGS-OUT1) to heat the WGS inlet stream (WGS-IN1). The f.o.b. pricing for the heat exchanger is given by:

$$C_P = F_P F_M F_L C_B$$

where F_L is the tube length correction and F_P is the pressure factor based on the shell-side pressure, P, in psig:

$$F_P = 0.9803 + 0.018\left(\frac{P}{100}\right) + 0.0017\left(\frac{P}{100}\right)^2$$

the pressure factor is valid from 100 to 2,000 psig.

The base cost, C_B, for the floating head heat exchanger is:

$$C_B = \exp\{11.9052 - 0.8709[\ln(A)] + 0.09005[\ln(A)]^2\}$$

where A is the tube outside surface area.

The sizing and costing of the heat exchanger for WGS (WGS-HTX1) is shown in Table 7.9.1 below.

Table 7.9.1. Shell-and-Tube Heat Exchanger Costing Table.

Heat Exchanger Costing	
Equipment Category	Heat Exchangers
Subtype 1	Shell & Tube
Subtype 2	Floating Head
Shell/Tube Material	Carbon Steel/Carbon Steel
Tube Length (ft)	20
Surface Area, A (ft^2)	11800.31
Applicable Range (ft^2)	150 - 12,000
Shell-Side Pressure (psig)	14.51
Applicable Range (psig)	0 - 2,000
Equipment Base f.o.b. Cost	$115,356.60
Material Factor	1.00
Tube Length Factor	1.00
Pressure Factor	1.00
Bare-Module Factor	3.17
CE Index	500
Equipment Bare-Module Cost	$365,680.43

The heat exchanger will have an inlet shell side stream of mixed liquid and vapor (WGS-IN1), with a total flow rate of 4,851,750 kg/hr, inlet temperature of 107°C, and a pressure of 1 bar. The outlet stream from the shell side (WGS-IN2) will have a temperature of 300°C and a pressure of 10 bar. The heat exchanger will have an inlet tube side stream of

vapor (WGS-OUT1), with a total flow rate of 4,851,900 kg/hr, an inlet temperature of 486°C and a pressure of 10 bar. The outlet tube side stream (WGS-OUT2) will have a temperature of 152°C and a pressure of 10 bar. The total heat transfer area of the heat exchanger is 15,350 m^2 and the heat duty is 267,440 kcal/sec. Both the tube and shell sides will be made of carbon steel. There will be 14 heat exchangers to meet these requirements. The total bare module cost of these heat exchangers is $5,920,000.

The equipment specification sheet is shown in Table 7.9.2.

Table 7.9.2. WGS-HTX1 Heat Exchanger Equipment Specification Sheet.

Heat Exchanger				
Identification:	Item		Shell and Tube	
	Item No.		WGS-HTX1	
	Number Required		14	
Function:	To use the the Water-Gas Shift products to heat the reactants going into the reactor			
Operation:	Semi-Continuous			
Performance of Unit				
	Shell Side		*Tube Side*	
	Inlet	*Outlet*	*Inlet*	*Outlet*
Stream Name	WGS-IN1	WGS-IN2	WGS-OUT1	WGS-OUT2
Phase	Mixed	Vapor	Vapor	Mixed
Molar Flow Rate (kmol/hr)	14355.64	14355.64	14438.57	14438.57
Mass Flow Rate (kg/hr)	346553.57	346553.57	346564.29	346564.29
Carbon Monoxide	96907.82	96907.82	17747.06	17747.06
Carbon Dioxide	104214.59	104214.64	230402.25	230402.25
Hydrogen Gas	1082.22	1082.25	7052.00	7052.00
Water	143747.89	143747.89	91365.00	91365.00
Temperature (C)	105.60	300.00	486.60	152.04
Pressure (bar)	1.00	1.00	10.00	10.00
Design Data:	Equipment Type:		Floating Head	
	Flow Type:		Counter Current	
	Tube Side Material:		Carbon Steel	
	Shell Side Material:		Carbon Steel	
	Heat Transfer Area:		1096.090714	m^2
	Heat Duty:		19102754.88	cal/sec
	Tube Length:		6.10	m
Bare Module Cost Per Unit:				$365,627.28
Total Bare Module Cost:				$5,118,781.92

7.10 WGS-HTX2

A heat exchanger, shown in the Aspen process flow diagram as WGS-HTX2 in Section: WGS in Figures 5.2.1 and 5.5.1, is needed to cool the stream (WGS-OUT2) further using cooling water utilities. The f.o.b. pricing for the heat exchanger is given by:

$$C_P = F_P F_M F_L C_B$$

where F_L is the tube length correction and F_P is the pressure factor based on the shell-side pressure, P, in psig:

$$F_P = 0.9803 + 0.018\left(\frac{P}{100}\right) + 0.0017\left(\frac{P}{100}\right)^2$$

the pressure factor is valid from 100 to 2,000 psig.

The base cost, C_B, for the floating head heat exchanger is:

$$C_B = \exp\{11.9052 - 0.8709[\ln(A)] + 0.09005[\ln(A)]^2\}$$

where A is the tube outside surface area.

The sizing and costing of the heat exchanger for WGS (WGS-HTX2) is shown in Table 7.10.1 below.

Table 7.10.1. Shell-and-Tube Heat Exchanger Costing Table.

Heat Exchanger Costing	
Equipment Category	Heat Exchangers
Subtype 1	Shell & Tube
Subtype 2	Floating Head
Shell/Tube Material	Carbon Steel/Carbon Steel
Tube Length	20 ft
Surface Area, A, ft^2	11800.31
Applicable Range	150 - 12,000 ft^2
Shell-Side Pressure, psig	14.50
Applicable Range	0 - 2,000 psig
Equipment Base f.o.b. Cost	$115,356.60
Material Factor	1.00
Tube Length Factor	1.00
Pressure Factor	1.00
Bare-Module Factor	3.17
CE Index	500
Equipment Bare-Module Cost	$365,680.43

The heat exchanger will have a shell side inlet flow rate of 108,070,500 kg/hr of cooling water with a temperature of 20°C and a pressure of 1.01 bar. The outlet shell side temperature is 25°C with a temperature of 1.01 bar. The cost of the cooling water is $480/hr. The tube side of the heat exchanger will have an inlet (WGS-OUT2) flow rate of

4,851,900 kg/hr, a temperature of 152°C and a pressure of 10 bar. The outlet temperature of the tube side of the heat exchanger will be 50°C and the pressure will be 10 bar. The total heat transfer area of this heat exchanger is 10,970 m^2 and the heat duty is 149,680 kcal/sec.

Both the tube and shell sides will be made of carbon steel. There will be 10 heat exchangers to meet these requirements. The total bare module cost of these heat exchangers is $3,880,000.

The equipment specification sheet is shown in Table 7.10.2.

Table 7.10.2. WGS-HTX2 Heat Exchanger Equipment Specification Sheet.

Heat Exchanger					
Identification:	Item		Shell and Tube		
	Item No.		WGS-HTX2		
	Number Required		10		
Function:	To use cooling water to cool the products from the Water-Gas Shift Reactor				
Operation:	Semi-Continuous				
Performance of Unit					
	Shell Side		*Tube Side*		
	Inlet	*Outlet*	*Inlet*	*Outlet*	
Stream Name	CW	CW	WGS-OUT2	WGS-OUT3	
Phase	Liquid	Liquid	Vapor	Mixed	
Molar Flow Rate (kmol/hr)	194526900.00	194526900.00	20214.00	20214.00	
Mass Flow Rate (kg/hr)	10807050.00	10807050.00	485190.00	485190.00	
Carbon Monoxide	0.00	0.00	24845.88	24845.88	
Carbon Dioxide	0.00	0.00	322563.15	322563.15	
Hydrogen Gas	0.00	0.00	9872.80	9872.80	
Water	10807050.00	10807050.00	127911.00	127911.00	
Temperature (C)	20.00	25.00	152.04	50.00	
Pressure (bar)	1.01	1.01	10.00	10.00	
Design Data:	Equipment Type:		Floating Head		
	Flow Type:		Counter Current		
	Tube Side:		Carbon Steel		
	Shell Side:		Carbon Steel		
	Heat Transfer Area:		1096.5855	m^2	
	Heat Duty:		14968062.17	cal/sec	
	Tube Length:		6.10	m	
Cost of Cooling Water					3.1886 $/hr
Bare Module Cost Per Unit:					$365,680.43
Total Bare Module Cost:					$3,656,804.30

7.11 FT-HTX2

There will be a shell in tube heat exchanger, shown in the Aspen process flow diagram as FT-HTX2 in Section: FT in Figures 5.2.1 and 5.6.1, in order to cool the products (PROD-FT1) from the Fischer-Tropsch reactor (FT-RXR). The f.o.b. pricing for the heat exchanger is given by:

$$C_P = F_P F_M F_L C_B$$

where F_L is the tube length correction and F_P is the pressure factor based on the shell-side pressure, P, in psig:

$$F_P = 0.9803 + 0.018\left(\frac{P}{100}\right) + 0.0017\left(\frac{P}{100}\right)^2$$

the pressure factor is valid from 100 to 2,000 psig.

The base cost, C_B, for the floating head heat exchanger is:

$$C_B = \exp\{11.9052 - 0.8709[\ln(A)] + 0.09005[\ln(A)]^2\}$$

where A is the tube outside surface area.

The sizing and costing of the heat exchanger for FT (FT-HTX2) is shown in Table 7.11.1 below.

Table 7.11.1. Shell-and-Tube Heat Exchanger Costing Table.

Heat Exchanger Costing	
Equipment Category	Heat Exchangers
Subtype 1	Shell & Tube
Subtype 2	Floating Head
Shell/Tube Material	Carbon Steel/Carbon Steel
Tube Length	20 ft
Surface Area, A, ft^2	10517.29
Applicable Range	150 - 12,000 ft^2
Shell-Side Pressure, psig	14.50377
Applicable Range	0 - 2,000 psig
Equipment Base f.o.b. Cost	$105,119.77
Material Factor	1.00
Tube Length Factor	1.00
Pressure Factor	1.00
Bare-Module Factor	3.17
CE Index	500
Equipment Bare-Module Cost	$333,229.67.43

The total inlet flow rate to the shell side of the heating exchanger is 66,052,500 kg/hr of cooling water. The price of cooling water is $290/hr. The total inlet flow rate to the tube side of the heat exchanger (PROD-FT1) is 4,119,300 kg/hr of mixed products from the FT

reactor. The heat exchanger has a heat transfer area of 7,820 m^2 and a heat duty of 91,480 kcal/hr. The shell and tube side will both be made of carbon steel. There will be 8 heat exchangers to meet these requirements. The total bare module cost for the heat exchanger is $2,580,000.

The equipment specification sheet is shown in Table 7.11.2.

Table 7.11.2. FT-HTX2 Heat Exchanger Equipment Specification Sheet.

Heat Exchanger				
Identification:	Item		Shell and Tube	
	Item No.		FT-HTX2	
	Number Required		8	
Function:	To use cooling water to cool the products from the Fischer-Tropsch Reactor			
Operation:	Semi-Continuous			
Performance of Unit				
	Shell Side		*Tube Side*	
	Inlet	*Outlet*	*Inlet*	*Outlet*
Stream Name	CW	CW	PROD-FT1	PROD-FT2
Phase	Liquid	Liquid	Mixed	Mixed
Mass Flow Rate (kg/hr)	148618125.00	148618125.00	16094.17	16094.17
Molar Flow Rate (kmol/hr)	8256562.50	8256562.50	514912.50	514912.50
Carbon Monoxide	0.00	0.00	6088.76	6088.76
Carbon Dioxide	0.00	0.00	458566.69	458566.69
Hydrogen Gas	0.00	0.00	7973.50	7973.50
Water	8256562.50	8256562.50	24212.81	24212.81
C1	0.00	0.00	275.73	275.73
C2	0.00	0.00	490.44	490.44
C3	0.00	0.00	653.80	653.80
C4	0.00	0.00	774.22	774.22
C5	0.00	0.00	854.28	854.28
C6	0.00	0.00	895.93	895.93
C7	0.00	0.00	902.52	902.52
C8	0.00	0.00	890.09	890.09
C9	0.00	0.00	876.24	876.24
C10	0.00	0.00	860.56	860.56
C11	0.00	0.00	840.25	840.25
C12	0.00	0.00	814.94	814.94
C13	0.00	0.00	785.80	785.80
C14	0.00	0.00	752.85	752.85
C15	0.00	0.00	718.16	718.16
C16	0.00	0.00	681.25	681.25
C17	0.00	0.00	643.86	643.86
C18	0.00	0.00	607.70	607.70
C19	0.00	0.00	569.78	569.78
C20	0.00	0.00	534.41	534.41
C21	0.00	0.00	499.59	499.59
C22	0.00	0.00	464.47	464.47
C23	0.00	0.00	433.64	433.64
C24	0.00	0.00	402.33	402.33
C25	0.00	0.00	373.14	373.14
C26	0.00	0.00	344.63	344.63
C27	0.00	0.00	319.55	319.55
C28	0.00	0.00	293.99	293.99
C29	0.00	0.00	270.61	270.61
C30	0.00	0.00	249.91	249.91
Temperature (C)	20.00	25.00	200.00	30.00
Pressure (bar)	1.01	1.01	20.00	20.00
Design Data:	Equipment Type:		Floating Head	
	Flow Type:		Counter Current	
	Tube Side:		Carbon Steel	
	Shell Side:		Carbon Steel	
	Heat Transfer Area:		977.08875	m^2
	Heat Duty:		11435480.82	cal/sec
	Tube Length:		6.10	m
Cost of Cooling Water:			1.9488 $/hr	
Bare Module Cost Per Unit:			$333,229.67	
Total Bare Module Cost:			$2,665,837.36	

7.12 DECANT

A decanter, shown in the Aspen process flow diagram as DECANT in Section: FT in Figures 5.2.1 and 5.6.1, will be used to separate the water (H2O-REC) and liquid hydrocarbon products (PETROL). The decanter (horizontal pressure vessel) was sized by first calculating the volume of the vessel, using:

$$V = 2\left(\frac{F_L}{\rho_L}\right)\tau$$

where F_L is the flow rate of the liquid, ρ_L is the density of the liquid phase and τ is the residence time. The relation between length of the vessel and diameter of the vessel chosen was of:

$$L = 4D$$

The diameter of the vessel can be found using:

$$D = \left(\frac{V}{\pi}\right)^{1/3}$$

The f.o.b. pricing for the vertical pressure vessel is given by:

$$C_P = F_M C_V + C_{PL}$$

where C_V is the purchase cost of the empty vessel, C_{PL} is the cost for platforms and ladders, and F_M is the material factor. The purchase cost of the empty vessel is calculated by:

$$C_V = \exp\{7.0132 - 0.18255[\ln(W)] + 0.02297[\ln(W)]^2\}$$

where weight, W, is given by:

$$W = \pi(D_i + t_s)(L + 0.8D_i)t_s\rho$$

where t_S is the shell thickness. The added cost of platforms and ladders can be found using:

$$C_{PL} = 361.8(D_i)^{0.73960} + (L)^{0.70684}$$

where D_i is the vessel inner diameter and L is the length of the shell.

The sizing and costing of the decanter (DECANT) is shown in Table 7.12.1 below.

Table 7.12.1. DECANT Sizing & Costing Table.

Decanter Sizing & Costing	
Vessel Type	Horizontal
Vessel Material (Cost)	Carbon Steel
Material Factor	1
Height/Length (ft)	29.00
Diameter (ft)	7.09
Operating Pressure (psig)	72.52
Design Pressure (psig)	96
Material (Stress)	Carbon Steel (SA-285 Grade C)
Design Temperature (F)	-20 to 650
Maximum Allowable Stress (psig)	13750
Minimum Wall Thickness	
Inside Diameter Range (ft)	6 - 8
Minimum Thickness (in.)	0.38
Weld Efficiency	
Wall Thickness Range (in.)	< 1.25
Efficiency	0.85
Estimated Wall Thickness (in.)	0.35
Corrosion Allowance (in.)	0.13
Vessel Wall Thickness (in)	0.50
Vessel Weight (lbs)	15860
Vessel Cost	$46,853.17
Platforms & Ladders Cost	$2,983.63
Total f.o.b. Purchase Cost	$49,836.79
Bare-Module Factor	3.05
Total Bare-Module Cost	$152,002.22

The L-L equilibrium horizontal vessel will be made of carbon steel. The vessel has a diameter of 2.16 m, a length of 8.65 m, a wall thickness of 0.11 m and a residence time of 5 min. The plant will require 1 decanter with a flow rate of 39.5 L/min. The decanter will have an inlet (LIQ-FT) flow of 306,490 kg/hr, with a temperature of 25°C and a pressure of 15 bar. The continuous phase's flow rate is of 189,820 kg/hr (H2O-REC), at a temperature of 25°C and a pressure of 15 bar. The transportation fuel (PETROL) will have a flow rate of 116,680 kg/hr, at a temperature of 25°C and a pressure of 15 bar. The total bare module cost of the decanter is of $152,000.

The equipment specification sheet is shown in Table 7.12.2.

Table 7.12.2. DECANT Equipment Specification Sheet.

Decanter				
Identification:	Item		Horizontal Vessel	
	Item No.		DECANTER	
	Number Required		1	
Function:	To separate the unreacted water (H_2O) from the liquid hydrocarbons (C1-C30) and the			
Operation:	Semi-Continuous			
Performance of Unit				
	Inlet		*Outlet*	
Stream Name	LIQ-FT		H2O-REC	PETROL
Phase	Liquid		Liquid	Mixed
Molar Flow Rate (kmol/hr)	11274.36		10536.38	737.99
Mass Flow Rate (kg/hr)	306491.81		189815.72	116676.09
Carbon Monoxide	9.94		0.00	9.94
Carbon Dioxide	7491.08		0.00	7491.08
Hydrogen Gas	4.54		0.00	4.54
Water	189815.70		10536.38	179279.33
C1	1.19		0.00	1.19
C2	11.09		0.00	11.09
C3	49.54		0.00	49.54
C4	191.47		0.00	191.47
C5	639.09		0.00	639.09
C6	1735.29		0.00	1735.29
C7	3561.25		0.00	3561.25
C8	5376.16		0.00	5376.16
C9	6314.91		0.00	6314.91
C10	6627.98		0.00	6627.98
C11	6624.72		0.00	6624.72
C12	6487.22		0.00	6487.22
C13	6276.89		0.00	6276.89
C14	6019.37		0.00	6019.37
C15	5744.16		0.00	5744.16
C16	5449.62		0.00	5449.62
C17	5150.73		0.00	5150.73
C18	4861.59		0.00	4861.59
C19	4558.20		0.00	4558.20
C20	4275.27		0.00	4275.27
C21	3996.69		0.00	3996.69
C22	3715.74		0.00	3715.74
C23	3469.09		0.00	3469.09
C24	3218.66		0.00	3218.66
C25	2985.09		0.00	2985.09
C26	2757.01		0.00	2757.01
C27	2556.42		0.00	2556.42
C28	2351.94		0.00	2351.94
C29	2164.90		0.00	2164.90
C30	1999.27		0.00	1999.27
Temperature (C)	25.00		25.00	25.00
Pressure (bar)	15.00		15.00	15.00
Design Data:	Flash Type:	L-L Equilibrium	Diameter:	2.16 m
	Column Material:	Carbon Steel	Length:	8.65 m
	Total Flow:	39.51 L/min	Thickness:	0.11 m
	Per Vessel:	39.51 L/min	Residence Time:	5 min
Bare Module Cost Per Unit:			$152,002.22	
Total Bare Module Cost:			$152,002.22	

Section 8 – Energy Balance and Utility Requirements

The operation of this plant requires cooling water and electricity as utilities. One of the main advantages of the CR5 is the utilization of solar flux to heat the CR5 to the high temperatures necessary for the oxidation-reduction reactions to split CO_2, which is what allows this process to be feasible. However, additional utilities are necessary in other sections of the plant.

Heat integration was completed, primarily around the WGS reactor (WGS-RXR) in order to use the heat from the reaction to heat the incoming reactant streams to the reactor operating temperature. This eliminates the necessity of a hot utility, steam.

Overall, the plant produces an excess of heat, so no hot utilities are necessary throughout the plant. Cooling water is necessary for cooling requirements in the heat exchangers and other vessels. Electricity is necessary for the compressors and pumps.

8.1 Cooling Water

After heat integration, there are two heat exchangers that require cooling utilities, WGS-HTX2 and FT-HTX2, as shown in the Aspen process flow diagram in Figures 5.2.1, 5.5.1, and 5.6.1. Additionally, the Fischer-Tropsch reactor (FT-RXR – in Figures 5.2.1 and 5.6.1) must be cooled to keep the reactor under isothermal conditions even with an exothermic reaction. Fortunately, all three process units only require mild cooling conditions, and as such can use cooling water. The cooling water is assumed to be at an inlet 20°C and an outlet 25°C at atmospheric pressure.

WGS-HTX2 (in Figures 5.2.1 and 5.5.1) has a heat duty of 1.5E+8 cal/sec with a usage rate of cooling water of 1.08E+8 kg/hr yielding a cost of $480/hr. FT-HTX2 (in Figures 5.2.1 and 5.6.1) has a heat duty of 9.148E+7 cal/sec with a usage rate of cooling water of 6.61E+7 kg/hr yielding a cost of $290/hr. FT-RXR (in Figures 5.2.1 and 5.6.1) has a heat duty of 2.366E+8 cal/sec with a usage rate of cooling water of 1.71E+8 kg/hr yielding a cost of $760/hr. It is assumed that this cooling water will be utilized from a local hydrologic source, i.e. is abundant and sustainable, or will be recycled in order to minimize overall water consumption. The cooling water utilities have an annual cost of $5,270,000.

8.2 Electricity

Electricity is a major component of the proposed project, as clarified in Table 8.2.1, with a total electricity requirement of 1300-1500 MW assuming demand for additional electricity for lighting and other supporting infrastructure.

Table 8.2.1. Electricity Demands.

Block Name	Block Type	Electricity (MW)
COMPRESS	Compressor	541.88
FT-COMP	Compressor	758.65
H2O-PUMP	Pump	0.53
CR5/Parabolic Dish Array		0.43
		1301 MW

There are several options for addressing this concern: combustion of GASPURGE for electricity generation (Section 8.3) and power recovery from O2 (Section 8.4). As stated below, these two options come close to fulfilling the plant's entire electricity requirements, as shown below, with a total unmet electrical need of ~300MW, as shown in Table 8.2.2.

Table 8.2.2. Electricity Options.

Overall Demand	**1301.48**	**MW**
TURBINE	-79.64	MW
GASPURGE Burning	-918.57	MW
Overall Electricity	**303.27**	**MW**

Economic analysis presented in Section 11 assumes purchasing this need from existing power plants in the area at a cost of $0.06/kWh. Additional economic analysis may be necessary to explore the different alternative options for advanced electricity requirements and the best options for fulfilling this leftover electricity demand.

8.3 Combustion of GASPURGE for Electricity Generation

The stream GASPURGE (shown in Figure 5.2.1, Figure 5.6.1, and Table 5.7.1), which prevents a buildup of inerts and other chemical species in the system, has a significant flow of hydrogen with a small flow of carbon monoxide and light end hydrocarbons. This purge flow could be utilized for power production. Assuming the lower heating value (i.e. that in complete combustion, the outlet products are CO_2 and water vapor, for conservative analysis), the combustion of this stream to produce electricity has a capacity for ~920 MW, with the full calculation and analysis shown in Appendix C.1. The calculations were

completed assuming power generation utilizing a combined cycle scheme, using both the heat of combustion as well as the heat from the product flue gas. This production would fulfill a significant portion of the plant's electricity demand, while introducing costs with the necessary process equipment and associated maintenance.

8.4 Power Recovery from O2

Additionally, there is a significant amount of energy leaving the system through the oxygen product stream from the CR5 (O2 – shown in Figure 5.2.1, Figure 5.4.1, and Table 5.7.1). While it seems to be uneconomical to sell this O_2 product due to its low pressure, low purity, and need for additional infrastructure, as further outlined in Section 9.2, it may be viable to recover heat. Heat can be recovered from the stream and utilized to generate electricity. Since the stream is at low pressure and high temperature, it would not be feasible to run the stream through a gas turbine directly. Instead, heat transfer in a heat exchanger to a high-pressure water stream at its bubble point could recover the energy. The transfer of heat would lower the temperature of the O_2 and vaporize the water, producing high-pressure steam (20 bar). This high-pressure steam could then be utilized to run a turbine and generate electricity. An Aspen Plus flowsheet and model are shown in Appendix C.2. The addition of these turbines to the CR5 assembly has a capacity for ~80MW.

Section 9 – Alternative Process Sequences

9.1 Continuous vs. Semi-Continuous Production

The CR5 segment of the plant will only produce carbon monoxide during sunlight hours. Storage tanks will be set up to store the amount of carbon monoxide produced during 2 hours of CR5 operation plus 10% of additional carbon monoxide so that production of petrol product remains constant during the day, even with variations in solar flux particularly during sunrise and sunset. Therefore, the sunlight to transportation fuel plant will operate semi-continuously. Semi-continuous operation is preferable because this strategy only requires 22 storage tanks that each store 1 million gallons of gas with a total cost of $11.8 MM rather than 134 storage tanks with a total cost of $72.7 MM that are needed for the plant to operate continuously. The semi-continuous production mode allows for cost savings on storage tanks as well as savings on land required to house the storage tanks. The startup and shutdown costs are approximated as 1% of total capital cost of the equipment, as suggest by Sieder, 2009. These costs total $290,000,000/yr, a relatively large portion of operating expenses. Although the stress of daily startup/shutdown will be omitted in the continuous scenario, the stress of an additional 140% operation will require frequent catalyst replacement as well. Further discussion can be found in Section 11.6.

9.2 Selling O_2 Product

Considerations and ultimately, decisions, had to be undertaken concerning the O_2 product produced from the CR5. Schemes that allowed for the selling of the gas were considered. Selling the O_2 produced could have raised the bottom line, by introducing another product revenue stream into the economic analysis. However, analysis shows that it is uneconomical to sell this O_2 product due to its low pressure, low purity, and need for additional infrastructure. A system of heat exchangers and turbines, as discussed in Section 8.4, is utilized to recover power from the heat of the O_2 stream (O2). Additional compressors and piping, however, would be necessary to capture, transport, and sell the O_2. Overall, it appeared to be cost-ineffective to sell the O_2 product at this time considering all the additional process equipment, utility requirements, associated maintenance, and the relatively low price of $56/ton O_2 (Kim, 2011). Schemes for power recovery options from the thermal energy of the O_2 are shown in Appendix C and discussed in Section 8.4.

9.3 Separating CO_2-CO

The primary plant design dictates that CO_2 will be obtained from a CO_2 pipeline and that the unreacted CO_2 exiting the CR5 reactors is only recycled after the Fischer-Tropsch reaction. Currently the cost of CO_2 is assumed to be .035 USD per kg of CO2. (Kim, 2011) An alternative process sequence would separate CO_2 from flue gas using MEA (monoethanolamine) in order to obtain CO_2 for the CR5 reaction while also using MEA to separate CO_2 from the CO after the CR5 reactions. The use of MEA separation results in a price for CO_2 of 0.0396 USD per kg CO_2. (Kim, 2011) Therefore, the price of CO_2 is similar for both scenarios. However, the extra costs of the MEA equipment and maintenance of this equipment do not make it a clear choice for the process sequence.

CO_2 separation is also an important consideration within the plant. Outputs from both the CR5 and WGS contain a mixed stream of carbon dioxide and carbon monoxide. If possible, it would be ideal to separate the CO_2 from the CO to enable significantly smaller piping and process equipment, as well as simplicity. However, separation of CO_2 from CO is extremely difficult, thus highly energy intensive and expensive, requiring MEA absorption techniques or cryogenic distillation. For the process, it did not appear economically feasible based on the advice of industrial consultants. In avoiding the separation, however, several process changes had to be considered.

The high volume of CO_2 in the streams negatively affects the equilibrium of the water gas shift reaction according to Le Châtelier's Principle. Thus, the water flow rate into the water gas shift reaction had to be appropriately manipulated to push equilibrium towards the products.

The large amount of CO_2 in the system, however, also had unintended benefits. The inert CO_2 keeps the streams out of flammability and explosion limits. Additionally the excess gas serves as a diluent, keeping the reactors near isothermal even when run adiabatically, dramatically reducing potential utility costs.

9.4 Co-Location

Another consideration is co-locating with an oxyfuel plant, in order to directly sell the oxygen gas produced from the CR5 reactions. Currently, this hot O_2 while heat is being recovered using a heat exchanger. The co-location option would also allow the CO_2 to be obtained from the oxyfuel plant. This symbiotic relationship could be mutually beneficial for both the sunlight to transportation fuels plant and the oxyfuel plant. Additionally, the oxyfuel plant would also provide a source for our electricity requirement. However, this

consideration was not chosen due to the high capital cost associated with the isolation and purification necessary to obtain the CO_2 stream from the oxyfuel plant. Additionally, the collection of our O_2 product would require additional piping and other infrastructure.

Section 10 – Fixed Capital Investment Summary

Total capital investment includes the cost of 150 CR5 reactors, the water-gas shift reactor, the Fischer-Tropsch reactor, storage tanks, compressors, piping and land. For all installed equipment, an installation cost of 63% of purchase cost is included in the economic evaluation (Seider, 2009).

10.1 CR5s

A breakdown of the fixed capital cost of each CR5 unit in a piece-wise manner indicates a price per parabolic disk of $25,000 and a price per CR5 reactor of $2,300, for a total of $27,300 (Kim, 2011). This price represents an upper-bracket of the price that will be paid for the 150 CR5s in the solar to transportation fuel plant, as economies of scale are expected to exist upon purchasing the reactors in such a large quantity. The breakdown of these costs can be seen in Table 10.1.1 below.

Table 10.1.1. CR5 cost breakdown.

Mirror Module	$61
Support structure	$40
Drives	$69
Electrical/Constols	$9
Pedestal	$32
Overhead	$42
Field wiring	$14
Foundation	$4
Field align/checkout	$12
Price per m2	$285
Size of parabolic disk (m2)	88
Price of Parabolic Disk	$25,054
Shell	$60
Ring/pipe	$14
Shaft/sprocket	$4
Insulation blanket	$36
Inner housing	$224
Refractory assembly	$904
Ring assembly	$532
Insulating panels	$328
Window	$1
Installation Cost	10.00%
CR5 Price	$2,314
Price per unit	$27,367
Number of Units	150
Economies of Scale	20%
Total CR5 Cost	$3,284,081

Additionally, the technology is expected to improve, allowing for a more streamlined production. To account for these economies of scale and technological advancements, a discount of 20% was applied to the total cost of the CR5 units. The cost of these reactors is a one-time, upfront cost, depreciated using a 5-year MACRS depreciation schedule.

10.2 Water Gas Shift Reactor

The capital cost of the water-gas shift (WGS) reactor (WGS-RXR) is based on:

$$C = (4.57 \times 10^4) V^{0.67}$$

where C is the capital cost and V is the volume of the reactor. The volume of the reactor is equal to the volumetric flow rate, 4MM m^3/hr divided by the residence time, 1 second, all divided by the void fraction of 0.375. Three WGS reactors will be used. The total cost of the water gas shift reactors is $45MM. The cost of the reactor is a one-time, upfront cost, depreciated using a 5-year MACRS depreciation schedule.

The expected price of the catalyst is $1 B, based on a percent-weighted cost of each component. The breakdown of this cost can be seen in Table 10.2.1.

Table 10.2.1. WGS Reactor Catalyst Cost Breakdown.

	Price ($/kg)	Weight Percent
Fe2O3	$53.80	73%
Al2O3	$65.60	15%
Cr2O3	$87.80	8%
CuO	$78.25	4%
Total Catalyst ($/kg)	$59.27	
Density (kg/m3)	3950	
Volume Catalyst (m^3)	4417	
Price of Catalyst per m3	$234,109	
Cost of Catalyst	**$1,033,979,650**	

Due to the increased amount of stress upon the system as a result of the daily startup and shutdown, the catalyst will be replaced every 5 years.

10.3 Fischer-Tropsch Reactor

The capital cost of the Fischer-Tropsch (FT) reactor (FT-RXR) is modeled in the same way as the water gas shift reactor, by Equation 13.2.1. The volumetric flow rate of the FT reactor is 4,005,000 m^3/hr. The void fraction associated with the packed bed is the same as the WGS reactor, 0.375. The residence time of the FT reactor is 1 second. Three FT reactors will be required. The total cost of the FT reactor is $14MM. This cost is a one-time, upfront payment depreciated over 5 years following the 5-year MACRS schedule.

The expected price of the catalyst is $1.3 B, based on a weighted averaged price of each component. The breakdown of this pricing can be seen in Table 10.3.1.

Table 10.3.1. FT Reactor Catalyst Cost Breakdown.

	Price ($/kg)	Percent
Co	$0.01	30%
Re	$3,000	4.5%
Al2O3	$65.60	65.5%
Total Cost ($/kg)	$177.97	
Density (kg/m3)	3950	
Volume Catalyst (m^3)	1,854	
Price of Catalyst per (m^3)	$702,990	
Cost of Catalyst	**$1,303,460,604**	

Due to the increased amount of stress upon the system as a result of the daily startup and shutdown, the catalyst will be replaced every 5 years.

10.4 Storage Tanks

Storage tanks will be required for two primary uses: CR5 product storage and FT final product storage. CR5 products will be stored in order to provide a steady flow rate of CO into the water gas shift (Section: WGS in Figures 5.2.1 and 5.5.1) and Fischer-Tropsch (Section: FT in Figures 5.2.1 and 5.6.1) sections, making up for inconsistent solar flux throughout the day. CR5s, unlike the water gas shift (WGS-RXR) and Fischer-Tropsch (FT-RXR) reactors, are dependent on incoming solar radiation. To provide for this buffer, storage capacity for 2 hours of average CR5 production will be available. This is a total volume of 16.5 MM gallons. Additionally, storage capacity for 5 days of production will be available. This is a total volume of 2.2 MM gallons. The storage tanks will be floating roof tanks, with a maximum capacity of 1 MM gallons each (Seider, 2009). The storage tanks will account for a 10% empty minimum. Three floating roof storage tanks of 8 MM gal capacity will be available for product storage and 19 of 10 MM gal capacity available for CR5 outlet storage. The total cost of the tanks was calculated using

$$C = 475V^{0.51}$$

where C is the total cost per tank and V is the total volume (accounting for 10% empty space at all times). The total purchase cost for these 22 storage tanks will be $11.8 MM.

10.5 Compressors & Pumps

Centrifugal compressors, which have a maximum capacity of 30,000 hp, will be used. The total capacity required for the WGS compressors and the FT compressors are 540,000 hp and 760,000 hp, respectively. Consequently, 19 compressors with 28,500 hp

each will be required for the WGS and 26 compressors with 29,000 hp will be required for the FT. The total cost of each compressor is calculated using

$$C = 7.58 * EXP(0.8 + LN(P))$$

Where P is the power, in horsepower. The total cost of these 45 compressors is $275MM, which occurs upfront and depreciates over a 5-year period.

Centrifugal pumps, which have a maximum capacity of 3,200 hp, will be used. Fifteen centrifugal pumps are necessary for the power requirements of the plant. The total price of these pumps will be $710,000. This is a one time, depreciable cost.

10.6 Piping

The total capital cost associated with the piping required for the plant is calculated according to Seider, 2009 at 68% of total delivered equipment cost. This cost is a total of $1.7MM, as a one time, depreciable cost.

10.7 Land

The land required for the 150 CR5s is estimated based on the method used in Kim, 2011. This land requirement is 40,000 m^2. The land required for the storage tank, WGS reactor and FT reactor is based on the diameters, which are 15 m, 53.12 m and 39.78 m, respectively. An additional 10% of the total land is allocated for the compressors. Twenty percent additional land is required for roads and void space. The total land required is 77,000 m^2. The cost of this land is $1,560 /acre, according to USDA average pasture land prices in Texas for 2013 (USDA, 2013).

Section 11 – Operating Cost and Economic Analysis

11.1 Model Assumptions

In determining the economic feasibility of the sunlight to transportation fuels plant, several key assumptions were made regarding the economic model. In accordance with Seider, 2009 maintenance costs are 8.02% of the total depreciable cost; taxes are 40% of the pre-tax earnings; selling expenses are 3% of sales; administrative expenses are 2% of sales and management incentive compensation is 1.25% of sales (Seider, 2009). These are in line with a liquid and gas processing plant in a rural location. In order to account for year-over-year increases in the prices of goods and services, an annually compounding interest rate of 2% was used. The number of laborers, plumbers, electricians, chemical engineers, software developers, and plant operators followed the logic outlined in Seider, 2009 as well as guidance from Sandia National Laboratory. The salaries for each type of employee were taken from the United States Department of Labor, Bureau of Labor Statistics (US Dept Labor, 2012). Additionally, operating supplies and services were assumed 6% of the total wages and compensation (Seider, 2009). Operating overhead was assumed 22.8% of 125% total wage costs plus maintenance (Seider, 2009).

In order to allow for startup time, the production level of the plant is scheduled to ramp up. Production will begin in the fourth year of operation. The first year of production will be at 50% plant capacity, followed by a year of 75% production and all subsequent years will operate at 95% plant capacity.

For all capital investments in plant, property and equipment, with the exception of land, a MACRS 5-year depreciation schedule was used. An installation cost of 63% was applied to these capital investments as well.

11.2 Commodity Pricing

The sunlight to transportation fuels plant consumes water and carbon dioxide, producing a mixture of hydrocarbons. The price of water is assumed to be $0.001/kg. The price of carbon dioxide has been evaluated by Kim, 2011. This evaluation revealed that CO_2 is priced at $0.035/kg when sourced from a closely located CO_2 pipeline. If the CO_2 pipeline is of significant distance from the plant, this price will increase. In the economic evaluation, direct location is assumed.

The hydrocarbon product was priced at a premium to crude oil, due to the higher purity of the hydrocarbon product. This premium is assumed to be 2X.

11.3 Other Sources of Revenue

Due to the renewable nature of the sunlight to transportation fuels plant, renewable fuel subsidies and carbon credits are expected to be other sources of revenue. The renewable fuel subsidy is expected to be $0.38/gal, declining linearly over 15 years. This subsidy is to be provided by the US government to incentivize the production of renewable fuel. The carbon credit is expected to be $10/ton of CO_2 consumed that is produced by other industrial plants.

11.4 Daily Startup/Shutdown Costs

In response to the inconsistent solar flux and complete lack of flux during the day, the reactors will need to be started up and shutdown at the beginning and end of each day. In line with Seider, 2009, the cost associated with this will be 1% of the capital cost of each reactor.

11.5 Profitability Analysis

In order to determine economic feasibility, a net present value analysis was performed, using a base case discount rate of 13% over a 30 year time period. Based on this analysis, the sunlight to transportation fuel plant is not economically desirable. The net present value proves to be negative, at a value of -$5.5 B. This result is largely due to the upfront capital expense associated with the reactors storage tanks and compressors. Moreover, the operating expenses are high due primarily to the daily startup and shutdown costs for the reactors. The amount of revenue produced by the plant is substantial, however. Consequently, it is likely that the project would be economically desirable if these capital costs and operating costs could be mitigated. This mitigation could be a result of CR5 technological advancements as well as a method of running the plant continuously, in order to reduce to number of storage tanks and the daily startup/shutdown costs.

11.6 Sensitivity Analyses

It is important to note that many of the assumptions used in this evaluation are subject to change. Consequently, a sensitivity analysis was run on five of these assumptions: the discount rate, the price of crude, the amount of fuel subsidy and carbon credits, the economies of scale associated with the CR5 reactors and the daily startup/shutdown costs. Three cases were run in this analysis: best, base and worst. The best-case scenario utilizes a 10% discount rate, $120/barrel cost of crude, $0.50/gal fuel subsidy, $15/ton carbon

credits, 30% economies of scale on the CR5 reactors and startup/shutdown cost of 0.1% of capital cost. The base case scenario utilizes 13% discount rate, $100 price of crude oil, $0.38/gal fuel subsidy, $10/ton carbon credit, 20% economies of scale on the CR5 reactors and startup/shutdown cost of 1% of capital cost. The worst-case scenario utilizes an 18% discount rate, $90/barrel price of crude oil, $0.25/gal fuel subsidy, no carbon credit, no economies of scale on the CR5 reactors and startup/shutdown cost of 2% of capital costs. These sensitivities are summarized in Table 11.6.1.

Table 11.6.1 Sensitivity analysis variables.

	Discount Rate	**Price of Crude**	**Fuel Subsidy**	**Carbon Credit**	**Economies of CR5**	**Startup Cost**
Best Case	10%	$120	$0.50	$15	30%	0.10%
Base Case	13%	$100	$0.38	$10	20%	1%
Worst Case	18%	$90	$0.25	$0	0%	2%

In order to validate the assumption that largest drivers of the unfavorable nature of this project are the daily startup costs and the Fischer-Tropsch and water gas shift catalysts, additional scenarios were created to excluded these large recurring costs. These scenarios include base case values for the six variables outlined in Table 11.6.1. Continuous operation points to the Fischer-Tropsch and water gas shift reactors operating continuously throughout the night. This scenario requires an additional 109 storage tanks to allow for continuous flow of CR5 output to these reactors. However, the daily startup/shutdown cost associated with these reactors is no longer a factor. Additionally a scenario was evaluated where the cost of the Fischer-Tropsch and water gas shift catalysts were omitted. These two scenarios were also combined. Figure 11.6.1 shows the end of year cumulative cash flow of the three scenarios described above in solid lines and the scenarios for startup/shutdown cost and catalyst cost in dashed lines.

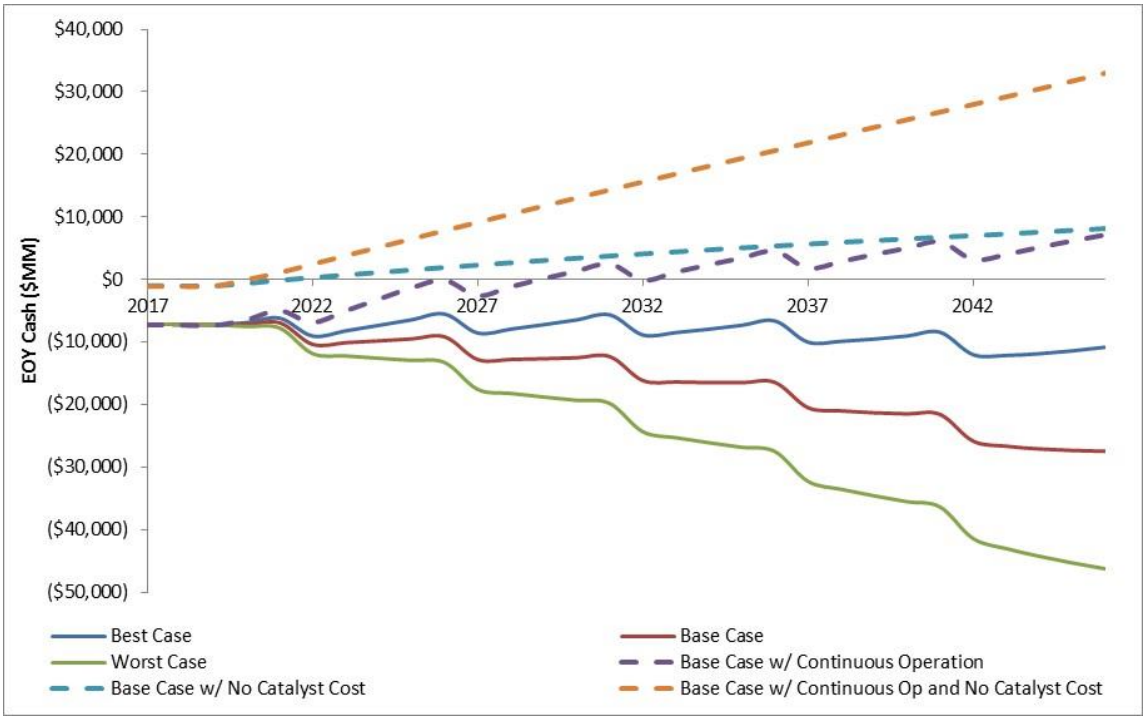

Figure 11.6.1. End of year cash projections for best, base and worst-case scenarios and base case with continuous operation, no catalyst and both over 30-year period.

As can be seen in the three scenarios, none of the sensitivities create a scenario in which the project breaks even. This points to the largest factor in cash is the five year renewal period for the catalysts. The non-linear nature of these projections is a function of the replacement cost of the catalyst every five years. Additionally, the fuel subsidies decay over a 15-year period. This is a result of the high operating expenses. Figure 11.6.2 shows annual earnings/(losses) for the same time period using the same sensitivity data.

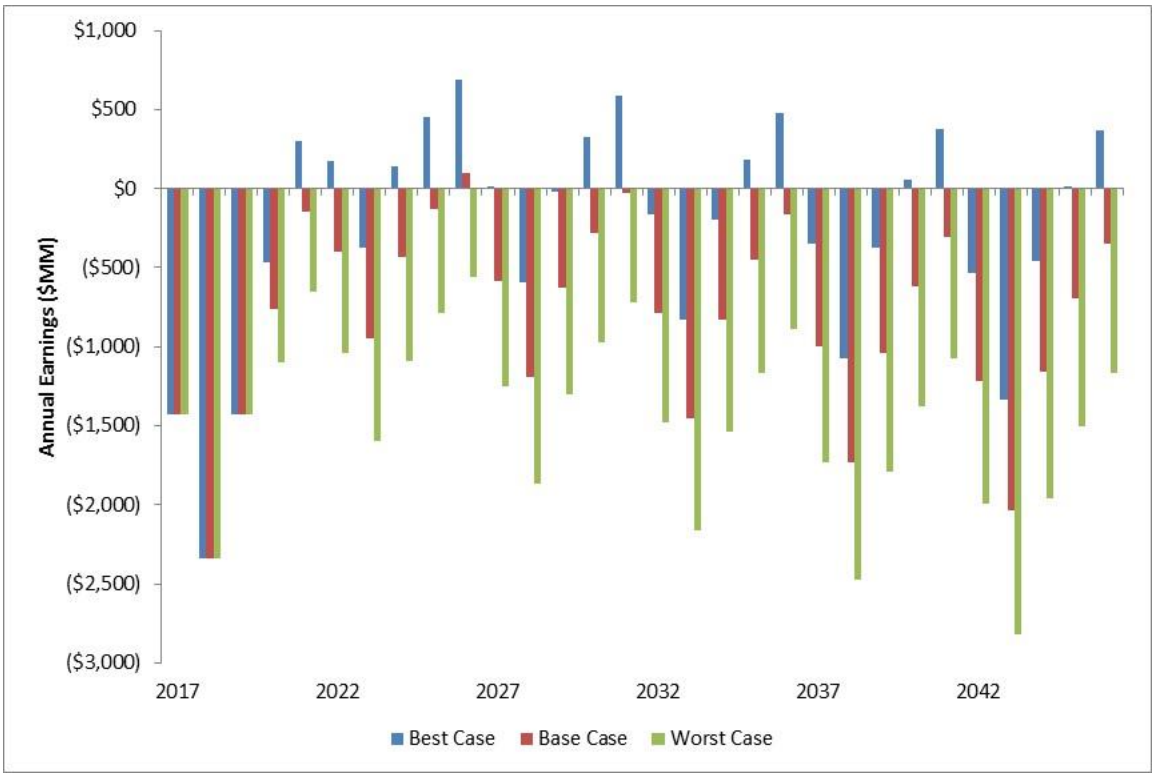

Figure 11.6.2 Annual Earnings/(Losses) for best, base and worst-case scenarios over 30 year period.

This chart reflects the large upfront costs and non-linear nature of the operating expenses, due to catalyst replacements and the resulting depreciation. The losses for all three scenarios are identical for the three years of construction (years 1-3). This is because the variables upon which the sensitivity analysis is run do not impact the upfront costs associated with construction of the plant. As can be seen in Figure 11.6.2, the plant will create profits in 12 of the 30 years in the best-case scenario, 1 of the 30 years in the base case and no years in the worst case. Despite the 12 years of net profit in the best-case scenario, the net present value of this scenario is not positive, supporting the conclusion that this scenario does not lead to overall profitability.

The startup/shutdown costs and the catalyst costs were further evaluated with respect to the base case scenario described above. The alternatives of continuous operation, no catalyst cost and continuous operation with no catalyst cost are show in Figure 11.6.3.

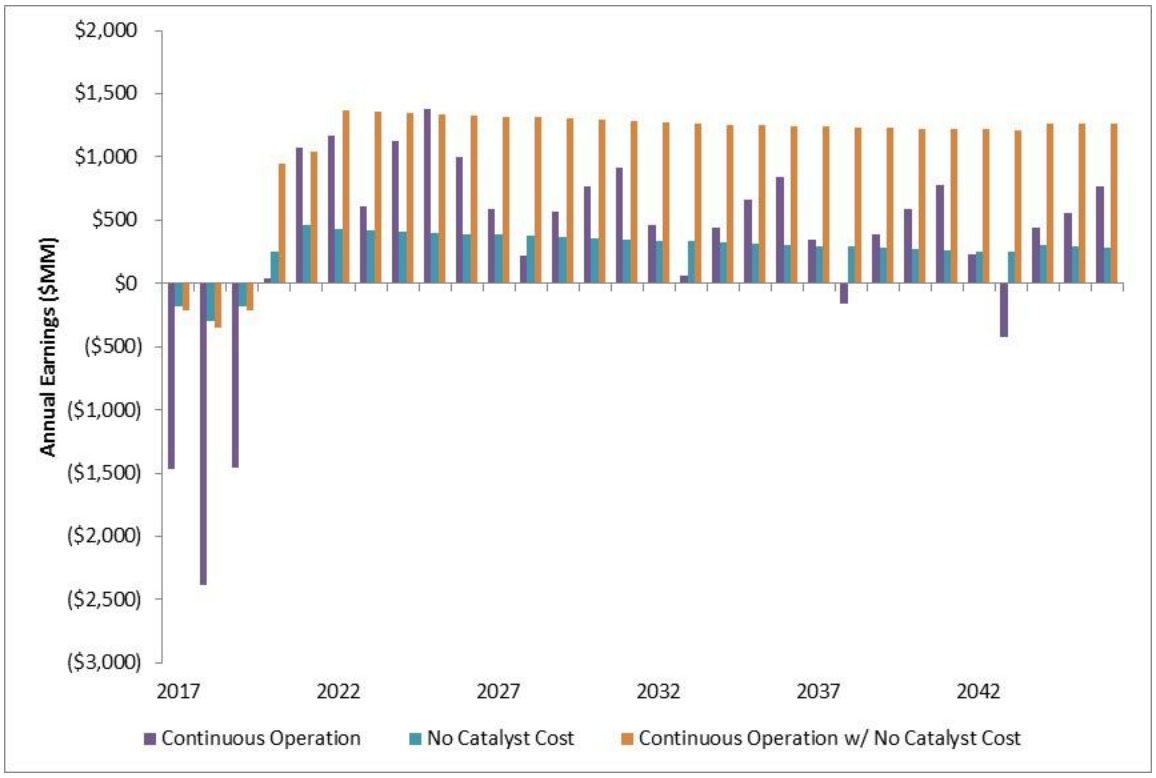

Figure 11.6.3 Annual Earnings/(Losses) for the base case scenario [13% discount rate, $100 crude oil price, $0.38 fuel subsidy, $10 carbon credit, 20% economies on CR5s, startup costs at 1% of capital cost] continuous operation, no catalyst and both over 30 year period.

As can be seen in Figure 11.6.4, removing these large recurring costs creates profitability in the fourth year (first year of operation) for all three alternative. However, it is important to note that although the economic analysis indicates feasibility, non-economic factors, such as operational control and safety hazards make continuous operation a less feasible alternative. The economic results of no catalyst costs are unrealistic. However, these results indicate that the high capital cost of the Fischer-Tropsch catalyst greatly impacts the favorability of this project. Consequently, these results point to the possibility of a favorable CR5 sunlight to transportation fuels plant if further research allowed for the use of a process that is not dependent on such high cost catalysts.

The undesirable nature of this project under the three original scenarios is further supported by the net present values for the three scenarios, in Table 11.6.2. Additionally in this table, the positive effect of continuous operation and no catalyst costs can be seen.

Table 11.6.2 Net present value over 30-year period for best, base and worst-case scenarios as well as alternatives with continuous operation, no catalyst cost and both.

Best Case	Base Case	Worst Case
($3,672,165,586)	($5,451,167,444)	($5,412,784,754)

Continuous Operation	No Catalyst Cost	Continuous Op w/ No Catalyst Cost
($441,201,574)	$1,067,009,580	$4,494,705,897

In conclusion, the plant will not have viable cash on hand, nor will it be profitable, in any of the three original scenarios. However, it is possible that further research that would allow for continuous operation and/or lower catalyst costs would lead to profitability. Further detail on financials can be found in Appendix D, Financials.

Section 12 – Other Important Considerations

12.1 Environmental Considerations

The sunlight to transportation fuels plant has a significant environment impact. Overall, the plant is highly environmentally friendly, utilizing a renewable resource to produce fuel energy from CO_2, a greenhouse gas. However, there are a number of environmental considerations to take into account.

It should first be noted that while the plant produces transportation fuels in an environmentally friendly manner, the transportation fuels themselves are still non-renewable resources, whose combustion releases carbon dioxide and other greenhouse gases into the atmosphere.

Of primary consideration, the plant has significant amounts of hydrogen, carbon monoxide, carbon dioxide, and hydrocarbon vapors circulating around the site in a system of pipes, tanks, and chemical processes. These gases are all greenhouse gases in some capacity, and extreme effort should be taken to minimize their release into the atmosphere, via leaks or flaring. The potential for leaks has been addressed below for their additional safety concerns. Efforts to minimize flaring or purging from the system have focused on maximizing the number and efficiency of recycle streams. Additionally, the light end hydrocarbon products will be utilized within the plant for utility requirements, where possible, to minimize both flaring and additional non-renewable utility fuel purchases.

Water also exists throughout the plant, as a feedstock to the water gas shift reactor and a product from Fischer-Tropsch. This water is contact with all of the fluids (primarily gases) in the system. As such, the water will be contaminated by the Fischer-Tropsch oil hydrocarbon products and metal catalysts. As such, the water cannot be released into the local surroundings, due to the deleterious effects on local ecological systems. Again, efforts were made to minimize outflow of wastewater by employing a number of recycle streams throughout the processes. The wastewater that is purged from the system will be utilized for secondary oil recovery in oil fields near the plant.

Lastly, for a plant of this size, overall environmental footprint is of concern – care was taken to choose a location where land resources are abundant and water stress is minimized. Proximity to the refineries buying our FT oil products also minimizes the environmental impacts of transporting our products far distances.

12.2 Plant Control

Process control will be an important factor in several aspects of the overall plant operation. Primary areas of importance for plant control attention will be storage tanks interfacing the semi-continuous CR5 operation and continuous WGS-FT operation, flow controls, and temperature controls for the reactors.

The storage tanks are an interesting control issue within the plant. The storage tanks holding the outlet CO_2/CO mixture from the CR5s will be a complex issue due to demand for constant outflow to the continuous WGS-FT operation, but the inlet (output from the CR5s) varies as a function of solar flux. Thus, the inlet will have changing flow rates and compositions depending on the solar flux with flows and CO yield peaking during the day and going to zero at night. Additionally, this will alter day to day due to weather conditions, etc. The controller, thus, plays an important role in providing a consistent output that does not change with input disturbances, yet is robust to handle the potentially high perturbations.

Flow controls are an important factor in plant control due primarily to the high number of streams, particularly recycles and purges, occurring within the plant. Flow controls at the splitters will be of paramount concern to have the appropriate purge flow to prevent buildup in the system. Additionally, flow to the reactors needs to be controlled to keep reactants in specified ratios, such as the 2.1:1 H_2:CO ratio necessary of steams entering the FT reactor (FT-Gas1 and FT-Gas2).

The temperature controls of the reactor will also be an important consideration, mostly to keep efficiency and yield of the reactors at a maximal level. The CR5s counter rotating rings can be assumed thermally efficient and thus self-regulating. The FT and WGS reactors, however, have highly exothermic reactions and the temperature needs to be controlled for maximum efficiency. The WGS reactor is run adiabatically, but has temperature limits and the FT reaction should occur at low temperatures. Controllers will be necessary to maintain these conditions.

12.3 Plant Layout

The entire plant will contain several key features including 150 CR5 reactors, 19 CR5 product-holding tanks, a Fischer-Tropsch section, a WGS section, and 3 final holding tanks. In order to optimize solar flux capture, the150 CR5 reactors will be laid out in a grid array. In order to account for the shadows as a result of shifting solar angle, 69% of the land allocated for the CR5 reactors will be empty (*Development of a CR5 Facility*, 2012). This grid

will occupy 90% of the entire property. An additional 5% of the property will be allocated to access roads to the FT and WGS reactors and CR5 product and final product storage units, located at the center of the property. These reactors and storage units will occupy the remaining 5% of the property. Piping will run from the CR5 units to the primary storage tank, which will then be connected via piping to the WGS and FT reactors. Recycle piping will also be required to recycle the unreacted CO_2 from the FT reactor to the CR5 units. Along these pipes, compressors will be used to move the gaseous materials.

12.4 Plant Safety

Safety concerns are paramount in this plant due to the high number of dangerous chemicals found throughout the plant. Safety concerns for each chemical compound are explained fully in Appendix A. The two primary safety concerns are due to the potential for combustion and asphyxiation. All streams in the plant are kept outside of explosion limits, made easy by the large volume of carbon dioxide that circulates within the plant. The main concern for combustion is due to the proximity of carbon monoxide streams to oxygen streams in the CR5s. Concerns also exist for the flammability of components, particularly for the CO and FT oil stored in storage tanks.

Additionally, there exists the potential for asphyxiation both from the toxicity of carbon monoxide, but also from the high levels of carbon dioxide. As such, monitors will be spaced throughout the plant to alert workers if levels become too high. Ladders will be present along the roads in the CR5 arrays to allow workers to reach air containing viable amounts of oxygen.

12.5 Location

The plant location is a function of several key factors including average daily solar flux, access to CO_2, availability of water, and proximity to the customer refineries. Additionally, the large amount of land required for the level of production specified is a consideration. As seen in Figure 12.5.1, solar flux alone indicates favorable conditions for the plant location in the southwest United States. This Mojave Desert region receives the highest average solar flux per any area in the United States with an average of 7.7 $kWh/m^2/day$.

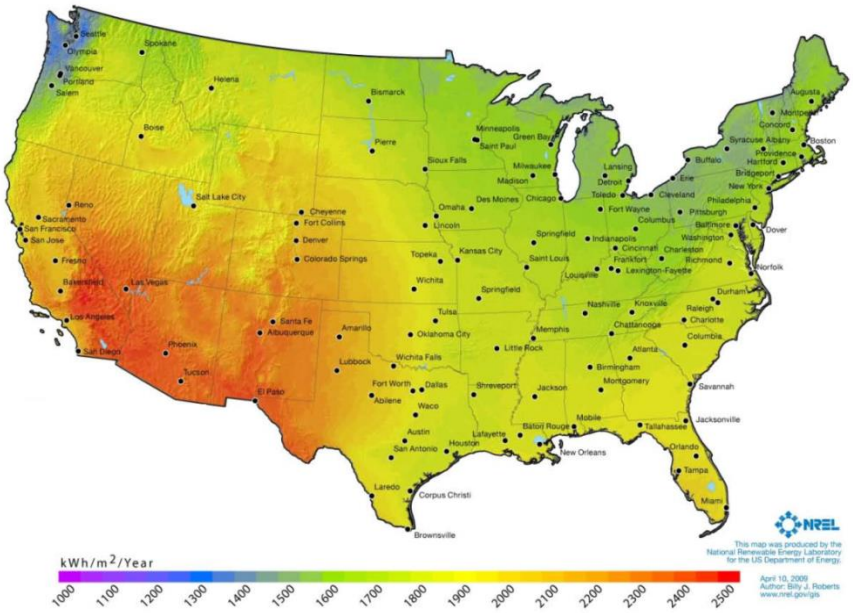

Figure 12.5.1. Average Solar Flux for Mainland United States. Image adapted from the National Renewable Energy Laboratory (NREL).

Feed CO_2 can be accessed in several ways including MEA absorption, CO_2 pipelines, and co-location with a plant whose waste streams are high in CO_2. An economic evaluation conducted by Kim, et al indicates that MEA absorption and purchase are equivalent when direct collocation is possible (Kim, 2011). Forgoing the necessary equipment for MEA absorption, as well as the associated upkeep, the options of co-location and CO_2 pipelines were explored as the best alternatives. Consequently, it is necessary to locate the plant within close proximity of such a plant or pipeline. Existing CO_2 pipelines and formations are shown in Figure 12.5.2.

Figure 12.5.2. Existing CO_2 Infrastructure in the Mainland United States. Image provided by Duke University, Nicholas School of the Environment.

Additionally, the plant requires water as a feedstock (for the water gas shift section of the plant) and as such should be in an area with available water. Water availability is typically lower in desert areas of high solar flux, ideal for this plant. Thus, efforts were made to make the decision for location on an area with minimal water stress. Water stress, as a measure of overall water availability, is shown in Figure 12.5.3.

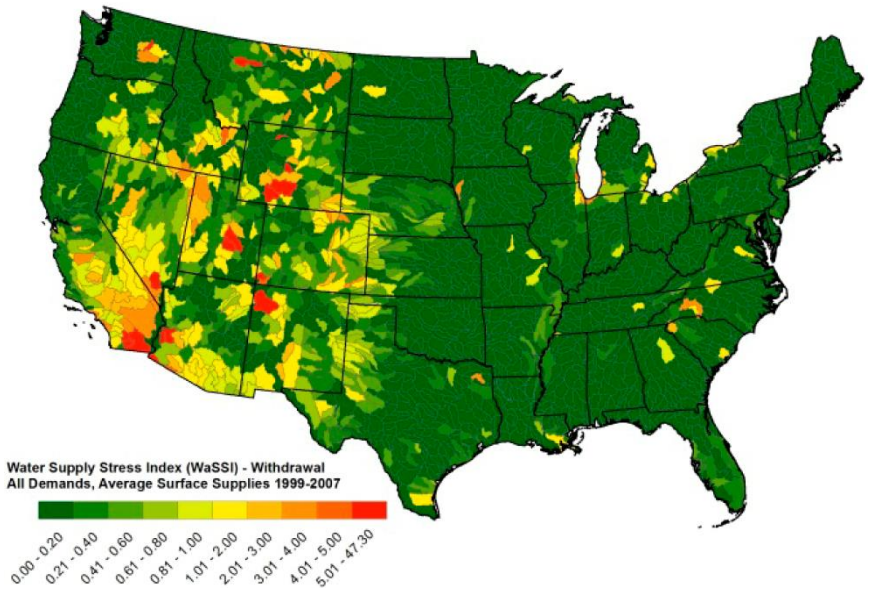

Figure 12.5.3. Water Supply Stress for the Mainland United States. Image provided by K. Averyt et al.

Combining these criteria of high solar flux, CO_2 infrastructure, and minimal water stress, West Texas was chosen as an ideal location. Western Texas allows for not only the favorable solar flux, CO_2 access, and water availability but also provides a high density of customers and has a relatively less densely populated land mass, allowing for easier purchase of the land required.

Section 13 – Conclusions

Given the economic forecast, it appears that due to the coexistence of high capital costs and high operating costs, the sunlight to transportation fuels plant will never be economically attractive given current technological and market considerations, as presented in this report. Even considering the best-case scenario of 10% discount rate the NPV is -$3.7 billion dollars after 30 years.

Further research and evaluation should be conducted in the realm of technological innovation. The major technological advancement area is in the catalysts for the water gas shift and Fischer-Tropsch reactions. Both catalysts, and particularly the Fischer-Tropsch catalyst (due to the high cost of Rhenium), are significant detractors from the profitability. This high cost is compounded by the need for frequent replacement of these catalysts. Additionally, the products created by the Fischer-Tropsch reaction are nonspecific. Research which would allow for use of a reaction with a lower capital cost and more concentrated gasoline output would significantly improve the return on investment of this project.

Moreover, increasing the overall efficiency of the CR5 would increase the total production levels, while maintaining operational and capital costs. The CR5 currently requires sub-atmospheric pressures due to the vapor pressures of gaseous products versus iron oxide at the high temperatures. Raising the operating pressure of the CR5 would lower CR5 electricity requirements, but most importantly, reduce the demand for compressing later in the plant. The compressors currently necessary are a high cost and high utility requirement for the overall plant. Reducing this demand would help the sunlight to transportation fuels plant become viable.

Although not currently economically feasible, utilizing CR5s in conversion of sunlight to transportation fuels is a worthwhile research endeavor. The capability to produce liquid transportation fuels while utilizing sunlight and reducing greenhouse gas emissions is a valuable opportunity for future energy production. Using the CR5 technology developed at Sandia National Laboratory to convert sunlight to transportation fuels while avoiding the high capital costs associated with the Fischer-Tropsch reaction would result in an economically favorable opportunity and should consequently be further explored.

Section 14 – Acknowledgements

The team would like to gratefully acknowledge the following people for their invaluable contributions to this report:

Dr. Matthew Targett
Prof. Talid Sinno
Prof. Leonard Fabiano

Additionally, the team wishes to acknowledge the helpful suggestions and guidance from all the industrial consultants that volunteered their time to the CBE 459: Process Systems Senior Design Projects of 2013-2014.

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Appendix A – Materials Safety Data Sheets

A.1 Carbon Dioxide

SIGMA-ALDRICH sigma-aldrich.com

Material Safety Data Sheet

Version 3.5
Revision Date 12/05/2012
Print Date 03/21/2014

1. PRODUCT AND COMPANY IDENTIFICATION

Product name	:	Carbon dioxide
Product Number	:	295108
Brand	:	Aldrich
Supplier	:	Sigma-Aldrich 3050 Spruce Street SAINT LOUIS MO 63103 USA
Telephone	:	+1 800-325-5832
Fax	:	+1 800-325-5052
Emergency Phone # (For both supplier and manufacturer)	:	(314) 776-6555
Preparation Information	:	Sigma-Aldrich Corporation Product Safety - Americas Region 1-800-521-8956

2. HAZARDS IDENTIFICATION

Emergency Overview

OSHA Hazards
Compressed Gas

GHS Classification
Gases under pressure (Liquefied gas)

GHS Label elements, including precautionary statements

Pictogram

Signal word: Warning

Hazard statement(s)
H280: Contains gas under pressure; may explode if heated.

Precautionary statement(s)
P410 + P403: Protect from sunlight. Store in a well-ventilated place.

HMIS Classification

Health hazard:	0
Flammability:	0
Physical hazards:	0

NFPA Rating

Health hazard:	0
Fire:	0
Reactivity Hazard:	0

Potential Health Effects

Inhalation	May be harmful if inhaled. May cause respiratory tract irritation.
Skin	May cause severe frostbite. May be harmful if absorbed through skin. May cause skin irritation.
Eyes	May cause eye irritation.
Ingestion	May be harmful if swallowed.

Aggravated Medical Condition Acts as a simple asphyxiant by displacing air.,

3. COMPOSITION/INFORMATION ON INGREDIENTS

Formula : CO_2
Molecular Weight : 44.01 g/mol

Component		Concentration
Carbon dioxide		
CAS-No.	124-38-9	-
EC-No.	204-696-9	

4. FIRST AID MEASURES

General advice
Consult a physician. Show this safety data sheet to the doctor in attendance.Move out of dangerous area.

If inhaled
If breathed in, move person into fresh air. If not breathing, give artificial respiration. Consult a physician.

In case of skin contact
Wash off with soap and plenty of water. Consult a physician.

In case of eye contact
Flush eyes with water as a precaution.

If swallowed
Never give anything by mouth to an unconscious person. Rinse mouth with water. Consult a physician.

5. FIREFIGHTING MEASURES

Conditions of flammability
Not flammable or combustible.

Suitable extinguishing media
Use water spray, alcohol-resistant foam, dry chemical or carbon dioxide.

Special protective equipment for firefighters
Wear self contained breathing apparatus for fire fighting if necessary.

Hazardous combustion products
Hazardous decomposition products formed under fire conditions. - Carbon oxides

Further information
Use water spray to cool unopened containers.

6. ACCIDENTAL RELEASE MEASURES

Personal precautions
Avoid breathing vapors, mist or gas. Ensure adequate ventilation. Evacuate personnel to safe areas.

Environmental precautions
Do not let product enter drains.

Methods and materials for containment and cleaning up
Clean up promptly by sweeping or vacuum.

7. HANDLING AND STORAGE

Conditions for safe storage
Keep container tightly closed in a dry and well-ventilated place.

Contents under pressure. Avoid heating above: 50°C

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

Components with workplace control parameters

Components	CAS-No.	Value	Control parameters	Basis
Carbon dioxide	124-38-9	TWA	5,000 ppm	USA. ACGIH Threshold Limit Values (TLV)
Remarks	Asphyxia			
		STEL	30,000 ppm	USA. ACGIH Threshold Limit Values (TLV)
	Asphyxia			
		TWA	10,000 ppm 18,000 mg/m3	USA. OSHA - TABLE Z-1 Limits for Air Contaminants - 1910.1000
	Exposures under 10,000 ppm to be cited as de minimus.			
		STEL	30,000 ppm 54,000 mg/m3	USA. OSHA - TABLE Z-1 Limits for Air Contaminants - 1910.1000
		TWA	5,000 ppm 9,000 mg/m3	USA. Occupational Exposure Limits (OSHA) - Table Z-1 Limits for Air Contaminants
	The value in mg/m3 is approximate.			
		TWA	5,000 ppm 9,000 mg/m3	USA. NIOSH Recommended Exposure Limits
	Normal constituent of air (about 300 ppm).			
		ST	30,000 ppm 54,000 mg/m3	USA. NIOSH Recommended Exposure Limits
	Normal constituent of air (about 300 ppm).			

Personal protective equipment

Respiratory protection
Where risk assessment shows air-purifying respirators are appropriate use a full-face respirator with multi-purpose combination (US) or type AXBEK (EN 14387) respirator cartridges as a backup to engineering controls. If the respirator is the sole means of protection, use a full-face supplied air respirator. Use respirators and components tested and approved under appropriate government standards such as NIOSH (US) or CEN (EU).

Hand protection
Handle with gloves. Gloves must be inspected prior to use. Use proper glove removal technique (without touching glove's outer surface) to avoid skin contact with this product. Dispose of contaminated gloves after use in accordance with applicable laws and good laboratory practices. Wash and dry hands.

Full contact
Material: butyl-rubber
Minimum layer thickness: 0.3 mm
Break through time: 480 min
Material tested:Butoject® (KCL 897 / Aldrich Z677647, Size M)

Splash protection
Material: Chloroprene
Minimum layer thickness: 0.6 mm
Break through time: 30 min
Material tested:Camapren® (KCL 722 / Aldrich Z677493, Size M)

data source: KCL GmbH, D-36124 Eichenzell, phone +49 (0)6659 87300, e-mail sales@kcl.de, test method: EN374
If used in solution, or mixed with other substances, and under conditions which differ from EN 374, contact the supplier of the CE approved gloves. This recommendation is advisory only and must be evaluated by an Industrial Hygienist familiar with the specific situation of anticipated use by our customers. It should not be construed as offering an approval for any specific use scenario.

Eye protection
Use equipment for eye protection tested and approved under appropriate government standards such as NIOSH (US) or EN 166(EU).

Skin and body protection
impervious clothing, The type of protective equipment must be selected according to the concentration and amount of the dangerous substance at the specific workplace.

Hygiene measures
Handle in accordance with good industrial hygiene and safety practice. Wash hands before breaks and at the end of workday.

9. PHYSICAL AND CHEMICAL PROPERTIES

Appearance

Form	Liquefied gas
Colour	no data available

Safety data

pH	no data available
Melting point/freezing point	Melting point/range: -78.5 °C (-109.3 °F) - lit.
Boiling point	no data available
Sublimation point	-78.5 °C (-109.3 °F)
Flash point	not applicable
Ignition temperature	no data available
Auto-ignition temperature	no data available
Lower explosion limit	no data available
Upper explosion limit	no data available
Vapour pressure	57,249 hPa (42,940 mmHg) at 20 °C (68 °F)
Density	no data available
Water solubility	no data available
Partition coefficient: n-octanol/water	no data available
Relative vapor density	1.52 - (Air = 1.0)
Odour	no data available
Odour Threshold	no data available
Evaporation rate	no data available

10. STABILITY AND REACTIVITY

Chemical stability
Stable under recommended storage conditions.

Possibility of hazardous reactions
no data available

Conditions to avoid
no data available

Materials to avoid
no data available

Hazardous decomposition products
Hazardous decomposition products formed under fire conditions. - Carbon oxides
Other decomposition products - no data available

11. TOXICOLOGICAL INFORMATION

Acute toxicity

Oral LD50
no data available

Inhalation LC50
no data available

Dermal LD50
no data available

Other information on acute toxicity
no data available

Skin corrosion/irritation
no data available

Serious eye damage/eye irritation
no data available

Respiratory or skin sensitization
no data available

Germ cell mutagenicity
no data available

Carcinogenicity

IARC:	No component of this product present at levels greater than or equal to 0.1% is identified as probable, possible or confirmed human carcinogen by IARC.
ACGIH:	No component of this product present at levels greater than or equal to 0.1% is identified as a carcinogen or potential carcinogen by ACGIH.
NTP:	No component of this product present at levels greater than or equal to 0.1% is identified as a known or anticipated carcinogen by NTP.
OSHA:	No component of this product present at levels greater than or equal to 0.1% is identified as a carcinogen or potential carcinogen by OSHA.

Reproductive toxicity

no data available

Teratogenicity

no data available

Specific target organ toxicity - single exposure (Globally Harmonized System)
no data available

Specific target organ toxicity - repeated exposure (Globally Harmonized System)
no data available

Aspiration hazard
no data available

Potential health effects

Inhalation	May be harmful if inhaled. May cause respiratory tract irritation.
Ingestion	May be harmful if swallowed.
Skin	May cause severe frostbite. May be harmful if absorbed through skin. May cause skin

	irritation.
Eyes	May cause eye irritation.
Aggravated Medical Condition	Acts as a simple asphyxiant by displacing air.,

Signs and Symptoms of Exposure
Nausea, Dizziness, Headache, Low to medium concentrations of carbon dioxide can:, affect regulation of blood circulation, affect the acidity of body fluids, respiratory difficulties, At high concentrations:, Breathing difficulties, Increased pulse rate, change in body acidity, Very high concentrations can cause:, Unconsciousness, death

Synergistic effects
no data available

Additional Information
RTECS: FF6400000

12. ECOLOGICAL INFORMATION

Toxicity

no data available

Persistence and degradability
no data available

Bioaccumulative potential
no data available

Mobility in soil
no data available

PBT and vPvB assessment
no data available

Other adverse effects

no data available

13. DISPOSAL CONSIDERATIONS

Product
Offer surplus and non-recyclable solutions to a licensed disposal company. Contact a licensed professional waste disposal service to dispose of this material.

Contaminated packaging
Dispose of as unused product.

14. TRANSPORT INFORMATION

DOT (US)
UN number: 1013 Class: 2.2
Proper shipping name: Carbon dioxide
Reportable Quantity (RQ):
Marine Pollutant: No
Poison Inhalation Hazard: No

IMDG
UN number: 1013 Class: 2.2 EMS-No: F-C, S-V
Proper shipping name: CARBON DIOXIDE
Marine Pollutant: No

IATA
UN number: 1013 Class: 2.2
Proper shipping name: Carbon dioxide

15. REGULATORY INFORMATION

OSHA Hazards
Compressed Gas

SARA 302 Components
SARA 302: No chemicals in this material are subject to the reporting requirements of SARA Title III, Section 302.

SARA 313 Components
SARA 313: This material does not contain any chemical components with known CAS numbers that exceed the threshold (De Minimis) reporting levels established by SARA Title III, Section 313.

SARA 311/312 Hazards
Sudden Release of Pressure Hazard

Massachusetts Right To Know Components

	CAS-No.	Revision Date
Carbon dioxide	124-38-9	1993-04-24

Pennsylvania Right To Know Components

	CAS-No.	Revision Date
Carbon dioxide	124-38-9	1993-04-24

New Jersey Right To Know Components

	CAS-No.	Revision Date
Carbon dioxide	124-38-9	1993-04-24

California Prop. 65 Components
This product does not contain any chemicals known to State of California to cause cancer, birth defects, or any other reproductive harm.

A.2 Carbon Monoxide

SIGMA-ALDRICH sigma-aldrich.com

Material Safety Data Sheet

Version 3.4
Revision Date 12/05/2012
Print Date 03/21/2014

1. PRODUCT AND COMPANY IDENTIFICATION

Product name	:	Carbon monoxide
Product Number	:	295116
Brand	:	Aldrich
Supplier	:	Sigma-Aldrich 3050 Spruce Street SAINT LOUIS MO 63103 USA
Telephone	:	+1 800-325-5832
Fax	:	+1 800-325-5052
Emergency Phone # (For both supplier and manufacturer)	:	(314) 776-6555
Preparation Information	:	Sigma-Aldrich Corporation Product Safety - Americas Region 1-800-521-8956

2. HAZARDS IDENTIFICATION

Emergency Overview

OSHA Hazards
Flammable gas, Compressed Gas, Target Organ Effect, Teratogen

Target Organs

Blood, Nerves.

GHS Classification
Flammable gases (Category 1)
Gases under pressure (Compressed gas)
Acute toxicity, Inhalation (Category 3)
Reproductive toxicity (Category 1A)
Specific target organ toxicity - repeated exposure, Inhalation (Category 1)

GHS Label elements, including precautionary statements

Pictogram

Signal word: Danger

Hazard statement(s)

H220	Extremely flammable gas.
H280	Contains gas under pressure; may explode if heated.
H331	Toxic if inhaled.
H360	May damage fertility or the unborn child.
H372	Causes damage to organs through prolonged or repeated exposure if inhaled.

Precautionary statement(s)

P201	Obtain special instructions before use.
P210	Keep away from heat/sparks/open flames/hot surfaces. - No smoking.
P261	Avoid breathing dust/ fume/ gas/ mist/ vapours/ spray.
P311	Call a POISON CENTER or doctor/ physician.
P410 + P403	Protect from sunlight. Store in a well-ventilated place.

HMIS Classification

Health hazard:	2
Chronic Health Hazard:	*
Flammability:	4
Physical hazards:	0

NFPA Rating

Health hazard:	2
Fire:	4
Reactivity Hazard:	0

Potential Health Effects

Inhalation	May be harmful if inhaled. May cause respiratory tract irritation.
Skin	May be harmful if absorbed through skin. May cause skin irritation.
Eyes	May cause eye irritation.
Ingestion	May be harmful if swallowed.

3. COMPOSITION/INFORMATION ON INGREDIENTS

Formula : CO
Molecular Weight : 28.01 g/mol

Component		Concentration
Carbon monoxide		
CAS-No.	630-08-0	-
EC-No.	211-128-3	
Index-No.	006-001-00-2	

4. FIRST AID MEASURES

General advice
Consult a physician. Show this safety data sheet to the doctor in attendance.Move out of dangerous area.

If inhaled
If breathed in, move person into fresh air. If not breathing, give artificial respiration. Consult a physician.

In case of skin contact
Wash off with soap and plenty of water. Take victim immediately to hospital. Consult a physician.

In case of eye contact
Flush eyes with water as a precaution.

If swallowed
Do NOT induce vomiting. Never give anything by mouth to an unconscious person. Rinse mouth with water. Consult a physician.

5. FIREFIGHTING MEASURES

Conditions of flammability
Flammable in the presence of an oxidizing gas (eg air), a source of ignition, and when the concentration of the gas is between the lower and upper explosive limits. Keep away from heat/sparks/open flame/hot surface/oxidizing gas. No smoking.

Suitable extinguishing media
Use water spray, alcohol-resistant foam, dry chemical or carbon dioxide.

Special protective equipment for firefighters
Wear self contained breathing apparatus for fire fighting if necessary.

Hazardous combustion products
Hazardous decomposition products formed under fire conditions. - Carbon oxides

Further information
Use water spray to cool unopened containers.

6. ACCIDENTAL RELEASE MEASURES

Personal precautions
Wear respiratory protection. Avoid breathing vapors, mist or gas. Ensure adequate ventilation. Remove all sources of ignition. Evacuate personnel to safe areas. Beware of vapours accumulating to form explosive concentrations. Vapours can accumulate in low areas.

Environmental precautions
Prevent further leakage or spillage if safe to do so. Do not let product enter drains.

Methods and materials for containment and cleaning up
Clean up promptly by sweeping or vacuum.

7. HANDLING AND STORAGE

Precautions for safe handling
Avoid contact with skin and eyes. Avoid inhalation of vapour or mist.
Use explosion-proof equipment. Keep away from sources of ignition - No smoking. Take measures to prevent the build up of electrostatic charge.

Conditions for safe storage
Keep container tightly closed in a dry and well-ventilated place.

Contents under pressure.

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

Components with workplace control parameters

Components	CAS-No.	Value	Control parameters	Basis
Carbon monoxide	630-08-0	C	200 ppm 229 mg/m3	USA. OSHA - TABLE Z-1 Limits for Air Contaminants - 1910.1000
Remarks	Sampling for the carbon monoxide ceiling shall be averaged over 5 minutes but an instantaneous reading over 1500 ppm shall not be exceeded.			
		TWA	50 ppm 55 mg/m3	USA. Occupational Exposure Limits (OSHA) - Table Z-1 Limits for Air Contaminants
	The value in mg/m3 is approximate.			
		TWA	25 ppm	USA. ACGIH Threshold Limit Values (TLV)
	Carboxyhemoglobinemia Substances for which there is a Biological Exposure Index or Indices (see BEI® section)			
		TWA	35 ppm 40 mg/m3	USA. OSHA - TABLE Z-1 Limits for Air Contaminants - 1910.1000
		TWA	35 ppm 40 mg/m3	USA. NIOSH Recommended Exposure Limits
		C	200 ppm 229 mg/m3	USA. NIOSH Recommended Exposure Limits

Personal protective equipment

Respiratory protection
Where risk assessment shows air-purifying respirators are appropriate use a full-face respirator with multi-purpose combination (US) or type AXBEK (EN 14387) respirator cartridges as a backup to engineering controls. If the respirator is the sole means of protection, use a full-face supplied air respirator. Use respirators and components tested and approved under appropriate government standards such as NIOSH (US) or CEN (EU).

Hand protection
Handle with gloves. Gloves must be inspected prior to use. Use proper glove removal technique (without touching glove's outer surface) to avoid skin contact with this product. Dispose of contaminated gloves after use in accordance with applicable laws and good laboratory practices. Wash and dry hands.

Full contact

Material: butyl-rubber
Minimum layer thickness: 0.3 mm
Break through time: 480 min
Material tested:Butoject® (KCL 897 / Aldrich Z677647, Size M)

Splash protection
Material: Chloroprene
Minimum layer thickness: 0.6 mm
Break through time: 30 min
Material tested:Camapren® (KCL 722 / Aldrich Z677493, Size M)

data source: KCL GmbH, D-36124 Eichenzell, phone +49 (0)6659 87300, e-mail sales@kcl.de, test method: EN374
If used in solution, or mixed with other substances, and under conditions which differ from EN 374, contact the supplier of the CE approved gloves. This recommendation is advisory only and must be evaluated by an Industrial Hygienist familiar with the specific situation of anticipated use by our customers. It should not be construed as offering an approval for any specific use scenario.

Eye protection
Face shield and safety glasses Use equipment for eye protection tested and approved under appropriate government standards such as NIOSH (US) or EN 166(EU).

Skin and body protection
Complete suit protecting against chemicals, Flame retardant antistatic protective clothing, The type of protective equipment must be selected according to the concentration and amount of the dangerous substance at the specific workplace.

Hygiene measures
Avoid contact with skin, eyes and clothing. Wash hands before breaks and immediately after handling the product.

9. PHYSICAL AND CHEMICAL PROPERTIES

Appearance

Form	Compressed gas
Colour	no data available

Safety data

pH	no data available
Melting point/freezing point	Melting point/range: -205 °C (-337 °F) - lit.
Boiling point	-191.5 °C (-312.7 °F) - lit.
Flash point	no data available
Ignition temperature	609 °C (1,128 °F)
Auto-ignition temperature	no data available
Lower explosion limit	12.5 %(V)
Upper explosion limit	74 %(V)
Vapour pressure	no data available
Density	no data available
Water solubility	no data available
Partition coefficient: n-octanol/water	no data available
Relative vapor density	0.97 - (Air = 1.0)
Odour	no data available
Odour Threshold	no data available

Evaporation rate no data available

10. STABILITY AND REACTIVITY

Chemical stability
Stable under recommended storage conditions.

Possibility of hazardous reactions
no data available

Conditions to avoid
Heat, flames and sparks. Extremes of temperature and direct sunlight.

Materials to avoid
Sodium/sodium oxides, Potassium, Strong oxidizing agents

Hazardous decomposition products
Hazardous decomposition products formed under fire conditions. - Carbon oxides
Other decomposition products - no data available

11. TOXICOLOGICAL INFORMATION

Acute toxicity

Oral LD50
Inhalation LC50
LC50 Inhalation - rat - 4 h - 1807 ppm

Dermal LD50
no data available

Other information on acute toxicity
no data available

Skin corrosion/irritation
no data available

Serious eye damage/eye irritation
no data available

Respiratory or skin sensitization
no data available

Germ cell mutagenicity

no data available

Carcinogenicity

IARC:	No component of this product present at levels greater than or equal to 0.1% is identified as probable, possible or confirmed human carcinogen by IARC.
ACGIH:	No component of this product present at levels greater than or equal to 0.1% is identified as a carcinogen or potential carcinogen by ACGIH.
NTP:	No component of this product present at levels greater than or equal to 0.1% is identified as a known or anticipated carcinogen by NTP.
OSHA:	No component of this product present at levels greater than or equal to 0.1% is identified as a carcinogen or potential carcinogen by OSHA.

Reproductive toxicity

no data available

Teratogenicity

Known human reproductive toxicant

Specific target organ toxicity - single exposure (Globally Harmonized System)
no data available

Specific target organ toxicity - repeated exposure (Globally Harmonized System)
Inhalation - Causes damage to organs through prolonged or repeated exposure.

Aspiration hazard
no data available

Potential health effects

Inhalation	May be harmful if inhaled. May cause respiratory tract irritation.
Ingestion	May be harmful if swallowed.
Skin	May be harmful if absorbed through skin. May cause skin irritation.
Eyes	May cause eye irritation.

Signs and Symptoms of Exposure
Blood disorders

Synergistic effects
no data available

Additional Information
RTECS: FG3500000

12. ECOLOGICAL INFORMATION

Toxicity

no data available

Persistence and degradability
no data available

Bioaccumulative potential
no data available

Mobility in soil
no data available

PBT and vPvB assessment
no data available

Other adverse effects

no data available

13. DISPOSAL CONSIDERATIONS

Product
Burn in a chemical incinerator equipped with an afterburner and scrubber but exert extra care in igniting as this material is highly flammable. Offer surplus and non-recyclable solutions to a licensed disposal company. Contact a licensed professional waste disposal service to dispose of this material.

Contaminated packaging
Dispose of as unused product.

14. TRANSPORT INFORMATION

DOT (US)
UN number: 1016 Class: 2.3 (2.1)
Proper shipping name: Carbon monoxide, compressed
Reportable Quantity (RQ):
Marine Pollutant: No
Poison Inhalation Hazard: Hazard zone D

IMDG
UN number: 1016 Class: 2.3 (2.1) EMS-No: F-D, S-U
Proper shipping name: CARBON MONOXIDE, COMPRESSED
Marine Pollutant: No

IATA
UN number: 1016 Class: 2.3 (2.1)
Proper shipping name: Carbon monoxide, compressed
IATA Passenger: Not permitted for transport
IATA Cargo: Not permitted for transport

15. REGULATORY INFORMATION

OSHA Hazards
Flammable gas, Compressed Gas, Target Organ Effect, Teratogen

SARA 302 Components
SARA 302: No chemicals in this material are subject to the reporting requirements of SARA Title III, Section 302.

SARA 313 Components
SARA 313: This material does not contain any chemical components with known CAS numbers that exceed the threshold (De Minimis) reporting levels established by SARA Title III, Section 313.

SARA 311/312 Hazards
Fire Hazard, Sudden Release of Pressure Hazard, Chronic Health Hazard

Massachusetts Right To Know Components

	CAS-No.	Revision Date
Carbon monoxide	630-08-0	1993-04-24

Pennsylvania Right To Know Components

	CAS-No.	Revision Date
Carbon monoxide	630-08-0	1993-04-24

New Jersey Right To Know Components

	CAS-No.	Revision Date
Carbon monoxide	630-08-0	1993-04-24

California Prop. 65 Components

	CAS-No.	Revision Date
WARNING! This product contains a chemical known to the State of California to cause birth defects or other reproductive harm. Carbon monoxide	630-08-0	2007-09-28

A.3 Oxygen

SIGMA-ALDRICH sigma-aldrich.com

Material Safety Data Sheet

Version 3.3
Revision Date 12/05/2012
Print Date 03/21/2014

1. PRODUCT AND COMPANY IDENTIFICATION

Product name	:	Oxygen
Product Number	:	295604
Brand	:	Aldrich
Supplier	:	Sigma-Aldrich 3050 Spruce Street SAINT LOUIS MO 63103 USA
Telephone	:	+1 800-325-5832
Fax	:	+1 800-325-5052
Emergency Phone # (For both supplier and manufacturer)	:	(314) 776-6555
Preparation Information	:	Sigma-Aldrich Corporation Product Safety - Americas Region 1-800-521-8956

2. HAZARDS IDENTIFICATION

Emergency Overview

OSHA Hazards
Compressed Gas

GHS Classification
Oxidising gases (Category 1)
Gases under pressure (Compressed gas)

GHS Label elements, including precautionary statements

Pictogram

Signal word Danger

Hazard statement(s)

H270	May cause or intensify fire; oxidiser.
H280	Contains gas under pressure; may explode if heated.

Precautionary statement(s)

P220	Keep/Store away from clothing/ combustible materials.
P410 + P403	Protect from sunlight. Store in a well-ventilated place.

HMIS Classification

Health hazard:	0
Flammability:	0
Physical hazards:	0

NFPA Rating

Health hazard:	0
Fire:	0
Reactivity Hazard:	0
Special hazard.:	OX

Potential Health Effects

Inhalation May be harmful if inhaled. May cause respiratory tract irritation.

Skin	May be harmful if absorbed through skin. May cause skin irritation.
Eyes	May cause eye irritation.
Ingestion	May be harmful if swallowed.

3. COMPOSITION/INFORMATION ON INGREDIENTS

Formula : O_2
Molecular Weight : 32.00 g/mol

Component		Concentration
Oxygen		
CAS-No.	7782-44-7	-
EC-No.	231-956-9	
Index-No.	008-001-00-8	

4. FIRST AID MEASURES

General advice
Consult a physician. Show this safety data sheet to the doctor in attendance.Move out of dangerous area.

If inhaled
If breathed in, move person into fresh air. If not breathing, give artificial respiration. Consult a physician.

In case of skin contact
Wash off with soap and plenty of water. Consult a physician.

In case of eye contact
Flush eyes with water as a precaution.

If swallowed
Never give anything by mouth to an unconscious person. Rinse mouth with water. Consult a physician.

5. FIREFIGHTING MEASURES

Conditions of flammability
Not flammable or combustible.

Suitable extinguishing media
Use water spray, alcohol-resistant foam, dry chemical or carbon dioxide.

Special protective equipment for firefighters
Wear self contained breathing apparatus for fire fighting if necessary.

Hazardous combustion products
no data available**Further information**
Use water spray to cool unopened containers.

6. ACCIDENTAL RELEASE MEASURES

Personal precautions
Avoid breathing vapors, mist or gas. Ensure adequate ventilation. Evacuate personnel to safe areas.

Environmental precautions
Prevent further leakage or spillage if safe to do so. Do not let product enter drains.

Methods and materials for containment and cleaning up
Contain spillage, and then collect with an electrically protected vacuum cleaner or by wet-brushing and place in container for disposal according to local regulations (see section 13).

7. HANDLING AND STORAGE

Precautions for safe handling
Keep away from sources of ignition - No smoking.

Conditions for safe storage
Keep container tightly closed in a dry and well-ventilated place.

Contents under pressure.

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

Contains no substances with occupational exposure limit values.

Personal protective equipment

Respiratory protection
Where risk assessment shows air-purifying respirators are appropriate use a full-face respirator with multi-purpose combination (US) or type AXBEK (EN 14387) respirator cartridges as a backup to engineering controls. If the respirator is the sole means of protection, use a full-face supplied air respirator. Use respirators and components tested and approved under appropriate government standards such as NIOSH (US) or CEN (EU).

Hand protection
Handle with gloves. Gloves must be inspected prior to use. Use proper glove removal technique (without touching glove's outer surface) to avoid skin contact with this product. Dispose of contaminated gloves after use in accordance with applicable laws and good laboratory practices. Wash and dry hands.

Full contact
Material: butyl-rubber
Minimum layer thickness: 0.3 mm
Break through time: 480 min
Material tested:Butoject® (KCL 897 / Aldrich Z677647, Size M)

Splash protection
Material: Chloroprene
Minimum layer thickness: 0.6 mm
Break through time: 30 min
Material tested:Camapren® (KCL 722 / Aldrich Z677493, Size M)

data source: KCL GmbH, D-36124 Eichenzell, phone +49 (0)6659 87300, e-mail sales@kcl.de, test method: EN374
If used in solution, or mixed with other substances, and under conditions which differ from EN 374, contact the supplier of the CE approved gloves. This recommendation is advisory only and must be evaluated by an Industrial Hygienist familiar with the specific situation of anticipated use by our customers. It should not be construed as offering an approval for any specific use scenario.

Eye protection
Face shield and safety glasses Use equipment for eye protection tested and approved under appropriate government standards such as NIOSH (US) or EN 166(EU).

Skin and body protection
Complete suit protecting against chemicals, The type of protective equipment must be selected according to the concentration and amount of the dangerous substance at the specific workplace.

Hygiene measures
Handle in accordance with good industrial hygiene and safety practice. Wash hands before breaks and at the end of workday.

9. PHYSICAL AND CHEMICAL PROPERTIES

Appearance

Form	Compressed gas
Colour	colourless

Safety data

pH	no data available
Melting point/freezing point	Melting point/range: -218 °C (-360 °F) - lit.
Boiling point	-183 °C (-297 °F) - lit.
Flash point	no data available
Ignition temperature	no data available

Auto-ignition temperature	no data available
Lower explosion limit	no data available
Upper explosion limit	no data available
Vapour pressure	no data available
Density	no data available
Water solubility	no data available
Partition coefficient: n-octanol/water	no data available
Relative vapor density	1.1 - (Air = 1.0) 1.1 - (Air = 1.0)
Odour	odourless
Odour Threshold	no data available
Evaporation rate	no data available

10. STABILITY AND REACTIVITY

Chemical stability
Stable under recommended storage conditions.

Possibility of hazardous reactions
no data available

Conditions to avoid
no data available

Materials to avoid
Phosphorus, Organic materials, Powdered metals

Hazardous decomposition products
no data available

11. TOXICOLOGICAL INFORMATION

Acute toxicity

Oral LD50
no data available

Inhalation LC50
no data available

Dermal LD50
no data available

Other information on acute toxicity
no data available

Skin corrosion/irritation
no data available

Serious eye damage/eye irritation
no data available

Respiratory or skin sensitization
no data available

Germ cell mutagenicity
no data available

Carcinogenicity

IARC:	No component of this product present at levels greater than or equal to 0.1% is identified as probable, possible or confirmed human carcinogen by IARC.
ACGIH:	No component of this product present at levels greater than or equal to 0.1% is identified as a carcinogen or potential carcinogen by ACGIH.
NTP:	No component of this product present at levels greater than or equal to 0.1% is identified as a known or anticipated carcinogen by NTP.
OSHA:	No component of this product present at levels greater than or equal to 0.1% is identified as a carcinogen or potential carcinogen by OSHA.

Reproductive toxicity

no data available

Teratogenicity

no data available

Specific target organ toxicity - single exposure (Globally Harmonized System)
no data available

Specific target organ toxicity - repeated exposure (Globally Harmonized System)
no data available

Aspiration hazard
no data available

Potential health effects

Inhalation	May be harmful if inhaled. May cause respiratory tract irritation.
Ingestion	May be harmful if swallowed.
Skin	May be harmful if absorbed through skin. May cause skin irritation.
Eyes	May cause eye irritation.

Signs and Symptoms of Exposure
Nausea, Dizziness, Unconsciousness, May be harmful.

Synergistic effects
no data available

Additional Information
RTECS: RS2060000

12. ECOLOGICAL INFORMATION

Toxicity

no data available

Persistence and degradability
no data available

Bioaccumulative potential
no data available

Mobility in soil
no data available

PBT and vPvB assessment
no data available

Other adverse effects

no data available

13. DISPOSAL CONSIDERATIONS

Product
Burn in a chemical incinerator equipped with an afterburner and scrubber but exert extra care in igniting as this material is highly flammable. Offer surplus and non-recyclable solutions to a licensed disposal company. Contact a licensed professional waste disposal service to dispose of this material.

Contaminated packaging
Dispose of as unused product.

14. TRANSPORT INFORMATION

DOT (US)
UN number: 1072 Class: 2.2 (5.1)
Proper shipping name: Oxygen, compressed
Marine Pollutant: No
Poison Inhalation Hazard: No

IMDG
UN number: 1072 Class: 2.2 (5.1) EMS-No: F-C, S-W
Proper shipping name: OXYGEN, COMPRESSED
Marine Pollutant: No

IATA
UN number: 1072 Class: 2.2 (5.1)
Proper shipping name: Oxygen, compressed

15. REGULATORY INFORMATION

OSHA Hazards
Compressed Gas

SARA 302 Components
SARA 302: No chemicals in this material are subject to the reporting requirements of SARA Title III, Section 302.

SARA 313 Components
SARA 313: This material does not contain any chemical components with known CAS numbers that exceed the threshold (De Minimis) reporting levels established by SARA Title III, Section 313.

SARA 311/312 Hazards
Sudden Release of Pressure Hazard

Massachusetts Right To Know Components

	CAS-No.	Revision Date
Oxygen	7782-44-7	2007-03-01

Pennsylvania Right To Know Components

	CAS-No.	Revision Date
Oxygen	7782-44-7	2007-03-01

New Jersey Right To Know Components

	CAS-No.	Revision Date
Oxygen	7782-44-7	2007-03-01

California Prop. 65 Components
This product does not contain any chemicals known to State of California to cause cancer, birth defects, or any other reproductive harm.

A.4 Hydrogen

SIGMA-ALDRICH sigma-aldrich.com

Material Safety Data Sheet

Version 3.3
Revision Date 12/05/2012
Print Date 03/21/2014

1. PRODUCT AND COMPANY IDENTIFICATION

Product name	:	Hydrogen
Product Number	:	295396
Brand	:	Aldrich
Supplier	:	Sigma-Aldrich 3050 Spruce Street SAINT LOUIS MO 63103 USA
Telephone	:	+1 800-325-5832
Fax	:	+1 800-325-5052
Emergency Phone # (For both supplier and manufacturer)	:	(314) 776-6555
Preparation Information	:	Sigma-Aldrich Corporation Product Safety - Americas Region 1-800-521-8956

2. HAZARDS IDENTIFICATION

Emergency Overview

OSHA Hazards
Flammable gas, Compressed Gas

GHS Classification
Gases under pressure (Compressed gas)

GHS Label elements, including precautionary statements

Pictogram

Signal word Warning

Hazard statement(s)
H280 Contains gas under pressure; may explode if heated.

Precautionary statement(s)
P410 + P403 Protect from sunlight. Store in a well-ventilated place.

HMIS Classification

Health hazard:	0
Flammability:	4
Physical hazards:	3

NFPA Rating

Health hazard:	0
Fire:	4
Reactivity Hazard:	0

Potential Health Effects

Inhalation	May be harmful if inhaled. May cause respiratory tract irritation.
Skin	May be harmful if absorbed through skin. May cause skin irritation.
Eyes	May cause eye irritation.
Ingestion	May be harmful if swallowed.

3. COMPOSITION/INFORMATION ON INGREDIENTS

Formula : H_2
Molecular Weight : 2.02 g/mol

Component		Concentration
Hydrogen		
CAS-No.	1333-74-0	-
EC-No.	215-605-7	
Index-No.	001-001-00-9	

4. FIRST AID MEASURES

General advice
Consult a physician. Show this safety data sheet to the doctor in attendance.Move out of dangerous area.

If inhaled
If breathed in, move person into fresh air. If not breathing, give artificial respiration. Consult a physician.

In case of skin contact
Wash off with soap and plenty of water. Consult a physician.

In case of eye contact
Flush eyes with water as a precaution.

If swallowed
Never give anything by mouth to an unconscious person. Rinse mouth with water. Consult a physician.

5. FIREFIGHTING MEASURES

Conditions of flammability
Flammable in the presence of an oxidizing gas (eg air), a source of ignition, and when the concentration of the gas is between the lower and upper explosive limits. Keep away from heat/sparks/open flame/hot surface/oxidizing gas. No smoking.

Suitable extinguishing media
Use water spray, alcohol-resistant foam, dry chemical or carbon dioxide.

Special protective equipment for firefighters
Wear self contained breathing apparatus for fire fighting if necessary.

Hazardous combustion products
Hazardous decomposition products formed under fire conditions. - Nature of decomposition products not known.

Further information
Use water spray to cool unopened containers.

6. ACCIDENTAL RELEASE MEASURES

Personal precautions
Avoid breathing vapors, mist or gas. Ensure adequate ventilation. Evacuate personnel to safe areas.

Environmental precautions
Do not let product enter drains.

Methods and materials for containment and cleaning up
Clean up promptly by sweeping or vacuum.

7. HANDLING AND STORAGE

Conditions for safe storage
Keep container tightly closed in a dry and well-ventilated place.

Contents under pressure.

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

Contains no substances with occupational exposure limit values.

Personal protective equipment

Respiratory protection
Where risk assessment shows air-purifying respirators are appropriate use a full-face respirator with multi-purpose combination (US) or type AXBEK (EN 14387) respirator cartridges as a backup to engineering controls. If the respirator is the sole means of protection, use a full-face supplied air respirator. Use respirators and components tested and approved under appropriate government standards such as NIOSH (US) or CEN (EU).

Hand protection
Handle with gloves. Gloves must be inspected prior to use. Use proper glove removal technique (without touching glove's outer surface) to avoid skin contact with this product. Dispose of contaminated gloves after use in accordance with applicable laws and good laboratory practices. Wash and dry hands.

Splash protection
Material: butyl-rubber
Minimum layer thickness: 0.3 mm
Break through time: 60 min
Material tested:Butoject® (KCL 897 / Aldrich Z677647, Size M)

data source: KCL GmbH, D-36124 Eichenzell, phone +49 (0)6659 87300, e-mail sales@kcl.de, test method: EN374
If used in solution, or mixed with other substances, and under conditions which differ from EN 374, contact the supplier of the CE approved gloves. This recommendation is advisory only and must be evaluated by an Industrial Hygienist familiar with the specific situation of anticipated use by our customers. It should not be construed as offering an approval for any specific use scenario.

Eye protection
Use equipment for eye protection tested and approved under appropriate government standards such as NIOSH (US) or EN 166(EU).

Skin and body protection
impervious clothing, The type of protective equipment must be selected according to the concentration and amount of the dangerous substance at the specific workplace.

Hygiene measures
Handle in accordance with good industrial hygiene and safety practice. Wash hands before breaks and at the end of workday.

9. PHYSICAL AND CHEMICAL PROPERTIES

Appearance

Form	Compressed gas
Colour	colourless

Safety data

pH	no data available
Melting point/freezing point	Melting point/range: -259.2 °C (-434.6 °F) - lit.
Boiling point	-252.8 °C (-423.0 °F) - lit.
Flash point	< -150 °C (< -238 °F) - closed cup
Ignition temperature	571 °C (1,060 °F)
Auto-ignition temperature	no data available
Lower explosion limit	4 %(V)
Upper explosion limit	74.2 %(V)
Vapour pressure	no data available

Density	no data available
Water solubility	0.00196 g/l at 0 °C (32 °F)
Partition coefficient: n-octanol/water	no data available
Relative vapor density	0.08
Odour	no data available
Odour Threshold	no data available
Evaporation rate	no data available

10. STABILITY AND REACTIVITY

Chemical stability
Stable under recommended storage conditions.

Possibility of hazardous reactions
no data available

Conditions to avoid
no data available

Materials to avoid
Oxidizing agents

Hazardous decomposition products
Hazardous decomposition products formed under fire conditions. - Nature of decomposition products not known.
Other decomposition products - no data available

11. TOXICOLOGICAL INFORMATION

Acute toxicity

Oral LD50
no data available

Inhalation LC50
no data available

Dermal LD50
no data available

Other information on acute toxicity
no data available

Skin corrosion/irritation
no data available

Serious eye damage/eye irritation
no data available

Respiratory or skin sensitization
no data available

Germ cell mutagenicity
no data available

Carcinogenicity

IARC:	No component of this product present at levels greater than or equal to 0.1% is identified as probable, possible or confirmed human carcinogen by IARC.
ACGIH:	No component of this product present at levels greater than or equal to 0.1% is identified as a carcinogen or potential carcinogen by ACGIH.
NTP:	No component of this product present at levels greater than or equal to 0.1% is identified as a

known or anticipated carcinogen by NTP.

OSHA: No component of this product present at levels greater than or equal to 0.1% is identified as a carcinogen or potential carcinogen by OSHA.

Reproductive toxicity

no data available

Teratogenicity

no data available

Specific target organ toxicity - single exposure (Globally Harmonized System)
no data available

Specific target organ toxicity - repeated exposure (Globally Harmonized System)
no data available

Aspiration hazard
no data available

Potential health effects

Inhalation	May be harmful if inhaled. May cause respiratory tract irritation.
Ingestion	May be harmful if swallowed.
Skin	May be harmful if absorbed through skin. May cause skin irritation.
Eyes	May cause eye irritation.

Signs and Symptoms of Exposure
To the best of our knowledge, the chemical, physical, and toxicological properties have not been thoroughly investigated.

Synergistic effects
no data available

Additional Information
RTECS: MW8900000

12. ECOLOGICAL INFORMATION

Toxicity

no data available

Persistence and degradability
no data available

Bioaccumulative potential
no data available

Mobility in soil
no data available

PBT and vPvB assessment
no data available

Other adverse effects

no data available

13. DISPOSAL CONSIDERATIONS

Product
Offer surplus and non-recyclable solutions to a licensed disposal company. Contact a licensed professional waste disposal service to dispose of this material.

Contaminated packaging
Dispose of as unused product.

14. TRANSPORT INFORMATION

DOT (US)
UN number: 1049 Class: 2.1
Proper shipping name: Hydrogen, compressed
Marine Pollutant: No
Poison Inhalation Hazard: No

IMDG
UN number: 1049 Class: 2.1 EMS-No: F-D, S-U
Proper shipping name: HYDROGEN, COMPRESSED
Marine Pollutant: No

IATA
UN number: 1049 Class: 2.1
Proper shipping name: Hydrogen, compressed
IATA Passenger: Not permitted for transport

15. REGULATORY INFORMATION

OSHA Hazards
Flammable gas, Compressed Gas

SARA 302 Components
SARA 302: No chemicals in this material are subject to the reporting requirements of SARA Title III, Section 302.

SARA 313 Components
SARA 313: This material does not contain any chemical components with known CAS numbers that exceed the threshold (De Minimis) reporting levels established by SARA Title III, Section 313.

SARA 311/312 Hazards
Fire Hazard, Sudden Release of Pressure Hazard

Massachusetts Right To Know Components

	CAS-No.	Revision Date
Hydrogen	1333-74-0	1993-04-24

Pennsylvania Right To Know Components

	CAS-No.	Revision Date
Hydrogen	1333-74-0	1993-04-24

New Jersey Right To Know Components

	CAS-No.	Revision Date
Hydrogen	1333-74-0	1993-04-24

California Prop. 65 Components
This product does not contain any chemicals known to State of California to cause cancer, birth defects, or any other reproductive harm.

A.5 Methane

SIGMA-ALDRICH sigma-aldrich.com

Material Safety Data Sheet

Version 3.3
Revision Date 12/05/2012
Print Date 03/21/2014

1. PRODUCT AND COMPANY IDENTIFICATION

Product name	:	Methane
Product Number	:	295477
Brand	:	Aldrich
Supplier	:	Sigma-Aldrich 3050 Spruce Street SAINT LOUIS MO 63103 USA
Telephone	:	+1 800-325-5832
Fax	:	+1 800-325-5052
Emergency Phone # (For both supplier and manufacturer)	:	(314) 776-6555
Preparation Information	:	Sigma-Aldrich Corporation Product Safety - Americas Region 1-800-521-8956

2. HAZARDS IDENTIFICATION

Emergency Overview

OSHA Hazards
Flammable gas

Not a dangerous substance according to GHS.

HMIS Classification

Health hazard:	0
Flammability:	4
Physical hazards:	3

NFPA Rating

Health hazard:	0
Fire:	4
Reactivity Hazard:	0

Potential Health Effects

Inhalation	May be harmful if inhaled. May cause respiratory tract irritation.
Skin	May be harmful if absorbed through skin. May cause skin irritation.
Eyes	May cause eye irritation.
Ingestion	May be harmful if swallowed.

3. COMPOSITION/INFORMATION ON INGREDIENTS

Formula	:	CH_4
Molecular Weight	:	16.04 g/mol

Component		Concentration
Methane		
CAS-No.	74-82-8	-
EC-No.	200-812-7	
Index-No.	601-001-00-4	

4. FIRST AID MEASURES

General advice
Move out of dangerous area.

If inhaled
If breathed in, move person into fresh air. If not breathing, give artificial respiration.

In case of skin contact
Wash off with soap and plenty of water.

In case of eye contact
Flush eyes with water as a precaution.

If swallowed
Never give anything by mouth to an unconscious person. Rinse mouth with water.

5. FIREFIGHTING MEASURES

Conditions of flammability
Flammable in the presence of an oxidizing gas (eg air), a source of ignition, and when the concentration of the gas is between the lower and upper explosive limits. Keep away from heat/sparks/open flame/hot surface/oxidizing gas. No smoking.

Suitable extinguishing media
Use water spray, alcohol-resistant foam, dry chemical or carbon dioxide.

Special protective equipment for firefighters
Wear self contained breathing apparatus for fire fighting if necessary.

Hazardous combustion products
Hazardous decomposition products formed under fire conditions. - Carbon oxides

6. ACCIDENTAL RELEASE MEASURES

Personal precautions
Avoid breathing vapors, mist or gas.

Environmental precautions
Do not let product enter drains.

Methods and materials for containment and cleaning up
Clean up promptly by sweeping or vacuum.

7. HANDLING AND STORAGE

Conditions for safe storage
Keep container tightly closed in a dry and well-ventilated place.

Contents under pressure.

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

Components with workplace control parameters

Components	CAS-No.	Value	Control parameters	Basis
Methane	74-82-8	TWA	1,000 ppm	USA. ACGIH Threshold Limit Values (TLV)
Remarks	Central Nervous System impairment Cardiac sensitization			

Personal protective equipment

Respiratory protection
Where risk assessment shows air-purifying respirators are appropriate use a full-face respirator with multi-purpose combination (US) or type AXBEK (EN 14387) respirator cartridges as a backup to engineering controls. If the respirator is the sole means of protection, use a full-face supplied air respirator. Use respirators and components tested and approved under appropriate government standards such as NIOSH (US) or CEN (EU).

Hand protection
Handle with gloves. Gloves must be inspected prior to use. Use proper glove removal technique (without touching glove's outer surface) to avoid skin contact with this product. Dispose of contaminated gloves after use in accordance with applicable laws and good laboratory practices. Wash and dry hands.

Full contact
Material: Fluorinated rubber
Minimum layer thickness: 0.7 mm
Break through time: 480 min
Material tested:Vitoject® (KCL 890 / Aldrich Z677698, Size M)

Splash protection
Material: Nitrile rubber
Minimum layer thickness: 0.4 mm
Break through time: 60 min
Material tested:Camatril® (KCL 730 / Aldrich Z677442, Size M)

data source: KCL GmbH, D-36124 Eichenzell, phone +49 (0)6659 87300, e-mail sales@kcl.de, test method: EN374
If used in solution, or mixed with other substances, and under conditions which differ from EN 374, contact the supplier of the CE approved gloves. This recommendation is advisory only and must be evaluated by an Industrial Hygienist familiar with the specific situation of anticipated use by our customers. It should not be construed as offering an approval for any specific use scenario.

Eye protection
Use equipment for eye protection tested and approved under appropriate government standards such as NIOSH (US) or EN 166(EU).

Skin and body protection
impervious clothing, The type of protective equipment must be selected according to the concentration and amount of the dangerous substance at the specific workplace.

Hygiene measures
General industrial hygiene practice.

9. PHYSICAL AND CHEMICAL PROPERTIES

Appearance

Form	gaseous
Colour	colourless

Safety data

pH	no data available
Melting point/freezing point	Melting point/range: -183 °C (-297 °F) - lit.
Boiling point	-161 °C (-258 °F) - lit.
Flash point	-188 °C (-306 °F) - closed cup
Ignition temperature	537 °C (999 °F)
Auto-ignition temperature	no data available
Lower explosion limit	5 %(V)
Upper explosion limit	15 %(V)
Vapour pressure	no data available

Density	0.716 g/cm3 at 25 °C (77 °F)
Water solubility	3.5 g/l at 17 °C (63 °F)
Partition coefficient: n-octanol/water	no data available
Relative vapor density	0.55 - (Air = 1.0)
Odour	no data available
Odour Threshold	no data available
Evaporation rate	no data available

10. STABILITY AND REACTIVITY

Chemical stability
Stable under recommended storage conditions.

Possibility of hazardous reactions
no data available

Conditions to avoid
no data available

Materials to avoid
Strong oxidizing agents

Hazardous decomposition products
Hazardous decomposition products formed under fire conditions. - Carbon oxides
Other decomposition products - no data available

11. TOXICOLOGICAL INFORMATION

Acute toxicity

Oral LD50
no data available

Inhalation LC50
no data available

Dermal LD50
no data available

Other information on acute toxicity
no data available

Skin corrosion/irritation
no data available

Serious eye damage/eye irritation
no data available

Respiratory or skin sensitization
no data available

Germ cell mutagenicity
no data available

Carcinogenicity

IARC:	No component of this product present at levels greater than or equal to 0.1% is identified as probable, possible or confirmed human carcinogen by IARC.
ACGIH:	No component of this product present at levels greater than or equal to 0.1% is identified as a carcinogen or potential carcinogen by ACGIH.
NTP:	No component of this product present at levels greater than or equal to 0.1% is identified as a

known or anticipated carcinogen by NTP.

OSHA: No component of this product present at levels greater than or equal to 0.1% is identified as a carcinogen or potential carcinogen by OSHA.

Reproductive toxicity

no data available

Teratogenicity

no data available

Specific target organ toxicity - single exposure (Globally Harmonized System)
no data available

Specific target organ toxicity - repeated exposure (Globally Harmonized System)
no data available

Aspiration hazard
no data available

Potential health effects

Inhalation	May be harmful if inhaled. May cause respiratory tract irritation.
Ingestion	May be harmful if swallowed.
Skin	May be harmful if absorbed through skin. May cause skin irritation.
Eyes	May cause eye irritation.

Signs and Symptoms of Exposure
To the best of our knowledge, the chemical, physical, and toxicological properties have not been thoroughly investigated.

Synergistic effects
no data available

Additional Information
RTECS: PA1490000

12. ECOLOGICAL INFORMATION

Toxicity

no data available

Persistence and degradability
no data available

Bioaccumulative potential
no data available

Mobility in soil
no data available

PBT and vPvB assessment
no data available

Other adverse effects

no data available

13. DISPOSAL CONSIDERATIONS

Product
Offer surplus and non-recyclable solutions to a licensed disposal company. Contact a licensed professional waste disposal service to dispose of this material.

Contaminated packaging
Dispose of as unused product.

14. TRANSPORT INFORMATION

DOT (US)
UN number: 1971 Class: 2.1
Proper shipping name: Methane, compressed
Marine Pollutant: No
Poison Inhalation Hazard: No

IMDG
UN number: 1971 Class: 2.1 EMS-No: F-D, S-U
Proper shipping name: METHANE, COMPRESSED
Marine Pollutant: No

IATA
UN number: 1971 Class: 2.1
Proper shipping name: Methane, compressed
IATA Passenger: Not permitted for transport

15. REGULATORY INFORMATION

OSHA Hazards
Flammable gas

SARA 302 Components
SARA 302: No chemicals in this material are subject to the reporting requirements of SARA Title III, Section 302.

SARA 313 Components
SARA 313: This material does not contain any chemical components with known CAS numbers that exceed the threshold (De Minimis) reporting levels established by SARA Title III, Section 313.

SARA 311/312 Hazards
Fire Hazard

Massachusetts Right To Know Components

	CAS-No.	Revision Date
Methane	74-82-8	1993-04-24

Pennsylvania Right To Know Components

	CAS-No.	Revision Date
Methane	74-82-8	1993-04-24

New Jersey Right To Know Components

	CAS-No.	Revision Date
Methane	74-82-8	1993-04-24

California Prop. 65 Components
This product does not contain any chemicals known to State of California to cause cancer, birth defects, or any other reproductive harm.

A.6 Ethane

SIGMA-ALDRICH sigma-aldrich.com

Material Safety Data Sheet

Version 3.3
Revision Date 12/05/2012
Print Date 03/21/2014

1. PRODUCT AND COMPANY IDENTIFICATION

Product name	:	Ethane
Product Number	:	295302
Brand	:	Aldrich
Supplier	:	Sigma-Aldrich 3050 Spruce Street SAINT LOUIS MO 63103 USA
Telephone	:	+1 800-325-5832
Fax	:	+1 800-325-5052
Emergency Phone # (For both supplier and manufacturer)	:	(314) 776-6555
Preparation Information	:	Sigma-Aldrich Corporation Product Safety - Americas Region 1-800-521-8956

2. HAZARDS IDENTIFICATION

Emergency Overview

OSHA Hazards
Flammable gas

GHS Classification
Flammable gases (Category 1)
Gases under pressure (Liquefied gas)

GHS Label elements, including precautionary statements

Pictogram

Signal word: Danger

Hazard statement(s)

H220	Extremely flammable gas.
H280	Contains gas under pressure; may explode if heated.

Precautionary statement(s)

P210	Keep away from heat/sparks/open flames/hot surfaces. - No smoking.
P410 + P403	Protect from sunlight. Store in a well-ventilated place.

HMIS Classification

Health hazard:	0
Flammability:	4
Physical hazards:	3

NFPA Rating

Health hazard:	0
Fire:	4
Reactivity Hazard:	0

Potential Health Effects

Inhalation	May be harmful if inhaled. May cause respiratory tract irritation.
Skin	May be harmful if absorbed through skin. May cause skin irritation.

Eyes	May cause eye irritation.
Ingestion	May be harmful if swallowed.

3. COMPOSITION/INFORMATION ON INGREDIENTS

Formula : C_2H_6
Molecular Weight : 30.07 g/mol

Component		Concentration
Ethane		
CAS-No.	74-84-0	-
EC-No.	200-814-8	
Index-No.	601-002-00-X	

4. FIRST AID MEASURES

General advice
Consult a physician. Show this safety data sheet to the doctor in attendance.Move out of dangerous area.

If inhaled
If breathed in, move person into fresh air. If not breathing, give artificial respiration. Consult a physician.

In case of skin contact
Wash off with soap and plenty of water. Consult a physician.

In case of eye contact
Flush eyes with water as a precaution.

If swallowed
Do NOT induce vomiting. Never give anything by mouth to an unconscious person. Rinse mouth with water. Consult a physician.

5. FIREFIGHTING MEASURES

Conditions of flammability
Flammable in the presence of an oxidizing gas (eg air), a source of ignition, and when the concentration of the gas is between the lower and upper explosive limits. Keep away from heat/sparks/open flame/hot surface/oxidizing gas. No smoking.

Suitable extinguishing media
Use water spray, alcohol-resistant foam, dry chemical or carbon dioxide.

Special protective equipment for firefighters
Wear self contained breathing apparatus for fire fighting if necessary.

Hazardous combustion products
Hazardous decomposition products formed under fire conditions. - Carbon oxides

Further information
Use water spray to cool unopened containers.

6. ACCIDENTAL RELEASE MEASURES

Personal precautions
Avoid breathing vapors, mist or gas. Ensure adequate ventilation. Remove all sources of ignition. Evacuate personnel to safe areas. Beware of vapours accumulating to form explosive concentrations. Vapours can accumulate in low areas.

Environmental precautions
Prevent further leakage or spillage if safe to do so. Do not let product enter drains.

Methods and materials for containment and cleaning up
Clean up promptly by sweeping or vacuum.

7. HANDLING AND STORAGE

Precautions for safe handling
Avoid inhalation of vapour or mist.
Use explosion-proof equipment. Keep away from sources of ignition - No smoking. Take measures to prevent the build up of electrostatic charge.

Conditions for safe storage
Keep container tightly closed in a dry and well-ventilated place.

Contents under pressure.

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

Components with workplace control parameters

Components	CAS-No.	Value	Control parameters	Basis
Ethane	74-84-0	TWA	1,000 ppm	USA. ACGIH Threshold Limit Values (TLV)
Remarks	Central Nervous System impairment Cardiac sensitization			

Personal protective equipment

Respiratory protection
Where risk assessment shows air-purifying respirators are appropriate use a full-face respirator with multi-purpose combination (US) or type AXBEK (EN 14387) respirator cartridges as a backup to engineering controls. If the respirator is the sole means of protection, use a full-face supplied air respirator. Use respirators and components tested and approved under appropriate government standards such as NIOSH (US) or CEN (EU).

Hand protection
Handle with gloves. Gloves must be inspected prior to use. Use proper glove removal technique (without touching glove's outer surface) to avoid skin contact with this product. Dispose of contaminated gloves after use in accordance with applicable laws and good laboratory practices. Wash and dry hands.

Full contact
Material: Fluorinated rubber
Minimum layer thickness: 0.7 mm
Break through time: 480 min
Material tested:Vitoject® (KCL 890 / Aldrich Z677698, Size M)

Splash protection
Material: Nitrile rubber
Minimum layer thickness: 0.4 mm
Break through time: 60 min
Material tested:Camatril® (KCL 730 / Aldrich Z677442, Size M)

data source: KCL GmbH, D-36124 Eichenzell, phone +49 (0)6659 87300, e-mail sales@kcl.de, test method: EN374
If used in solution, or mixed with other substances, and under conditions which differ from EN 374, contact the supplier of the CE approved gloves. This recommendation is advisory only and must be evaluated by an Industrial Hygienist familiar with the specific situation of anticipated use by our customers. It should not be construed as offering an approval for any specific use scenario.

Eye protection
Face shield and safety glasses Use equipment for eye protection tested and approved under appropriate government standards such as NIOSH (US) or EN 166(EU).

Skin and body protection
impervious clothing, Flame retardant antistatic protective clothing, The type of protective equipment must be selected according to the concentration and amount of the dangerous substance at the specific workplace.

Hygiene measures
Handle in accordance with good industrial hygiene and safety practice. Wash hands before breaks and at the end of workday.

9. PHYSICAL AND CHEMICAL PROPERTIES

Appearance

Form	gaseous
Colour	no data available

Safety data

pH	no data available
Melting point/freezing point	Melting point/range: -172 °C (-278 °F) - lit.
Boiling point	-88 °C (-126 °F) - lit.
Flash point	-135 °C (-211 °F) - closed cup
Ignition temperature	472 °C (882 °F)
Auto-ignition temperature	no data available
Lower explosion limit	2.9 %(V)
Upper explosion limit	13 %(V)
Vapour pressure	38,453 hPa (28,842 mmHg) at 21.1 °C (70.0 °F)
Density	0.362 g/cm3 at 20 °C (68 °F)
Water solubility	no data available
Partition coefficient: n-octanol/water	no data available
Relative vapor density	1.04 - (Air = 1.0)
Odour	no data available
Odour Threshold	no data available
Evaporation rate	no data available

10. STABILITY AND REACTIVITY

Chemical stability
Stable under recommended storage conditions.

Possibility of hazardous reactions
no data available

Conditions to avoid
Heat, flames and sparks. Extremes of temperature and direct sunlight.

Materials to avoid
Strong oxidizing agents

Hazardous decomposition products
Hazardous decomposition products formed under fire conditions. - Carbon oxides
Other decomposition products - no data available

11. TOXICOLOGICAL INFORMATION

Acute toxicity

Oral LD50
no data available

Inhalation LC50
no data available

Dermal LD50

no data available

Other information on acute toxicity
no data available

Skin corrosion/irritation
no data available

Serious eye damage/eye irritation
no data available

Respiratory or skin sensitization
no data available

Germ cell mutagenicity
no data available

Carcinogenicity

IARC:	No component of this product present at levels greater than or equal to 0.1% is identified as probable, possible or confirmed human carcinogen by IARC.
ACGIH:	No component of this product present at levels greater than or equal to 0.1% is identified as a carcinogen or potential carcinogen by ACGIH.
NTP:	No component of this product present at levels greater than or equal to 0.1% is identified as a known or anticipated carcinogen by NTP.
OSHA:	No component of this product present at levels greater than or equal to 0.1% is identified as a carcinogen or potential carcinogen by OSHA.

Reproductive toxicity

no data available

Teratogenicity

no data available

Specific target organ toxicity - single exposure (Globally Harmonized System)
no data available

Specific target organ toxicity - repeated exposure (Globally Harmonized System)
no data available

Aspiration hazard
no data available

Potential health effects

Inhalation	May be harmful if inhaled. May cause respiratory tract irritation.
Ingestion	May be harmful if swallowed.
Skin	May be harmful if absorbed through skin. May cause skin irritation.
Eyes	May cause eye irritation.

Signs and Symptoms of Exposure
narcosis, To the best of our knowledge, the chemical, physical, and toxicological properties have not been thoroughly investigated.

Synergistic effects
no data available

Additional Information
RTECS: KH3800000

12. ECOLOGICAL INFORMATION

Toxicity

no data available

Persistence and degradability
no data available

Bioaccumulative potential
no data available

Mobility in soil
no data available

PBT and vPvB assessment
no data available

Other adverse effects

no data available

13. DISPOSAL CONSIDERATIONS

Product
Burn in a chemical incinerator equipped with an afterburner and scrubber but exert extra care in igniting as this material is highly flammable. Offer surplus and non-recyclable solutions to a licensed disposal company. Contact a licensed professional waste disposal service to dispose of this material.

Contaminated packaging
Dispose of as unused product.

14. TRANSPORT INFORMATION

DOT (US)
UN number: 1035 Class: 2.1
Proper shipping name: Ethane
Marine Pollutant: No
Poison Inhalation Hazard: No

IMDG
UN number: 1035 Class: 2.1 EMS-No: F-D, S-U
Proper shipping name: ETHANE
Marine Pollutant: No

IATA
UN number: 1035 Class: 2.1
Proper shipping name: Ethane
IATA Passenger: Not permitted for transport

15. REGULATORY INFORMATION

OSHA Hazards
Flammable gas

SARA 302 Components
SARA 302: No chemicals in this material are subject to the reporting requirements of SARA Title III, Section 302.

SARA 313 Components
SARA 313: This material does not contain any chemical components with known CAS numbers that exceed the threshold (De Minimis) reporting levels established by SARA Title III, Section 313.

SARA 311/312 Hazards
Fire Hazard

Massachusetts Right To Know Components

	CAS-No.	Revision Date
Ethane	74-84-0	1993-04-24

Pennsylvania Right To Know Components

	CAS-No.	Revision Date
Ethane	74-84-0	1993-04-24

New Jersey Right To Know Components

	CAS-No.	Revision Date
Ethane	74-84-0	1993-04-24

California Prop. 65 Components

This product does not contain any chemicals known to State of California to cause cancer, birth defects, or any other reproductive harm.

A.7 Propane

SIGMA-ALDRICH sigma-aldrich.com

SAFETY DATA SHEET

Version 3.5
Revision Date 03/19/2014
Print Date 03/21/2014

1. PRODUCT AND COMPANY IDENTIFICATION

1.1 Product identifiers

Product name	:	Propane
Product Number	:	536172
Brand	:	Aldrich
Index-No.	:	601-003-00-5
REACH No.	:	A registration number is not available for this substance as the substance or its uses are exempted from registration, the annual tonnage does not require a registration or the registration is envisaged for a later registration deadline.
CAS-No.	:	74-98-6

1.2 Relevant identified uses of the substance or mixture and uses advised against

Identified uses	:	Laboratory chemicals, Manufacture of substances

1.3 Details of the supplier of the safety data sheet

Company	:	Sigma-Aldrich 3050 Spruce Street SAINT LOUIS MO 63103 USA
Telephone	:	+1 800-325-5832
Fax	:	+1 800-325-5052

1.4 Emergency telephone number

Emergency Phone #	:	(314) 776-6555

2. HAZARDS IDENTIFICATION

2.1 Classification of the substance or mixture

GHS Classification in accordance with 29 CFR 1910 (OSHA HCS)
Flammable gases (Category 1), H220
Gases under pressure (Liquefied gas), H280

For the full text of the H-Statements mentioned in this Section, see Section 16.

2.2 GHS Label elements, including precautionary statements

Pictogram

Signal word: Danger

Hazard statement(s)

H220	Extremely flammable gas.
H280	Contains gas under pressure; may explode if heated.

Precautionary statement(s)

P210	Keep away from heat/sparks/open flames/hot surfaces. - No smoking.
P377	Leaking gas fire: Do not extinguish, unless leak can be stopped safely.
P381	Eliminate all ignition sources if safe to do so.
P410 + P403	Protect from sunlight. Store in a well-ventilated place.

2.3 Hazards not otherwise classified (HNOC) or not covered by GHS - none

3. COMPOSITION/INFORMATION ON INGREDIENTS

3.1 Substances

Formula	:	C_3H_8
Molecular Weight	:	44.1 g/mol
CAS-No.	:	74-98-6
EC-No.	:	200-827-9
Index-No.	:	601-003-00-5

Hazardous components

Component	Classification	Concentration
Propane		
	Flam. Gas 1; Press. Gas ; H220, H280	-

For the full text of the H-Statements mentioned in this Section, see Section 16.

4. FIRST AID MEASURES

4.1 Description of first aid measures

General advice
Consult a physician. Show this safety data sheet to the doctor in attendance.Move out of dangerous area.

If inhaled
If breathed in, move person into fresh air. If not breathing, give artificial respiration. Consult a physician.

In case of skin contact
Wash off with soap and plenty of water. Consult a physician.

In case of eye contact
Flush eyes with water as a precaution.

If swallowed
Do NOT induce vomiting. Never give anything by mouth to an unconscious person. Rinse mouth with water. Consult a physician.

4.2 Most important symptoms and effects, both acute and delayed
The most important known symptoms and effects are described in the labelling (see section 2.2) and/or in section 11

4.3 Indication of any immediate medical attention and special treatment needed
no data available

5. FIREFIGHTING MEASURES

5.1 Extinguishing media

Suitable extinguishing media
Use water spray, alcohol-resistant foam, dry chemical or carbon dioxide.

5.2 Special hazards arising from the substance or mixture
Carbon oxides

5.3 Advice for firefighters
Wear self contained breathing apparatus for fire fighting if necessary.

5.4 Further information
Use water spray to cool unopened containers.

6. ACCIDENTAL RELEASE MEASURES

6.1 Personal precautions, protective equipment and emergency procedures
Avoid breathing vapours, mist or gas. Ensure adequate ventilation. Remove all sources of ignition. Evacuate personnel to safe areas. Beware of vapours accumulating to form explosive concentrations. Vapours can accumulate in low areas.
For personal protection see section 8.

6.2 Environmental precautions
Prevent further leakage or spillage if safe to do so. Do not let product enter drains.

6.3 Methods and materials for containment and cleaning up
Clean up promptly by sweeping or vacuum.

6.4 Reference to other sections
For disposal see section 13.

7. HANDLING AND STORAGE

7.1 Precautions for safe handling
Avoid inhalation of vapour or mist.
Use explosion-proof equipment.Keep away from sources of ignition - No smoking.Take measures to prevent the build up of electrostatic charge.
For precautions see section 2.2.

7.2 Conditions for safe storage, including any incompatibilities
Keep container tightly closed in a dry and well-ventilated place.

Contents under pressure.

7.3 Specific end use(s)
Apart from the uses mentioned in section 1.2 no other specific uses are stipulated

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

8.1 Control parameters

Components with workplace control parameters

Component	CAS-No.	Value	Control parameters	Basis
Propane	74-98-6	TWA	1,000 ppm	USA. ACGIH Threshold Limit Values (TLV)
	Remarks	Central Nervous System impairment Cardiac sensitization		
		TWA	1,000 ppm 1,800 mg/m3	USA. Occupational Exposure Limits (OSHA) - Table Z-1 Limits for Air Contaminants
		The value in mg/m3 is approximate.		
		TWA	1,000 ppm 1,800 mg/m3	USA. OSHA - TABLE Z-1 Limits for Air Contaminants - 1910.1000
		TWA	1,000 ppm 1,800 mg/m3	USA. NIOSH Recommended Exposure Limits

8.2 Exposure controls

Appropriate engineering controls
Handle in accordance with good industrial hygiene and safety practice. Wash hands before breaks and at the end of workday.

Personal protective equipment

Eye/face protection
Face shield and safety glasses Use equipment for eye protection tested and approved under appropriate government standards such as NIOSH (US) or EN 166(EU).

Skin protection
Handle with gloves. Gloves must be inspected prior to use. Use proper glove removal technique (without touching glove's outer surface) to avoid skin contact with this product. Dispose of contaminated gloves after use in accordance with applicable laws and good laboratory practices. Wash and dry hands.

Full contact
Material: Fluorinated rubber
Minimum layer thickness: 0.7 mm
Break through time: 480 min
Material tested:Vitoject® (KCL 890 / Aldrich Z677698, Size M)

Splash contact
Material: Nitrile rubber
Minimum layer thickness: 0.4 mm
Break through time: 60 min
Material tested:Camatril® (KCL 730 / Aldrich Z677442, Size M)

data source: KCL GmbH, D-36124 Eichenzell, phone +49 (0)6659 87300, e-mail sales@kcl.de, test method: EN374
If used in solution, or mixed with other substances, and under conditions which differ from EN 374, contact the supplier of the CE approved gloves. This recommendation is advisory only and must be evaluated by an industrial hygienist and safety officer familiar with the specific situation of anticipated use by our customers. It should not be construed as offering an approval for any specific use scenario.

Body Protection
impervious clothing, Flame retardant antistatic protective clothing, The type of protective equipment must be selected according to the concentration and amount of the dangerous substance at the specific workplace.

Respiratory protection
Where risk assessment shows air-purifying respirators are appropriate use a full-face respirator with multi-purpose combination (US) or type AXBEK (EN 14387) respirator cartridges as a backup to engineering controls. If the respirator is the sole means of protection, use a full-face supplied air respirator. Use respirators and components tested and approved under appropriate government standards such as NIOSH (US) or CEN (EU).

Control of environmental exposure
Prevent further leakage or spillage if safe to do so. Do not let product enter drains.

9. PHYSICAL AND CHEMICAL PROPERTIES

9.1 Information on basic physical and chemical properties

a)	Appearance	Form: Liquefied gas
b)	Odour	no data available
c)	Odour Threshold	no data available
d)	pH	no data available
e)	Melting point/freezing point	Melting point/range: -188 °C (-306 °F) - lit.
f)	Initial boiling point and boiling range	-42.1 °C (-43.8 °F) - lit.
g)	Flash point	-104 °C (-155 °F) - closed cup
h)	Evapouration rate	no data available
i)	Flammability (solid, gas)	no data available
j)	Upper/lower flammability or explosive limits	Upper explosion limit: 9.5 %(V) Lower explosion limit: 2.1 %(V)
k)	Vapour pressure	13,096 hPa (9,823 mmHg) at 37.7 °C (99.9 °F) 8,531.6 hPa (6,399.2 mmHg) at 21.1 °C (70.0 °F)
l)	Vapour density	1.52 - (Air = 1.0)
m)	Relative density	0.564 g/mL at 20 °C (68 °F)
n)	Water solubility	no data available
o)	Partition coefficient: n-octanol/water	no data available
p)	Auto-ignition temperature	no data available
q)	Decomposition temperature	no data available

r)	Viscosity	no data available
s)	Explosive properties	no data available
t)	Oxidizing properties	no data available

9.2 Other safety information

Relative vapour density 1.52 - (Air = 1.0)

10. STABILITY AND REACTIVITY

10.1 Reactivity
no data available

10.2 Chemical stability
Stable under recommended storage conditions.

10.3 Possibility of hazardous reactions
no data available

10.4 Conditions to avoid
Heat, flames and sparks. Extremes of temperature and direct sunlight.

10.5 Incompatible materials
Strong oxidizing agents

10.6 Hazardous decomposition products
Other decomposition products - no data available
In the event of fire: see section 5

11. TOXICOLOGICAL INFORMATION

11.1 Information on toxicological effects

Acute toxicity
no data available

Inhalation: no data available

Dermal: no data available

no data available

Skin corrosion/irritation
no data available

Serious eye damage/eye irritation
no data available

Respiratory or skin sensitisation
no data available

Germ cell mutagenicity
no data available

Carcinogenicity

IARC:	No component of this product present at levels greater than or equal to 0.1% is identified as probable, possible or confirmed human carcinogen by IARC.
ACGIH:	No component of this product present at levels greater than or equal to 0.1% is identified as a carcinogen or potential carcinogen by ACGIH.
NTP:	No component of this product present at levels greater than or equal to 0.1% is identified as a known or anticipated carcinogen by NTP.
OSHA:	No component of this product present at levels greater than or equal to 0.1% is identified as a carcinogen or potential carcinogen by OSHA.

Reproductive toxicity
no data available

no data available

Specific target organ toxicity - single exposure
no data available

Specific target organ toxicity - repeated exposure
no data available

Aspiration hazard
no data available

Additional Information
RTECS: TX2275000

Dizziness, Drowsiness, Unconsciousness

12. ECOLOGICAL INFORMATION

12.1 Toxicity
no data available

12.2 Persistence and degradability
no data available

12.3 Bioaccumulative potential
no data available

12.4 Mobility in soil
no data available

12.5 Results of PBT and vPvB assessment
PBT/vPvB assessment not available as chemical safety assessment not required/not conducted

12.6 Other adverse effects

no data available

13. DISPOSAL CONSIDERATIONS

13.1 Waste treatment methods

Product
Burn in a chemical incinerator equipped with an afterburner and scrubber but exert extra care in igniting as this material is highly flammable. Offer surplus and non-recyclable solutions to a licensed disposal company. Contact a licensed professional waste disposal service to dispose of this material.

Contaminated packaging
Dispose of as unused product.

14. TRANSPORT INFORMATION

DOT (US)
UN number: 1978 Class: 2.1
Proper shipping name: Propane
Marine pollutant: No
Poison Inhalation Hazard: No

IMDG
UN number: 1978 Class: 2.1 EMS-No: F-D, S-U
Proper shipping name: PROPANE
Marine pollutant: No

IATA
UN number: 1978 Class: 2.1
Proper shipping name: Propane
IATA Passenger: Not permitted for transport

15. REGULATORY INFORMATION

REACH No.	:	A registration number is not available for this substance as the substance or its uses are exempted from registration, the annual tonnage does not require a registration or the registration is envisaged for a later registration deadline.

SARA 302 Components
SARA 302: No chemicals in this material are subject to the reporting requirements of SARA Title III, Section 302.

SARA 313 Components
SARA 313: This material does not contain any chemical components with known CAS numbers that exceed the threshold (De Minimis) reporting levels established by SARA Title III, Section 313.

SARA 311/312 Hazards
Fire Hazard, Sudden Release of Pressure Hazard

Massachusetts Right To Know Components

	CAS-No.	Revision Date
Propane	74-98-6	1993-04-24

Pennsylvania Right To Know Components

	CAS-No.	Revision Date
Propane	74-98-6	1993-04-24

New Jersey Right To Know Components

	CAS-No.	Revision Date
Propane	74-98-6	1993-04-24

California Prop. 65 Components
This product does not contain any chemicals known to State of California to cause cancer, birth defects, or any other reproductive harm.

16. OTHER INFORMATION

Full text of H-Statements referred to under sections 2 and 3.

Flam. Gas	Flammable gases
H220	Extremely flammable gas.
H280	Contains gas under pressure; may explode if heated.
Press. Gas	Gases under pressure

HMIS Rating

Health hazard:	0
Chronic Health Hazard:	
Flammability:	4
Physical Hazard	3

NFPA Rating

Health hazard:	0
Fire Hazard:	4
Reactivity Hazard:	0

A.8 Butane

SIGMA-ALDRICH sigma-aldrich.com

Material Safety Data Sheet

Version 3.5
Revision Date 09/17/2012
Print Date 03/21/2014

1. PRODUCT AND COMPANY IDENTIFICATION

Product name	:	Butane
Product Number	:	494402
Brand	:	Aldrich
Supplier	:	Sigma-Aldrich 3050 Spruce Street SAINT LOUIS MO 63103 USA
Telephone	:	+1 800-325-5832
Fax	:	+1 800-325-5052
Emergency Phone # (For both supplier and manufacturer)	:	(314) 776-6555
Preparation Information	:	Sigma-Aldrich Corporation Product Safety - Americas Region 1-800-521-8956

2. HAZARDS IDENTIFICATION

Emergency Overview

OSHA Hazards
Flammable gas, Target Organ Effect

Target Organs

Central nervous system

GHS Classification
Flammable gases (Category 1)
Gases under pressure (Liquefied gas)

GHS Label elements, including precautionary statements

Pictogram

Signal word: Danger

Hazard statement(s)

H220	Extremely flammable gas.
H280	Contains gas under pressure; may explode if heated.

Precautionary statement(s)

P210	Keep away from heat/sparks/open flames/hot surfaces. - No smoking.
P410 + P403	Protect from sunlight. Store in a well-ventilated place.

HMIS Classification

Health hazard:	0
Chronic Health Hazard:	*
Flammability:	4
Physical hazards:	3

NFPA Rating

Health hazard:	0
Fire:	4
Reactivity Hazard:	0

Potential Health Effects

Inhalation	May be harmful if inhaled. May cause respiratory tract irritation.
Skin	May be harmful if absorbed through skin. May cause skin irritation.
Eyes	May cause eye irritation.
Ingestion	May be harmful if swallowed.

3. COMPOSITION/INFORMATION ON INGREDIENTS

Formula : C_4H_{10}
Molecular Weight : 58.12 g/mol

Component		Concentration
Butane		
CAS-No.	106-97-8	-
EC-No.	203-448-7	
Index-No.	601-004-00-0	

4. FIRST AID MEASURES

General advice
Consult a physician. Show this safety data sheet to the doctor in attendance.Move out of dangerous area.

If inhaled
If breathed in, move person into fresh air. If not breathing, give artificial respiration. Consult a physician.

In case of skin contact
Wash off with soap and plenty of water. Consult a physician.

In case of eye contact
Flush eyes with water as a precaution.

If swallowed
Do NOT induce vomiting. Never give anything by mouth to an unconscious person. Rinse mouth with water. Consult a physician.

5. FIREFIGHTING MEASURES

Conditions of flammability
Flammable in the presence of an oxidizing gas (eg air), a source of ignition, and when the concentration of the gas is between the lower and upper explosive limits. Keep away from heat/sparks/open flame/hot surface/oxidizing gas. No smoking.

Suitable extinguishing media
Use water spray, alcohol-resistant foam, dry chemical or carbon dioxide.

Special protective equipment for firefighters
Wear self contained breathing apparatus for fire fighting if necessary.

Hazardous combustion products
Hazardous decomposition products formed under fire conditions. - Carbon oxides

Further information
Use water spray to cool unopened containers.

6. ACCIDENTAL RELEASE MEASURES

Personal precautions
Avoid breathing vapors, mist or gas. Ensure adequate ventilation. Remove all sources of ignition. Evacuate personnel to safe areas. Beware of vapours accumulating to form explosive concentrations. Vapours can accumulate in low areas.

Environmental precautions
Prevent further leakage or spillage if safe to do so. Do not let product enter drains.

Methods and materials for containment and cleaning up
Clean up promptly by sweeping or vacuum.

7. HANDLING AND STORAGE

Precautions for safe handling
Avoid inhalation of vapour or mist.
Use explosion-proof equipment. Keep away from sources of ignition - No smoking. Take measures to prevent the build up of electrostatic charge.

Conditions for safe storage
Keep container tightly closed in a dry and well-ventilated place.

Contents under pressure.

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

Components with workplace control parameters

Components	CAS-No.	Value	Control parameters	Basis
Butane	106-97-8	TWA	800 ppm 1,900 mg/m3	USA. OSHA - TABLE Z-1 Limits for Air Contaminants - 1910.1000
		TWA	1,000 ppm	USA. ACGIH Threshold Limit Values (TLV)
		TWA	1,000 ppm	USA. ACGIH Threshold Limit Values (TLV)
Remarks	Central Nervous System impairment Cardiac sensitization			
		TWA	800 ppm 1,900 mg/m3	USA. NIOSH Recommended Exposure Limits
	Also see specific listing for Isobutane.			

Personal protective equipment

Respiratory protection
Where risk assessment shows air-purifying respirators are appropriate use a full-face respirator with multi-purpose combination (US) or type AXBEK (EN 14387) respirator cartridges as a backup to engineering controls. If the respirator is the sole means of protection, use a full-face supplied air respirator. Use respirators and components tested and approved under appropriate government standards such as NIOSH (US) or CEN (EU).

Hand protection
Handle with gloves. Gloves must be inspected prior to use. Use proper glove removal technique (without touching glove's outer surface) to avoid skin contact with this product. Dispose of contaminated gloves after use in accordance with applicable laws and good laboratory practices. Wash and dry hands.

Immersion protection
Material: Fluorinated rubber
Minimum layer thickness: 0.7 mm
Break through time: > 480 min
Material tested:Vitoject® (Aldrich Z677698, Size M)

Splash protection
Material: Nitrile rubber
Minimum layer thickness: 0.4 mm
Break through time: > 30 min
Material tested:Camatril® (Aldrich Z677442, Size M)

data source: KCL GmbH, D-36124 Eichenzell, phone +49 (0)6659 873000, e-mail sales@kcl.de, test method: EN374
If used in solution, or mixed with other substances, and under conditions which differ from EN 374, contact the supplier of the CE approved gloves. This recommendation is advisory only and must be evaluated by an Industrial Hygienist familiar with the specific situation of anticipated use by our customers. It should not be construed as offering an approval for any specific use scenario.

Eye protection
Face shield and safety glasses Use equipment for eye protection tested and approved under appropriate government standards such as NIOSH (US) or EN 166(EU).

Skin and body protection
impervious clothing, Flame retardant antistatic protective clothing, The type of protective equipment must be selected according to the concentration and amount of the dangerous substance at the specific workplace.

Hygiene measures
Handle in accordance with good industrial hygiene and safety practice. Wash hands before breaks and at the end of workday.

9. PHYSICAL AND CHEMICAL PROPERTIES

Appearance

Form	gaseous
Colour	no data available

Safety data

pH	no data available
Melting point/freezing point	Melting point/range: -138 °C (-216 °F) - lit.
Boiling point	-0.5 °C (31.1 °F) - lit.
Flash point	no data available
Ignition temperature	405 °C (761 °F)
Autoignition temperature	no data available
Lower explosion limit	1.8 %(V)
Upper explosion limit	8.4 %(V)
Vapour pressure	2,426 hPa (1,820 mmHg) at 25 °C (77 °F) 3,556.67 hPa (2,667.72 mmHg) at 37.7 °C (99.9 °F)
Density	0.579 g/mL at 20 °C (68 °F)
Water solubility	no data available
Partition coefficient: n-octanol/water	log Pow: 2.89
Relative vapour density	2.33
Odour	odourless
Odour Threshold	no data available
Evaporation rate	no data available

10. STABILITY AND REACTIVITY

Chemical stability
Stable under recommended storage conditions.

Possibility of hazardous reactions
no data available

Conditions to avoid
Heat, flames and sparks. Extremes of temperature and direct sunlight.

Materials to avoid
no data available

Hazardous decomposition products
Hazardous decomposition products formed under fire conditions. - Carbon oxides
Other decomposition products - no data available

11. TOXICOLOGICAL INFORMATION

Acute toxicity

Oral LD50
no data available

Inhalation LC50
LC50 Inhalation - rat - 4 h - 658,000 mg/m3

Dermal LD50
no data available

Other information on acute toxicity
no data available

Skin corrosion/irritation
no data available

Serious eye damage/eye irritation
no data available

Respiratory or skin sensitization
no data available

Germ cell mutagenicity
no data available

Carcinogenicity

IARC:	No component of this product present at levels greater than or equal to 0.1% is identified as probable, possible or confirmed human carcinogen by IARC.
ACGIH:	No component of this product present at levels greater than or equal to 0.1% is identified as a carcinogen or potential carcinogen by ACGIH.
NTP:	No component of this product present at levels greater than or equal to 0.1% is identified as a known or anticipated carcinogen by NTP.
OSHA:	No component of this product present at levels greater than or equal to 0.1% is identified as a carcinogen or potential carcinogen by OSHA.

Reproductive toxicity

no data available

Teratogenicity

no data available

Specific target organ toxicity - single exposure (Globally Harmonized System)
no data available

Specific target organ toxicity - repeated exposure (Globally Harmonized System)
no data available

Aspiration hazard
no data available

Potential health effects

Inhalation	May be harmful if inhaled. May cause respiratory tract irritation.
Ingestion	May be harmful if swallowed.
Skin	May be harmful if absorbed through skin. May cause skin irritation.

Eyes	May cause eye irritation.

Signs and Symptoms of Exposure
Central nervous system depression, giddiness, Shortness of breath, narcosis, Dermal contact with rapidly evaporating liquid could result in freezing of the tissues or frostbite., Exposure can cause numbness, tingling, and weakness in extremities., Cyanosis, Pulmonary edema. Effects may be delayed., Abdominal pain, Nausea, Vomiting

Synergistic effects
no data available

Additional Information
RTECS: EJ4200000

12. ECOLOGICAL INFORMATION

Toxicity

no data available

Persistence and degradability
no data available

Bioaccumulative potential
no data available

Mobility in soil
no data available

PBT and vPvB assessment
no data available

Other adverse effects

no data available

13. DISPOSAL CONSIDERATIONS

Product
Burn in a chemical incinerator equipped with an afterburner and scrubber but exert extra care in igniting as this material is highly flammable. Offer surplus and non-recyclable solutions to a licensed disposal company. Contact a licensed professional waste disposal service to dispose of this material.

Contaminated packaging
Dispose of as unused product.

14. TRANSPORT INFORMATION

DOT (US)
UN number: 1011 Class: 2.1
Proper shipping name: Butane
Reportable Quantity (RQ):
Marine pollutant: No
Poison Inhalation Hazard: No

IMDG
UN number: 1011 Class: 2.1 EMS-No: F-D, S-U
Proper shipping name: BUTANE
Marine pollutant: No

IATA
UN number: 1011 Class: 2.1
Proper shipping name: Butane
IATA Passenger: Not permitted for transport

15. REGULATORY INFORMATION

OSHA Hazards
Flammable gas, Target Organ Effect

SARA 302 Components
SARA 302: No chemicals in this material are subject to the reporting requirements of SARA Title III, Section 302.

SARA 313 Components
SARA 313: This material does not contain any chemical components with known CAS numbers that exceed the threshold (De Minimis) reporting levels established by SARA Title III, Section 313.

SARA 311/312 Hazards
Fire Hazard, Chronic Health Hazard

Massachusetts Right To Know Components

	CAS-No.	Revision Date
Butane	106-97-8	1994-04-01

Pennsylvania Right To Know Components

	CAS-No.	Revision Date
Butane	106-97-8	1994-04-01

New Jersey Right To Know Components

	CAS-No.	Revision Date
Butane	106-97-8	1994-04-01

California Prop. 65 Components
This product does not contain any chemicals known to State of California to cause cancer, birth defects, or any other reproductive harm.

A.9 Fischer-Tropsch Oil (C5-C30)

Syntroleum®
Material Safety Data Sheet

Product Name: **FT Oil**	Revision Date: Sep. 24, 2003
Page 1 of 8	Previous Revision: Sept. 05, 2003

1. CHEMICAL PRODUCT AND COMPANY IDENTIFICATION

Product Name: **FT Oil**
Synonyms: Fischer-Tropsch Oil; Liquid Paraffin; Light Fischer-Tropsch Liquid; LFTL
Product Code: Not applicable
MSDS Code: Not applicable
Chemical Family: Hydrocarbon

Responsible Party: Syntroleum® Corporation
4322 South 49th West Ave.
Tulsa, OK 74107

For product information contact Syntroleum® Corporation:
8am – 4pm, U.S. Central Time, Mon – Fri: 918-764-4358

EMERGENCY INFORMATION

24-Hour Emergency Telephone Number:

For Chemical Emergencies:
Spill, Leak, Fire or Accident
Call CHEMTREC
North America: (800) 424-9300
Others: (703) 527-3887 (collect)

Health Hazards: Aspiration hazard if swallowed. Can enter lungs and cause damage. Avoid contact with eyes, skin and clothing. Do not taste or swallow. Wash thoroughly after handling.

Physical Hazards: Extremely flammable liquid and vapor. Vapor may cause a flash fire. Keep away from heat, sparks, flames, or other sources of ignition (e.g., static electricity, pilot lights, mechanical/electrical equipment).

Physical Form: Liquid
Appearance: Colorless to faintly yellow
Odor: Acrid to sweet paraffin

NFPA HAZARD CLASS:
0 = no special hazards
4 = maximum hazard class

1	Health
4	Flammability
0	Reactivity

2. COMPOSITION / INFORMATION ON INGREDIENTS

#	Component	CAS No.	Approx. Wt%
1	Fischer-Tropsch Light Oil, C_5-C_{30} alkane rich and containing olefins and alcohols.	None	100%
2	n-Hexane	110-54-3	< 5%

Note: Material contains <0.001 wt% sulfur.

3. HAZARDS IDENTIFICATION

POTENTIAL HEALTH EFFECTS:

Eye Contact: Contact may cause irritation including stinging, watering, and redness and swelling.

Skin Contact: May cause skin irritation. Contact may cause redness, burning, drying and cracking of the skin and skin damage.

Inhalation (Breathing): Expected to have a low degree of toxicity by inhalation.

Ingestion (Swallowing): No harmful effects expected from ingestion. ASPIRATION HAZARD – This material can enter lungs during swallowing or vomiting and cause lung inflammation and damage.

Signs & Symptoms: Effects of overexposure may include irritation of the nose, throat and digestive tract, nausea, vomiting, transient excitation followed by signs of nervous system depression (e.g., headache, drowsiness, dizziness, loss of coordination, and fatigue), pulmonary edema (accumulation of fluids in the lungs) and pneumonitis (inflammation of the lungs).

Aggravated Medical Conditions: Conditions aggravated by exposure may include skin, respiratory (asthma-like), male reproductive and peripheral nerve disorders.

Developmental: No data.

Cancer: No data.

Target Organs: Overexposure to a component may cause injury to the peripheral nervous system (see Section 11). There is limited evidence from animal studies that overexposure may cause injury to the male reproductive system.

Other Comments: Reports have associated repeated and prolonged occupational overexposure to solvents with permanent brain and nervous system damage (sometimes referred to as Solvent or Painters' Syndrome). Intentional misuse by deliberately concentrating and inhaling this material may be harmful or fatal.

4. FIRST AID MEASURES

Eye: If irritation or redness develops, move victim away from exposure and into fresh air. Flush eyes with clean water. For direct contact, hold eyelids apart and flush affected eye(s) with clean water for at least 15 minutes. If symptoms persist, seek medical attention.

Skin: First aid is not normally required. If irritation or redness develops, remove contaminated shoes, clothing, and constrictive jewelry and flush affected area(s) with mild soap and water. Wash contaminated clothing prior to reuse. If symptoms persist, seek medical attention.

Inhalation (Breathing): First aid is not normally required. If breathing difficulties develop, move victim away from source of exposure into fresh air and seek immediate medical attention.

Ingestion (Swallowing): Aspiration hazard: Do not induce vomiting or give anything by mouth because this material can enter the lungs and cause severe lung damage. If victim is drowsy or unconscious and vomiting, place on the left side with the head down. If possible, do not leave victim unattended and observe closely for adequacy of breathing. Seek medical attention.

5. FIRE FIGHTING MEASURES

Flammable Properties: Flash Point (PMCC): <73°F (<23°C)
OSHA Flammability Class: Flammable Liquid
LEL (vol%): No data UEL (vol%): No data
Autoignition Temperature: No data

Combustion Products: Carbon dioxide, carbon monoxide, water vapor.

Extinguishing Media: Dry chemical, carbon dioxide, or alcohol or polymer foam is recommended. Water may be ineffective for extinguishment, unless used under favorable conditions by experienced fire fighters. Carbon dioxide can displace oxygen. Use caution when applying carbon dioxide in confined spaces.

Special Fire Fighting Procedures & Precautions: For fires beyond the incipient stage, emergency responders in the immediate hazard area should wear bunker gear. When the potential chemical hazard is unknown, in enclosed or confined spaces, or when explicitly required by DOT, a self-contained breathing apparatus should be worn. In addition, wear other appropriate protective equipment as conditions warrant (see Section 8). Isolate immediate hazard area and keep unauthorized personnel out. Stop spill/release if it can be done with minimal risk. Move undamaged containers from immediate hazard area if it can be done with minimal risk. Water spray may be useful in minimizing or dispersing vapors and to protect personnel. Cool equipment exposed to fire with water, if it can be done with minimal risk. Avoid spreading burning liquid with water used for cooling purposes.

Unusual Fire & Explosion Hazards: This material is flammable and can be ignited by heat, sparks, flames, or other sources of ignition (e.g., static electricity, pilot lights, or mechanical/electrical equipment). May create vapor/air explosion hazard indoors, outdoors, or in sewers. Vapors are heavier than air and can accumulate in low areas. If container is not properly cooled, it can rupture in the heat of a fire.

6. ACCIDENTAL RELEASE MEASURES

Spill or Leak Procedures: Extremely flammable. Keep all sources of ignition and hot surfaces away from spill/release. The use of explosion-proof equipment is recommended. Stay upwind and away from spill/release. Notify persons downwind of spill/release, isolate immediate hazard area and keep unauthorized personnel out. Stop spill/release if it can be done with minimal risk. Wear appropriate protective equipment including respiratory protection as conditions warrant (see Section 8). Prevent spilled material from entering sewers, storm drains, other unauthorized treatment drainage systems, and natural waterways. Dike far ahead of spill for later recovery or disposal. Spilled material may be absorbed into an appropriate absorbent material (e.g., sand or vermiculite). Notify fire authorities and appropriate federal, state, and local agencies. Immediate cleanup of any spill is recommended. **If spill of any amount is made into or upon navigable waters, the contiguous zone, or adjoining shorelines, notify the National Response Center (phone number 800-424-8802).**

Environmental Hazards: No data.

7. HANDLING/STORAGE

Handling: Open container slowly to relieve any pressure. Bond and ground all equipment when transferring from one vessel to another. Can accumulate static charge by flow or agitation. Can be ignited by static discharge. The use of explosion-proof equipment is recommended and may be required (see appropriate fire codes). Do not enter confined spaces such as tanks or pits without following proper entry procedures such as ASTM D-4276 and 29CFR 1910.146. The use of appropriate respiratory protection is advised when concentrations exceed any established exposure limits (see Section 8). Wash thoroughly after handling. Do not wear contaminated clothing or shoes. Keep contaminated clothing away from sources of ignition such as sparks or open flames. Use good personal hygiene practice.

"Empty" containers can retain residue and may be dangerous. Do not pressurize, cut, weld, braze, solder, drill, grind, or expose such containers to heat, flame, sparks or other sources of ignition. They may explode and cause injury bunged, and promptly shipped to the supplier or a drum conditioner. All containers should be disposed of in an environmentally safe manner and in accordance with governmental regulations.

Before working on or in tanks which contain or have contained this material, refer to OSHA Regulations, ANSI Z49.1 and other governmental and industrial references pertaining to cleaning, repairing, welding, or other contemplated operations.

Storage: Keep container(s) tightly closed. Use and store this material in cool, dry, well-ventilated areas away from heat, direct sunlight, hot metal surfaces, and all sources of ignition. Post area "No Smoking or Open Flame". Store only in approved containers. Keep away from any incompatible material (see Section 10). Protect container(s) against physical damage. Outdoor or detached storage is preferred. Indoor storage should meet OSHA standards and appropriate fire codes.

8. EXPOSURE CONTROLS / PERSONAL PROTECTION

Occupational Exposure Limits

Substance Name	CAS No.	Agency	Limits	Notes
Fischer-Tropsch Light Oil, C_5-C_{30} alkane rich and containing olefins and alcohols.	None	100%	None established	yes
n-Hexane	110-54-3	ACGIH OSHA NIOSH REL NIOSH IDHL	50 ppm 8-hr TWA (skin) 500 ppm 8-hr PEL 50 ppm 10-hr day/40-hr week 1,100 ppm	yes

Note: Country, state, local, or other agencies or advisory groups may have established more stringent limits. Consult an industrial hygienist or similar professional, or your local agencies, for further information.

Personal Protective Equipment (PPE) and Protective Measures

Respiratory Protection: A NIOSH certified air-purifying respirator with an organic vapor cartridge may be used under conditions where airborne concentrations are expected to exceed exposure limits. Protection provided by air purifying respirators is limited (see manufacturer's respirator selection guide). Use a positive pressure air-supplied respirator if there is potential for uncontrolled release, exposure levels are not known, or any other circumstances where air-purifying respirators may not provide adequate protection. A respiratory protection program that meets regulatory requirements (OSHA, ANSI, etc) must be followed whenever workplace conditions warrant a respirator's use.

Protective Clothing: Not required based on the hazards of the material. However, it is considered good practice to wear gloves when handling chemicals (see glove manufacturer literature for information on permeability to paraffinic solvents). Depending on conditions of use, an apron and/or arm covers may be necessary.

Eye/Face Protection: Approved eye protection to safeguard against potential eye contact, irritation, or injury is recommended. Depending on conditions of use, a face shield and safety glasses or goggles may be necessary.

Additional Protective Measures: Additional ventilation may be required to reduce exposure to vapors. Where explosive mixtures may be present, electrical systems safe for such locations must be used (see appropriate electrical codes). Eye wash and quick-drench shower facilities should be available in the work area. Thoroughly clean shoes and wash contaminated clothing before reuse. Impervious clothing should be worn as needed.

9. PHYSICAL & CHEMICAL PROPERTIES

Note: Unless otherwise indicated, values are determined at 68°F (20°C) and atmospheric pressure (760 mm Hg). Data is typical, individual samples may vary.

Flash Point (PMCC): <73°F (<23°C)
Autoignition Temperature: No data
Appearance: Colorless or faintly yellow; may be cloudy from wax crystals below 70°F
Physical State: Liquid
Odor: Acrid to mild paraffin
Vapor Pressure: No data
Vapor Density (air = 1): >1
Viscosity at 40°C: around 1 cP
Approx. Boiling Range: 70°F – 680°F (21°C – 360°C)
Freezing Point: <41°F (<5°C); may 'gel' below 50°F
Solubility in water: Slightly soluble
pH: Not applicable
Specific Gravity: 0.72

10. STABILITY & REACTIVITY

Chemical Stability: Stable under normal conditions of storage and handling. Flammable liquid and vapor. Vapor can cause a flash fire.

Conditions to Avoid: Avoid all possible sources of ignition (see Sections 5 and 7).

Incompatible Materials: Avoid contact with strong oxidizing agents.

Hazardous Polymerization: Will not occur.

11. TOXICOLOGICAL INFORMATION

n-Hexane (CAS # 110-54-3)

Target Organ(s): Excess exposure to n-hexane can result in peripheral neuropathies. The initial symptoms are symmetrical sensory numbness and paresthesias of distal portions of the extremities. Motor weakness is typically observed in muscles of the toes and fingers but may also involve muscles of the arms, thighs and forearms. The onset of these symptoms may be delayed for several months to a year after the beginning of exposure. The neurotoxic properties of n-hexane are potentiated by exposure to methyl ethyl ketone and methyl isobutyl ketone. Prolonged exposure to high concentrations of n-hexane (>1,000 ppm) has resulted in decreased sperm count and degenerative changes in the testes of rats but not those of mice.

12. DISPOSAL CONSIDERATIONS

This material, if discarded as produced, would be a RCRA "characteristic" hazardous waste due to the characteristic of ignitability (D001). If the material is spilled to soil or water, characteristic testing of the contaminated materials is recommended. Further, this material, once it becomes a waste, is subject to the land disposal restrictions in 40 CFR 268.40 and may require treatment prior to disposal to meet specific standards. Consult state and local regulations to determine whether they are more stringent than the federal requirements.

Container contents should be completely used and containers should be emptied prior to discard. Container rinse material could be considered a RCRA hazardous waste depending on the cleaning agent used and must be disposed of with care and in full compliance with federal, state and local regulations.

13. TRANSPORT INFORMATION

	USA DOT	IMO
Shipping Name:	Flammable liquids N.O.S. (paraffins and isoparaffins)	No data
Hazard Class & Div.:	3 (Flammable Liquid)	No data
ID Number:	UN1993	No data
Packing Group:	I	No data
Label(s):	Flammable	No data
Placard(s):	Flammable	No data
Notes:	none	none

	RID/ADR	ICAO/IATA
Shipping Name:	No data	No data
Hazard Class:	No data	No data
Hazard Sub-class:	No data	not applicable
Packing Group:	not applicable	No data
ID Number:	No data	No data
Danger Number:	No data	not applicable
Label(s):	No data	No data
Notes:	none	none

14. REGULATORY INFORMATION

This material is listed on the following country inventory lists: None known

TSCA – exempt under CFR 720.30 and CFR 720.36.

This material contains the following list of chemicals subject to the reporting requirements of SARA 313 and 40 CFR 372: **n-Hexane (CAS# 110-54-3)**

This material contains the following list of chemicals subject to the reporting requirements of California Proposition 65: None known

NTP, IARC, or OSHA has not identified this material as a carcinogen.

EPA (CERCLA) reportable quantity: RQ #1 **n-Hexane (CAS# 110-54-3); 5000 lbs**

For details on the latest regulatory requirements you should contact the appropriate agency in your state or country.

15. DOCUMENTARY INFORMATION

Current Issue Date: Sept. 25, 2003 Previous Issue Date: Sept. 05, 2003

Section	Brief description of change(s) from previous MSDS
12	Added clarification and removed 'disposition of drums' wording

16. DISCLAIMER OF EXPRESSED & IMPLIED WARRANTIES

The information in this document is believed to be correct as of the date issued. HOWEVER, NO WARRANTY OF MERCHANT LIABILITY, FITNESS FOR ANY PARTICULAR PURPOSE, OR ANY OTHER WARRANTY IS EXPRESSED OR IS TO BE IMPLIED REGARDING THE ACCURACY OR COMPLETENESS OF THIS INFORMATION, THE RESULTS TO BE OBTAINED FROM THE USE OF THIS INFORMATION OR THE PRODUCT, THE SAFETY OF THIS PRODUCT, OR THE HAZARDS RELATED TO ITS USE. This information and product are furnished on the condition that the person receiving them shall make his/her own determination as to the suitability of the product for his/her particular purpose and on the condition that he/she assume the risk of his/her use thereof.

A.10 Iron (II) Oxide

SIGMA-ALDRICH sigma-aldrich.com

Material Safety Data Sheet

Version 5.4
Revision Date 01/19/2012
Print Date 03/21/2014

1. PRODUCT AND COMPANY IDENTIFICATION

Product name	:	Iron(II) oxide
Product Number	:	400866
Brand	:	Aldrich
Supplier	:	Sigma-Aldrich 3050 Spruce Street SAINT LOUIS MO 63103 USA
Telephone	:	+1 800-325-5832
Fax	:	+1 800-325-5052
Emergency Phone # (For both supplier and manufacturer)	:	(314) 776-6555
Preparation Information	:	Sigma-Aldrich Corporation Product Safety - Americas Region 1-800-521-8956

2. HAZARDS IDENTIFICATION

Emergency Overview

OSHA Hazards
Flammable solid

GHS Classification
Flammable solids (Category 2)

GHS Label elements, including precautionary statements

Pictogram

Signal word Warning

Hazard statement(s)
H228 Flammable solid.

Precautionary statement(s)
P210 Keep away from heat/sparks/open flames/hot surfaces. - No smoking.

HMIS Classification

Health hazard:	0
Flammability:	3
Physical hazards:	3

NFPA Rating

Health hazard:	0
Fire:	3
Reactivity Hazard:	3

Potential Health Effects

Inhalation	May be harmful if inhaled. May cause respiratory tract irritation.
Skin	May be harmful if absorbed through skin. May cause skin irritation.
Eyes	May cause eye irritation.
Ingestion	May be harmful if swallowed.

3. COMPOSITION/INFORMATION ON INGREDIENTS

Formula	:	FeO
Molecular Weight	:	71.84 g/mol

No ingredients are hazardous according to OHSA criteria.

4. FIRST AID MEASURES

General advice
Consult a physician. Show this safety data sheet to the doctor in attendance.Move out of dangerous area.

If inhaled
If breathed in, move person into fresh air. If not breathing, give artificial respiration. Consult a physician.

In case of skin contact
Wash off with soap and plenty of water. Consult a physician.

In case of eye contact
Flush eyes with water as a precaution.

If swallowed
Do NOT induce vomiting. Never give anything by mouth to an unconscious person. Rinse mouth with water. Consult a physician.

5. FIREFIGHTING MEASURES

Conditions of flammability
Flammable in the presence of a source of ignition, through friction or retained heat. Keep away from heat/sparks/open flame/hot surface. No smoking.

Suitable extinguishing media
Use water spray, alcohol-resistant foam, dry chemical or carbon dioxide.

Special protective equipment for firefighters
Wear self contained breathing apparatus for fire fighting if necessary.

Hazardous combustion products
Hazardous decomposition products formed under fire conditions. - Iron oxides

Further information
Use water spray to cool unopened containers.

6. ACCIDENTAL RELEASE MEASURES

Personal precautions
Avoid dust formation. Avoid breathing vapors, mist or gas. Ensure adequate ventilation. Remove all sources of ignition. Evacuate personnel to safe areas.

Environmental precautions
Prevent further leakage or spillage if safe to do so. Do not let product enter drains.

Methods and materials for containment and cleaning up
Sweep up and shovel. Contain spillage, and then collect with an electrically protected vacuum cleaner or by wet-brushing and place in container for disposal according to local regulations (see section 13). Keep in suitable, closed containers for disposal. Contain spillage, pick up with an electrically protected vacuum cleaner or by wet-brushing and transfer to a container for disposal according to local regulations (see section 13).

7. HANDLING AND STORAGE

Precautions for safe handling
Avoid formation of dust and aerosols.
Provide appropriate exhaust ventilation at places where dust is formed. Keep away from sources of ignition - No smoking. Take measures to prevent the build up of electrostatic charge.

Conditions for safe storage
Keep container tightly closed in a dry and well-ventilated place.

Air sensitive. Keep in a dry place.

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

Contains no substances with occupational exposure limit values.

Personal protective equipment

Respiratory protection
Where risk assessment shows air-purifying respirators are appropriate use a full-face particle respirator type N100 (US) or type P3 (EN 143) respirator cartridges as a backup to engineering controls. If the respirator is the sole means of protection, use a full-face supplied air respirator. Use respirators and components tested and approved under appropriate government standards such as NIOSH (US) or CEN (EU).

Hand protection
Handle with gloves. Gloves must be inspected prior to use. Use proper glove removal technique (without touching glove's outer surface) to avoid skin contact with this product. Dispose of contaminated gloves after use in accordance with applicable laws and good laboratory practices. Wash and dry hands.

Eye protection
Safety glasses with side-shields conforming to EN166 Use equipment for eye protection tested and approved under appropriate government standards such as NIOSH (US) or EN 166(EU).

Skin and body protection
Flame retardant antistatic protective clothing, The type of protective equipment must be selected according to the concentration and amount of the dangerous substance at the specific workplace.

Hygiene measures
Handle in accordance with good industrial hygiene and safety practice. Wash hands before breaks and at the end of workday.

9. PHYSICAL AND CHEMICAL PROPERTIES

Appearance

Form	powder
Colour	no data available

Safety data

pH	no data available
Melting point/freezing point	no data available
Boiling point	no data available
Flash point	no data available
Flammability (solid, gas)	The substance or mixture is a flammable solid with the category 2.
Ignition temperature	no data available
Autoignition temperature	no data available
Lower explosion limit	no data available
Upper explosion limit	no data available
Vapour pressure	no data available
Density	5.7 g/mL at 25 °C (77 °F)
Water solubility	no data available
Partition coefficient: n-octanol/water	no data available
Relative vapour density	no data available

Odour	no data available
Odour Threshold	no data available
Evaporation rate	no data available

10. STABILITY AND REACTIVITY

Chemical stability
Stable under recommended storage conditions.

Possibility of hazardous reactions
no data available

Conditions to avoid
Heat, flames and sparks. Extremes of temperature and direct sunlight.

Materials to avoid
no data available

Hazardous decomposition products
Hazardous decomposition products formed under fire conditions. - Iron oxides
Other decomposition products - no data available

11. TOXICOLOGICAL INFORMATION

Acute toxicity

Oral LD50
no data available

Inhalation LC50
no data available

Dermal LD50
no data available

Other information on acute toxicity
no data available

Skin corrosion/irritation
no data available

Serious eye damage/eye irritation
no data available

Respiratory or skin sensitization
no data available

Germ cell mutagenicity
no data available

Carcinogenicity

IARC:	No component of this product present at levels greater than or equal to 0.1% is identified as probable, possible or confirmed human carcinogen by IARC.
ACGIH:	No component of this product present at levels greater than or equal to 0.1% is identified as a carcinogen or potential carcinogen by ACGIH.
NTP:	No component of this product present at levels greater than or equal to 0.1% is identified as a known or anticipated carcinogen by NTP.
OSHA:	No component of this product present at levels greater than or equal to 0.1% is identified as a carcinogen or potential carcinogen by OSHA.

Reproductive toxicity

no data available

Teratogenicity

no data available

Specific target organ toxicity - single exposure (Globally Harmonized System)
no data available

Specific target organ toxicity - repeated exposure (Globally Harmonized System)
no data available

Aspiration hazard
no data available

Potential health effects

Inhalation	May be harmful if inhaled. May cause respiratory tract irritation.
Ingestion	May be harmful if swallowed.
Skin	May be harmful if absorbed through skin. May cause skin irritation.
Eyes	May cause eye irritation.

Signs and Symptoms of Exposure
Overdose of iron compounds may have a corrosive effect on the gastrointestinal mucosa and be followed by necrosis, perforation, and stricture formation. Several hours may elapse before symptoms that can include epigastric pain, diarrhea, vomiting, nausea, and hematemesis occur. After apparent recovery a person may experience metabolic acidosis, convulsions, and coma hours or days later. Further complications may develop leading to acute liver necrosis that can result in death due to hepatic coma., To the best of our knowledge, the chemical, physical, and toxicological properties have not been thoroughly investigated.

Synergistic effects
no data available

Additional Information
RTECS: Not available

12. ECOLOGICAL INFORMATION

Toxicity

no data available

Persistence and degradability
no data available

Bioaccumulative potential
no data available

Mobility in soil
no data available

PBT and vPvB assessment
no data available

Other adverse effects

no data available

13. DISPOSAL CONSIDERATIONS

Product
Burn in a chemical incinerator equipped with an afterburner and scrubber but exert extra care in igniting as this material is highly flammable. Offer surplus and non-recyclable solutions to a licensed disposal company.

Contaminated packaging
Dispose of as unused product.

14. TRANSPORT INFORMATION

DOT (US)
UN number: 3178 Class: 4.1 Packing group: II

Proper shipping name: Flammable solid, inorganic, n.o.s. (iron oxide)
Marine pollutant: No
Poison Inhalation Hazard: No

IMDG
UN number: 3178 Class: 4.1 Packing group: II EMS-No: F-A, S-G
Proper shipping name: FLAMMABLE SOLID, INORGANIC, N.O.S. (iron oxide)
Marine pollutant: No

IATA
UN number: 3178 Class: 4.1 Packing group: II
Proper shipping name: Flammable solid, inorganic, n.o.s. (iron oxide)

15. REGULATORY INFORMATION

OSHA Hazards
Flammable solid

SARA 302 Components
SARA 302: No chemicals in this material are subject to the reporting requirements of SARA Title III, Section 302.

SARA 313 Components
SARA 313: This material does not contain any chemical components with known CAS numbers that exceed the threshold (De Minimis) reporting levels established by SARA Title III, Section 313.

SARA 311/312 Hazards
Fire Hazard

Massachusetts Right To Know Components
No components are subject to the Massachusetts Right to Know Act.

Pennsylvania Right To Know Components

	CAS-No.	Revision Date
iron oxide	1345-25-1	

New Jersey Right To Know Components

	CAS-No.	Revision Date
iron oxide	1345-25-1	

California Prop. 65 Components
This product does not contain any chemicals known to State of California to cause cancer, birth defects, or any other reproductive harm.

A.11 Iron (III) Oxide

SIGMA-ALDRICH sigma-aldrich.com

Material Safety Data Sheet

Version 4.3
Revision Date 05/17/2013
Print Date 03/21/2014

1. PRODUCT AND COMPANY IDENTIFICATION

Product name	:	Iron(III) oxide
Product Number	:	343005
Brand	:	Sigma-Aldrich
Supplier	:	Sigma-Aldrich 3050 Spruce Street SAINT LOUIS MO 63103 USA
Telephone	:	+1 800-325-5832
Fax	:	+1 800-325-5052
Emergency Phone # (For both supplier and manufacturer)	:	(314) 776-6555
Preparation Information	:	Sigma-Aldrich Corporation Product Safety - Americas Region 1-800-521-8956

2. HAZARDS IDENTIFICATION

Emergency Overview

OSHA Hazards
Irritant

GHS Classification
Skin irritation (Category 2)
Eye irritation (Category 2A)
Specific target organ toxicity - single exposure (Category 3)

GHS Label elements, including precautionary statements

Pictogram

Signal word: Warning

Hazard statement(s)

H315	Causes skin irritation.
H319	Causes serious eye irritation.
H335	May cause respiratory irritation.

Precautionary statement(s)

P261	Avoid breathing dust/ fume/ gas/ mist/ vapours/ spray.
P305 + P351 + P338	IF IN EYES: Rinse cautiously with water for several minutes. Remove contact lenses, if present and easy to do. Continue rinsing.

HMIS Classification

Health hazard:	2
Flammability:	0
Physical hazards:	0

NFPA Rating

Health hazard:	2
Fire:	0
Reactivity Hazard:	0

Potential Health Effects

Inhalation	May be harmful if inhaled. Causes respiratory tract irritation.
Skin	May be harmful if absorbed through skin. Causes skin irritation.
Eyes	Causes eye irritation.
Ingestion	May be harmful if swallowed.

3. COMPOSITION/INFORMATION ON INGREDIENTS

Synonyms : Ferric oxide

Formula : Fe_2O_3

Molecular Weight : 159.69 g/mol

Component		Concentration
Diiron trioxide		
CAS-No.	1309-37-1	-
EC-No.	215-168-2	

4. FIRST AID MEASURES

General advice
Consult a physician. Show this safety data sheet to the doctor in attendance.Move out of dangerous area.

If inhaled
If breathed in, move person into fresh air. If not breathing, give artificial respiration. Consult a physician.

In case of skin contact
Wash off with soap and plenty of water. Consult a physician.

In case of eye contact
Rinse thoroughly with plenty of water for at least 15 minutes and consult a physician.

If swallowed
Never give anything by mouth to an unconscious person. Rinse mouth with water. Consult a physician.

5. FIREFIGHTING MEASURES

Suitable extinguishing media
Use water spray, alcohol-resistant foam, dry chemical or carbon dioxide.

Special protective equipment for firefighters
Wear self contained breathing apparatus for fire fighting if necessary.

Hazardous combustion products
Hazardous decomposition products formed under fire conditions. - Iron oxides

6. ACCIDENTAL RELEASE MEASURES

Personal precautions
Use personal protective equipment. Avoid dust formation. Avoid breathing vapours, mist or gas. Ensure adequate ventilation. Evacuate personnel to safe areas. Avoid breathing dust.

Environmental precautions
Do not let product enter drains.

Methods and materials for containment and cleaning up
Pick up and arrange disposal without creating dust. Sweep up and shovel. Keep in suitable, closed containers for disposal.

7. HANDLING AND STORAGE

Precautions for safe handling
Avoid contact with skin and eyes. Avoid formation of dust and aerosols.
Provide appropriate exhaust ventilation at places where dust is formed. Normal measures for preventive fire protection.

Conditions for safe storage
Keep container tightly closed in a dry and well-ventilated place.

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

Components with workplace control parameters

Components	CAS-No.	Value	Control parameters	Basis
Diiron trioxide	1309-37-1	TWA	5 mg/m3	USA. ACGIH Threshold Limit Values (TLV)
Remarks	Pneumoconiosis Not classifiable as a human carcinogen			
		TWA	10 mg/m3	USA. OSHA - TABLE Z-1 Limits for Air Contaminants - 1910.1000
	See Appendix D - Substances with No Established RELs			
		TWA	5 mg/m3	USA. NIOSH Recommended Exposure Limits
		TWA	10 mg/m3	USA. Occupational Exposure Limits (OSHA) - Table Z-1 Limits for Air Contaminants
		TWA	15 mg/m3	USA. Occupational Exposure Limits (OSHA) - Table Z-1 Limits for Air Contaminants
		TWA	5 mg/m3	USA. Occupational Exposure Limits (OSHA) - Table Z-1 Limits for Air Contaminants

Personal protective equipment

Respiratory protection
For nuisance exposures use type P95 (US) or type P1 (EU EN 143) particle respirator.For higher level protection use type OV/AG/P99 (US) or type ABEK-P2 (EU EN 143) respirator cartridges. Use respirators and components tested and approved under appropriate government standards such as NIOSH (US) or CEN (EU).

Hand protection
Handle with gloves. Gloves must be inspected prior to use. Use proper glove removal technique (without touching glove's outer surface) to avoid skin contact with this product. Dispose of contaminated gloves after use in accordance with applicable laws and good laboratory practices. Wash and dry hands.

Full contact
Material: Nitrile rubber
Minimum layer thickness: 0.11 mm
Break through time: 480 min
Material tested:Dermatril® (KCL 740 / Aldrich Z677272, Size M)

Splash contact
Material: Nitrile rubber
Minimum layer thickness: 0.11 mm
Break through time: 480 min
Material tested:Dermatril® (KCL 740 / Aldrich Z677272, Size M)

data source: KCL GmbH, D-36124 Eichenzell, phone +49 (0)6659 87300, e-mail sales@kcl.de, test method: EN374
If used in solution, or mixed with other substances, and under conditions which differ from EN 374, contact the supplier of the CE approved gloves. This recommendation is advisory only and must be evaluated by an industrial hygienist and safety officer familiar with the specific situation of anticipated use by our customers. It should not be construed as offering an approval for any specific use scenario.

Eye protection
Safety glasses with side-shields conforming to EN166 Use equipment for eye protection tested and approved under appropriate government standards such as NIOSH (US) or EN 166(EU).

Skin and body protection
impervious clothing, The type of protective equipment must be selected according to the concentration and amount of the dangerous substance at the specific workplace.

Hygiene measures
Handle in accordance with good industrial hygiene and safety practice. Wash hands before breaks and at the end of workday.

9. PHYSICAL AND CHEMICAL PROPERTIES

Appearance

Form	Pieces solid
Colour	no data available

Safety data

pH	no data available
Melting point/freezing point	Melting point/range: 1,538 °C (2,800 °F)
Boiling point	no data available
Flash point	not applicable
Ignition temperature	no data available
Auto-ignition temperature	no data available
Lower explosion limit	no data available
Upper explosion limit	no data available
Vapour pressure	no data available
Density	5.120 g/cm3
Water solubility	insoluble
Partition coefficient: n-octanol/water	no data available
Relative vapour density	no data available
Odour	no data available
Odour Threshold	no data available
Evapouration rate	no data available

10. STABILITY AND REACTIVITY

Chemical stability
Stable under recommended storage conditions.

Possibility of hazardous reactions
no data available

Conditions to avoid
no data available

Materials to avoid
Chloroformates, Peroxides, Strong acidsStrong acids, Peroxides, Chloroformates

Hazardous decomposition products
Hazardous decomposition products formed under fire conditions. - Iron oxides
Other decomposition products - no data available

11. TOXICOLOGICAL INFORMATION

Acute toxicity

Oral LD50
no data available

Inhalation LC50
Dermal LD50
no data available

Other information on acute toxicity
no data available

Skin corrosion/irritation
Skin - Human - Skin irritation

Skin - Human - Skin irritation

Serious eye damage/eye irritation
Eyes - Human - Eye irritation

Eyes - Human - Moderate eye irritation

Respiratory or skin sensitisation
no data available

Germ cell mutagenicity

no data available

Carcinogenicity

Carcinogenicity - rat - Subcutaneous
Tumorigenic:Equivocal tumorigenic agent by RTECS criteria. Tumorigenic:Tumors at site or application.

This product is or contains a component that is not classifiable as to its carcinogenicity based on its IARC, ACGIH, NTP, or EPA classification.

IARC:	3 - Group 3: Not classifiable as to its carcinogenicity to humans (Diiron trioxide)
NTP:	No component of this product present at levels greater than or equal to 0.1% is identified as a known or anticipated carcinogen by NTP.
OSHA:	No component of this product present at levels greater than or equal to 0.1% is identified as a carcinogen or potential carcinogen by OSHA.

Reproductive toxicity

no data available

Teratogenicity

no data available

Specific target organ toxicity - single exposure (Globally Harmonized System)
Inhalation - May cause respiratory irritation.

Specific target organ toxicity - repeated exposure (Globally Harmonized System)
no data available

Aspiration hazard
no data available

Potential health effects

Inhalation	May be harmful if inhaled. Causes respiratory tract irritation.
Ingestion	May be harmful if swallowed.
Skin	May be harmful if absorbed through skin. Causes skin irritation.
Eyes	Causes eye irritation.

Signs and Symptoms of Exposure
Long term inhalation exposure to iron (oxide fume or dust) can cause siderosis. Siderosis is considered to be a benign pneumoconiosis and does not normally cause significant physiologic impairment. Siderosis can be observed on x-rays with the lungs having a mottled appearance., To the best of our knowledge, the chemical, physical, and toxicological properties have not been thoroughly investigated.
Long term inhalation exposure to iron (oxide fume or dust) can cause siderosis. Siderosis is considered to be a benign pneumoconiosis and does not normally cause significant physiologic impairment. Siderosis can be observed on x-rays with the lungs having a mottled appearance.

Synergistic effects
no data available

Additional Information
RTECS: NO7400000

12. ECOLOGICAL INFORMATION

Toxicity

no data available

Persistence and degradability
no data available

Bioaccumulative potential
no data available

Mobility in soil
no data available

PBT and vPvB assessment
no data available

Other adverse effects

no data available

13. DISPOSAL CONSIDERATIONS

Product
Offer surplus and non-recyclable solutions to a licensed disposal company. Contact a licensed professional waste disposal service to dispose of this material.

Contaminated packaging
Dispose of as unused product.

14. TRANSPORT INFORMATION

DOT (US)
Not dangerous goods

IMDG
Not dangerous goods

IATA
Not dangerous goods

15. REGULATORY INFORMATION

OSHA Hazards
Irritant

SARA 302 Components
SARA 302: No chemicals in this material are subject to the reporting requirements of SARA Title III, Section 302.

SARA 313 Components
SARA 313: This material does not contain any chemical components with known CAS numbers that exceed the threshold (De Minimis) reporting levels established by SARA Title III, Section 313.

SARA 311/312 Hazards
Acute Health Hazard

Massachusetts Right To Know Components

	CAS-No.	Revision Date
Diiron trioxide	1309-37-1	2007-03-01

Pennsylvania Right To Know Components

	CAS-No.	Revision Date
Diiron trioxide	1309-37-1	2007-03-01

New Jersey Right To Know Components

	CAS-No.	Revision Date
Diiron trioxide	1309-37-1	2007-03-01

California Prop. 65 Components
This product does not contain any chemicals known to State of California to cause cancer, birth defects, or any other reproductive harm.

A.12 Cobalt

SIGMA-ALDRICH

sigma-aldrich.com

Material Safety Data Sheet

Version 3.3
Revision Date 10/29/2012
Print Date 03/21/2014

1. PRODUCT AND COMPANY IDENTIFICATION

Product name	:	Cobalt
Product Number	:	60784
Brand	:	Aldrich
Supplier	:	Sigma-Aldrich 3050 Spruce Street SAINT LOUIS MO 63103 USA
Telephone	:	+1 800-325-5832
Fax	:	+1 800-325-5052
Emergency Phone # (For both supplier and manufacturer)	:	(314) 776-6555
Preparation Information	:	Sigma-Aldrich Corporation Product Safety - Americas Region 1-800-521-8956

2. HAZARDS IDENTIFICATION

Emergency Overview

OSHA Hazards
Flammable solid, Carcinogen, Respiratory sensitiser

Target Organs

Kidney, Eyes, Skin, Respiratory system

GHS Classification
Respiratory sensitization (Category 1)
Acute aquatic toxicity (Category 1)

GHS Label elements, including precautionary statements

Pictogram

Signal word Danger

Hazard statement(s)

H334	May cause allergy or asthma symptoms or breathing difficulties if inhaled.
H400	Very toxic to aquatic life.

Precautionary statement(s)

P261	Avoid breathing dust/ fume/ gas/ mist/ vapours/ spray.
P273	Avoid release to the environment.
P342 + P311	If experiencing respiratory symptoms: Call a POISON CENTER or doctor/ physician.

HMIS Classification

Health hazard:	2
Chronic Health Hazard:	*
Flammability:	3
Physical hazards:	3

NFPA Rating

Health hazard:	2
Fire:	3

Reactivity Hazard: 3

Potential Health Effects

Inhalation	May be harmful if inhaled. May cause respiratory tract irritation.
Skin	May be harmful if absorbed through skin. May cause skin irritation.
Eyes	May cause eye irritation.
Ingestion	May be harmful if swallowed.

3. COMPOSITION/INFORMATION ON INGREDIENTS

Formula : Co
Molecular Weight : 58.93 g/mol

Component		Concentration
Cobalt		
CAS-No.	7440-48-4	-
EC-No.	231-158-0	
Index-No.	027-001-00-9	

4. FIRST AID MEASURES

General advice
Consult a physician. Show this safety data sheet to the doctor in attendance.Move out of dangerous area.

If inhaled
If breathed in, move person into fresh air. If not breathing, give artificial respiration. Consult a physician.

In case of skin contact
Wash off with soap and plenty of water. Consult a physician.

In case of eye contact
Flush eyes with water as a precaution.

If swallowed
Never give anything by mouth to an unconscious person. Rinse mouth with water. Consult a physician.

5. FIREFIGHTING MEASURES

Conditions of flammability
Flammable in the presence of a source of ignition, through friction or retained heat. Keep away from heat/sparks/open flame/hot surface. No smoking.

Suitable extinguishing media
Use water spray, alcohol-resistant foam, dry chemical or carbon dioxide.

Special protective equipment for firefighters
Wear self contained breathing apparatus for fire fighting if necessary.

Hazardous combustion products
Hazardous decomposition products formed under fire conditions. - Cobalt/cobalt oxides

6. ACCIDENTAL RELEASE MEASURES

Personal precautions
Use personal protective equipment. Avoid dust formation. Avoid breathing vapors, mist or gas. Ensure adequate ventilation. Evacuate personnel to safe areas. Avoid breathing dust.

Environmental precautions
Prevent further leakage or spillage if safe to do so. Do not let product enter drains. Discharge into the environment must be avoided.

Methods and materials for containment and cleaning up
Pick up and arrange disposal without creating dust. Sweep up and shovel. Keep in suitable, closed containers for disposal.

7. HANDLING AND STORAGE

Precautions for safe handling
Avoid contact with skin and eyes. Avoid formation of dust and aerosols.
Provide appropriate exhaust ventilation at places where dust is formed.

Conditions for safe storage
Keep container tightly closed in a dry and well-ventilated place.

Air sensitive. Handle and store under inert gas. Keep in a dry place.

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

Components with workplace control parameters

Components	CAS-No.	Value	Control parameters	Basis
Cobalt	7440-48-4	TWA	0.1 mg/m3	USA. Occupational Exposure Limits (OSHA) - Table Z-1 Limits for Air Contaminants
		TWA	0.02 mg/m3	USA. ACGIH Threshold Limit Values (TLV)
Remarks	Pulmonary function Asthma Myocardial effects Substances for which there is a Biological Exposure Index or Indices (see BEI® section) Confirmed animal carcinogen with unknown relevance to humans			
		TWA	0.05 mg/m3	USA. OSHA - TABLE Z-1 Limits for Air Contaminants - 1910.1000
		TWA	0.05 mg/m3	USA. NIOSH Recommended Exposure Limits

Personal protective equipment

Respiratory protection
For nuisance exposures use type P95 (US) or type P1 (EU EN 143) particle respirator.For higher level protection use type OV/AG/P99 (US) or type ABEK-P2 (EU EN 143) respirator cartridges. Use respirators and components tested and approved under appropriate government standards such as NIOSH (US) or CEN (EU).

Hand protection
Handle with gloves. Gloves must be inspected prior to use. Use proper glove removal technique (without touching glove's outer surface) to avoid skin contact with this product. Dispose of contaminated gloves after use in accordance with applicable laws and good laboratory practices. Wash and dry hands.

Immersion protection
Material: Nitrile rubber
Minimum layer thickness: 0.11 mm
Break through time: > 480 min
Material tested:Dermatril® (Aldrich Z677272, Size M)

Splash protection
Material: Nitrile rubber
Minimum layer thickness: 0.11 mm
Break through time: > 30 min
Material tested:Dermatril® (Aldrich Z677272, Size M)

data source: KCL GmbH, D-36124 Eichenzell, phone +49 (0)6659 873000, e-mail sales@kcl.de, test method: EN374
If used in solution, or mixed with other substances, and under conditions which differ from EN 374, contact the supplier of the CE approved gloves. This recommendation is advisory only and must be evaluated by an Industrial Hygienist familiar with the specific situation of anticipated use by our customers. It should not be construed as offering an approval for any specific use scenario.

Eye protection
Face shield and safety glasses Use equipment for eye protection tested and approved under appropriate government standards such as NIOSH (US) or EN 166(EU).

Skin and body protection
Complete suit protecting against chemicals, The type of protective equipment must be selected according to the

Acute toxicity

Oral LD50
LD50 Oral - rat - 6,171 mg/kg
Remarks: Behavioral:Somnolence (general depressed activity). Behavioral:Ataxia. Diarrhoea

Inhalation LC50
no data available

Dermal LD50
no data available

Other information on acute toxicity
no data available

Skin corrosion/irritation
no data available

Serious eye damage/eye irritation
no data available

Respiratory or skin sensitization
May cause allergic respiratory reaction.

Germ cell mutagenicity

no data available

Carcinogenicity

This product is or contains a component that has been reported to be possibly carcinogenic based on its IARC, ACGIH, NTP, or EPA classification.

IARC:	2B - Group 2B: Possibly carcinogenic to humans (Cobalt)
	2A - Group 2A: Probably carcinogenic to humans (Cobalt)
	2B - Group 2B: Possibly carcinogenic to humans (Cobalt)
IARC:	2B - Group 2B: Possibly carcinogenic to humans (Cobalt)
	2A - Group 2A: Probably carcinogenic to humans (Cobalt)
	2B - Group 2B: Possibly carcinogenic to humans (Cobalt)
NTP:	No component of this product present at levels greater than or equal to 0.1% is identified as a known or anticipated carcinogen by NTP.
OSHA:	No component of this product present at levels greater than or equal to 0.1% is identified as a carcinogen or potential carcinogen by OSHA.

Reproductive toxicity

no data available

Teratogenicity

no data available

Specific target organ toxicity - single exposure (Globally Harmonized System)
no data available

Specific target organ toxicity - repeated exposure (Globally Harmonized System)

no data available

Aspiration hazard
no data available

Potential health effects

Inhalation	May be harmful if inhaled. May cause respiratory tract irritation.
Ingestion	May be harmful if swallowed.
Skin	May be harmful if absorbed through skin. May cause skin irritation.
Eyes	May cause eye irritation.

Signs and Symptoms of Exposure
Kidney injury may occur., Damage to the eyes., Lung irritation, Throat., Rash, Vomiting, Diarrhoea

Synergistic effects
no data available

Additional Information
RTECS: GF8750000

12. ECOLOGICAL INFORMATION

Toxicity

Toxicity to algae	IC50 - Pseudokirchneriella subcapitata (green algae) - 0.05 mg/l - 72 h

Persistence and degradability

Bioaccumulative potential

Bioaccumulation	Rudarius ercodes - 8 Weeks Bioconcentration factor (BCF): 2.16

Mobility in soil
no data available

PBT and vPvB assessment
no data available

Other adverse effects

An environmental hazard cannot be excluded in the event of unprofessional handling or disposal.

Very toxic to aquatic life.

13. DISPOSAL CONSIDERATIONS

Product
Offer surplus and non-recyclable solutions to a licensed disposal company. Contact a licensed professional waste disposal service to dispose of this material.

Contaminated packaging
Dispose of as unused product.

14. TRANSPORT INFORMATION

DOT (US)
UN number: 3089 Class: 4.1 Packing group: II
Proper shipping name: Metal powders, flammable, n.o.s.
Marine pollutant: No
Poison Inhalation Hazard: No

IMDG
UN number: 3089 Class: 4.1 Packing group: II EMS-No: F-G, S-G
Proper shipping name: METAL POWDER, FLAMMABLE, N.O.S.
Marine pollutant: No

IATA
UN number: 3089 Class: 4.1 Packing group: II

Proper shipping name: Metal powder, flammable, n.o.s.

15. REGULATORY INFORMATION

OSHA Hazards
Flammable solid, Carcinogen, Respiratory sensitiser

SARA 302 Components
SARA 302: No chemicals in this material are subject to the reporting requirements of SARA Title III, Section 302.

SARA 313 Components
The following components are subject to reporting levels established by SARA Title III, Section 313:

	CAS-No.	Revision Date
Cobalt	7440-48-4	2007-07-01

SARA 311/312 Hazards
Fire Hazard, Acute Health Hazard, Chronic Health Hazard

Massachusetts Right To Know Components

	CAS-No.	Revision Date
Cobalt	7440-48-4	2007-07-01

Pennsylvania Right To Know Components

	CAS-No.	Revision Date
Cobalt	7440-48-4	2007-07-01

New Jersey Right To Know Components

	CAS-No.	Revision Date
Cobalt	7440-48-4	2007-07-01

California Prop. 65 Components

	CAS-No.	Revision Date
WARNING! This product contains a chemical known to the State of California to cause cancer. Cobalt	7440-48-4	2007-09-28

A.13 Rhenium

SIGMA-ALDRICH sigma-aldrich.com

Material Safety Data Sheet

Version 4.2
Revision Date 11/30/2012
Print Date 04/12/2014

1. PRODUCT AND COMPANY IDENTIFICATION

Product name	:	Rhenium
Product Number	:	204188
Brand	:	Aldrich
Supplier	:	Sigma-Aldrich 3050 Spruce Street SAINT LOUIS MO 63103 USA
Telephone	:	+1 800-325-5832
Fax	:	+1 800-325-5052
Emergency Phone # (For both supplier and manufacturer)	:	(314) 776-6555
Preparation Information	:	Sigma-Aldrich Corporation Product Safety - Americas Region 1-800-521-8956

2. HAZARDS IDENTIFICATION

Emergency Overview

OSHA Hazards
Flammable solid

GHS Classification
Flammable solids (Category 1)

GHS Label elements, including precautionary statements

Pictogram

Signal word Danger

Hazard statement(s)
H228 Flammable solid.

Precautionary statement(s)
P210 Keep away from heat/sparks/open flames/hot surfaces. - No smoking.

HMIS Classification

Health hazard:	0
Flammability:	0
Physical hazards:	3

NFPA Rating

Health hazard:	0
Fire:	0
Reactivity Hazard:	3

Potential Health Effects

Inhalation	May be harmful if inhaled. May cause respiratory tract irritation.
Skin	May be harmful if absorbed through skin. May cause skin irritation.
Eyes	May cause eye irritation.
Ingestion	May be harmful if swallowed.

3. COMPOSITION/INFORMATION ON INGREDIENTS

Formula	:	Re
Molecular Weight	:	186.21 g/mol

No ingredients are hazardous according to OHSA criteria.

4. FIRST AID MEASURES

General advice
Consult a physician. Show this safety data sheet to the doctor in attendance.Move out of dangerous area.

If inhaled
If breathed in, move person into fresh air. If not breathing, give artificial respiration. Consult a physician.

In case of skin contact
Wash off with soap and plenty of water. Consult a physician.

In case of eye contact
Flush eyes with water as a precaution.

If swallowed
Do NOT induce vomiting. Never give anything by mouth to an unconscious person. Rinse mouth with water. Consult a physician.

5. FIREFIGHTING MEASURES

Suitable extinguishing media
Use water spray, alcohol-resistant foam, dry chemical or carbon dioxide.

Special protective equipment for firefighters
Wear self contained breathing apparatus for fire fighting if necessary.

Hazardous combustion products
Hazardous decomposition products formed under fire conditions. - rhenium oxides

Further information
Use water spray to cool unopened containers.

6. ACCIDENTAL RELEASE MEASURES

Personal precautions
Avoid dust formation. Avoid breathing vapors, mist or gas. Ensure adequate ventilation. Remove all sources of ignition. Evacuate personnel to safe areas.

Environmental precautions
Prevent further leakage or spillage if safe to do so. Do not let product enter drains.

Methods and materials for containment and cleaning up
Sweep up and shovel. Contain spillage, and then collect with an electrically protected vacuum cleaner or by wet-brushing and place in container for disposal according to local regulations (see section 13). Keep in suitable, closed containers for disposal. Contain spillage, pick up with an electrically protected vacuum cleaner or by wet-brushing and transfer to a container for disposal according to local regulations (see section 13).

7. HANDLING AND STORAGE

Precautions for safe handling
Avoid formation of dust and aerosols.
Provide appropriate exhaust ventilation at places where dust is formed. Keep away from sources of ignition - No smoking. Take measures to prevent the build up of electrostatic charge.

Conditions for safe storage
Store in cool place. Keep container tightly closed in a dry and well-ventilated place.

Keep in a dry place.

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

Contains no substances with occupational exposure limit values.

Personal protective equipment

Respiratory protection
Where risk assessment shows air-purifying respirators are appropriate use a full-face particle respirator type N100 (US) or type P3 (EN 143) respirator cartridges as a backup to engineering controls. If the respirator is the sole means of protection, use a full-face supplied air respirator. Use respirators and components tested and approved under appropriate government standards such as NIOSH (US) or CEN (EU).

Hand protection
Handle with gloves. Gloves must be inspected prior to use. Use proper glove removal technique (without touching glove's outer surface) to avoid skin contact with this product. Dispose of contaminated gloves after use in accordance with applicable laws and good laboratory practices. Wash and dry hands.

Full contact
Material: Nitrile rubber
Minimum layer thickness: 0.11 mm
Break through time: 480 min
Material tested:Dermatril® (KCL 740 / Aldrich Z677272, Size M)

Splash protection
Material: Nitrile rubber
Minimum layer thickness: 0.11 mm
Break through time: 480 min
Material tested:Dermatril® (KCL 740 / Aldrich Z677272, Size M)

data source: KCL GmbH, D-36124 Eichenzell, phone +49 (0)6659 87300, e-mail sales@kcl.de, test method: EN374
If used in solution, or mixed with other substances, and under conditions which differ from EN 374, contact the supplier of the CE approved gloves. This recommendation is advisory only and must be evaluated by an Industrial Hygienist familiar with the specific situation of anticipated use by our customers. It should not be construed as offering an approval for any specific use scenario.

Eye protection
Safety glasses with side-shields conforming to EN166 Use equipment for eye protection tested and approved under appropriate government standards such as NIOSH (US) or EN 166(EU).

Skin and body protection
Flame retardant antistatic protective clothing, The type of protective equipment must be selected according to the concentration and amount of the dangerous substance at the specific workplace.

Hygiene measures
Handle in accordance with good industrial hygiene and safety practice. Wash hands before breaks and at the end of workday.

9. PHYSICAL AND CHEMICAL PROPERTIES

Appearance

Form	powder
Colour	grey

Safety data

pH	no data available
Melting point/freezing point	Melting point/range: 3,180 °C (5,756 °F) - lit.
Boiling point	5,627 °C (10,161 °F) - lit.
Flash point	no data available
Flammability (solid, gas)	The substance or mixture is a flammable solid with the category 1.
Ignition temperature	no data available

Auto-ignition temperature	no data available
Lower explosion limit	no data available
Upper explosion limit	no data available
Vapour pressure	no data available
Density	21.02 g/cm3
Water solubility	no data available
Partition coefficient: n-octanol/water	no data available
Relative vapor density	no data available
Odour	no data available
Odour Threshold	no data available
Evaporation rate	no data available

10. STABILITY AND REACTIVITY

Chemical stability
Stable under recommended storage conditions.

Possibility of hazardous reactions
no data available

Conditions to avoid
Heat, flames and sparks. Extremes of temperature and direct sunlight.

Materials to avoid
Strong oxidizing agentsStrong acids, Strong oxidizing agents

Hazardous decomposition products
Hazardous decomposition products formed under fire conditions. - rhenium oxides
Other decomposition products - no data available

11. TOXICOLOGICAL INFORMATION

Acute toxicity

Oral LD50
no data available

Inhalation LC50
no data available

Dermal LD50
no data available

Other information on acute toxicity
no data available

Skin corrosion/irritation
no data available

Serious eye damage/eye irritation
no data available

Respiratory or skin sensitization
no data available

Germ cell mutagenicity
no data available

Carcinogenicity

IARC:	No component of this product present at levels greater than or equal to 0.1% is identified as probable, possible or confirmed human carcinogen by IARC.
ACGIH:	No component of this product present at levels greater than or equal to 0.1% is identified as a carcinogen or potential carcinogen by ACGIH.
NTP:	No component of this product present at levels greater than or equal to 0.1% is identified as a known or anticipated carcinogen by NTP.
OSHA:	No component of this product present at levels greater than or equal to 0.1% is identified as a carcinogen or potential carcinogen by OSHA.

Reproductive toxicity

no data available

Teratogenicity

no data available

Specific target organ toxicity - single exposure (Globally Harmonized System)
no data available

Specific target organ toxicity - repeated exposure (Globally Harmonized System)
no data available

Aspiration hazard
no data available

Potential health effects

Inhalation	May be harmful if inhaled. May cause respiratory tract irritation.
Ingestion	May be harmful if swallowed.
Skin	May be harmful if absorbed through skin. May cause skin irritation.
Eyes	May cause eye irritation.

Signs and Symptoms of Exposure
To the best of our knowledge, the chemical, physical, and toxicological properties have not been thoroughly investigated.

Synergistic effects
no data available

Additional Information
RTECS: VI0780000

12. ECOLOGICAL INFORMATION

Toxicity

no data available

Persistence and degradability
no data available

Bioaccumulative potential
no data available

Mobility in soil
no data available

PBT and vPvB assessment
no data available

Other adverse effects

no data available

13. DISPOSAL CONSIDERATIONS

Product
Burn in a chemical incinerator equipped with an afterburner and scrubber but exert extra care in igniting as this material is highly flammable. Offer surplus and non-recyclable solutions to a licensed disposal company.

Contaminated packaging
Dispose of as unused product.

14. TRANSPORT INFORMATION

DOT (US)
UN number: 3089 Class: 4.1 Packing group: II
Proper shipping name: Metal powders, flammable, n.o.s.
Marine Pollutant: No
Poison Inhalation Hazard: No

IMDG
UN number: 3089 Class: 4.1 Packing group: II EMS-No: F-G, S-G
Proper shipping name: METAL POWDER, FLAMMABLE, N.O.S.
Marine Pollutant: No

IATA
UN number: 3089 Class: 4.1 Packing group: II
Proper shipping name: Metal powder, flammable, n.o.s.

15. REGULATORY INFORMATION

OSHA Hazards
Flammable solid

SARA 302 Components
SARA 302: No chemicals in this material are subject to the reporting requirements of SARA Title III, Section 302.

SARA 313 Components
SARA 313: This material does not contain any chemical components with known CAS numbers that exceed the threshold (De Minimis) reporting levels established by SARA Title III, Section 313.

SARA 311/312 Hazards
Fire Hazard

Massachusetts Right To Know Components
No components are subject to the Massachusetts Right to Know Act.

Pennsylvania Right To Know Components

	CAS-No.	Revision Date
Rhenium	7440-15-5	

New Jersey Right To Know Components

	CAS-No.	Revision Date
Rhenium	7440-15-5	

California Prop. 65 Components
This product does not contain any chemicals known to State of California to cause cancer, birth defects, or any other reproductive harm.

Appendix B – Aspen Results

B.1 Input Summary

```
;Input Summary created by Aspen Plus Rel. 28.0 at 15:58:11 Fri Mar 28, 2014
;Directory S:\public_html\Complete Aspen with HTX_1  Filename
C:\Users\scdan\AppData\Local\Temp\~ap2c25.txt
;


DYNAMICS
    DYNAMICS RESULTS=ON

TITLE 'SUNLIGHT TO CONVERT CO2 INTO TRANSPORTATION FUELS'

IN-UNITS MET PRESSURE=bar TEMPERATURE=C DELTA-T=C PDROP=bar  &
        INVERSE-PRES='1/bar'

DEF-STREAMS CONVEN ALL

SIM-OPTIONS MASS-BAL-CHE=YES FREE-WATER=YES NPHASE=2 UTL-REQD=NO

MODEL-OPTION

DATABANKS 'APV82 PURE28' / 'APV82 AQUEOUS' / 'APV82 SOLIDS' /  &
        'APV82 INORGANIC' / NOASPENPCD

PROP-SOURCES 'APV82 PURE28' / 'APV82 AQUEOUS' / 'APV82 SOLIDS' &
         / 'APV82 INORGANIC'

COMPONENTS
    H2 H2 /
    CO2 CO2 /
    CO CO /
    O2 O2 /
    H2O H2O /
    FE3O4 FE3O4 /
    FEO FEO /
    C8 C8H18-1 /
    C1 CH4 /
    C2 C2H6 /
    C3 C3H8 /
    C4 C4H10-1 /
    C5 C5H12-1 /
    C6 C6H14-1 /
    C7 C7H16-1 /
    C9 C9H20-1 /
    C10 C10H22-1 /
    C11 C11H24 /
    C12 C12H26 /
    C13 C13H28 /
    C14 C14H30 /
    C15 C15H32 /
    C16 C16H34 /
    C17 C17H36 /
    C18 C18H38 /
    C19 C19H40 /
    C20 C20H42 /
    C21 C21H44 /
    C22 C22H46 /
    C23 C23H48 /
    C24 C24H50 /
    C25 C25H52 /
    C26 C26H54 /
    C27 C27H56 /
    C28 C28H58 /
    C29 C29H60 /
    C30 C30H62

CISOLID-COMPS FE3O4 FEO
```

```
SOLVE
    RUN-MODE MODE=SIM

FLOWSHEET CR5
    BLOCK SPLITO2 IN=REDOUT OUT=O2 HOTFEO
    BLOCK COOL IN=HOTFEO OUT=COOLFEO CR5-HEAT
    BLOCK OX IN=COOLFEO CO2-CR5 OUT=OXOUT
    BLOCK SPLITCO IN=OXOUT OUT=COOLF3O4 CR5-OUT
    BLOCK HEAT IN=CFE3O4 CR5-HEAT OUT=HOTF3O4
    BLOCK RED IN=HOTF3O4 OUT=REDOUT

FLOWSHEET FT
    BLOCK MIX-FT IN=GAS-WGSF CO-FT GAS-FT4 OUT=GAS-FT1
    BLOCK FT-RXR IN=GAS-FT2 OUT=PROD-FT1
    BLOCK FLASH-FT IN=PROD-FT2 OUT=GAS-FT3 LIQ-FT
    BLOCK SPLITGAS IN=GAS-FT3 OUT=GAS-FT4 GAS-FT5 GASPURGE
    BLOCK DECANT IN=LIQ-FT OUT=PETROL H2O-REC
    BLOCK FT-COMP IN=GAS-FT1 OUT=GAS-FT2
    BLOCK FT-HTX2 IN=PROD-FT1 OUT=PROD-FT2

FLOWSHEET
    BLOCK SPLIT-CO IN=CO2-CO-2 OUT=CO-WGS CO-FT
    BLOCK MULT IN=CR5-OUT OUT=CO2-CO-1
    BLOCK MIXCO2 IN=CO2-IN GAS-FT5 OUT=CO2-CR5
    BLOCK COMPRESS IN=CO2-CO-1 OUT=CO2-CO-2

FLOWSHEET WGS
    BLOCK MIX-WGS IN=CO-WGS H2O-WGS2 H2O-REC H2O-IN2 OUT= &
        WGS-IN1
    BLOCK WGS-RXR IN=WGS-IN2 OUT=WGS-OUT1
    BLOCK F-WGS IN=WGS-OUT3 OUT=GAS-WGSF H2O-WGS1
    BLOCK SPLITH2O IN=H2O-WGS1 OUT=H2O-WGS2 H2OPURGE
    BLOCK H2O-PUMP IN=H2O-IN1 OUT=H2O-IN2
    BLOCK WGS-HTX1 IN=WGS-OUT1 WGS-IN1 OUT=WGS-OUT2 WGS-IN2
    BLOCK WGS-HTX2 IN=WGS-OUT2 OUT=WGS-OUT3

PROPERTIES RK-SOAVE
    PROPERTIES PENG-ROB

PROP-DATA PRKBV-1
    IN-UNITS MET PRESSURE=bar TEMPERATURE=C DELTA-T=C PDROP=bar  &
        INVERSE-PRES='1/bar'
    PROP-LIST PRKBV
    BPVAL H2 CO2 -.1622000000 0.0 0.0 -273.1500000 726.8500000
    BPVAL CO2 H2 -.1622000000 0.0 0.0 -273.1500000 726.8500000
    BPVAL H2 CO .0919000000 0.0 0.0 -273.1500000 726.8500000
    BPVAL CO H2 .0919000000 0.0 0.0 -273.1500000 726.8500000
    BPVAL CO2 H2O .1200000000 0.0 0.0 -273.1500000 726.8500000
    BPVAL H2O CO2 .1200000000 0.0 0.0 -273.1500000 726.8500000
    BPVAL H2 C1 .0156000000 0.0 0.0 -273.1500000 726.8500000
    BPVAL C1 H2 .0156000000 0.0 0.0 -273.1500000 726.8500000
    BPVAL CO2 C1 .0919000000 0.0 0.0 -273.1500000 726.8500000
    BPVAL C1 CO2 .0919000000 0.0 0.0 -273.1500000 726.8500000
    BPVAL CO C1 .0300000000 0.0 0.0 -273.1500000 726.8500000
    BPVAL C1 CO .0300000000 0.0 0.0 -273.1500000 726.8500000
    BPVAL C8 C1 .0496000000 0.0 0.0 -273.1500000 726.8500000
    BPVAL C1 C8 .0496000000 0.0 0.0 -273.1500000 726.8500000
    BPVAL H2 C2 -.0667000000 0.0 0.0 -273.1500000 726.8500000
    BPVAL C2 H2 -.0667000000 0.0 0.0 -273.1500000 726.8500000
    BPVAL CO2 C2 .1322000000 0.0 0.0 -273.1500000 726.8500000
    BPVAL C2 CO2 .1322000000 0.0 0.0 -273.1500000 726.8500000
    BPVAL CO C2 -.0226000000 0.0 0.0 -273.1500000 726.8500000
    BPVAL C2 CO -.0226000000 0.0 0.0 -273.1500000 726.8500000
    BPVAL C8 C2 .0185000000 0.0 0.0 -273.1500000 726.8500000
    BPVAL C2 C8 .0185000000 0.0 0.0 -273.1500000 726.8500000
    BPVAL C1 C2 -2.6000000E-3 0.0 0.0 -273.1500000 726.8500000
    BPVAL C2 C1 -2.6000000E-3 0.0 0.0 -273.1500000 726.8500000
    BPVAL H2 C3 -.0833000000 0.0 0.0 -273.1500000 726.8500000
    BPVAL C3 H2 -.0833000000 0.0 0.0 -273.1500000 726.8500000
    BPVAL CO2 C3 .1241000000 0.0 0.0 -273.1500000 726.8500000
    BPVAL C3 CO2 .1241000000 0.0 0.0 -273.1500000 726.8500000
    BPVAL CO C3 .0259000000 0.0 0.0 -273.1500000 726.8500000
```

```
    BPVAL C3 CO .0259000000 0.0 0.0 -273.1500000 726.8500000
    BPVAL C1 C3 .0140000000 0.0 0.0 -273.1500000 726.8500000
    BPVAL C3 C1 .0140000000 0.0 0.0 -273.1500000 726.8500000
    BPVAL C2 C3 1.10000000E-3 0.0 0.0 -273.1500000 726.8500000
    BPVAL C3 C2 1.10000000E-3 0.0 0.0 -273.1500000 726.8500000
    BPVAL H2 C4 -.3970000000 0.0 0.0 -273.1500000 726.8500000
    BPVAL C4 H2 -.3970000000 0.0 0.0 -273.1500000 726.8500000
    BPVAL CO2 C4 .1333000000 0.0 0.0 -273.1500000 726.8500000
    BPVAL C4 CO2 .1333000000 0.0 0.0 -273.1500000 726.8500000
    BPVAL C1 C4 .0133000000 0.0 0.0 -273.1500000 726.8500000
    BPVAL C4 C1 .0133000000 0.0 0.0 -273.1500000 726.8500000
    BPVAL C2 C4 9.60000000E-3 0.0 0.0 -273.1500000 726.8500000
    BPVAL C4 C2 9.60000000E-3 0.0 0.0 -273.1500000 726.8500000
    BPVAL C3 C4 3.30000000E-3 0.0 0.0 -273.1500000 726.8500000
    BPVAL C4 C3 3.30000000E-3 0.0 0.0 -273.1500000 726.8500000
    BPVAL CO2 C5 .1222000000 0.0 0.0 -273.1500000 726.8500000
    BPVAL C5 CO2 .1222000000 0.0 0.0 -273.1500000 726.8500000
    BPVAL C8 C5 0.0 0.0 0.0 -273.1500000 726.8500000
    BPVAL C5 C8 0.0 0.0 0.0 -273.1500000 726.8500000
    BPVAL C1 C5 .0230000000 0.0 0.0 -273.1500000 726.8500000
    BPVAL C5 C1 .0230000000 0.0 0.0 -273.1500000 726.8500000
    BPVAL C2 C5 7.80000000E-3 0.0 0.0 -273.1500000 726.8500000
    BPVAL C5 C2 7.80000000E-3 0.0 0.0 -273.1500000 726.8500000
    BPVAL C3 C5 .0267000000 0.0 0.0 -273.1500000 726.8500000
    BPVAL C5 C3 .0267000000 0.0 0.0 -273.1500000 726.8500000
    BPVAL C4 C5 .0174000000 0.0 0.0 -273.1500000 726.8500000
    BPVAL C5 C4 .0174000000 0.0 0.0 -273.1500000 726.8500000
    BPVAL H2 C6 -.0300000000 0.0 0.0 -273.1500000 726.8500000
    BPVAL C6 H2 -.0300000000 0.0 0.0 -273.1500000 726.8500000
    BPVAL CO2 C6 .1100000000 0.0 0.0 -273.1500000 726.8500000
    BPVAL C6 CO2 .1100000000 0.0 0.0 -273.1500000 726.8500000
    BPVAL C1 C6 .0422000000 0.0 0.0 -273.1500000 726.8500000
    BPVAL C6 C1 .0422000000 0.0 0.0 -273.1500000 726.8500000
    BPVAL C2 C6 -.0100000000 0.0 0.0 -273.1500000 726.8500000
    BPVAL C6 C2 -.0100000000 0.0 0.0 -273.1500000 726.8500000
    BPVAL C3 C6 7.00000000E-4 0.0 0.0 -273.1500000 726.8500000
    BPVAL C6 C3 7.00000000E-4 0.0 0.0 -273.1500000 726.8500000
    BPVAL C4 C6 -5.6000000E-3 0.0 0.0 -273.1500000 726.8500000
    BPVAL C6 C4 -5.6000000E-3 0.0 0.0 -273.1500000 726.8500000
    BPVAL H2 C7 -.1167000000 0.0 0.0 -273.1500000 726.8500000
    BPVAL C7 H2 -.1167000000 0.0 0.0 -273.1500000 726.8500000
    BPVAL CO2 C7 .1000000000 0.0 0.0 -273.1500000 726.8500000
    BPVAL C7 CO2 .1000000000 0.0 0.0 -273.1500000 726.8500000
    BPVAL C1 C7 .0352000000 0.0 0.0 -273.1500000 726.8500000
    BPVAL C7 C1 .0352000000 0.0 0.0 -273.1500000 726.8500000
    BPVAL C2 C7 6.70000000E-3 0.0 0.0 -273.1500000 726.8500000
    BPVAL C7 C2 6.70000000E-3 0.0 0.0 -273.1500000 726.8500000
    BPVAL C3 C7 5.60000000E-3 0.0 0.0 -273.1500000 726.8500000
    BPVAL C7 C3 5.60000000E-3 0.0 0.0 -273.1500000 726.8500000
    BPVAL C4 C7 3.30000000E-3 0.0 0.0 -273.1500000 726.8500000
    BPVAL C7 C4 3.30000000E-3 0.0 0.0 -273.1500000 726.8500000
    BPVAL C5 C7 7.40000000E-3 0.0 0.0 -273.1500000 726.8500000
    BPVAL C7 C5 7.40000000E-3 0.0 0.0 -273.1500000 726.8500000
    BPVAL C6 C7 -7.8000000E-3 0.0 0.0 -273.1500000 726.8500000
    BPVAL C7 C6 -7.8000000E-3 0.0 0.0 -273.1500000 726.8500000
    BPVAL C1 C9 .0474000000 0.0 0.0 -273.1500000 726.8500000
    BPVAL C9 C1 .0474000000 0.0 0.0 -273.1500000 726.8500000
    BPVAL CO2 C10 .1141000000 0.0 0.0 -273.1500000 726.8500000
    BPVAL C10 CO2 .1141000000 0.0 0.0 -273.1500000 726.8500000
    BPVAL C1 C10 .0422000000 0.0 0.0 -273.1500000 726.8500000
    BPVAL C10 C1 .0422000000 0.0 0.0 -273.1500000 726.8500000
    BPVAL C2 C10 .0144000000 0.0 0.0 -273.1500000 726.8500000
    BPVAL C10 C2 .0144000000 0.0 0.0 -273.1500000 726.8500000
    BPVAL C3 C10 0.0 0.0 0.0 -273.1500000 726.8500000
    BPVAL C10 C3 0.0 0.0 0.0 -273.1500000 726.8500000
    BPVAL C4 C10 7.80000000E-3 0.0 0.0 -273.1500000  &
        726.8500000
    BPVAL C10 C4 7.80000000E-3 0.0 0.0 -273.1500000  &
        726.8500000

PROP-DATA RKSKBV-1
    IN-UNITS MET PRESSURE=bar TEMPERATURE=C DELTA-T=C PDROP=bar  &
```

```
    INVERSE-PRES='1/bar'
PROP-LIST RKSKBV
BPVAL H2 CO2 -.3426000000 0.0 0.0 -273.1500000 726.8500000
BPVAL CO2 H2 -.3426000000 0.0 0.0 -273.1500000 726.8500000
BPVAL H2 CO .0804000000 0.0 0.0 -273.1500000 726.8500000
BPVAL CO H2 .0804000000 0.0 0.0 -273.1500000 726.8500000
BPVAL H2 C1 -.0222000000 0.0 0.0 -273.1500000 726.8500000
BPVAL C1 H2 -.0222000000 0.0 0.0 -273.1500000 726.8500000
BPVAL H2 C2 -.1667000000 0.0 0.0 -273.1500000 726.8500000
BPVAL C2 H2 -.1667000000 0.0 0.0 -273.1500000 726.8500000
BPVAL H2 C3 -.2359000000 0.0 0.0 -273.1500000 726.8500000
BPVAL C3 H2 -.2359000000 0.0 0.0 -273.1500000 726.8500000
BPVAL H2 C4 -.5100000000 0.0 0.0 -273.1500000 726.8500000
BPVAL C4 H2 -.5100000000 0.0 0.0 -273.1500000 726.8500000
BPVAL H2 C6 -.0800000000 0.0 0.0 -273.1500000 726.8500000
BPVAL C6 H2 -.0800000000 0.0 0.0 -273.1500000 726.8500000
BPVAL H2 C7 -.2200000000 0.0 0.0 -273.1500000 726.8500000
BPVAL C7 H2 -.2200000000 0.0 0.0 -273.1500000 726.8500000
BPVAL CO2 H2O .0737000000 0.0 0.0 -273.1500000 726.8500000
BPVAL H2O CO2 .0737000000 0.0 0.0 -273.1500000 726.8500000
BPVAL CO2 C1 .0933000000 0.0 0.0 -273.1500000 726.8500000
BPVAL C1 CO2 .0933000000 0.0 0.0 -273.1500000 726.8500000
BPVAL CO2 C2 .1363000000 0.0 0.0 -273.1500000 726.8500000
BPVAL C2 CO2 .1363000000 0.0 0.0 -273.1500000 726.8500000
BPVAL CO2 C3 .1289000000 0.0 0.0 -273.1500000 726.8500000
BPVAL C3 CO2 .1289000000 0.0 0.0 -273.1500000 726.8500000
BPVAL CO2 C4 .1430000000 0.0 0.0 -273.1500000 726.8500000
BPVAL C4 CO2 .1430000000 0.0 0.0 -273.1500000 726.8500000
BPVAL CO2 C5 .1311000000 0.0 0.0 -273.1500000 726.8500000
BPVAL C5 CO2 .1311000000 0.0 0.0 -273.1500000 726.8500000
BPVAL CO2 C6 .1178000000 0.0 0.0 -273.1500000 726.8500000
BPVAL C6 CO2 .1178000000 0.0 0.0 -273.1500000 726.8500000
BPVAL CO2 C7 .1100000000 0.0 0.0 -273.1500000 726.8500000
BPVAL C7 CO2 .1100000000 0.0 0.0 -273.1500000 726.8500000
BPVAL CO2 C10 .1304000000 0.0 0.0 -273.1500000 726.8500000
BPVAL C10 CO2 .1304000000 0.0 0.0 -273.1500000 726.8500000
BPVAL CO C1 .0322000000 0.0 0.0 -273.1500000 726.8500000
BPVAL C1 CO .0322000000 0.0 0.0 -273.1500000 726.8500000
BPVAL CO C2 -.0278000000 0.0 0.0 -273.1500000 726.8500000
BPVAL C2 CO -.0278000000 0.0 0.0 -273.1500000 726.8500000
BPVAL CO C3 .0156000000 0.0 0.0 -273.1500000 726.8500000
BPVAL C3 CO .0156000000 0.0 0.0 -273.1500000 726.8500000
BPVAL C8 C1 .0448000000 0.0 0.0 -273.1500000 726.8500000
BPVAL C1 C8 .0448000000 0.0 0.0 -273.1500000 726.8500000
BPVAL C8 C2 .0170000000 0.0 0.0 -273.1500000 726.8500000
BPVAL C2 C8 .0170000000 0.0 0.0 -273.1500000 726.8500000
BPVAL C8 C5 -2.2000000E-3 0.0 0.0 -273.1500000 726.8500000
BPVAL C5 C8 -2.2000000E-3 0.0 0.0 -273.1500000 726.8500000
BPVAL C1 C2 -7.8000000E-3 0.0 0.0 -273.1500000 726.8500000
BPVAL C2 C1 -7.8000000E-3 0.0 0.0 -273.1500000 726.8500000
BPVAL C1 C3 9.00000000E-3 0.0 0.0 -273.1500000 726.8500000
BPVAL C3 C1 9.00000000E-3 0.0 0.0 -273.1500000 726.8500000
BPVAL C1 C4 5.60000000E-3 0.0 0.0 -273.1500000 726.8500000
BPVAL C4 C1 5.60000000E-3 0.0 0.0 -273.1500000 726.8500000
BPVAL C1 C5 .0190000000 0.0 0.0 -273.1500000 726.8500000
BPVAL C5 C1 .0190000000 0.0 0.0 -273.1500000 726.8500000
BPVAL C1 C6 .0374000000 0.0 0.0 -273.1500000 726.8500000
BPVAL C6 C1 .0374000000 0.0 0.0 -273.1500000 726.8500000
BPVAL C1 C7 .0307000000 0.0 0.0 -273.1500000 726.8500000
BPVAL C7 C1 .0307000000 0.0 0.0 -273.1500000 726.8500000
BPVAL C1 C9 .0448000000 0.0 0.0 -273.1500000 726.8500000
BPVAL C9 C1 .0448000000 0.0 0.0 -273.1500000 726.8500000
BPVAL C1 C10 .0411000000 0.0 0.0 -273.1500000 726.8500000
BPVAL C10 C1 .0411000000 0.0 0.0 -273.1500000 726.8500000
BPVAL C2 C3 -2.2000000E-3 0.0 0.0 -273.1500000 726.8500000
BPVAL C3 C2 -2.2000000E-3 0.0 0.0 -273.1500000 726.8500000
BPVAL C2 C4 6.70000000E-3 0.0 0.0 -273.1500000 726.8500000
BPVAL C4 C2 6.70000000E-3 0.0 0.0 -273.1500000 726.8500000
BPVAL C2 C5 5.60000000E-3 0.0 0.0 -273.1500000 726.8500000
BPVAL C5 C2 5.60000000E-3 0.0 0.0 -273.1500000 726.8500000
BPVAL C2 C6 -.0156000000 0.0 0.0 -273.1500000 726.8500000
BPVAL C6 C2 -.0156000000 0.0 0.0 -273.1500000 726.8500000
```

```
    BPVAL C2 C7 4.10000000E-3 0.0 0.0 -273.1500000 726.8500000
    BPVAL C7 C2 4.10000000E-3 0.0 0.0 -273.1500000 726.8500000
    BPVAL C2 C10 .0152000000 0.0 0.0 -273.1500000 726.8500000
    BPVAL C10 C2 .0152000000 0.0 0.0 -273.1500000 726.8500000
    BPVAL C3 C4 0.0 0.0 0.0 -273.1500000 726.8500000
    BPVAL C4 C3 0.0 0.0 0.0 -273.1500000 726.8500000
    BPVAL C3 C5 .0233000000 0.0 0.0 -273.1500000 726.8500000
    BPVAL C5 C3 .0233000000 0.0 0.0 -273.1500000 726.8500000
    BPVAL C3 C6 -2.2000000E-3 0.0 0.0 -273.1500000 726.8500000
    BPVAL C6 C3 -2.2000000E-3 0.0 0.0 -273.1500000 726.8500000
    BPVAL C3 C7 4.40000000E-3 0.0 0.0 -273.1500000 726.8500000
    BPVAL C7 C3 4.40000000E-3 0.0 0.0 -273.1500000 726.8500000
    BPVAL C3 C10 0.0 0.0 0.0 -273.1500000 726.8500000
    BPVAL C10 C3 0.0 0.0 0.0 -273.1500000 726.8500000
    BPVAL C4 C5 .0204000000 0.0 0.0 -273.1500000 726.8500000
    BPVAL C5 C4 .0204000000 0.0 0.0 -273.1500000 726.8500000
    BPVAL C4 C6 -.0111000000 0.0 0.0 -273.1500000 726.8500000
    BPVAL C6 C4 -.0111000000 0.0 0.0 -273.1500000 726.8500000
    BPVAL C4 C7 -4.0000000E-4 0.0 0.0 -273.1500000 726.8500000
    BPVAL C7 C4 -4.0000000E-4 0.0 0.0 -273.1500000 726.8500000
    BPVAL C4 C10 6.70000000E-3 0.0 0.0 -273.1500000  &
        726.8500000
    BPVAL C10 C4 6.70000000E-3 0.0 0.0 -273.1500000  &
        726.8500000
    BPVAL C5 C7 1.90000000E-3 0.0 0.0 -273.1500000 726.8500000
    BPVAL C7 C5 1.90000000E-3 0.0 0.0 -273.1500000 726.8500000
    BPVAL C6 C7 -1.1000000E-3 0.0 0.0 -273.1500000 726.8500000
    BPVAL C7 C6 -1.1000000E-3 0.0 0.0 -273.1500000 726.8500000

STREAM CFE3O4
    SUBSTREAM MIXED TEMP=600. <K> PRES=0.2 <atm>  &
        MOLE-FLOW=100000. <kmol/day>
    MOLE-FRAC FE3O4 1.

STREAM CO2-CO-2
    SUBSTREAM MIXED TEMP=326.85187 PRES=1
    MOLE-FLOW CO2 910.839411 / CO 1362.04683

STREAM CO2-IN
    SUBSTREAM MIXED TEMP=600. <K> PRES=0.2  &
        MOLE-FLOW=10344. <kmol/day>
    MOLE-FRAC CO2 1.

STREAM GAS-FT2
    SUBSTREAM MIXED TEMP=32.9340088 PRES=1
    MOLE-FLOW H2 899.974194 / CO2 2005.51865 / CO 473.799629 / &
        H2O 1.12607122 / C8 0.00841046788 / C1 0.553382917 /  &
        C2 0.520997757 / C3 0.460652528 / C4 0.373330735 /  &
        C5 0.242259016 / C6 0.108242541 / C7 0.03457144 /  &
        C9 0.00219810138 / C10 0.00064510010 / C11  &
        0.00017352852 / C12 4.427114E-005 / C13 9.810680E-006 /  &
        C14 2.889395E-006 / C15 7.491546E-007 / C16  &
        2.173309E-007 / C17 4.925686E-008 / C18 1.367604E-008 /  &
        C19 3.682926E-009 / C20 8.078200E-010 / C21  &
        2.331789E-010 / C22 7.552322E-011 / C23 1.569097E-011 /  &
        C24 3.916102E-012 / C25 1.142251E-012 / C26  &
        9.103604E-013 / C27 8.587405E-013 / C28 8.021853E-013 /  &
        C29 7.465200E-013 / C30 7.037712E-013

STREAM H2O-IN1
    SUBSTREAM MIXED TEMP=25 PRES=1 MOLE-FLOW=230.
    MOLE-FRAC H2O 1

DEF-STREAMS HEAT CR5-HEAT

BLOCK MIX-FT MIXER
    PARAM PRES=1. NPHASE=2
    BLOCK-OPTION FREE-WATER=YES

BLOCK MIX-WGS MIXER
    PARAM PRES=1. NPHASE=2
    BLOCK-OPTION FREE-WATER=YES
```

```
BLOCK MIXCO2 MIXER
    PARAM NPHASE=2
    BLOCK-OPTION FREE-WATER=YES

BLOCK SPLIT-CO FSPLIT
    PARAM NPHASE=2
    FRAC CO-WGS 0.95
    BLOCK-OPTION FREE-WATER=YES

BLOCK SPLITGAS FSPLIT
    PARAM PRES=1. NPHASE=2
    FRAC GAS-FT4 0.1 / GASPURGE 0.65
    BLOCK-OPTION FREE-WATER=YES

BLOCK SPLITH2O FSPLIT
    PARAM NPHASE=2
    FRAC H2O-WGS2 0.95
    BLOCK-OPTION FREE-WATER=YES

BLOCK DECANT SEP2
    PARAM NPHASE=2
    FRAC STREAM=H2O-REC SUBSTREAM=MIXED COMPS=H2 CO2 CO O2  &
        H2O FE3O4 FEO C8 C1 C2 C3 C4 C5 C6 C7 C9 C10 C11  &
        C12 C13 C14 C15 C16 C17 C18 C19 C20 C21 C22 C23  &
        C24 C25 C26 C27 C28 C29 C30 FRACS=0. 0. 0. 0. 1.  &
        0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.  &
        0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.  &
        0. 0.
    BLOCK-OPTION FREE-WATER=YES

BLOCK SPLITCO SEP2
    PARAM PRES=1. NPHASE=2
    FRAC STREAM=CR5-OUT SUBSTREAM=MIXED COMPS=H2 CO2 CO O2  &
        H2O FE3O4 FEO C8 C1 C2 C3 C4 C5 C6 C7 C9 C10 C11  &
        C12 C13 C14 C15 C16 C17 C18 C19 C20 C21 C22 C23  &
        C24 C25 C26 C27 C28 C29 C30 FRACS=1. 1. 1. 1. 1.  &
        0. 0. 1. 1. 1. 1. 1. 1. 1. 1. 1. 1. 1. 1.  &
        1. 1. 1. 1. 1. 1. 1. 1. 1. 1. 1. 1. 1. 1.  &
        1. 1.
    BLOCK-OPTION FREE-WATER=YES

BLOCK SPLITO2 SEP2
    PARAM NPHASE=2
    FRAC STREAM=HOTFEO SUBSTREAM=MIXED COMPS=H2 CO2 CO O2  &
        H2O FE3O4 FEO C8 C1 C2 C3 C4 C5 C6 C7 C9 C10 C11  &
        C12 C13 C14 C15 C16 C17 C18 C19 C20 C21 C22 C23  &
        C24 C25 C26 C27 C28 C29 C30 FRACS=0. 0. 0. 0. 0.  &
        1. 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.  &
        0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.  &
        0. 0.
    BLOCK-OPTION FREE-WATER=YES

BLOCK COOL HEATER
    PARAM PRES=0.2 <atm> DELT=-1700. <K> NPHASE=2
    BLOCK-OPTION FREE-WATER=YES

BLOCK HEAT HEATER
    PARAM PRES=0.2 <atm> NPHASE=2
    BLOCK-OPTION FREE-WATER=YES

BLOCK F-WGS FLASH2
    PARAM TEMP=25. PRES=5. NPHASE=2
    BLOCK-OPTION FREE-WATER=YES

BLOCK FLASH-FT FLASH2
    PARAM TEMP=25. PRES=15. NPHASE=2
    BLOCK-OPTION FREE-WATER=YES

BLOCK FT-HTX2 HEATX
    PARAM T-HOT=30. MIN-TAPP=5.
    FEEDS HOT=PROD-FT1
```

```
    OUTLETS-HOT PROD-FT2
    REFERENCE COLD-UTIL=CW

BLOCK WGS-HTX1 HEATX
    PARAM T-COLD=300. MIN-TAPP=10.
    FEEDS HOT=WGS-OUT1 COLD=WGS-IN1
    OUTLETS-HOT WGS-OUT2
    OUTLETS-COLD WGS-IN2

BLOCK WGS-HTX2 HEATX
    PARAM T-HOT=50. MIN-TAPP=10.
    FEEDS HOT=WGS-OUT2
    OUTLETS-HOT WGS-OUT3
    REFERENCE COLD-UTIL=CW

BLOCK FT-RXR RSTOIC
    PARAM TEMP=200. PRES=20. NPHASE=2 HEAT-OF-REAC=YES
    STOIC 1 MIXED H2 -441853. / CO -208408. / C1 2581. /  &
        C2 2450. / C3 2229. / C4 2008. / C5 1799. / C6  &
        1609. / C7 1437. / C8 1282. / C9 1143. / C10  &
        1019. / C11 908. / C12 809. / C13 721. / C14 642. / &
        C15 572. / C16 509. / C17 453. / C18 404. / C19  &
        359. / C20 320. / C21 285. / C22 253. / C23 226. / &
        C24 201. / C25 179. / C26 159. / C27 142. / C28  &
        126. / C29 112. / C30 100. / H2O 208408.
    CONV 1 MIXED CO 0.85
    HEAT-RXN REACNO=1 CID=CO
    BLOCK-OPTION FREE-WATER=YES
    UTILITY UTILITY-ID=CW

BLOCK OX RSTOIC
    PARAM TEMP=600. <K> PRES=0.2 <atm> NPHASE=2
    STOIC 1 MIXED CO2 -1. / FEO -3. / CO 1. / FE3O4 1.
    CONV 1 MIXED CO2 0.5916
    BLOCK-OPTION FREE-WATER=YES

BLOCK RED RSTOIC
    PARAM TEMP=2300. <K> PRES=0.2 <atm> NPHASE=2
    STOIC 1 MIXED FE3O4 -1. / O2 0.5 / FEO 3.
    CONV 1 MIXED FE3O4 0.5916
    BLOCK-OPTION FREE-WATER=YES

BLOCK WGS-RXR RGIBBS
    PARAM PRES=10. NPHASE=2 MAXIT=50 DUTY=0. <kJ/hr>
    PROD H2 / CO2 / CO / H2O

BLOCK H2O-PUMP PUMP
    PARAM PRES=10.

BLOCK COMPRESS COMPR
    PARAM TYPE=ISENTROPIC PRES=10. SB-MAXIT=30 SB-TOL=0.0001

BLOCK FT-COMP COMPR
    PARAM TYPE=ISENTROPIC PRES=20. SB-MAXIT=30 SB-TOL=0.0001

BLOCK MULT MULT
    PARAM FACTOR=1.

UTILITY CW GENERAL
    DESCRIPTION "Cooling Water, Inlet Temp=20 C, Outlet Temp=25 C"
    COST ENERGY-PRICE=2.12E-007 <$/kJ>
    PARAM UTILITY-TYPE=WATER PRES=1. <atm> PRES-OUT=1. <atm>  &
        TIN=20. TOUT=25. CALOPT=FLASH MIN-TAPP=5.  &
        HTC=0.0135 <GJ/hr-sqm-C>

EO-CONV-OPTI

CONV-OPTIONS
    PARAM TOL=0.0001 UPDATE=NO

STREAM-REPOR MASSFLOW
```

B.2 Block Reports

```
BLOCK:  COMPRESS MODEL: COMPR
------------------------------
  INLET STREAM:          CO2-CO-1
  OUTLET STREAM:         CO2-CO-2
  PROPERTY OPTION SET:   RK-SOAVE  STANDARD RKS EQUATION OF STATE
  FREE WATER OPTION SET: SYSOP12   ASME STEAM TABLE
  SOLUBLE WATER OPTION:  THE MAIN PROPERTY OPTION SET (RK-SOAVE).

                     ***  MASS AND ENERGY BALANCE  ***
                                  IN              OUT        RELATIVE DIFF.
   TOTAL BALANCE
      MOLE(KMOL/HR )            626.810         626.810         0.00000
      MASS(KG/HR   )            19931.2         19931.2         0.00000
      ENTHALPY(CAL/SEC )     -0.814581E+07   -0.728297E+07   -0.105924

                     ***  CO2 EQUIVALENT SUMMARY ***
   FEED STREAMS CO2E            10330.5      KG/HR
   PRODUCT STREAMS CO2E         10330.5      KG/HR
   NET STREAMS CO2E PRODUCTION  0.00000      KG/HR
   UTILITIES CO2E PRODUCTION    0.00000      KG/HR
   TOTAL CO2E PRODUCTION        0.00000      KG/HR

                          ***  INPUT DATA  ***

  ISENTROPIC CENTRIFUGAL COMPRESSOR
   OUTLET PRESSURE  BAR                                    10.0000
   ISENTROPIC EFFICIENCY                                    0.72000
   MECHANICAL EFFICIENCY                                    1.00000

                          ***  RESULTS  ***

   INDICATED  HORSEPOWER REQUIREMENT  KW                3,612.54
   BRAKE      HORSEPOWER REQUIREMENT  KW                3,612.54
   NET WORK REQUIRED                  KW                3,612.54
   POWER LOSSES                       KW                    0.0
   ISENTROPIC HORSEPOWER REQUIREMENT  KW                2,601.03
   CALCULATED OUTLET TEMP  C                              849.587
   ISENTROPIC TEMPERATURE  C                              709.580
   EFFICIENCY (POLYTR/ISENTR) USED                          0.72000
   OUTLET VAPOR FRACTION                                    1.00000
   HEAD DEVELOPED,       M-KGF/KG                       47,906.3
   MECHANICAL EFFICIENCY USED                               1.00000
   INLET HEAT CAPACITY RATIO                                1.29279
   INLET VOLUMETRIC FLOW RATE , L/MIN                   521,346.
   OUTLET VOLUMETRIC FLOW RATE, L/MIN                    97,805.1
   INLET  COMPRESSIBILITY FACTOR                            1.00037
   OUTLET COMPRESSIBILITY FACTOR                            1.00293
   AV. ISENT. VOL. EXPONENT                                 1.27479
   AV. ISENT. TEMP EXPONENT                                 1.27272
   AV. ACTUAL VOL. EXPONENT                                 1.37596
   AV. ACTUAL TEMP EXPONENT                                 1.37386

BLOCK:  COOL     MODEL: HEATER
------------------------------
  INLET STREAM:          HOTFEO
  OUTLET STREAM:         COOLFEO
  OUTLET HEAT STREAM:    CR5-HEAT
  PROPERTY OPTION SET:   RK-SOAVE  STANDARD RKS EQUATION OF STATE
  FREE WATER OPTION SET: SYSOP12   ASME STEAM TABLE
  SOLUBLE WATER OPTION:  THE MAIN PROPERTY OPTION SET (RK-SOAVE).

                     ***  MASS AND ENERGY BALANCE  ***
                                  IN              OUT        RELATIVE DIFF.
   TOTAL BALANCE
      MOLE(KMOL/HR )            9096.67         9096.67         0.00000
      MASS(KG/HR   )            925306.         925306.         0.00000
      ENTHALPY(CAL/SEC )     -0.153438E+09   -0.153438E+09    0.194230E-15

                     ***  CO2 EQUIVALENT SUMMARY ***
```

```
  FEED STREAMS CO2E             0.00000      KG/HR
  PRODUCT STREAMS CO2E          0.00000      KG/HR
  NET STREAMS CO2E PRODUCTION   0.00000      KG/HR
  UTILITIES CO2E PRODUCTION     0.00000      KG/HR
  TOTAL CO2E PRODUCTION         0.00000      KG/HR

                         ***  INPUT DATA  ***
 TWO    PHASE  TP  FLASH
 FREE WATER CONSIDERED
 SPECIFIED TEMPERATURE CHANGE         C                    -1,700.00
 SPECIFIED PRESSURE                   BAR                      0.20265
 MAXIMUM NO. ITERATIONS                                       30
 CONVERGENCE TOLERANCE                                         0.000100000


                          ***  RESULTS  ***
 OUTLET TEMPERATURE    C                                      326.85
 OUTLET PRESSURE       BAR                                   0.20265
 HEAT DUTY             CAL/SEC                              -0.92287E+08
 OUTLET VAPOR FRACTION                                       0.0000
 OUTLET: 1ST LIQUID/TOTAL LIQUID                             0.0000


BLOCK:  DECANT   MODEL: SEP2
------------------------------
 INLET STREAM:          LIQ-FT
 OUTLET STREAMS:        PETROL      H2O-REC
 PROPERTY OPTION SET:   RK-SOAVE  STANDARD RKS EQUATION OF STATE
 FREE WATER OPTION SET: SYSOP12   ASME STEAM TABLE
 SOLUBLE WATER OPTION:  THE MAIN PROPERTY OPTION SET (RK-SOAVE).

                     ***  MASS AND ENERGY BALANCE  ***
                                IN              OUT        RELATIVE DIFF.
  TOTAL BALANCE
     MOLE(KMOL/HR )           75.1624         75.1624         0.00000
     MASS(KG/HR   )           2043.28         2043.28        0.222558E-15
     ENTHALPY(CAL/SEC )    -0.146040E+07   -0.146049E+07    0.626403E-04

                     ***  CO2 EQUIVALENT SUMMARY ***
  FEED STREAMS CO2E            50.1381      KG/HR
  PRODUCT STREAMS CO2E         50.1381      KG/HR
  NET STREAMS CO2E PRODUCTION  0.00000      KG/HR
  UTILITIES CO2E PRODUCTION    0.00000      KG/HR
  TOTAL CO2E PRODUCTION        0.00000      KG/HR


                         ***  INPUT DATA  ***

 FLASH SPECS FOR STREAM PETROL
 TWO    PHASE  TP  FLASH
 FREE WATER CONSIDERED
 PRESSURE DROP         BAR                                    0.0
 MAXIMUM NO. ITERATIONS                                      30
 CONVERGENCE TOLERANCE                                        0.000100000

 FLASH SPECS FOR STREAM H2O-REC
 TWO    PHASE  TP  FLASH
 FREE WATER CONSIDERED
 PRESSURE DROP         BAR                                    0.0
 MAXIMUM NO. ITERATIONS                                      30
 CONVERGENCE TOLERANCE                                        0.000100000


                          ***  RESULTS  ***

 HEAT DUTY             CAL/SEC                               -91.486

STREAM=   PETROL     SUBSTREAM= MIXED
   COMPONENT = H2        SPLIT FRACTION =          1.00000
   COMPONENT = CO2       SPLIT FRACTION =          1.00000
```

```
    COMPONENT = CO        SPLIT FRACTION =          1.00000
    COMPONENT = C8        SPLIT FRACTION =          1.00000
    COMPONENT = C1        SPLIT FRACTION =          1.00000
    COMPONENT = C2        SPLIT FRACTION =          1.00000
    COMPONENT = C3        SPLIT FRACTION =          1.00000
    COMPONENT = C4        SPLIT FRACTION =          1.00000
    COMPONENT = C5        SPLIT FRACTION =          1.00000
    COMPONENT = C6        SPLIT FRACTION =          1.00000
    COMPONENT = C7        SPLIT FRACTION =          1.00000
    COMPONENT = C9        SPLIT FRACTION =          1.00000
    COMPONENT = C10       SPLIT FRACTION =          1.00000
    COMPONENT = C11       SPLIT FRACTION =          1.00000
    COMPONENT = C12       SPLIT FRACTION =          1.00000
    COMPONENT = C13       SPLIT FRACTION =          1.00000
    COMPONENT = C14       SPLIT FRACTION =          1.00000
    COMPONENT = C15       SPLIT FRACTION =          1.00000
    COMPONENT = C16       SPLIT FRACTION =          1.00000
    COMPONENT = C17       SPLIT FRACTION =          1.00000
    COMPONENT = C18       SPLIT FRACTION =          1.00000
    COMPONENT = C19       SPLIT FRACTION =          1.00000
    COMPONENT = C20       SPLIT FRACTION =          1.00000
    COMPONENT = C21       SPLIT FRACTION =          1.00000
    COMPONENT = C22       SPLIT FRACTION =          1.00000
    COMPONENT = C23       SPLIT FRACTION =          1.00000
    COMPONENT = C24       SPLIT FRACTION =          1.00000
    COMPONENT = C25       SPLIT FRACTION =          1.00000
    COMPONENT = C26       SPLIT FRACTION =          1.00000
    COMPONENT = C27       SPLIT FRACTION =          1.00000
    COMPONENT = C28       SPLIT FRACTION =          1.00000
    COMPONENT = C29       SPLIT FRACTION =          1.00000
    COMPONENT = C30       SPLIT FRACTION =          1.00000

 STREAM=   H2O-REC    SUBSTREAM= MIXED
    COMPONENT = H2O       SPLIT FRACTION =          1.00000

BLOCK:  F-WGS    MODEL: FLASH2
------------------------------
  INLET STREAM:          WGS-OUT3
  OUTLET VAPOR STREAM:   GAS-WGSF
  OUTLET LIQUID STREAM:  H2O-WGS1
  PROPERTY OPTION SET:   RK-SOAVE  STANDARD RKS EQUATION OF STATE
  FREE WATER OPTION SET: SYSOP12   ASME STEAM TABLE
  SOLUBLE WATER OPTION:  THE MAIN PROPERTY OPTION SET (RK-SOAVE).

                     ***  MASS AND ENERGY BALANCE  ***
                                  IN               OUT        RELATIVE DIFF.
   TOTAL BALANCE
      MOLE(KMOL/HR )            1347.60          1347.60       -0.545521E-11
      MASS(KG/HR   )            32346.2          32346.2       -0.409459E-11
      ENTHALPY(CAL/SEC )      -0.220327E+08    -0.221541E+08    0.548068E-02

                     ***  CO2 EQUIVALENT SUMMARY ***
   FEED STREAMS CO2E             21504.2      KG/HR
   PRODUCT STREAMS CO2E          21504.2      KG/HR
   NET STREAMS CO2E PRODUCTION   0.00000      KG/HR
   UTILITIES CO2E PRODUCTION     0.00000      KG/HR
   TOTAL CO2E PRODUCTION         0.00000      KG/HR

                          ***  INPUT DATA  ***
  TWO    PHASE  TP  FLASH
  FREE WATER CONSIDERED
  SPECIFIED TEMPERATURE C                                    25.0000
  SPECIFIED PRESSURE    BAR                                   5.00000
  MAXIMUM NO. ITERATIONS                                     30
  CONVERGENCE TOLERANCE                                       0.000100000

                          ***  RESULTS  ***
  OUTLET TEMPERATURE    C                                     25.000
  OUTLET PRESSURE       BAR                                    5.0000
  HEAT DUTY             CAL/SEC                           -0.12142E+06
  VAPOR FRACTION                                           0.65307
  1ST LIQUID/TOTAL LIQUID                                   0.0000
```

V-L1-L2 PHASE EQUILIBRIUM :

COMP	F(I)	X1(I)	X2(I)	Y(I)	K1(I)	K2(I)
H2	0.242	0.130	0.00	0.371	46.4	
CO2	0.363	0.807	0.00	0.555	11.2	
CO	0.439E-01	0.379E-01	0.00	0.672E-01	28.8	
H2O	0.351	0.252E-01	1.00	0.662E-02	4.27	0.662E-02

BLOCK: FLASH-FT MODEL: FLASH2

INLET STREAM: PROD-FT2
OUTLET VAPOR STREAM: GAS-FT3
OUTLET LIQUID STREAM: LIQ-FT
PROPERTY OPTION SET: RK-SOAVE STANDARD RKS EQUATION OF STATE
FREE WATER OPTION SET: SYSOP12 ASME STEAM TABLE
SOLUBLE WATER OPTION: THE MAIN PROPERTY OPTION SET (RK-SOAVE).

*** MASS AND ENERGY BALANCE ***

	IN	OUT	RELATIVE DIFF.
TOTAL BALANCE			
MOLE(KMOL/HR)	858.356	858.356	0.132447E-15
MASS(KG/HR)	27462.2	27462.2	0.114883E-10
ENTHALPY(CAL/SEC)	-0.160957E+08	-0.161014E+08	0.354731E-03

*** CO2 EQUIVALENT SUMMARY ***

FEED STREAMS CO2E	24824.5	KG/HR
PRODUCT STREAMS CO2E	24824.5	KG/HR
NET STREAMS CO2E PRODUCTION	0.00000	KG/HR
UTILITIES CO2E PRODUCTION	0.00000	KG/HR
TOTAL CO2E PRODUCTION	0.00000	KG/HR

*** INPUT DATA ***

TWO PHASE TP FLASH		
FREE WATER CONSIDERED		
SPECIFIED TEMPERATURE	C	25.0000
SPECIFIED PRESSURE	BAR	15.0000
MAXIMUM NO. ITERATIONS		30
CONVERGENCE TOLERANCE		0.000100000

*** RESULTS ***

OUTLET TEMPERATURE	C	25.000
OUTLET PRESSURE	BAR	15.000
HEAT DUTY	CAL/SEC	-5711.7
VAPOR FRACTION		0.91243
1ST LIQUID/TOTAL LIQUID		0.66378E-01

V-L1-L2 PHASE EQUILIBRIUM :

COMP	F(I)	X1(I)	X2(I)	Y(I)	K1(I)	K2(I)
H2	0.246	0.301E-02	0.00	0.269	89.5	
CO2	0.647	0.227	0.00	0.708	3.11	
CO	0.135E-01	0.474E-03	0.00	0.148E-01	31.2	0.191E-02
H2O	0.835E-01	0.139E-01	1.00	0.184E-02	0.132	0.184E-02
C8	0.484E-03	0.629E-01	0.00	0.130E-03	0.207E-02	
C1	0.107E-02	0.987E-04	0.00	0.117E-02	11.8	
C2	0.101E-02	0.493E-03	0.00	0.111E-02	2.25	
C3	0.921E-03	0.150E-02	0.00	0.100E-02	0.666	
C4	0.828E-03	0.440E-02	0.00	0.879E-03	0.200	
C5	0.736E-03	0.118E-01	0.00	0.731E-03	0.618E-01	
C6	0.646E-03	0.269E-01	0.00	0.537E-03	0.199E-01	
C7	0.560E-03	0.475E-01	0.00	0.311E-03	0.654E-02	
C9	0.424E-03	0.658E-01	0.00	0.461E-04	0.701E-03	
C10	0.376E-03	0.622E-01	0.00	0.153E-04	0.247E-03	
C11	0.334E-03	0.566E-01	0.00	0.530E-05	0.935E-04	
C12	0.297E-03	0.509E-01	0.00	0.161E-05	0.317E-04	
C13	0.265E-03	0.455E-01	0.00	0.439E-06	0.965E-05	
C14	0.236E-03	0.405E-01	0.00	0.149E-06	0.367E-05	
C15	0.210E-03	0.361E-01	0.00	0.457E-07	0.127E-05	
C16	0.187E-03	0.322E-01	0.00	0.154E-07	0.478E-06	
C17	0.166E-03	0.286E-01	0.00	0.425E-08	0.148E-06	
C18	0.148E-03	0.255E-01	0.00	0.139E-08	0.544E-07	

C19	0.132E-03	0.227E-01	0.00	0.442E-09	0.195E-07
C20	0.118E-03	0.202E-01	0.00	0.119E-09	0.590E-08
C21	0.105E-03	0.180E-01	0.00	0.402E-10	0.223E-08
C22	0.929E-04	0.160E-01	0.00	0.149E-10	0.931E-09
C23	0.830E-04	0.143E-01	0.00	0.384E-11	0.269E-09
C24	0.738E-04	0.127E-01	0.00	0.115E-11	0.905E-10
C25	0.657E-04	0.113E-01	0.00	0.392E-12	0.347E-10
C26	0.584E-04	0.100E-01	0.00	0.111E-12	0.111E-10
C27	0.521E-04	0.897E-02	0.00	0.259E-13	0.289E-11
C28	0.463E-04	0.796E-02	0.00	0.111E-13	0.140E-11
C29	0.411E-04	0.708E-02	0.00	0.440E-14	0.621E-12
C30	0.367E-04	0.632E-02	0.00	0.319E-14	0.505E-12

BLOCK: FT-COMP MODEL: COMPR

INLET STREAM: GAS-FT1
OUTLET STREAM: GAS-FT2
PROPERTY OPTION SET: RK-SOAVE STANDARD RKS EQUATION OF STATE
FREE WATER OPTION SET: SYSOP12 ASME STEAM TABLE
SOLUBLE WATER OPTION: THE MAIN PROPERTY OPTION SET (RK-SOAVE).

*** MASS AND ENERGY BALANCE ***

	IN	OUT	RELATIVE DIFF.
TOTAL BALANCE			
MOLE(KMOL/HR)	989.747	989.747	0.00000
MASS(KG/HR)	27462.2	27462.2	0.461003E-13
ENTHALPY(CAL/SEC)	-0.151168E+08	-0.139088E+08	-0.799109E-01

*** CO2 EQUIVALENT SUMMARY ***

FEED STREAMS CO2E	24498.2	KG/HR
PRODUCT STREAMS CO2E	24498.2	KG/HR
NET STREAMS CO2E PRODUCTION	0.00000	KG/HR
UTILITIES CO2E PRODUCTION	0.00000	KG/HR
TOTAL CO2E PRODUCTION	0.00000	KG/HR

*** INPUT DATA ***

POLYTROPIC COMPRESSOR USING ASME METHOD

OUTLET PRESSURE BAR	20.0000
POLYTROPIC EFFICIENCY	0.72000
MECHANICAL EFFICIENCY	1.00000

*** RESULTS ***

INDICATED HORSEPOWER REQUIREMENT	KW	5,057.66
BRAKE HORSEPOWER REQUIREMENT	KW	5,057.66
NET WORK REQUIRED	KW	5,057.66
POWER LOSSES	KW	0.0
ISENTROPIC HORSEPOWER REQUIREMENT	KW	3,197.18
CALCULATED OUTLET TEMP C		525.386
EFFICIENCY (POLYTR/ISENTR) USED		0.72000
OUTLET VAPOR FRACTION		1.00000
HEAD DEVELOPED, M-KGF/KG		48,677.5
MECHANICAL EFFICIENCY USED		1.00000
INLET HEAT CAPACITY RATIO		1.32130
INLET VOLUMETRIC FLOW RATE , L/MIN		444,960.
OUTLET VOLUMETRIC FLOW RATE, L/MIN		55,126.8
INLET COMPRESSIBILITY FACTOR		0.99903
OUTLET COMPRESSIBILITY FACTOR		1.00670
AV. ISENT. VOL. EXPONENT		1.29213
AV. ISENT. TEMP EXPONENT		1.28799
AV. ACTUAL VOL. EXPONENT		1.43450
AV. ACTUAL TEMP EXPONENT		1.42926

BLOCK: FT-HTX2 MODEL: HEATX

HOT SIDE:

INLET STREAM: PROD-FT1
OUTLET STREAM: PROD-FT2
PROPERTY OPTION SET: RK-SOAVE STANDARD RKS EQUATION OF STATE
FREE WATER OPTION SET: SYSOP12 ASME STEAM TABLE

```
SOLUBLE WATER OPTION:  THE MAIN PROPERTY OPTION SET (RK-SOAVE).
COLD SIDE:
----------
INLET UTILITY:            CW
OUTLET UTILITY:           CW
PROPERTY OPTION SET:   RK-SOAVE  STANDARD RKS EQUATION OF STATE

                    ***  MASS AND ENERGY BALANCE  ***
                                    IN               OUT        RELATIVE DIFF.
 TOTAL BALANCE
    MOLE(KMOL/HR )             858.356          858.356          0.00000
    MASS(KG/HR   )             27462.2          27462.2          0.00000
    ENTHALPY(CAL/SEC )      -0.154858E+08    -0.160957E+08    0.378916E-01

                    ***  CO2 EQUIVALENT SUMMARY ***
 FEED STREAMS CO2E             24824.5      KG/HR
 PRODUCT STREAMS CO2E          24824.5      KG/HR
 NET STREAMS CO2E PRODUCTION   0.00000      KG/HR
 UTILITIES CO2E PRODUCTION     0.00000      KG/HR
 TOTAL CO2E PRODUCTION         0.00000      KG/HR

                       ***  INPUT DATA  ***

FLASH SPECS FOR HOT SIDE:
TWO    PHASE      FLASH
FREE WATER CONSIDERED
MAXIMUM NO. ITERATIONS                                  30
CONVERGENCE TOLERANCE                                    0.000100000

FLOW DIRECTION AND SPECIFICATION:
  COUNTERCURRENT   HEAT EXCHANGER
  SPECIFIED HOT OUTLET TEMP
  SPECIFIED VALUE               C                       30.0000
  LMTD CORRECTION FACTOR                                 1.00000

PRESSURE SPECIFICATION:
  HOT  SIDE PRESSURE DROP       BAR                      0.0000
  COLD SIDE OUTLET PRESSURE     BAR                      1.0132

HEAT TRANSFER COEFFICIENT SPECIFICATION:
  HOT LIQUID    COLD LIQUID     CAL/SEC-SQCM-K           0.0203
  HOT 2-PHASE   COLD LIQUID     CAL/SEC-SQCM-K           0.0203
  HOT VAPOR     COLD LIQUID     CAL/SEC-SQCM-K           0.0203
  HOT LIQUID    COLD 2-PHASE    CAL/SEC-SQCM-K           0.0203
  HOT 2-PHASE   COLD 2-PHASE    CAL/SEC-SQCM-K           0.0203
  HOT VAPOR     COLD 2-PHASE    CAL/SEC-SQCM-K           0.0203
  HOT LIQUID    COLD VAPOR      CAL/SEC-SQCM-K           0.0203
  HOT 2-PHASE   COLD VAPOR      CAL/SEC-SQCM-K           0.0203
  HOT VAPOR     COLD VAPOR      CAL/SEC-SQCM-K           0.0203

                       ***  OVERALL RESULTS  ***

STREAMS:
                ---------------------------------------
                |                                     |
PROD-FT1  ----->|                HOT                  |-----> PROD-FT2
T=  2.0000D+02  |                                     |       T=  3.0000D+01
P=  2.0000D+01  |                                     |       P=  2.0000D+01
V=  9.9920D-01  |                                     |       V=  9.1197D-01
                |                                     |
CW        <-----|                COLD                 |<----- CW
T=  2.5000D+01  |                                     |       T=  2.0000D+01
P=  1.0132D+00  |                                     |       P=  1.0132D+00
V=  0.0000D+00  |                                     |       V=  0.0000D+00
                ---------------------------------------

DUTY AND AREA:
  CALCULATED HEAT DUTY          CAL/SEC             609892.3104
  CALCULATED (REQUIRED) AREA    SQM                     52.1114
  ACTUAL EXCHANGER AREA         SQM                     52.1114
  PER CENT OVER-DESIGN                                   0.0000
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  HEAT TRANSFER COEFFICIENT:
    AVERAGE COEFFICIENT (DIRTY)    CAL/SEC-SQCM-K          0.0203
    UA (DIRTY)                     CAL/SEC-K           10579.6019

  LOG-MEAN TEMPERATURE DIFFERENCE:
    LMTD CORRECTION FACTOR                                 1.0000
    LMTD (CORRECTED)               C                      57.6479
    NUMBER OF SHELLS IN SERIES                              1

  PRESSURE DROP:
    HOTSIDE, TOTAL                 BAR                     0.0000
    COLDSIDE, TOTAL                BAR                     0.0000

                      ***  ASSOCIATED  UTILITIES  ***

 UTILITY ID FOR WATER                          CW
 RATE OF CONSUMPTION                  4.4035+05  KG/HR
 COST                                    1.9488  $/HR

                       ***  ZONE RESULTS  ***

  TEMPERATURE LEAVING EACH ZONE:

                                  HOT
        ------------------------------------------------------------
        |                                                          |
HOT IN  |                           COND                           | HOT OUT
------> |                                                          |------>
 200.0  |                                                          |   30.0
        |                                                          |
COLDOUT |                           LIQ                            | COLDIN
<------ |                                                          |<------
  25.0  |                                                          |   20.0
        |                                                          |
        ------------------------------------------------------------
                                  COLD

  ZONE HEAT TRANSFER AND AREA:

  ZONE       HEAT DUTY       AREA       LMTD       AVERAGE U       UA
             CAL/SEC         SQM         C         CAL/SEC-SQCM-K  CAL/SEC-K
    1     609892.310        52.1114      57.6479     0.0203       10579.6019

BLOCK:  FT-RXR   MODEL: RSTOIC
------------------------------
  INLET STREAM:          GAS-FT2
  OUTLET STREAM:         PROD-FT1
  PROPERTY OPTION SET:   RK-SOAVE  STANDARD RKS EQUATION OF STATE
  FREE WATER OPTION SET: SYSOP12   ASME STEAM TABLE
  SOLUBLE WATER OPTION:  THE MAIN PROPERTY OPTION SET (RK-SOAVE).

                     ***  MASS AND ENERGY BALANCE  ***
                             IN          OUT       GENERATION   RELATIVE DIFF.
  TOTAL BALANCE
  MOLE(KMOL/HR )          989.747       858.356      -131.391     -0.114865E-15
  MASS(KG/HR   )          27462.2       27462.2                   -0.459678E-13
  ENTHALPY(CAL/SEC )   -0.139088E+08 -0.154858E+08                0.101835

                     ***  CO2 EQUIVALENT SUMMARY ***
   FEED STREAMS CO2E             24498.2      KG/HR
   PRODUCT STREAMS CO2E          24824.5      KG/HR
   NET STREAMS CO2E PRODUCTION   326.309      KG/HR
   UTILITIES CO2E PRODUCTION     0.00000      KG/HR
   TOTAL CO2E PRODUCTION         326.309      KG/HR

                         ***  INPUT DATA  ***
  STOICHIOMETRY MATRIX:

   REACTION #   1:
    SUBSTREAM MIXED   :
    H2       -0.442E+06CO       -0.208E+06H2O       0.208E+06C8
0.128E+04
```

```
     C1        0.258E+04C2        0.245E+04C3        0.223E+04C4
0.201E+04
     C5        0.180E+04C6        0.161E+04C7        0.144E+04C9
0.114E+04
     C10       0.102E+04C11        908.    C12        809.    C13        721.
     C14        642.    C15        572.    C16        509.    C17        453.
     C18        404.    C19        359.    C20        320.    C21        285.
     C22        253.    C23        226.    C24        201.    C25        179.
     C26        159.    C27        142.    C28        126.    C29        112.
     C30        100.


   REACTION CONVERSION SPECS: NUMBER=    1
     REACTION #   1:
     SUBSTREAM:MIXED    KEY COMP:CO       CONV FRAC: 0.8500



   TWO    PHASE  TP  FLASH
   FREE WATER CONSIDERED
   SPECIFIED TEMPERATURE C                                    200.000
   SPECIFIED PRESSURE    BAR                                   20.0000
   MAXIMUM NO. ITERATIONS                                      30
   CONVERGENCE TOLERANCE                                        0.000100000
   SIMULTANEOUS REACTIONS
   GENERATE COMBUSTION REACTIONS FOR FEED SPECIES          NO

                          ***  RESULTS  ***
   OUTLET TEMPERATURE    C                                     200.00
   OUTLET PRESSURE       BAR                                   20.000
   HEAT DUTY             CAL/SEC                              -0.15770E+07
   VAPOR FRACTION                                              0.99920
   1ST LIQUID/TOTAL LIQUID                                     1.0000

   HEAT OF REACTIONS:

     REACTION          REFERENCE          HEAT OF
     NUMBER            COMPONENT          REACTION
                                           CAL/MOL
      1                   CO                -37599.

   REACTION EXTENTS:

      REACTION          REACTION
      NUMBER            EXTENT
                        KMOL/HR
      1                 0.31523E-03

   V-L1-L2 PHASE EQUILIBRIUM :

      COMP           F(I)      X1(I)     X2(I)     Y(I)      K1(I)     K2(I)
      H2            0.246     0.716E-02  0.00     0.246      34.4
      CO2           0.647     0.803E-01  0.00     0.648      8.07
      CO            0.135E-01 0.608E-03  0.00     0.135E-01  22.2
      H2O           0.835E-01 0.428E-01  1.00     0.835E-01  1.95     0.753
      C8            0.484E-03 0.163E-02  0.00     0.483E-03 0.297
      C1            0.107E-02 0.827E-04  0.00     0.107E-02  12.9
      C2            0.101E-02 0.162E-03  0.00     0.101E-02  6.27
      C3            0.921E-03 0.252E-03  0.00     0.922E-03  3.65
      C4            0.828E-03 0.390E-03  0.00     0.828E-03  2.12
      C5            0.736E-03 0.579E-03  0.00     0.736E-03  1.27
      C6            0.646E-03 0.836E-03  0.00     0.646E-03 0.772
      C7            0.560E-03 0.118E-02  0.00     0.559E-03 0.476
      C9            0.424E-03 0.228E-02  0.00     0.423E-03 0.186
      C10           0.376E-03 0.328E-02  0.00     0.373E-03 0.114
      C11           0.334E-03 0.441E-02  0.00     0.331E-03 0.750E-01
      C12           0.297E-03 0.622E-02  0.00     0.293E-03 0.471E-01
      C13           0.265E-03 0.885E-02  0.00     0.258E-03 0.292E-01
      C14           0.236E-03 0.122E-01  0.00     0.226E-03 0.186E-01
      C15           0.210E-03 0.166E-01  0.00     0.197E-03 0.118E-01
      C16           0.187E-03 0.221E-01  0.00     0.169E-03 0.765E-02
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     C17           0.166E-03 0.298E-01  0.00     0.143E-03 0.479E-02
     C18           0.148E-03 0.376E-01  0.00     0.118E-03 0.315E-02
     C19           0.132E-03 0.463E-01  0.00     0.948E-04 0.205E-02
     C20           0.118E-03 0.564E-01  0.00     0.724E-04 0.128E-02
     C21           0.105E-03 0.635E-01  0.00     0.538E-04 0.847E-03
     C22           0.929E-04 0.674E-01  0.00     0.389E-04 0.577E-03
     C23           0.830E-04 0.718E-01  0.00     0.255E-04 0.354E-03
     C24           0.738E-04 0.717E-01  0.00     0.164E-04 0.229E-03
     C25           0.657E-04 0.689E-01  0.00     0.106E-04 0.153E-03
     C26           0.584E-04 0.650E-01  0.00     0.631E-05 0.971E-04
     C27           0.521E-04 0.606E-01  0.00     0.355E-05 0.586E-04
     C28           0.463E-04 0.548E-01  0.00     0.232E-05 0.422E-04
     C29           0.411E-04 0.495E-01  0.00     0.148E-05 0.299E-04
     C30           0.367E-04 0.447E-01  0.00     0.876E-06 0.196E-04

                        ***  ASSOCIATED  UTILITIES  ***

 UTILITY ID FOR WATER                          CW
 RATE OF CONSUMPTION                    1.1386+06  KG/HR
 COST                                      5.0391  $/HR

BLOCK:  H2O-PUMP MODEL: PUMP
------------------------------
  INLET STREAM:          H2O-IN1
  OUTLET STREAM:         H2O-IN2
  PROPERTY OPTION SET:   RK-SOAVE  STANDARD RKS EQUATION OF STATE
  FREE WATER OPTION SET: SYSOP12   ASME STEAM TABLE
  SOLUBLE WATER OPTION:  THE MAIN PROPERTY OPTION SET (RK-SOAVE).

                      ***  MASS AND ENERGY BALANCE  ***
                                   IN              OUT        RELATIVE DIFF.
   TOTAL BALANCE
      MOLE(KMOL/HR )            230.000         230.000          0.00000
      MASS(KG/HR   )            4143.51         4143.51          0.00000
      ENTHALPY(CAL/SEC )     -0.436160E+07   -0.436076E+07   -0.192408E-03

                      ***  CO2 EQUIVALENT SUMMARY ***
   FEED STREAMS CO2E             0.00000      KG/HR
   PRODUCT STREAMS CO2E          0.00000      KG/HR
   NET STREAMS CO2E PRODUCTION   0.00000      KG/HR
   UTILITIES CO2E PRODUCTION     0.00000      KG/HR
   TOTAL CO2E PRODUCTION         0.00000      KG/HR

                         ***  INPUT DATA  ***
   OUTLET PRESSURE  BAR                                    10.0000
   DRIVER EFFICIENCY                                        1.00000

   FLASH SPECIFICATIONS:
   2 PHASE FLASH
   FREE WATER CONSIDERED
   MAXIMUM NUMBER OF ITERATIONS                            30
   TOLERANCE                                               0.000100000

                          ***  RESULTS  ***
   VOLUMETRIC FLOW RATE  L/MIN                            69.2547
   PRESSURE CHANGE  BAR                                    9.00000
   NPSH AVAILABLE   M-KGF/KG                               9.90287
   FLUID POWER  KW                                         1.03882
   BRAKE POWER  KW                                         3.51360
   ELECTRICITY  KW                                         3.51360
   PUMP EFFICIENCY USED                                    0.29566
   NET WORK REQUIRED  KW                                   3.51360
   HEAD DEVELOPED M-KGF/KG                                92.0352

BLOCK:  HEAT     MODEL: HEATER
------------------------------
  INLET STREAM:          CFE3O4
  INLET HEAT STREAM:     CR5-HEAT
  OUTLET STREAM:         HOTF3O4
  PROPERTY OPTION SET:   RK-SOAVE  STANDARD RKS EQUATION OF STATE
  FREE WATER OPTION SET: SYSOP12   ASME STEAM TABLE
  SOLUBLE WATER OPTION:  THE MAIN PROPERTY OPTION SET (RK-SOAVE).
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                    ***  MASS AND ENERGY BALANCE  ***
                                 IN              OUT        RELATIVE DIFF.
 TOTAL BALANCE
    MOLE(KMOL/HR )            4166.67         4166.67          0.00000
    MASS(KG/HR   )            964744.         964744.          0.00000
    ENTHALPY(CAL/SEC )     -0.201595E+09   -0.201595E+09    0.147832E-15

                    ***  CO2 EQUIVALENT SUMMARY ***
 FEED STREAMS CO2E            0.00000      KG/HR
 PRODUCT STREAMS CO2E         0.00000      KG/HR
 NET STREAMS CO2E PRODUCTION  0.00000      KG/HR
 UTILITIES CO2E PRODUCTION    0.00000      KG/HR
 TOTAL CO2E PRODUCTION        0.00000      KG/HR

                         ***  INPUT DATA  ***
 TWO    PHASE  PQ  FLASH
 FREE WATER CONSIDERED
 SPECIFIED PRESSURE                  BAR                       0.20265
 DUTY FROM INLET HEAT STREAM(S)      CAL/SEC                   0.922867+08
 MAXIMUM NO. ITERATIONS                                       30
 CONVERGENCE TOLERANCE                                         0.000100000


                         ***  RESULTS  ***
 OUTLET TEMPERATURE    C                                      1916.3
 OUTLET PRESSURE       BAR                                   0.20265
 OUTLET VAPOR FRACTION                                        0.0000
 OUTLET: 1ST LIQUID/TOTAL LIQUID                              0.0000


BLOCK:  MIX-FT   MODEL: MIXER
------------------------------
 INLET STREAMS:         GAS-WGSF    CO-FT       GAS-FT4
 OUTLET STREAM:         GAS-FT1
 PROPERTY OPTION SET:   RK-SOAVE  STANDARD RKS EQUATION OF STATE
 FREE WATER OPTION SET: SYSOP12   ASME STEAM TABLE
 SOLUBLE WATER OPTION:  THE MAIN PROPERTY OPTION SET (RK-SOAVE).

                    ***  MASS AND ENERGY BALANCE  ***
                                 IN              OUT        RELATIVE DIFF.
 TOTAL BALANCE
    MOLE(KMOL/HR )             989.742         989.747       -0.461865E-05
    MASS(KG/HR   )             27462.2         27462.2       -0.199992E-05
    ENTHALPY(CAL/SEC )     -0.151168E+08   -0.151168E+08    0.199028E-05

                    ***  CO2 EQUIVALENT SUMMARY ***
 FEED STREAMS CO2E            24498.2      KG/HR
 PRODUCT STREAMS CO2E         24498.2      KG/HR
 NET STREAMS CO2E PRODUCTION  0.487757E-01  KG/HR
 UTILITIES CO2E PRODUCTION    0.00000      KG/HR
 TOTAL CO2E PRODUCTION        0.487757E-01  KG/HR

                         ***  INPUT DATA  ***
 TWO    PHASE      FLASH
 FREE WATER CONSIDERED
 MAXIMUM NO. ITERATIONS                                       30
 CONVERGENCE TOLERANCE                                         0.000100000
 OUTLET PRESSURE   BAR                                       1.00000

BLOCK:  MIX-WGS  MODEL: MIXER
------------------------------
 INLET STREAMS:         CO-WGS      H2O-WGS2    H2O-REC     H2O-IN2
 OUTLET STREAM:         WGS-IN1
 PROPERTY OPTION SET:   RK-SOAVE  STANDARD RKS EQUATION OF STATE
 FREE WATER OPTION SET: SYSOP12   ASME STEAM TABLE
 SOLUBLE WATER OPTION:  THE MAIN PROPERTY OPTION SET (RK-SOAVE).

                    ***  MASS AND ENERGY BALANCE  ***
                                 IN              OUT        RELATIVE DIFF.
```

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   TOTAL BALANCE
      MOLE(KMOL/HR )            1339.86         1339.86         0.00000
      MASS(KG/HR   )            32345.0         32345.0         0.00000
      ENTHALPY(CAL/SEC )      -0.210338E+08   -0.210338E+08    0.354219E-15

                      ***  CO2 EQUIVALENT SUMMARY ***
   FEED STREAMS CO2E             9813.95      KG/HR
   PRODUCT STREAMS CO2E          9813.95      KG/HR
   NET STREAMS CO2E PRODUCTION   0.00000      KG/HR
   UTILITIES CO2E PRODUCTION     0.00000      KG/HR
   TOTAL CO2E PRODUCTION         0.00000      KG/HR

                           ***  INPUT DATA  ***
  TWO    PHASE      FLASH
  FREE WATER CONSIDERED
  MAXIMUM NO. ITERATIONS                                    30
  CONVERGENCE TOLERANCE                                      0.000100000
  OUTLET PRESSURE   BAR                                     1.00000

BLOCK:  MIXCO2   MODEL: MIXER
------------------------------
  INLET STREAMS:          CO2-IN      GAS-FT5
  OUTLET STREAM:          CO2-CR5
  PROPERTY OPTION SET:    RK-SOAVE  STANDARD RKS EQUATION OF STATE
  FREE WATER OPTION SET: SYSOP12   ASME STEAM TABLE
  SOLUBLE WATER OPTION:  THE MAIN PROPERTY OPTION SET (RK-SOAVE).

                      ***  MASS AND ENERGY BALANCE  ***
                                  IN              OUT        RELATIVE DIFF.
   TOTAL BALANCE
      MOLE(KMOL/HR )             626.798         626.798         0.00000
      MASS(KG/HR   )             25323.0         25323.0        0.304566E-13
      ENTHALPY(CAL/SEC )      -0.145424E+08   -0.145424E+08   -0.303559E-13

                      ***  CO2 EQUIVALENT SUMMARY ***
   FEED STREAMS CO2E             25161.8      KG/HR
   PRODUCT STREAMS CO2E          25161.8      KG/HR
   NET STREAMS CO2E PRODUCTION   0.00000      KG/HR
   UTILITIES CO2E PRODUCTION     0.00000      KG/HR
   TOTAL CO2E PRODUCTION         0.00000      KG/HR

                           ***  INPUT DATA  ***
  TWO    PHASE      FLASH
  FREE WATER CONSIDERED
  MAXIMUM NO. ITERATIONS                                    30
  CONVERGENCE TOLERANCE                                      0.000100000
  OUTLET PRESSURE:  MINIMUM OF INLET STREAM PRESSURES

BLOCK:  OX       MODEL: RSTOIC
------------------------------
  INLET STREAMS:          COOLFEO     CO2-CR5
  OUTLET STREAM:          OXOUT
  PROPERTY OPTION SET:    RK-SOAVE  STANDARD RKS EQUATION OF STATE
  FREE WATER OPTION SET: SYSOP12   ASME STEAM TABLE
  SOLUBLE WATER OPTION:  THE MAIN PROPERTY OPTION SET (RK-SOAVE).

                      ***  MASS AND ENERGY BALANCE  ***
                             IN           OUT       GENERATION   RELATIVE DIFF.
  TOTAL BALANCE
  MOLE(KMOL/HR )          9723.46       9049.46       -674.004      0.374144E-15
  MASS(KG/HR   )          950629.       950629.                      0.00000
  ENTHALPY(CAL/SEC )   -0.260267E+09 -0.260454E+09                  0.718659E-03

                      ***  CO2 EQUIVALENT SUMMARY ***
   FEED STREAMS CO2E             25161.8      KG/HR
   PRODUCT STREAMS CO2E          10330.4      KG/HR
   NET STREAMS CO2E PRODUCTION  -14831.4      KG/HR
   UTILITIES CO2E PRODUCTION     0.00000      KG/HR
   TOTAL CO2E PRODUCTION        -14831.4      KG/HR

                           ***  INPUT DATA  ***
  STOICHIOMETRY MATRIX:
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```
 REACTION #   1:
  SUBSTREAM MIXED   :
  CO2       -1.00    CO         1.00    FE3O4      1.00    FEO       -3.00


REACTION CONVERSION SPECS: NUMBER=    1
  REACTION #   1:
  SUBSTREAM:MIXED    KEY COMP:CO2      CONV FRAC: 0.5916



TWO    PHASE  TP  FLASH
FREE WATER CONSIDERED
SPECIFIED TEMPERATURE C                                  326.850
SPECIFIED PRESSURE    BAR                                 0.20265
MAXIMUM NO. ITERATIONS                                   30
CONVERGENCE TOLERANCE                                     0.000100000
SIMULTANEOUS REACTIONS
GENERATE COMBUSTION REACTIONS FOR FEED SPECIES          NO

                         ***  RESULTS  ***
OUTLET TEMPERATURE    C                                   326.85
OUTLET PRESSURE       BAR                                0.20265
HEAT DUTY             CAL/SEC                            0.25212E+09
VAPOR FRACTION                                            1.0000
1ST LIQUID/TOTAL LIQUID                                   1.0000

REACTION EXTENTS:

   REACTION          REACTION
   NUMBER            EXTENT
                     KMOL/HR
   1                  337.00

V-L1-L2 PHASE EQUILIBRIUM :

   COMP           F(I)      X1(I)     X2(I)     Y(I)      K1(I)     K2(I)
   H2           0.841E-01 0.800E-01  0.00     0.841E-01 0.276E+04
   CO2          0.371     0.406      0.00     0.371     0.240E+04
   CO           0.542     0.511      0.00     0.542     0.279E+04  421.
   H2O          0.574E-03 0.831E-03  1.00     0.574E-03 0.181E+04  421.
   C8           0.406E-04 0.300E-04  0.00     0.406E-04 0.356E+04
   C1           0.365E-03 0.370E-03  0.00     0.365E-03 0.259E+04
   C2           0.346E-03 0.348E-03  0.00     0.346E-03 0.261E+04
   C3           0.312E-03 0.299E-03  0.00     0.312E-03 0.275E+04
   C4           0.275E-03 0.248E-03  0.00     0.275E-03 0.291E+04
   C5           0.228E-03 0.194E-03  0.00     0.228E-03 0.309E+04
   C6           0.168E-03 0.133E-03  0.00     0.168E-03 0.331E+04
   C7           0.971E-04 0.715E-04  0.00     0.971E-04 0.357E+04
   C9           0.144E-04 0.982E-05  0.00     0.144E-04 0.386E+04
   C10          0.479E-05 0.258E-05  0.00     0.479E-05 0.489E+04
   C11          0.165E-05 0.924E-06  0.00     0.165E-05 0.471E+04
   C12          0.504E-06 0.252E-06  0.00     0.504E-06 0.525E+04
   C13          0.137E-06 0.612E-07  0.00     0.137E-06 0.589E+04
   C14          0.464E-07 0.183E-07  0.00     0.464E-07 0.667E+04
   C15          0.143E-07 0.501E-08  0.00     0.143E-07 0.749E+04
   C16          0.480E-08 0.149E-08  0.00     0.480E-08 0.845E+04
   C17          0.133E-08 0.375E-09  0.00     0.133E-08 0.930E+04
   C18          0.434E-09 0.107E-09  0.00     0.434E-09 0.106E+05
   C19          0.138E-09 0.301E-10  0.00     0.138E-09 0.120E+05
   C20          0.372E-10 0.728E-11  0.00     0.372E-10 0.135E+05
   C21          0.125E-10 0.215E-11  0.00     0.125E-10 0.153E+05
   C22          0.465E-11 0.687E-12  0.00     0.465E-11 0.178E+05
   C23          0.120E-11 0.157E-12  0.00     0.120E-11 0.201E+05
   C24          0.359E-12 0.411E-13  0.00     0.359E-12 0.230E+05
   C25          0.123E-12 0.125E-13  0.00     0.123E-12 0.257E+05
   C26          0.347E-13 0.302E-14  0.00     0.347E-13 0.302E+05
   C27          0.810E-14 0.634E-15  0.00     0.810E-14 0.336E+05

BLOCK:  RED      MODEL: RSTOIC
```

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------------------------------
  INLET STREAM:          HOTF304
  OUTLET STREAM:         REDOUT
  PROPERTY OPTION SET:   RK-SOAVE  STANDARD RKS EQUATION OF STATE
  FREE WATER OPTION SET: SYSOP12   ASME STEAM TABLE
  SOLUBLE WATER OPTION:  THE MAIN PROPERTY OPTION SET (RK-SOAVE).

                     ***  MASS AND ENERGY BALANCE  ***
                             IN           OUT       GENERATION   RELATIVE DIFF.
  TOTAL BALANCE
  MOLE(KMOL/HR )          4166.67       10329.2       6162.50       0.00000
  MASS(KG/HR   )          964744.       964744.                    -0.241339E-15
  ENTHALPY(CAL/SEC )   -0.201595E+09 -0.147682E+09                  -0.267432

                     ***  CO2 EQUIVALENT SUMMARY ***
   FEED STREAMS CO2E             0.00000      KG/HR
   PRODUCT STREAMS CO2E          0.00000      KG/HR
   NET STREAMS CO2E PRODUCTION   0.00000      KG/HR
   UTILITIES CO2E PRODUCTION     0.00000      KG/HR
   TOTAL CO2E PRODUCTION         0.00000      KG/HR

                          ***  INPUT DATA  ***
  STOICHIOMETRY MATRIX:

   REACTION #   1:
    SUBSTREAM MIXED   :
    O2        0.500    FE3O4     -1.00    FEO        3.00


  REACTION CONVERSION SPECS: NUMBER=    1
    REACTION #   1:
    SUBSTREAM:MIXED    KEY COMP:FE3O4    CONV FRAC: 0.5916



  TWO    PHASE  TP  FLASH
  FREE WATER CONSIDERED
  SPECIFIED TEMPERATURE C                                  2,026.85
  SPECIFIED PRESSURE    BAR                                    0.20265
  MAXIMUM NO. ITERATIONS                                      30
  CONVERGENCE TOLERANCE                                       0.000100000
  SIMULTANEOUS REACTIONS
  GENERATE COMBUSTION REACTIONS FOR FEED SPECIES          NO

                           ***  RESULTS  ***
  OUTLET TEMPERATURE    C                                     2026.8
  OUTLET PRESSURE       BAR                                   0.20265
  HEAT DUTY             CAL/SEC                               0.20735E+09
  VAPOR FRACTION                                              1.0000
  1ST LIQUID/TOTAL LIQUID                                     1.0000

  REACTION EXTENTS:

     REACTION          REACTION
     NUMBER            EXTENT
                       KMOL/HR
     1                  2465.0

  V-L1-L2 PHASE EQUILIBRIUM :

     COMP           F(I)      X1(I)     X2(I)     Y(I)      K1(I)     K2(I)
     O2             1.00      1.00      0.00      1.00     0.139E+05

BLOCK:  SPLIT-CO MODEL: FSPLIT
------------------------------
  INLET STREAM:          CO2-CO-2
  OUTLET STREAMS:        CO-WGS      CO-FT
  PROPERTY OPTION SET:   RK-SOAVE  STANDARD RKS EQUATION OF STATE
  FREE WATER OPTION SET: SYSOP12   ASME STEAM TABLE
  SOLUBLE WATER OPTION:  THE MAIN PROPERTY OPTION SET (RK-SOAVE).
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```
                      ***  MASS AND ENERGY BALANCE  ***
                                    IN              OUT        RELATIVE DIFF.
   TOTAL BALANCE
      MOLE(KMOL/HR )            626.810         626.810          0.00000
      MASS(KG/HR   )            19931.2         19931.2          0.00000
      ENTHALPY(CAL/SEC )     -0.728297E+07   -0.728297E+07     0.00000

                      ***  CO2 EQUIVALENT SUMMARY ***
   FEED STREAMS CO2E             10330.5      KG/HR
   PRODUCT STREAMS CO2E          10330.5      KG/HR
   NET STREAMS CO2E PRODUCTION   0.00000      KG/HR
   UTILITIES CO2E PRODUCTION     0.00000      KG/HR
   TOTAL CO2E PRODUCTION         0.00000      KG/HR

                          ***  INPUT DATA  ***

  FRACTION OF FLOW                STRM=CO-WGS   FRAC=         0.95000

                          ***  RESULTS  ***

  STREAM= CO-WGS         SPLIT=          0.95000     KEY=  0    STREAM-ORDER=
1
          CO-FT                          0.050000          0
2

 BLOCK:  SPLITCO  MODEL: SEP2
 ------------------------------
   INLET STREAM:          OXOUT
   OUTLET STREAMS:        COOLF3O4    CR5-OUT
   PROPERTY OPTION SET:   RK-SOAVE  STANDARD RKS EQUATION OF STATE
   FREE WATER OPTION SET: SYSOP12   ASME STEAM TABLE
   SOLUBLE WATER OPTION:  THE MAIN PROPERTY OPTION SET (RK-SOAVE).

                      ***  MASS AND ENERGY BALANCE  ***
                                    IN              OUT        RELATIVE DIFF.
   TOTAL BALANCE
      MOLE(KMOL/HR )            9049.46         9049.46         0.402011E-15
      MASS(KG/HR   )            950629.         950629.         0.183692E-14
      ENTHALPY(CAL/SEC )     -0.260454E+09   -0.260454E+09    0.173959E-11

                      ***  CO2 EQUIVALENT SUMMARY ***
   FEED STREAMS CO2E             10330.4      KG/HR
   PRODUCT STREAMS CO2E          10330.4      KG/HR
   NET STREAMS CO2E PRODUCTION   0.00000      KG/HR
   UTILITIES CO2E PRODUCTION     0.00000      KG/HR
   TOTAL CO2E PRODUCTION         0.00000      KG/HR


                          ***  INPUT DATA  ***

   INLET PRESSURE   BAR                                      1.00000

   FLASH SPECS FOR STREAM COOLF3O4
   TWO    PHASE  TP  FLASH
   FREE WATER CONSIDERED
   PRESSURE DROP         BAR                                 0.0
   MAXIMUM NO. ITERATIONS                                   30
   CONVERGENCE TOLERANCE                                    0.000100000

   FLASH SPECS FOR STREAM CR5-OUT
   TWO    PHASE  TP  FLASH
   FREE WATER CONSIDERED
   PRESSURE DROP         BAR                                 0.0
   MAXIMUM NO. ITERATIONS                                   30
   CONVERGENCE TOLERANCE                                    0.000100000


                          ***  RESULTS  ***

   HEAT DUTY             CAL/SEC                          -0.45306E-03

  STREAM=   COOLF3O4   SUBSTREAM= MIXED
```

```
    COMPONENT = FE3O4     SPLIT FRACTION =          1.00000
    COMPONENT = FEO       SPLIT FRACTION =          1.00000

 STREAM=   CR5-OUT    SUBSTREAM= MIXED
    COMPONENT = H2        SPLIT FRACTION =          1.00000
    COMPONENT = CO2       SPLIT FRACTION =          1.00000
    COMPONENT = CO        SPLIT FRACTION =          1.00000
    COMPONENT = H2O       SPLIT FRACTION =          1.00000
    COMPONENT = C8        SPLIT FRACTION =          1.00000
    COMPONENT = C1        SPLIT FRACTION =          1.00000
    COMPONENT = C2        SPLIT FRACTION =          1.00000
    COMPONENT = C3        SPLIT FRACTION =          1.00000
    COMPONENT = C4        SPLIT FRACTION =          1.00000
    COMPONENT = C5        SPLIT FRACTION =          1.00000
    COMPONENT = C6        SPLIT FRACTION =          1.00000
    COMPONENT = C7        SPLIT FRACTION =          1.00000
    COMPONENT = C9        SPLIT FRACTION =          1.00000
    COMPONENT = C10       SPLIT FRACTION =          1.00000
    COMPONENT = C11       SPLIT FRACTION =          1.00000
    COMPONENT = C12       SPLIT FRACTION =          1.00000
    COMPONENT = C13       SPLIT FRACTION =          1.00000
    COMPONENT = C14       SPLIT FRACTION =          1.00000
    COMPONENT = C15       SPLIT FRACTION =          1.00000
    COMPONENT = C16       SPLIT FRACTION =          1.00000
    COMPONENT = C17       SPLIT FRACTION =          1.00000
    COMPONENT = C18       SPLIT FRACTION =          1.00000
    COMPONENT = C19       SPLIT FRACTION =          1.00000
    COMPONENT = C20       SPLIT FRACTION =          1.00000
    COMPONENT = C21       SPLIT FRACTION =          1.00000
    COMPONENT = C22       SPLIT FRACTION =          1.00000
    COMPONENT = C23       SPLIT FRACTION =          1.00000
    COMPONENT = C24       SPLIT FRACTION =          1.00000
    COMPONENT = C25       SPLIT FRACTION =          1.00000
    COMPONENT = C26       SPLIT FRACTION =          1.00000

 BLOCK:  SPLITGAS MODEL: FSPLIT
 ------------------------------
   INLET STREAM:          GAS-FT3
   OUTLET STREAMS:        GAS-FT4     GAS-FT5     GASPURGE
   PROPERTY OPTION SET:   RK-SOAVE  STANDARD RKS EQUATION OF STATE
   FREE WATER OPTION SET: SYSOP12   ASME STEAM TABLE
   SOLUBLE WATER OPTION:  THE MAIN PROPERTY OPTION SET (RK-SOAVE).

                       ***  MASS AND ENERGY BALANCE  ***
                                    IN              OUT        RELATIVE DIFF.
    TOTAL BALANCE
       MOLE(KMOL/HR )            783.193         783.193          0.00000
       MASS(KG/HR   )            25418.9         25418.9         0.887349E-13
       ENTHALPY(CAL/SEC )     -0.146410E+08   -0.146410E+08   -0.888001E-13

                       ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E             24774.4      KG/HR
    PRODUCT STREAMS CO2E          24774.4      KG/HR
    NET STREAMS CO2E PRODUCTION   0.00000      KG/HR
    UTILITIES CO2E PRODUCTION     0.00000      KG/HR
    TOTAL CO2E PRODUCTION         0.00000      KG/HR

                           ***  INPUT DATA  ***

   OUTLET PRESSURE   BAR                                    1.00000

   FRACTION OF FLOW                STRM=GAS-FT4  FRAC=         0.100000
                                   STRM=GASPURGE FRAC=         0.65000

                           ***  RESULTS  ***

   STREAM= GAS-FT4        SPLIT=          0.100000    KEY=  0    STREAM-ORDER=
1
           GAS-FT5                        0.25000           0
3
           GASPURGE                       0.65000           0
2
```

```
 BLOCK:  SPLITH2O MODEL: FSPLIT
 ------------------------------
   INLET STREAM:          H2O-WGS1
   OUTLET STREAMS:        H2O-WGS2    H2OPURGE
   PROPERTY OPTION SET:   RK-SOAVE  STANDARD RKS EQUATION OF STATE
   FREE WATER OPTION SET: SYSOP12   ASME STEAM TABLE
   SOLUBLE WATER OPTION:  THE MAIN PROPERTY OPTION SET (RK-SOAVE).

                      ***  MASS AND ENERGY BALANCE  ***
                                   IN              OUT        RELATIVE DIFF.
    TOTAL BALANCE
       MOLE(KMOL/HR )            467.519         467.519         0.00000
       MASS(KG/HR   )            8422.49         8422.49         0.00000
       ENTHALPY(CAL/SEC )     -0.886559E+07   -0.886559E+07     0.00000

                      ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E             0.00000      KG/HR
    PRODUCT STREAMS CO2E          0.00000      KG/HR
    NET STREAMS CO2E PRODUCTION   0.00000      KG/HR
    UTILITIES CO2E PRODUCTION     0.00000      KG/HR
    TOTAL CO2E PRODUCTION         0.00000      KG/HR

                           ***  INPUT DATA  ***

  FRACTION OF FLOW                 STRM=H2O-WGS2 FRAC=         0.95000

                            ***  RESULTS  ***

  STREAM= H2O-WGS2       SPLIT=          0.95000     KEY=  0    STREAM-ORDER=
1
          H2OPURGE                      0.050000          0
2

 BLOCK:  SPLITO2  MODEL: SEP2
 ----------------------------
   INLET STREAM:          REDOUT
   OUTLET STREAMS:        O2          HOTFEO
   PROPERTY OPTION SET:   RK-SOAVE  STANDARD RKS EQUATION OF STATE
   FREE WATER OPTION SET: SYSOP12   ASME STEAM TABLE
   SOLUBLE WATER OPTION:  THE MAIN PROPERTY OPTION SET (RK-SOAVE).

                      ***  MASS AND ENERGY BALANCE  ***
                                   IN              OUT        RELATIVE DIFF.
    TOTAL BALANCE
       MOLE(KMOL/HR )            10329.2         10329.2        0.176102E-15
       MASS(KG/HR   )            964744.         964744.        0.241339E-15
       ENTHALPY(CAL/SEC )     -0.147682E+09   -0.147682E+09    0.201800E-15

                      ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E             0.00000      KG/HR
    PRODUCT STREAMS CO2E          0.00000      KG/HR
    NET STREAMS CO2E PRODUCTION   0.00000      KG/HR
    UTILITIES CO2E PRODUCTION     0.00000      KG/HR
    TOTAL CO2E PRODUCTION         0.00000      KG/HR


                           ***  INPUT DATA  ***

   FLASH SPECS FOR STREAM O2
   TWO    PHASE  TP  FLASH
   FREE WATER CONSIDERED
   PRESSURE DROP         BAR                                  0.0
   MAXIMUM NO. ITERATIONS                                    30
   CONVERGENCE TOLERANCE                                      0.000100000

   FLASH SPECS FOR STREAM HOTFEO
   TWO    PHASE  TP  FLASH
   FREE WATER CONSIDERED
   PRESSURE DROP         BAR                                  0.0
   MAXIMUM NO. ITERATIONS                                    30
   CONVERGENCE TOLERANCE                                      0.000100000
```

```
                          ***  RESULTS  ***

 HEAT DUTY             CAL/SEC                          -0.28473E-07

 STREAM=   O2          SUBSTREAM= MIXED
    COMPONENT = O2         SPLIT FRACTION =          1.00000

 STREAM=   HOTFEO      SUBSTREAM= MIXED
    COMPONENT = FE3O4      SPLIT FRACTION =          1.00000
    COMPONENT = FEO        SPLIT FRACTION =          1.00000

BLOCK:  WGS-HTX1 MODEL: HEATX
------------------------------
  HOT SIDE:
  ---------
  INLET STREAM:             WGS-OUT1
  OUTLET STREAM:            WGS-OUT2
  PROPERTY OPTION SET:   RK-SOAVE  STANDARD RKS EQUATION OF STATE
  FREE WATER OPTION SET: SYSOP12   ASME STEAM TABLE
  SOLUBLE WATER OPTION:  THE MAIN PROPERTY OPTION SET (RK-SOAVE).
  COLD SIDE:
  ----------
  INLET STREAM:             WGS-IN1
  OUTLET STREAM:            WGS-IN2
  PROPERTY OPTION SET:   RK-SOAVE  STANDARD RKS EQUATION OF STATE
  FREE WATER OPTION SET: SYSOP12   ASME STEAM TABLE
  SOLUBLE WATER OPTION:  THE MAIN PROPERTY OPTION SET (RK-SOAVE).

                     ***  MASS AND ENERGY BALANCE  ***
                                  IN               OUT        RELATIVE DIFF.
   TOTAL BALANCE
      MOLE(KMOL/HR )            2687.46          2687.46          0.00000
      MASS(KG/HR   )            64691.2          64691.2          0.00000
      ENTHALPY(CAL/SEC )     -0.402858E+08    -0.402858E+08       0.00000

                     ***  CO2 EQUIVALENT SUMMARY ***
   FEED STREAMS CO2E             31318.2      KG/HR
   PRODUCT STREAMS CO2E          31318.2      KG/HR
   NET STREAMS CO2E PRODUCTION   0.00000      KG/HR
   UTILITIES CO2E PRODUCTION     0.00000      KG/HR
   TOTAL CO2E PRODUCTION         0.00000      KG/HR

                          ***  INPUT DATA  ***

  FLASH SPECS FOR HOT SIDE:
  TWO    PHASE      FLASH
  FREE WATER CONSIDERED
  MAXIMUM NO. ITERATIONS                                    30
  CONVERGENCE TOLERANCE                                      0.000100000

  FLASH SPECS FOR COLD SIDE:
  TWO    PHASE      FLASH
  FREE WATER CONSIDERED
  MAXIMUM NO. ITERATIONS                                    30
  CONVERGENCE TOLERANCE                                      0.000100000

  FLOW DIRECTION AND SPECIFICATION:
    COUNTERCURRENT   HEAT EXCHANGER
    SPECIFIED COLD OUTLET TEMP
    SPECIFIED VALUE               C                      300.0000
    LMTD CORRECTION FACTOR                                 1.00000

  PRESSURE SPECIFICATION:
    HOT  SIDE PRESSURE DROP       BAR                      0.0000
    COLD SIDE PRESSURE DROP       BAR                      0.0000

  HEAT TRANSFER COEFFICIENT SPECIFICATION:
    HOT LIQUID    COLD LIQUID     CAL/SEC-SQCM-K           0.0203
    HOT 2-PHASE   COLD LIQUID     CAL/SEC-SQCM-K           0.0203
    HOT VAPOR     COLD LIQUID     CAL/SEC-SQCM-K           0.0203
```

```
  HOT LIQUID    COLD 2-PHASE     CAL/SEC-SQCM-K           0.0203
  HOT 2-PHASE   COLD 2-PHASE     CAL/SEC-SQCM-K           0.0203
  HOT VAPOR     COLD 2-PHASE     CAL/SEC-SQCM-K           0.0203
  HOT LIQUID    COLD VAPOR       CAL/SEC-SQCM-K           0.0203
  HOT 2-PHASE   COLD VAPOR       CAL/SEC-SQCM-K           0.0203
  HOT VAPOR     COLD VAPOR       CAL/SEC-SQCM-K           0.0203

                     ***  OVERALL RESULTS  ***

  STREAMS:
                  ---------------------------------------
                  |                                     |
  WGS-OUT1  ----->|                HOT                  |-----> WGS-OUT2
  T=  4.8660D+02  |                                     |       T=  1.5204D+02
  P=  1.0000D+01  |                                     |       P=  1.0000D+01
  V=  1.0000D+00  |                                     |       V=  8.1616D-01
                  |                                     |
  WGS-IN2   <-----|                COLD                 |<----- WGS-IN1
  T=  3.0000D+02  |                                     |       T=  1.0557D+02
  P=  1.0000D+00  |                                     |       P=  1.0000D+00
  V=  1.0000D+00  |                                     |       V=  6.7432D-01
                  ---------------------------------------

  DUTY AND AREA:
    CALCULATED HEAT DUTY           CAL/SEC          1782923.7886
    CALCULATED (REQUIRED) AREA     SQM                  102.3018
    ACTUAL EXCHANGER AREA          SQM                  102.3018
    PER CENT OVER-DESIGN                                  0.0000

  HEAT TRANSFER COEFFICIENT:
    AVERAGE COEFFICIENT (DIRTY)    CAL/SEC-SQCM-K           0.0203
    UA (DIRTY)                     CAL/SEC-K            20769.2197

  LOG-MEAN TEMPERATURE DIFFERENCE:
    LMTD CORRECTION FACTOR                                1.0000
    LMTD (CORRECTED)               C                     85.8445
    NUMBER OF SHELLS IN SERIES                             1

  PRESSURE DROP:
    HOTSIDE, TOTAL                 BAR                    0.0000
    COLDSIDE, TOTAL                BAR                    0.0000

                     ***  ZONE RESULTS  ***

  TEMPERATURE LEAVING EACH ZONE:

                                  HOT
         ------------------------------------------------------------
         |                |                |                |
HOT IN   |        VAP     |        VAP     |        COND    | HOT OUT
------>  |                |                |                |------>
 486.6   |           324.5|           170.2|                |  152.0
         |                |                |                |
COLDOUT  |        VAP     |        BOIL    |        BOIL    | COLDIN
<------  |                |                |                |<------
 300.0   |           116.8|           113.4|                |  105.6
         |                |                |                |
         ------------------------------------------------------------
                                  COLD

  ZONE HEAT TRANSFER AND AREA:

  ZONE       HEAT DUTY       AREA       LMTD       AVERAGE U       UA
             CAL/SEC         SQM         C         CAL/SEC-SQCM-K  CAL/SEC-K
    1     573407.364        14.3425     196.9260     0.0203        2911.7903
    2     521528.734        22.0831     116.3271     0.0203        4483.2955
    3     687987.690        65.8763      51.4417     0.0203       13374.1340

BLOCK:  WGS-HTX2 MODEL: HEATX
------------------------------
  HOT SIDE:
  ---------
```

```
INLET STREAM:             WGS-OUT2
OUTLET STREAM:            WGS-OUT3
PROPERTY OPTION SET:   RK-SOAVE  STANDARD RKS EQUATION OF STATE
FREE WATER OPTION SET: SYSOP12   ASME STEAM TABLE
SOLUBLE WATER OPTION:  THE MAIN PROPERTY OPTION SET (RK-SOAVE).
COLD SIDE:
----------
INLET UTILITY:            CW
OUTLET UTILITY:           CW
PROPERTY OPTION SET:   RK-SOAVE  STANDARD RKS EQUATION OF STATE

                   ***  MASS AND ENERGY BALANCE  ***
                                IN              OUT        RELATIVE DIFF.
 TOTAL BALANCE
    MOLE(KMOL/HR )           1347.60         1347.60         0.00000
    MASS(KG/HR   )           32346.2         32346.2         0.00000
    ENTHALPY(CAL/SEC )    -0.210349E+08   -0.220327E+08    0.452904E-01

                   ***  CO2 EQUIVALENT SUMMARY ***
 FEED STREAMS CO2E             21504.2      KG/HR
 PRODUCT STREAMS CO2E          21504.2      KG/HR
 NET STREAMS CO2E PRODUCTION   0.00000      KG/HR
 UTILITIES CO2E PRODUCTION     0.00000      KG/HR
 TOTAL CO2E PRODUCTION         0.00000      KG/HR

                       ***  INPUT DATA  ***

FLASH SPECS FOR HOT SIDE:
TWO    PHASE      FLASH
FREE WATER CONSIDERED
MAXIMUM NO. ITERATIONS                                  30
CONVERGENCE TOLERANCE                                    0.000100000

FLOW DIRECTION AND SPECIFICATION:
  COUNTERCURRENT   HEAT EXCHANGER
  SPECIFIED HOT OUTLET TEMP
  SPECIFIED VALUE               C                       50.0000
  LMTD CORRECTION FACTOR                                   1.00000

PRESSURE SPECIFICATION:
  HOT  SIDE PRESSURE DROP       BAR                        0.0000
  COLD SIDE OUTLET PRESSURE     BAR                        1.0132

HEAT TRANSFER COEFFICIENT SPECIFICATION:
  HOT LIQUID    COLD LIQUID     CAL/SEC-SQCM-K             0.0203
  HOT 2-PHASE   COLD LIQUID     CAL/SEC-SQCM-K             0.0203
  HOT VAPOR     COLD LIQUID     CAL/SEC-SQCM-K             0.0203
  HOT LIQUID    COLD 2-PHASE    CAL/SEC-SQCM-K             0.0203
  HOT 2-PHASE   COLD 2-PHASE    CAL/SEC-SQCM-K             0.0203
  HOT VAPOR     COLD 2-PHASE    CAL/SEC-SQCM-K             0.0203
  HOT LIQUID    COLD VAPOR      CAL/SEC-SQCM-K             0.0203
  HOT 2-PHASE   COLD VAPOR      CAL/SEC-SQCM-K             0.0203
  HOT VAPOR     COLD VAPOR      CAL/SEC-SQCM-K             0.0203

                        ***  OVERALL RESULTS  ***

STREAMS:
                  ---------------------------------------
                  |                                     |
WGS-OUT2  ----->  |                HOT                  |-----> WGS-OUT3
T=  1.5204D+02    |                                     |       T=  5.0000D+01
P=  1.0000D+01    |                                     |       P=  1.0000D+01
V=  8.1616D-01    |                                     |       V=  6.5745D-01
                  |                                     |
CW          <-----|                COLD                 |<----- CW
T=  2.5000D+01    |                                     |       T=  2.0000D+01
P=  1.0132D+00    |                                     |       P=  1.0132D+00
V=  0.0000D+00    |                                     |       V=  0.0000D+00
                  ---------------------------------------

DUTY AND AREA:
  CALCULATED HEAT DUTY          CAL/SEC            997870.8113
```

```
    CALCULATED (REQUIRED) AREA     SQM                      73.1057
    ACTUAL EXCHANGER AREA          SQM                      73.1057
    PER CENT OVER-DESIGN                                     0.0000

  HEAT TRANSFER COEFFICIENT:
    AVERAGE COEFFICIENT (DIRTY)    CAL/SEC-SQCM-K            0.0203
    UA (DIRTY)                     CAL/SEC-K             14841.8443

  LOG-MEAN TEMPERATURE DIFFERENCE:
    LMTD CORRECTION FACTOR                                   1.0000
    LMTD (CORRECTED)               C                        67.2336
    NUMBER OF SHELLS IN SERIES                                 1

  PRESSURE DROP:
    HOTSIDE, TOTAL                 BAR                       0.0000
    COLDSIDE, TOTAL                BAR                       0.0000

                        ***  ASSOCIATED  UTILITIES  ***

 UTILITY ID FOR WATER                          CW
 RATE OF CONSUMPTION                    7.2047+05  KG/HR
 COST                                     3.1886  $/HR

                         ***  ZONE RESULTS  ***

  TEMPERATURE LEAVING EACH ZONE:

                                  HOT
         ------------------------------------------------------------
         |                                                          |
         |                                                          |
HOT IN   |                            COND                          | HOT OUT
-------> |                                                          |------>
 152.0   |                                                          |   50.0
         |                                                          |
COLDOUT  |                            LIQ                           | COLDIN
<------- |                                                          |<------
  25.0   |                                                          |   20.0
         |                                                          |
         ------------------------------------------------------------
                                  COLD

  ZONE HEAT TRANSFER AND AREA:

  ZONE       HEAT DUTY       AREA       LMTD       AVERAGE U       UA
             CAL/SEC         SQM         C         CAL/SEC-SQCM-K  CAL/SEC-K
    1     997870.811        73.1057      67.2336     0.0203       14841.8443

BLOCK:  WGS-RXR  MODEL: RGIBBS
------------------------------
  INLET STREAM:          WGS-IN2
  OUTLET STREAM:         WGS-OUT1
  PROPERTY OPTION SET:   RK-SOAVE  STANDARD RKS EQUATION OF STATE
  FREE WATER OPTION SET: SYSOP12   ASME STEAM TABLE
  SOLUBLE WATER OPTION:  THE MAIN PROPERTY OPTION SET (RK-SOAVE).

                      ***  MASS AND ENERGY BALANCE  ***
                             IN           OUT       GENERATION   RELATIVE DIFF.
  TOTAL BALANCE
  MOLE(KMOL/HR )          1339.86       1347.60       7.68012     -0.494118E-04
  MASS(KG/HR   )          32345.0       32346.2                   -0.370860E-04
  ENTHALPY(CAL/SEC )   -0.192509E+08 -0.192519E+08                 0.534795E-04

                      ***  CO2 EQUIVALENT SUMMARY ***
   FEED STREAMS CO2E             9813.95      KG/HR
   PRODUCT STREAMS CO2E          21504.2      KG/HR
   NET STREAMS CO2E PRODUCTION   11690.3      KG/HR
   UTILITIES CO2E PRODUCTION     0.00000      KG/HR
   TOTAL CO2E PRODUCTION         11690.3      KG/HR

                         ***  INPUT DATA  ***

  EQUILIBRIUM SPECIFICATIONS:
```

```
  BOTH PHASE AND CHEMICAL EQUILIBRIUM ARE CONSIDERED
  THE MAXIMUM NUMBER OF FLUID PHASES CONSIDERED IS 2
  INCLUDING A VAPOR PHASE
  CALCULATED TEMPERATURE    C                                  486.60
  TEMPERATURE FOR FREE ENERGY EVALUATION    C                  486.60
  SYSTEM PRESSURE       BAR                                    10.000
  SPECIFIED DUTY        CAL/SEC                                  0.0000

FLUID PHASE SPECIES IN PRODUCT LIST:
  H2 CO2 CO H2O

ATOM MATRIX:
ELEMENT      H    C    O    FE
  H2        2.00 0.00 0.00 0.00
  CO2       0.00 1.00 2.00 0.00
  CO        0.00 1.00 1.00 0.00
  O2        0.00 0.00 2.00 0.00
  H2O       2.00 0.00 1.00 0.00
  FE3O4     0.00 0.00 4.00 3.00
  FEO       0.00 0.00 1.00 1.00
  C8       18.00 8.00 0.00 0.00
  C1        4.00 1.00 0.00 0.00
  C2        6.00 2.00 0.00 0.00
  C3        8.00 3.00 0.00 0.00
  C4       10.00 4.00 0.00 0.00
  C5       12.00 5.00 0.00 0.00
  C6       14.00 6.00 0.00 0.00
  C7       16.00 7.00 0.00 0.00
  C9       20.00 9.00 0.00 0.00
  C10      22.0010.00 0.00 0.00
  C11      24.0011.00 0.00 0.00
  C12      26.0012.00 0.00 0.00
  C13      28.0013.00 0.00 0.00
  C14      30.0014.00 0.00 0.00
  C15      32.0015.00 0.00 0.00
  C16      34.0016.00 0.00 0.00
  C17      36.0017.00 0.00 0.00
  C18      38.0018.00 0.00 0.00
  C19      40.0019.00 0.00 0.00
  C20      42.0020.00 0.00 0.00
  C21      44.0021.00 0.00 0.00
  C22      46.0022.00 0.00 0.00
  C23      48.0023.00 0.00 0.00
  C24      50.0024.00 0.00 0.00
  C25      52.0025.00 0.00 0.00
  C26      54.0026.00 0.00 0.00
  C27      56.0027.00 0.00 0.00
  C28      58.0028.00 0.00 0.00
  C29      60.0029.00 0.00 0.00
  C30      62.0030.00 0.00 0.00

                       ***  RESULTS  ***
TEMPERATURE           C                                       486.60
PRESSURE              BAR                                     10.000
VAPOR FRACTION                                                1.0000
NUMBER OF FLUID PHASES                                                1

FLUID PHASE MOLE FRACTIONS:

PHASE              VAPOR
OF TYPE            VAPOR
PHASE FRACTION     1.000000
PLACED IN STREAM   WGS-OUT1
  H2              0.2422829
  CO2             0.3625873
  CO              0.4388158E-01
  H2O             0.3512482

KMOL/HR            1347.602
```

B.3 Utilities Report

```
UTILITY USAGE:  CW        (WATER)
---------------------------------

COOLING WATER, INLET TEMP=20 C, OUTLET TEMP=25 C
 INPUT DATA:

   INLET TEMPERATURE                  20.0000  C
   OUTLET TEMPERATURE                 25.0000  C
   INLET PRESSURE                      1.0133  BAR
   OUTLET PRESSURE                     1.0133  BAR
   HEAT TRANSFER COEFFICIENT        8.9567-02  CAL/SEC-SQCM-K
   PRICE                            8.8760-10  $/CAL
   INDEX TYPE                            FUEL

 RESULT:

   COOLING VALUE                       4.9861  CAL/GM
   INDEXED PRICE                    8.8760-10  $/CAL

 THIS UTILITY IS PURCHASED

 USAGE:

 BLOCK ID  MODEL         DUTY              USAGE RATE        COST
                         CAL/SEC           KG/HR             $/HR
 --------  ------------  ----------------  ----------------  ----------------
 WGS-HTX2  HEATX               9.9787+05         7.2047+05           3.1886
 FT-HTX2   HEATX               6.0989+05         4.4035+05           1.9488
 FT-RXR    RSTOIC              1.5770+06         1.1386+06           5.0391
                               ----------------  ----------------  ----------------
                 TOTAL:        3.1848+06         2.2994+06          10.1765
                               ================  ================  ================
```

B.4 Convergence Report

```
 CONVERGENCE BLOCK:  $OLVER13
 ----------------------------
     Tear Stream  :  CR5-HEAT
     Tolerance used:  0.100D-03

     MAXIT=   30 WAIT   1 ITERATIONS BEFORE ACCELERATING
     QMAX =   0.0     QMIN =  -5.0
     METHOD: WEGSTEIN      STATUS: CONVERGED
     TOTAL NUMBER OF ITERATIONS:     3
     NUMBER OF ITERATIONS ON LAST OUTER LOOP:     1

                          *** FINAL VALUES ***

VAR#  TEAR STREAM VAR  STREAM   SUBSTREA COMPONEN ATTRIBUT ELEMENT      UNIT         VALUE       PREV VALUE       ERR/TOL
----  ---------------  --------  -------- -------- -------- -------- ----------- ------------   ------------   ------------
   1  INFO-VAR         CR5-HEAT                   HEAT     Q                     3.8639+08      3.8639+08         0.0

                          *** ITERATION HISTORY ***

     TEAR STREAMS AND TEAR VARIABLES:

     ITERATION   MAX-ERR/TOL   STREAM ID      VARIABLE         SUBSTREA COMPONEN ATTRIBUT ELEMENT
     ---------   -----------   ---------      ----------------- -------- -------- -------- -------
          1       0.000        CR5-HEAT       INFO-VAR                          HEAT     Q

 CONVERGENCE BLOCK:  $OLVER14
 ----------------------------
     Tear Stream  :  GAS-FT1    WGS-IN2    H2O-WGS1
     Tolerance used:  0.100D-03  0.100D-03  0.100D-03
     Trace molefrac:  0.100D-05  0.100D-05  0.100D-05

     MAXIT=   30 WAIT   1 ITERATIONS BEFORE ACCELERATING
     QMAX =   0.0     QMIN =  -5.0
     METHOD: WEGSTEIN      STATUS: CONVERGED
     TOTAL NUMBER OF ITERATIONS:    33
     NUMBER OF ITERATIONS ON LAST OUTER LOOP:     2

                          *** FINAL VALUES ***

VAR#  TEAR STREAM VAR  STREAM   SUBSTREA COMPONEN ATTRIBUT ELEMENT      UNIT         VALUE       PREV VALUE       ERR/TOL
----  ---------------  --------  -------- -------- -------- -------- ----------- ------------   ------------   ------------
   1  TOTAL MOLEFLOW   GAS-FT1  MIXED                                KMOL/HR       989.7423       989.7469     -4.6187-02
   2  TOTAL MOLEFLOW   WGS-IN2  MIXED                                KMOL/HR      1339.8550      1339.9216       -0.4970
   3  TOTAL MOLEFLOW   H2O-WGS1 MIXED                                KMOL/HR       467.5193       467.5193     -1.5724-07
   4  MOLE-FLOW        GAS-FT1  MIXED    H2                          KMOL/HR       350.2317       350.2352       -0.1006
   5  MOLE-FLOW        GAS-FT1  MIXED    CO2                         KMOL/HR       555.7135       555.7147     -2.1410-02
   6  MOLE-FLOW        GAS-FT1  MIXED    CO                          KMOL/HR        77.2891        77.2889      1.4414-02
   7  MOLE-FLOW        GAS-FT1  MIXED    O2                          KMOL/HR         0.0            0.0            0.0
   8  MOLE-FLOW        GAS-FT1  MIXED    H2O                         KMOL/HR         5.9852         5.9852       -1.2983-02
   9  MOLE-FLOW        GAS-FT1  MIXED    FE3O4                       KMOL/HR         0.0            0.0            0.0
  10  MOLE-FLOW        GAS-FT1  MIXED    FEO                         KMOL/HR         0.0            0.0            0.0
  11  MOLE-FLOW        GAS-FT1  MIXED    C8                          KMOL/HR      1.1454-02      1.1454-02       -0.2864
  12  MOLE-FLOW        GAS-FT1  MIXED    C1                          KMOL/HR         0.1031         0.1031         0.8675
  13  MOLE-FLOW        GAS-FT1  MIXED    C2                          KMOL/HR      9.7584-02      9.7575-02         0.8633
  14  MOLE-FLOW        GAS-FT1  MIXED    C3                          KMOL/HR      8.8115-02      8.8108-02         0.8516
  15  MOLE-FLOW        GAS-FT1  MIXED    C4                          KMOL/HR      7.7451-02      7.7444-02         0.8142
  16  MOLE-FLOW        GAS-FT1  MIXED    C5                          KMOL/HR      6.4398-02      6.4394-02         0.7083
  17  MOLE-FLOW        GAS-FT1  MIXED    C6                          KMOL/HR      4.7276-02      4.7273-02         0.4664
  18  MOLE-FLOW        GAS-FT1  MIXED    C7                          KMOL/HR      2.7386-02      2.7386-02       8.5951-02
  19  MOLE-FLOW        GAS-FT1  MIXED    C9                          KMOL/HR      4.0644-03      4.0646-03       -0.4637
  20  MOLE-FLOW        GAS-FT1  MIXED    C10                         KMOL/HR      1.3519-03      1.3520-03       -0.4922
  21  MOLE-FLOW        GAS-FT1  MIXED    C11                         KMOL/HR      4.6670-04      4.6672-04       -0.5274
  22  MOLE-FLOW        GAS-FT1  MIXED    C12                         KMOL/HR      1.4227-04      1.4228-04       -0.5145
  23  MOLE-FLOW        GAS-FT1  MIXED    C13                         KMOL/HR      3.8665-05      3.8667-05       -0.4927
  24  MOLE-FLOW        GAS-FT1  MIXED    C14                         KMOL/HR      1.3096-05      1.3097-05       -0.4688
  25  MOLE-FLOW        GAS-FT1  MIXED    C15                         KMOL/HR      4.0291-06      4.0293-06       -0.4444
  26  MOLE-FLOW        GAS-FT1  MIXED    C16                         KMOL/HR      1.3539-06      1.3540-06       -0.4201
  27  MOLE-FLOW        GAS-FT1  MIXED    C17                         KMOL/HR      3.7431-07      3.7432-07       -0.3961
  28  MOLE-FLOW        GAS-FT1  MIXED    C18                         KMOL/HR      1.2234-07      1.2235-07       -0.3710
  29  MOLE-FLOW        GAS-FT1  MIXED    C19                         KMOL/HR      3.8929-08      3.8931-08       -0.3460
  30  MOLE-FLOW        GAS-FT1  MIXED    C20                         KMOL/HR      1.0504-08      1.0505-08       -0.3206
  31  MOLE-FLOW        GAS-FT1  MIXED    C21                         KMOL/HR      3.5394-09      3.5395-09       -0.2958
  32  MOLE-FLOW        GAS-FT1  MIXED    C22                         KMOL/HR      1.3117-09      1.3118-09       -0.2708
  33  MOLE-FLOW        GAS-FT1  MIXED    C23                         KMOL/HR      3.3798-10      3.3799-10       -0.2439
  34  MOLE-FLOW        GAS-FT1  MIXED    C24                         KMOL/HR      1.0132-10      1.0132-10       -0.2177
  35  MOLE-FLOW        GAS-FT1  MIXED    C25                         KMOL/HR      3.4565-11      3.4566-11       -0.1949
  36  MOLE-FLOW        GAS-FT1  MIXED    C26                         KMOL/HR      9.7860-12      9.7861-12       -0.1659
  37  MOLE-FLOW        GAS-FT1  MIXED    C27                         KMOL/HR      2.0308-12      2.0309-12       -0.1566
  38  MOLE-FLOW        GAS-FT1  MIXED    C28                         KMOL/HR      8.7091-13      8.7092-13       -0.1291
  39  MOLE-FLOW        GAS-FT1  MIXED    C29                         KMOL/HR      3.4440-13      3.4440-13       -0.1043
  40  MOLE-FLOW        GAS-FT1  MIXED    C30                         KMOL/HR      2.5004-13      2.5004-13     -4.3571-02
  41  PRESSURE         GAS-FT1  MIXED                                BAR             1.0000         1.0000         0.0
  42  MASS ENTHALPY    GAS-FT1  MIXED                                CAL/GM      -1981.6553     -1981.6553     -9.6361-05
  43  MOLE-FLOW        WGS-IN2  MIXED    H2                          KMOL/HR        50.1058        50.1058         0.0
  44  MOLE-FLOW        WGS-IN2  MIXED    CO2                         KMOL/HR       221.0120       221.0120         0.0
  45  MOLE-FLOW        WGS-IN2  MIXED    CO                          KMOL/HR       322.9061       322.9061         0.0
  46  MOLE-FLOW        WGS-IN2  MIXED    O2                          KMOL/HR         0.0            0.0            0.0
  47  MOLE-FLOW        WGS-IN2  MIXED    H2O                         KMOL/HR       744.7274       744.7940       -0.8940
  48  MOLE-FLOW        WGS-IN2  MIXED    FE3O4                       KMOL/HR         0.0            0.0            0.0
  49  MOLE-FLOW        WGS-IN2  MIXED    FEO                         KMOL/HR         0.0            0.0            0.0
  50  MOLE-FLOW        WGS-IN2  MIXED    C8                          KMOL/HR      2.4182-02      2.4182-02         0.0
  51  MOLE-FLOW        WGS-IN2  MIXED    C1                          KMOL/HR         0.2176         0.2176         0.0
  52  MOLE-FLOW        WGS-IN2  MIXED    C2                          KMOL/HR         0.2060         0.2060         0.0
  53  MOLE-FLOW        WGS-IN2  MIXED    C3                          KMOL/HR         0.1860         0.1860         0.0
  54  MOLE-FLOW        WGS-IN2  MIXED    C4                          KMOL/HR         0.1635         0.1635         0.0
  55  MOLE-FLOW        WGS-IN2  MIXED    C5                          KMOL/HR         0.1359         0.1359         0.0
  56  MOLE-FLOW        WGS-IN2  MIXED    C6                          KMOL/HR      9.9799-02      9.9799-02         0.0
  57  MOLE-FLOW        WGS-IN2  MIXED    C7                          KMOL/HR      5.7815-02      5.7815-02         0.0
  58  MOLE-FLOW        WGS-IN2  MIXED    C9                          KMOL/HR      8.5807-03      8.5807-03         0.0
  59  MOLE-FLOW        WGS-IN2  MIXED    C10                         KMOL/HR      2.8542-03      2.8542-03         0.0
  60  MOLE-FLOW        WGS-IN2  MIXED    C11                         KMOL/HR      9.8530-04      9.8530-04         0.0
  61  MOLE-FLOW        WGS-IN2  MIXED    C12                         KMOL/HR      3.0036-04      3.0036-04         0.0
  62  MOLE-FLOW        WGS-IN2  MIXED    C13                         KMOL/HR      8.1630-05      8.1630-05         0.0
  63  MOLE-FLOW        WGS-IN2  MIXED    C14                         KMOL/HR      2.7649-05      2.7649-05         0.0
  64  MOLE-FLOW        WGS-IN2  MIXED    C15                         KMOL/HR      8.5063-06      8.5063-06         0.0
  65  MOLE-FLOW        WGS-IN2  MIXED    C16                         KMOL/HR      2.8584-06      2.8584-06         0.0
  66  MOLE-FLOW        WGS-IN2  MIXED    C17                         KMOL/HR      7.9023-07      7.9023-07         0.0
  67  MOLE-FLOW        WGS-IN2  MIXED    C18                         KMOL/HR      2.5829-07      2.5829-07         0.0
  68  MOLE-FLOW        WGS-IN2  MIXED    C19                         KMOL/HR      8.2187-08      8.2187-08         0.0
  69  MOLE-FLOW        WGS-IN2  MIXED    C20                         KMOL/HR      2.2177-08      2.2177-08         0.0
  70  MOLE-FLOW        WGS-IN2  MIXED    C21                         KMOL/HR      7.4724-09      7.4724-09         0.0
  71  MOLE-FLOW        WGS-IN2  MIXED    C22                         KMOL/HR      2.7693-09      2.7693-09         0.0
  72  MOLE-FLOW        WGS-IN2  MIXED    C23                         KMOL/HR      7.1354-10      7.1354-10         0.0
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73	MOLE-FLOW	WGS-IN2	MIXED	C24	KMOL/HR	2.1390-10	2.1390-10	0.0
74	MOLE-FLOW	WGS-IN2	MIXED	C25	KMOL/HR	7.2972-11	7.2972-11	0.0
75	MOLE-FLOW	WGS-IN2	MIXED	C26	KMOL/HR	2.0660-11	2.0660-11	0.0
76	MOLE-FLOW	WGS-IN2	MIXED	C27	KMOL/HR	0.0	0.0	0.0
77	MOLE-FLOW	WGS-IN2	MIXED	C28	KMOL/HR	0.0	0.0	0.0
78	MOLE-FLOW	WGS-IN2	MIXED	C29	KMOL/HR	0.0	0.0	0.0
79	MOLE-FLOW	WGS-IN2	MIXED	C30	KMOL/HR	0.0	0.0	0.0
80	PRESSURE	WGS-IN2	MIXED		BAR	1.0000	1.0000	0.0
81	MASS ENTHALPY	WGS-IN2	MIXED		CAL/GM	-2142.6271	-2142.6619	0.1623
82	MOLE-FLOW	H2O-WGS1	MIXED	H2	KMOL/HR	0.0	0.0	0.0
83	MOLE-FLOW	H2O-WGS1	MIXED	CO2	KMOL/HR	0.0	0.0	0.0
84	MOLE-FLOW	H2O-WGS1	MIXED	CO	KMOL/HR	0.0	0.0	0.0
85	MOLE-FLOW	H2O-WGS1	MIXED	O2	KMOL/HR	0.0	0.0	0.0
86	MOLE-FLOW	H2O-WGS1	MIXED	H2O	KMOL/HR	467.5193	467.5193	-1.5724-07
87	MOLE-FLOW	H2O-WGS1	MIXED	FE3O4	KMOL/HR	0.0	0.0	0.0
88	MOLE-FLOW	H2O-WGS1	MIXED	FEO	KMOL/HR	0.0	0.0	0.0
89	MOLE-FLOW	H2O-WGS1	MIXED	C8	KMOL/HR	0.0	0.0	0.0
90	MOLE-FLOW	H2O-WGS1	MIXED	C1	KMOL/HR	0.0	0.0	0.0
91	MOLE-FLOW	H2O-WGS1	MIXED	C2	KMOL/HR	0.0	0.0	0.0
92	MOLE-FLOW	H2O-WGS1	MIXED	C3	KMOL/HR	0.0	0.0	0.0
93	MOLE-FLOW	H2O-WGS1	MIXED	C4	KMOL/HR	0.0	0.0	0.0
94	MOLE-FLOW	H2O-WGS1	MIXED	C5	KMOL/HR	0.0	0.0	0.0
95	MOLE-FLOW	H2O-WGS1	MIXED	C6	KMOL/HR	0.0	0.0	0.0
96	MOLE-FLOW	H2O-WGS1	MIXED	C7	KMOL/HR	0.0	0.0	0.0
97	MOLE-FLOW	H2O-WGS1	MIXED	C9	KMOL/HR	0.0	0.0	0.0
98	MOLE-FLOW	H2O-WGS1	MIXED	C10	KMOL/HR	0.0	0.0	0.0
99	MOLE-FLOW	H2O-WGS1	MIXED	C11	KMOL/HR	0.0	0.0	0.0
100	MOLE-FLOW	H2O-WGS1	MIXED	C12	KMOL/HR	0.0	0.0	0.0
101	MOLE-FLOW	H2O-WGS1	MIXED	C13	KMOL/HR	0.0	0.0	0.0
102	MOLE-FLOW	H2O-WGS1	MIXED	C14	KMOL/HR	0.0	0.0	0.0
103	MOLE-FLOW	H2O-WGS1	MIXED	C15	KMOL/HR	0.0	0.0	0.0
104	MOLE-FLOW	H2O-WGS1	MIXED	C16	KMOL/HR	0.0	0.0	0.0
105	MOLE-FLOW	H2O-WGS1	MIXED	C17	KMOL/HR	0.0	0.0	0.0
106	MOLE-FLOW	H2O-WGS1	MIXED	C18	KMOL/HR	0.0	0.0	0.0
107	MOLE-FLOW	H2O-WGS1	MIXED	C19	KMOL/HR	0.0	0.0	0.0
108	MOLE-FLOW	H2O-WGS1	MIXED	C20	KMOL/HR	0.0	0.0	0.0
109	MOLE-FLOW	H2O-WGS1	MIXED	C21	KMOL/HR	0.0	0.0	0.0
110	MOLE-FLOW	H2O-WGS1	MIXED	C22	KMOL/HR	0.0	0.0	0.0
111	MOLE-FLOW	H2O-WGS1	MIXED	C23	KMOL/HR	0.0	0.0	0.0
112	MOLE-FLOW	H2O-WGS1	MIXED	C24	KMOL/HR	0.0	0.0	0.0
113	MOLE-FLOW	H2O-WGS1	MIXED	C25	KMOL/HR	0.0	0.0	0.0
114	MOLE-FLOW	H2O-WGS1	MIXED	C26	KMOL/HR	0.0	0.0	0.0
115	MOLE-FLOW	H2O-WGS1	MIXED	C27	KMOL/HR	0.0	0.0	0.0
116	MOLE-FLOW	H2O-WGS1	MIXED	C28	KMOL/HR	0.0	0.0	0.0
117	MOLE-FLOW	H2O-WGS1	MIXED	C29	KMOL/HR	0.0	0.0	0.0
118	MOLE-FLOW	H2O-WGS1	MIXED	C30	KMOL/HR	0.0	0.0	0.0
119	PRESSURE	H2O-WGS1	MIXED		BAR	5.0000	5.0000	0.0
120	MASS ENTHALPY	H2O-WGS1	MIXED		CAL/GM	-3789.3920	-3789.3920	0.0

*** ITERATION HISTORY ***

TEAR STREAMS AND TEAR VARIABLES:

ITERATION	MAX-ERR/TOL	STREAM ID	VARIABLE	SUBSTREA	COMPONEN	ATTRIBUT	ELEMENT
1	-1.640	H2O-WGS1	TOTAL MOLEFLOW	MIXED			
2	-0.8940	WGS-IN2	MOLE-FLOW	MIXED	H2O		

B.5 Flowsheet Balance

OVERALL FLOWSHEET BALANCE

*** MASS AND ENERGY BALANCE ***

	IN	OUT	GENERATION	RELATIVE DIFF.
CONVENTIONAL COMPONENTS (KMOL/HR)				
H2	0.00000	137.124	137.112	-0.899152E-04
CO2	431.000	361.612	-69.3907	-0.557903E-05
CO	0.00000	7.53650	7.53513	-0.181759E-03
O2	0.00000	1232.50	1232.50	0.00000
H2O	230.000	24.3109	-205.756	-0.289629E-03
FE3O4	4166.67	2038.67	-2128.00	0.00000
FEO	0.00000	6383.99	6383.99	0.00000
C8	0.00000	0.379939	0.379938	-0.301814E-05
C1	0.00000	0.595999	0.596030	0.525001E-04
C2	0.00000	0.566282	0.566311	0.520657E-04
C3	0.00000	0.516607	0.516633	0.508305E-04
C4	0.00000	0.469458	0.469480	0.470027E-04
C5	0.00000	0.431133	0.431149	0.370127E-04
C6	0.00000	0.407392	0.407399	0.189120E-04
C7	0.00000	0.395164	0.395165	0.204878E-05
C9	0.00000	0.351723	0.351723	-0.187325E-05
C10	0.00000	0.318361	0.318361	-0.738140E-06
C11	0.00000	0.285240	0.285240	-0.301100E-06
C12	0.00000	0.254717	0.254717	-0.999018E-07
C13	0.00000	0.227196	0.227196	-0.287824E-07
C14	0.00000	0.202347	0.202347	-0.100855E-07
C15	0.00000	0.180301	0.180301	-0.295603E-08
C16	0.00000	0.160447	0.160447	-0.726030E-09
C17	0.00000	0.142797	0.142797	0.149020E-09
C18	0.00000	0.127351	0.127351	0.386920E-09
C19	0.00000	0.113166	0.113166	0.469716E-09
C20	0.00000	0.100872	0.100872	0.499568E-09
C21	0.00000	0.898394E-01	0.898394E-01	0.507137E-09
C22	0.00000	0.797522E-01	0.797522E-01	0.509643E-09
C23	0.00000	0.712411E-01	0.712411E-01	0.510790E-09
C24	0.00000	0.633604E-01	0.633604E-01	0.511071E-09
C25	0.00000	0.564254E-01	0.564254E-01	0.511150E-09
C26	0.00000	0.501209E-01	0.501209E-01	0.511181E-09
C27	0.00000	0.447621E-01	0.447621E-01	0.624615E-09
C28	0.00000	0.397185E-01	0.397185E-01	0.566010E-09
C29	0.00000	0.353053E-01	0.353053E-01	0.535579E-09
C30	0.00000	0.315226E-01	0.315226E-01	0.531022E-09
TOTAL BALANCE				
MOLE(KMOL/HR)	4827.67	10192.5	5364.78	-0.810271E-05
MASS(KG/HR)	987856.	987857.		-0.138044E-05
ENTHALPY(CAL/SEC)	-0.309126E+09	-0.256641E+09		-0.169783

*** CO2 EQUIVALENT SUMMARY ***

FEED STREAMS CO2E	18968.2	KG/HR
PRODUCT STREAMS CO2E	16153.5	KG/HR
NET STREAMS CO2E PRODUCTION	-2814.73	KG/HR
UTILITIES CO2E PRODUCTION	0.00000	KG/HR
TOTAL CO2E PRODUCTION	-2814.73	KG/HR

FLOWSHEET SECTION BALANCE: CR5

*** MASS AND ENERGY BALANCE ***

	IN	OUT	GENERATION	RELATIVE DIFF.
CONVENTIONAL COMPONENTS (KMOL/HR)				
H2	52.7342	52.7342	0.00000	0.00000
CO2	569.645	232.643	-337.002	-0.498937E-16
CO	2.89774	339.900	337.002	0.167236E-15
O2	0.00000	1232.50	1232.50	0.00000
H2O	0.359575	0.359575	0.00000	0.00000
FE3O4	4166.67	2038.67	-2128.00	0.00000

FEO	0.00000	6383.99	6383.99	0.00000
C8	0.254536E-01	0.254536E-01	0.00000	0.00000
C1	0.229041	0.229041	0.00000	0.00000
C2	0.216855	0.216855	0.00000	0.00000
C3	0.195814	0.195814	0.00000	0.00000
C4	0.172114	0.172114	0.00000	0.00000
C5	0.143108	0.143108	0.00000	0.00000
C6	0.105057	0.105057	0.00000	0.00000
C7	0.608582E-01	0.608582E-01	0.00000	0.00000
C9	0.903187E-02	0.903187E-02	0.00000	0.00000
C10	0.300427E-02	0.300427E-02	0.00000	0.00000
C11	0.103709E-02	0.103709E-02	0.00000	0.00000
C12	0.316149E-03	0.316149E-03	0.00000	0.00000
C13	0.859219E-04	0.859219E-04	0.00000	0.00000
C14	0.291026E-04	0.291026E-04	0.00000	0.00000
C15	0.895350E-05	0.895350E-05	0.00000	0.00000
C16	0.300875E-05	0.300875E-05	0.00000	0.00000
C17	0.831789E-06	0.831789E-06	0.00000	0.00000
C18	0.271872E-06	0.271872E-06	0.00000	0.00000
C19	0.865094E-07	0.865094E-07	0.00000	0.00000
C20	0.233431E-07	0.233431E-07	0.00000	0.00000
C21	0.786540E-08	0.786540E-08	0.00000	0.00000
C22	0.291498E-08	0.291498E-08	0.00000	0.00000
C23	0.751071E-09	0.751071E-09	0.00000	0.00000
C24	0.225150E-09	0.225150E-09	0.00000	0.00000
C25	0.768115E-10	0.768115E-10	0.00000	0.00000
C26	0.217465E-10	0.217465E-10	0.00000	0.00000
C27	0.507708E-11	0.00000	0.00000	1.00000
C28	0.217728E-11	0.00000	0.00000	1.00000
C29	0.860999E-12	0.00000	0.00000	1.00000
C30	0.625110E-12	0.00000	0.00000	1.00000
TOTAL BALANCE				
MOLE(KMOL/HR)	4793.46	10282.0	5488.50	0.884554E-15
MASS(KG/HR)	990067.	990067.		0.188133E-14
ENTHALPY(CAL/SEC)	-0.308424E+09	-0.254699E+09		-0.174194

*** CO2 EQUIVALENT SUMMARY ***

FEED STREAMS CO2E	25161.8	KG/HR
PRODUCT STREAMS CO2E	10330.4	KG/HR
NET STREAMS CO2E PRODUCTION	-14831.4	KG/HR
UTILITIES CO2E PRODUCTION	0.00000	KG/HR
TOTAL CO2E PRODUCTION	-14831.4	KG/HR

FLOWSHEET SECTION BALANCE: FT

*** MASS AND ENERGY BALANCE ***

	IN	OUT	GENERATION	RELATIVE DIFF.
CONVENTIONAL COMPONENTS (KMOL/HR)				
H2	540.090	400.810	-139.284	-0.652247E-05
CO2	1055.97	1055.97	0.00000	-0.112670E-05
CO	87.7233	22.0276	-65.6956	0.126993E-05
O2	0.00000	0.00000	0.00000	0.00000
H2O	77.5221	143.218	65.6956	-0.542571E-07
FE3O4	0.00000	0.00000	0.00000	0.00000
FEO	0.00000	0.00000	0.00000	0.00000
C8	0.416847	0.820967	0.404120	-0.399381E-06
C1	0.928107	1.74170	0.813598	0.513293E-05
C2	0.880721	1.65302	0.772304	0.509615E-05
C3	0.800536	1.50317	0.702639	0.499137E-05
C4	0.719023	1.35199	0.632974	0.466362E-05
C5	0.638640	1.20573	0.567091	0.378284E-05
C6	0.559724	1.06692	0.507199	0.206640E-05
C7	0.483408	0.936388	0.452980	0.251504E-06
C9	0.364819	0.725123	0.360303	-0.259710E-06
C10	0.322717	0.643933	0.321215	-0.103095E-06
C11	0.286744	0.572969	0.286225	-0.427061E-07
C12	0.255176	0.510194	0.255018	-0.140921E-07
C13	0.227321	0.454599	0.227278	-0.393590E-08
C14	0.202390	0.404765	0.202375	-0.126146E-08
C15	0.180314	0.360623	0.180309	-0.241017E-09

C16	0.160451	0.320901	0.160450	0.783205E-10
C17	0.142798	0.285595	0.142797	0.203672E-09
C18	0.127351	0.254703	0.127351	0.237771E-09
C19	0.113166	0.226332	0.113166	0.249644E-09
C20	0.100872	0.201745	0.100872	0.253926E-09
C21	0.898394E-01	0.179679	0.898394E-01	0.255013E-09
C22	0.797522E-01	0.159504	0.797522E-01	0.255373E-09
C23	0.712411E-01	0.142482	0.712411E-01	0.255538E-09
C24	0.633604E-01	0.126721	0.633604E-01	0.255579E-09
C25	0.564254E-01	0.112851	0.564254E-01	0.255590E-09
C26	0.501209E-01	0.100242	0.501209E-01	0.255594E-09
C27	0.447621E-01	0.895242E-01	0.447621E-01	0.255596E-09
C28	0.397185E-01	0.794369E-01	0.397185E-01	0.255596E-09
C29	0.353053E-01	0.706106E-01	0.353053E-01	0.255596E-09
C30	0.315226E-01	0.630452E-01	0.315226E-01	0.255596E-09
TOTAL BALANCE				
MOLE(KMOL/HR)	1769.78	1638.39	-131.391	-0.258298E-05
MASS(KG/HR)	52382.5	52382.5		-0.104848E-05
ENTHALPY(CAL/SEC)	-0.297484E+08	-0.301233E+08		0.124431E-01

*** CO2 EQUIVALENT SUMMARY ***

FEED STREAMS CO2E	46845.3	KG/HR
PRODUCT STREAMS CO2E	47171.6	KG/HR
NET STREAMS CO2E PRODUCTION	326.358	KG/HR
UTILITIES CO2E PRODUCTION	0.00000	KG/HR
TOTAL CO2E PRODUCTION	326.358	KG/HR

FLOWSHEET SECTION BALANCE: GLOBAL

*** MASS AND ENERGY BALANCE ***

	IN	OUT	RELATIVE DIFF.
CONVENTIONAL COMPONENTS (KMOL/HR)			
H2	693.027	693.036	-0.127076E-04
CO2	2067.64	2067.64	-0.587528E-06
CO	736.432	736.433	-0.201135E-05
O2	0.00000	0.00000	0.00000
H2O	1290.47	1290.47	-0.150522E-07
FE3O4	0.00000	0.00000	0.00000
FEO	0.00000	0.00000	0.00000
C8	0.490663	0.490664	-0.166882E-05
C1	1.59231	1.59228	0.140362E-04
C2	1.50958	1.50956	0.139508E-04
C3	1.36838	1.36836	0.137071E-04
C4	1.21814	1.21812	0.129383E-04
C5	1.05364	1.05363	0.108161E-04
C6	0.864386	0.864380	0.636279E-05
C7	0.659897	0.659896	0.869983E-06
C9	0.391012	0.391013	-0.120340E-05
C10	0.331430	0.331430	-0.508731E-06
C11	0.289751	0.289751	-0.211962E-06
C12	0.256093	0.256093	-0.712907E-07
C13	0.227570	0.227570	-0.208727E-07
C14	0.202474	0.202474	-0.755744E-08
C15	0.180340	0.180340	-0.247343E-08
C16	0.160460	0.160460	-0.882603E-09
C17	0.142800	0.142800	-0.258322E-09
C18	0.127352	0.127352	-0.886226E-10
C19	0.113166	0.113166	-0.295719E-10
C20	0.100872	0.100872	-0.828452E-11
C21	0.898394E-01	0.898394E-01	-0.288927E-11
C22	0.797522E-01	0.797522E-01	-0.110306E-11
C23	0.712411E-01	0.712411E-01	-0.286162E-12
C24	0.633604E-01	0.633604E-01	-0.858595E-13
C25	0.564254E-01	0.564254E-01	-0.293909E-13
C26	0.501209E-01	0.501209E-01	-0.789125E-14
C27	0.447621E-01	0.447621E-01	0.00000
C28	0.397185E-01	0.397185E-01	0.00000
C29	0.353053E-01	0.353053E-01	0.00000
C30	0.315226E-01	0.315226E-01	0.00000
TOTAL BALANCE			
MOLE(KMOL/HR)	4799.41	4799.42	-0.238120E-05

MASS(KG/HR)	137407.	137408.	-0.794419E-06
ENTHALPY(CAL/SEC)	-0.784597E+08	-0.792047E+08	0.940548E-02

*** CO2 EQUIVALENT SUMMARY ***

FEED STREAMS CO2E	91635.0	KG/HR
PRODUCT STREAMS CO2E	91635.0	KG/HR
NET STREAMS CO2E PRODUCTION	0.444990E-01	KG/HR
UTILITIES CO2E PRODUCTION	0.00000	KG/HR
TOTAL CO2E PRODUCTION	0.444990E-01	KG/HR

FLOWSHEET SECTION BALANCE: WGS

*** MASS AND ENERGY BALANCE ***

	IN	OUT	GENERATION	RELATIVE DIFF.
CONVENTIONAL COMPONENTS (KMOL/HR)				
H2	426.713	703.108	276.395	-0.323384E-15
CO2	930.647	1198.26	267.611	0.00000
CO	704.947	441.176	-263.771	-0.806350E-16
O2	0.00000	0.00000	0.00000	0.00000
H2O	1518.65	1247.27	-271.451	-0.438464E-04
FE3O4	0.00000	0.00000	0.00000	0.00000
FEO	0.00000	0.00000	0.00000	0.00000
C8	0.483634E-01	0.241817E-01	-0.241817E-01	0.00000
C1	0.435135	0.217568	-0.217568	0.00000
C2	0.411985	0.205992	-0.205992	0.00000
C3	0.372011	0.186006	-0.186006	0.00000
C4	0.326987	0.163494	-0.163494	0.00000
C5	0.271884	0.135942	-0.135942	0.00000
C6	0.199599	0.997993E-01	-0.997993E-01	0.00000
C7	0.115629	0.578147E-01	-0.578147E-01	0.00000
C9	0.171614E-01	0.858072E-02	-0.858072E-02	0.00000
C10	0.570843E-02	0.285421E-02	-0.285421E-02	0.00000
C11	0.197060E-02	0.985298E-03	-0.985298E-03	0.00000
C12	0.600718E-03	0.300359E-03	-0.300359E-03	0.00000
C13	0.163261E-03	0.816304E-04	-0.816304E-04	0.00000
C14	0.552979E-04	0.276490E-04	-0.276490E-04	0.00000
C15	0.170125E-04	0.850625E-05	-0.850625E-05	0.00000
C16	0.571689E-05	0.285845E-05	-0.285845E-05	0.00000
C17	0.158047E-05	0.790235E-06	-0.790235E-06	0.00000
C18	0.516579E-06	0.258289E-06	-0.258289E-06	0.00000
C19	0.164374E-06	0.821871E-07	-0.821871E-07	0.00000
C20	0.443534E-07	0.221767E-07	-0.221767E-07	0.00000
C21	0.149447E-07	0.747237E-08	-0.747237E-08	0.00000
C22	0.553863E-08	0.276932E-08	-0.276932E-08	0.00000
C23	0.142707E-08	0.713536E-09	-0.713536E-09	0.00000
C24	0.427796E-09	0.213898E-09	-0.213898E-09	0.00000
C25	0.145945E-09	0.729725E-10	-0.729725E-10	0.00000
C26	0.413192E-10	0.206596E-10	-0.206596E-10	0.00000
C27	0.00000	0.00000	0.00000	0.00000
C28	0.00000	0.00000	0.00000	0.00000
C29	0.00000	0.00000	0.00000	0.00000
C30	0.00000	0.00000	0.00000	0.00000
TOTAL BALANCE				
MOLE(KMOL/HR)	3583.17	3590.92	7.68012	-0.185433E-04
MASS(KG/HR)	89034.8	89036.0		-0.134731E-04
ENTHALPY(CAL/SEC)	-0.538960E+08	-0.540176E+08		0.225131E-02

*** CO2 EQUIVALENT SUMMARY ***

FEED STREAMS CO2E	41132.1	KG/HR
PRODUCT STREAMS CO2E	52822.4	KG/HR
NET STREAMS CO2E PRODUCTION	11690.3	KG/HR
UTILITIES CO2E PRODUCTION	0.00000	KG/HR
TOTAL CO2E PRODUCTION	11690.3	KG/HR

Stream	CFE3O4	CO-FT	CO-WGS	CO2-CO-1	CO2-CO-2	CO2-CR5	CO2-IN	COOLF3O4	COOLFEO	CR5-OUT
Temperature C	326.85	849.5872	849.5872	326.8509	849.5872	241.457	326.85	326.8509	326.85	326.8509
Pressure bar	0.20265	10	10	1	10	0.2	0.2	1	0.20265	1
Mass Flow kg/hr										
FE3O4	9.65E+05	0	0	0	0	0	0	4.72E+05	3.94E+05	0
FEO	0	0	0	0	0	0	0	4.59E+05	5.31E+05	0
CO2	0	511.9313	9726.695	10238.63	10238.63	25069.96	18968.22	0	0	10238.57
CO	0	476.0384	9044.73	9520.769	9520.769	81.16697	0	0	0	9520.727
O2	0	0	0	0	0	0	0	0	0	0
H2O	0	0.3239097	6.154284	6.478194	6.478194	6.477844	0	0	0	6.477844
H2	0	5.316176	101.0073	106.3235	106.3235	106.3058	0	0	0	106.3058
C1	0	0.1837045	3.490386	3.674091	3.674091	3.674449	0	0	0	3.674449
C2	0	0.3260063	6.194119	6.520126	6.520126	6.520759	0	0	0	6.520759
C3	0	0.431695	8.202205	8.6339	8.6339	8.634727	0	0	0	8.634727
C4	0	0.5001475	9.502802	10.00295	10.00295	10.00387	0	0	0	10.00387
C5	0	0.5162242	9.80826	10.32448	10.32448	10.32531	0	0	0	10.32531
C6	0	0.4526537	8.60042	9.053074	9.053074	9.053548	0	0	0	9.053548
C7	0	0.3049088	5.793267	6.098176	6.098176	6.098233	0	0	0	6.098233
C8	0	0.145384	2.762295	2.907679	2.907679	2.907586	0	0	0	2.907586
C9	0	0.0579234	1.100545	1.158468	1.158468	1.158408	0	0	0	1.158408
C10	0	0.0213742	0.4061107	0.427485	0.427485	0.427461	0	0	0	0.427461
C11	0	8.11E-03	0.1540135	0.1621195	0.1621195	0.1621099	0	0	0	0.1621099
C12	0	2.69E-03	0.0511626	0.0538554	0.0538554	0.0538523	0	0	0	0.0538523
C13	0	7.92E-04	0.0150498	0.0158419	0.0158419	0.015841	0	0	0	0.015841
C14	0	2.89E-04	5.49E-03	5.77E-03	5.77E-03	5.77E-03	0	0	0	5.77E-03
C15	0	9.51E-05	1.81E-03	1.90E-03	1.90E-03	1.90E-03	0	0	0	1.90E-03
C16	0	3.41E-05	6.47E-04	6.81E-04	6.81E-04	6.81E-04	0	0	0	6.81E-04
C17	0	1.00E-05	1.90E-04	2.00E-04	2.00E-04	2.00E-04	0	0	0	2.00E-04
C18	0	3.46E-06	6.57E-05	6.92E-05	6.92E-05	6.92E-05	0	0	0	6.92E-05
C19	0	1.16E-06	2.21E-05	2.32E-05	2.32E-05	2.32E-05	0	0	0	2.32E-05
C20	0	3.30E-07	6.27E-06	6.60E-06	6.60E-06	6.60E-06	0	0	0	6.60E-06
C21	0	1.17E-07	2.22E-06	2.33E-06	2.33E-06	2.33E-06	0	0	0	2.33E-06
C22	0	4.53E-08	8.60E-07	9.05E-07	9.05E-07	9.05E-07	0	0	0	9.05E-07
C23	0	1.22E-08	2.32E-07	2.44E-07	2.44E-07	2.44E-07	0	0	0	2.44E-07
C24	0	3.81E-09	7.24E-08	7.63E-08	7.63E-08	7.62E-08	0	0	0	7.62E-08
C25	0	1.35E-09	2.57E-08	2.71E-08	2.71E-08	2.71E-08	0	0	0	2.71E-08
C26	0	3.99E-10	7.58E-09	7.97E-09	7.97E-09	7.97E-09	0	0	0	7.97E-09
C27	0	0	0	0	0	1.93E-09	0	0	0	0
C28	0	0	0	0	0	8.60E-10	0	0	0	0
C29	0	0	0	0	0	3.52E-10	0	0	0	0
C30	0	0	0	0	0	2.64E-10	0	0	0	0
Total Flow kmol/hr	4166.667	31.34049	595.4692	626.8097	626.8097	626.7983	431	8422.663	9096.667	626.7983
Total Flow kg/hr	9.65E+05	996.5619	18934.68	19931.24	19931.24	25322.96	18968.22	9.31E+05	9.25E+05	19931.13
Total Flow L/min	3091.944	4890.253	92914.81	5.21E+05	97805.07	2.23E+06	1.79E+06	3293.907	3325.891	5.21E+05
Vapor Frac	0	1	1	1	1	1	1	0	0	1
Liquid Frac	0	0	0	0	0	0	0	0	0	0
Solid Frac	1	0	0	0	0	0	0	1	1	0
Density kg/L	5.20031	3.40E-03	3.40E-03	6.37E-04	3.40E-03	1.89E-04	1.76E-04	4.709187	4.63688	6.37E-04
Average MW	231.5386	31.79791	31.79791	31.79791	31.79791	40.40049	44.0098	110.4992	101.7192	31.79831

Stream (cont.)	GAS-FT1	GAS-FT2	GAS-FT3	GAS-FT4	GAS-FT5	GAS-WGSF	GASPURGE	H2O-IN1	H2O-IN2	H2O-REC
Temperature C	51.59631	525.3861	25	15.76559	15.76559	25	15.76559	25	25.53229	25
Pressure bar	1	20	15	1	1	5	1	1	10	15
Mass Flow kg/hr										
FE3O4	0	0	0	0	0	0	0	0	0	0
FEO	0	0	0	0	0	0	0	0	0	0
CO2	24456.89	24456.89	24406.95	2440.695	6101.738	21504.21	15864.52	0	0	0
CO	2164.894	2164.894	324.6679	32.46679	81.16697	1656.392	211.0341	0	0	0
O2	0	0	0	0	0	0	0	0	0	0
H2O	107.8248	107.8248	25.91138	2.591138	6.477844	104.9096	16.84239	4143.514	4143.514	1265.438
H2	706.0322	706.0322	425.2231	42.52231	106.3058	658.1866	276.395	0	0	0
C1	1.653341	1.653341	14.6978	1.46978	3.674449	0	9.553568	0	0	0
C2	2.934057	2.934057	26.08304	2.608304	6.520759	0	16.95397	0	0	0
C3	3.885255	3.885255	34.53891	3.453891	8.634727	0	22.45029	0	0	0
C4	4.501327	4.501327	40.01546	4.001546	10.00387	0	26.01005	0	0	0
C5	4.646018	4.646018	41.30123	4.130123	10.32531	0	26.8458	0	0	0
C6	4.073883	4.073883	36.21419	3.621419	9.053548	0	23.53922	0	0	0
C7	2.744178	2.744178	24.39293	2.439293	6.098233	0	15.85541	0	0	0
C8	1.308456	1.308456	11.63034	1.163034	2.907586	0	7.559723	0	0	0
C9	0.5213108	0.5213108	4.633632	0.4633632	1.158408	0	3.011861	0	0	0
C10	0.1923681	0.1923681	1.709844	0.1709844	0.427461	0	1.111399	0	0	0
C11	0.0729537	0.0729537	0.6484396	0.0648439	0.1621099	0	0.4214857	0	0	0
C12	0.0242349	0.0242349	0.2154092	0.0215409	0.0538523	0	0.140016	0	0	0
C13	7.13E-03	7.13E-03	0.0633641	6.34E-03	0.015841	0	0.0411866	0	0	0
C14	2.60E-03	2.60E-03	0.0230949	2.31E-03	5.77E-03	0	0.0150117	0	0	0
C15	8.56E-04	8.56E-04	7.61E-03	7.61E-04	1.90E-03	0	4.94E-03	0	0	0
C16	3.07E-04	3.07E-04	2.73E-03	2.73E-04	6.81E-04	0	1.77E-03	0	0	0
C17	9.00E-05	9.00E-05	8.00E-04	8.00E-05	2.00E-04	0	5.20E-04	0	0	0
C18	3.11E-05	3.11E-05	2.77E-04	2.77E-05	6.92E-05	0	1.80E-04	0	0	0
C19	1.05E-05	1.05E-05	9.29E-05	9.29E-06	2.32E-05	0	6.04E-05	0	0	0
C20	2.97E-06	2.97E-06	2.64E-05	2.64E-06	6.60E-06	0	1.71E-05	0	0	0
C21	1.05E-06	1.05E-06	9.33E-06	9.33E-07	2.33E-06	0	6.07E-06	0	0	0
C22	4.07E-07	4.07E-07	3.62E-06	3.62E-07	9.05E-07	0	2.35E-06	0	0	0
C23	1.10E-07	1.10E-07	9.75E-07	9.75E-08	2.44E-07	0	6.34E-07	0	0	0
C24	3.43E-08	3.43E-08	3.05E-07	3.05E-08	7.62E-08	0	1.98E-07	0	0	0
C25	1.22E-08	1.22E-08	1.08E-07	1.08E-08	2.71E-08	0	7.04E-08	0	0	0
C26	3.59E-09	3.59E-09	3.19E-08	3.19E-09	7.97E-09	0	2.07E-08	0	0	0
C27	7.73E-10	7.73E-10	7.73E-09	7.73E-10	1.93E-09	0	5.03E-09	0	0	0
C28	3.44E-10	3.44E-10	3.44E-09	3.44E-10	8.60E-10	0	2.23E-09	0	0	0
C29	1.41E-10	1.41E-10	1.41E-09	1.41E-10	3.52E-10	0	9.15E-10	0	0	0
C30	1.06E-10	1.06E-10	1.06E-09	1.06E-10	2.64E-10	0	6.87E-10	0	0	0
Total Flow kmol/hr	989.7469	989.7469	783.1932	78.31932	195.7983	880.0825	509.0756	230	230	70.24249
Total Flow kg/hr	27462.21	27462.21	25418.93	2541.893	6354.734	23923.7	16522.31	4143.514	4143.514	1265.438
Total Flow L/min	4.45E+05	55126.83	20796.53	31271.48	78178.7	72214.62	2.03E+05	69.25475	69.23641	21.13726
Vapor Frac	1	1	1	1	1	1	1	0	0	0
Liquid Frac	0	0	0	0	0	0	0	1	1	1
Solid Frac	0	0	0	0	0	0	0	0	0	0
Density kg/L	1.03E-03	8.30E-03	0.0203711	1.35E-03	1.35E-03	5.52E-03	1.35E-03	0.9971673	0.9974314	0.9977942
Average MW	27.7467	27.7467	32.45551	32.45551	32.45551	27.18348	32.45551	18.01528	18.01528	18.01528

Stream (cont.)	H2O-WGS1	H2O-WGS2	H2OPURGE	HOTF304	HOTFEO	LIQ-FT	O2	OXOUT	PETROL	PROD-FT1
Temperature C	25	25	25	1916.335	2026.85	25	2026.85	326.85	25	200
Pressure bar	5	5	5	0.20265	0.20265	15	0.20265	0.20265	15	20
Mass Flow kg/hr										
FE3O4	0	0	0	9.65E+05	3.94E+05	0	0	4.72E+05	0	0
FEO	0	0	0	0	5.31E+05	0	0	4.59E+05	0	0
CO2	0	0	0	0	0	49.94055	0	10238.57	49.94055	24456.89
CO	0	0	0	0	0	0.0662542	0	9520.727	0.0662542	324.7341
O2	0	0	0	0	0	0	5439.795	0	0	0
H2O	8422.491	8001.366	421.1245	0	0	1265.438	0	6.477844	0	1291.35
H2	0	0	0	0	0	0.0302607	0	106.3058	0.0302607	425.2533
C1	0	0	0	0	0	7.90E-03	0	3.674449	7.90E-03	14.7057
C2	0	0	0	0	0	0.0739097	0	6.520759	0.0739097	26.15695
C3	0	0	0	0	0	0.3302627	0	8.634727	0.3302627	34.86917
C4	0	0	0	0	0	1.276446	0	10.00387	1.276446	41.29191
C5	0	0	0	0	0	4.260596	0	10.32531	4.260596	45.56182
C6	0	0	0	0	0	11.56862	0	9.053548	11.56862	47.78281
C7	0	0	0	0	0	23.74164	0	6.098233	23.74164	48.13457
C8	0	0	0	0	0	35.84107	0	2.907586	35.84107	47.47141
C9	0	0	0	0	0	42.09938	0	1.158408	42.09938	46.73301
C10	0	0	0	0	0	44.18653	0	0.427461	44.18653	45.89637
C11	0	0	0	0	0	44.16481	0	0.1621099	44.16481	44.81325
C12	0	0	0	0	0	43.24816	0	0.0538523	43.24816	43.46356
C13	0	0	0	0	0	41.84593	0	0.015841	41.84593	41.90929
C14	0	0	0	0	0	40.12913	0	5.77E-03	40.12913	40.15223
C15	0	0	0	0	0	38.29437	0	1.90E-03	38.29437	38.30198
C16	0	0	0	0	0	36.33083	0	6.81E-04	36.33083	36.33356
C17	0	0	0	0	0	34.33817	0	2.00E-04	34.33817	34.33897
C18	0	0	0	0	0	32.41062	0	6.92E-05	32.41062	32.41089
C19	0	0	0	0	0	30.38803	0	2.32E-05	30.38803	30.38812
C20	0	0	0	0	0	28.50179	0	6.60E-06	28.50179	28.50182
C21	0	0	0	0	0	26.64459	0	2.33E-06	26.64459	26.6446
C22	0	0	0	0	0	24.77159	0	9.05E-07	24.77159	24.7716
C23	0	0	0	0	0	23.12728	0	2.44E-07	23.12728	23.12728
C24	0	0	0	0	0	21.4577	0	7.62E-08	21.4577	21.4577
C25	0	0	0	0	0	19.90057	0	2.71E-08	19.90057	19.90057
C26	0	0	0	0	0	18.38008	0	7.97E-09	18.38008	18.38008
C27	0	0	0	0	0	17.04279	0	1.93E-09	17.04279	17.04279
C28	0	0	0	0	0	15.6796	0	0	15.6796	15.6796
C29	0	0	0	0	0	14.43265	0	0	14.43265	14.43265
C30	0	0	0	0	0	13.32845	0	0	13.32845	13.32845
Total Flow kmol/hr	467.5193	444.1433	23.37596	4166.667	9096.667	75.16244	170.000	9049.461	4.919945	858.3556
Total Flow kg/hr	8422.491	8001.366	421.1245	9.65E+05	9.25E+05	2043.279	5439.795	9.51E+05	777.8406	27462.21
Total Flow L/min	140.7483	133.7109	7.037415	3091.944	3325.891	39.30533	6.34E+04	2.58E+06	18.22407	27950.27
Vapor Frac	0	0	0	0	0	0	1	0.0692636	3.60E-04	0.9991985
Liquid Frac	1	1	1	0	0	1	0	0	0.9996396	8.01E-04
Solid Frac	0	0	0	1	1	0	0	0.9307364	0	0
Density kg/L	0.9973467	0.9973467	0.9973467	5.20031	4.63688	0.8664129	3.39E-05	6.15E-03	0.7113674	0.0163756
Average MW	18.01528	18.01528	18.01528	231.5386	101.7192	27.18484	31.9988	105.0481	158.0994	31.99398

Stream (cont.)	PROD-FT2	REDOUT	WGS-IN1	WGS-IN2	WGS-OUT1	WGS-OUT2	WGS-OUT3
Temperature C	30	2026.85	105.5683	300	486.5958	152.037	50
Pressure bar	20	0.20265	1	1	10	10	10
Mass Flow kg/hr							
FE3O4	0	3.94E+05	0	0	0	0	0
FEO	0	5.31E+05	0	0	0	0	0
CO2	24456.89	0	9726.695	9726.695	21504.21	21504.21	21504.21
CO	324.7341	0	9044.73	9044.73	1656.392	1656.392	1656.392
O2	0	39438.52	0	0	0	0	0
H2O	1291.35	0	13416.47	13416.47	8527.4	8527.4	8527.4
H2	425.2533	0	101.0073	101.0073	658.1866	658.1866	658.1866
C1	14.7057	0	3.490386	3.490386	0	0	0
C2	26.15695	0	6.194119	6.194119	0	0	0
C3	34.86917	0	8.202205	8.202205	0	0	0
C4	41.29191	0	9.502802	9.502802	0	0	0
C5	45.56182	0	9.80826	9.80826	0	0	0
C6	47.78281	0	8.60042	8.60042	0	0	0
C7	48.13457	0	5.793267	5.793267	0	0	0
C8	47.47141	0	2.762295	2.762295	0	0	0
C9	46.73301	0	1.100545	1.100545	0	0	0
C10	45.89637	0	0.4061107	0.4061107	0	0	0
C11	44.81325	0	0.1540135	0.1540135	0	0	0
C12	43.46356	0	0.0511626	0.0511626	0	0	0
C13	41.90929	0	0.0150498	0.0150498	0	0	0
C14	40.15223	0	5.49E-03	5.49E-03	0	0	0
C15	38.30198	0	1.81E-03	1.81E-03	0	0	0
C16	36.33356	0	6.47E-04	6.47E-04	0	0	0
C17	34.33897	0	1.90E-04	1.90E-04	0	0	0
C18	32.41089	0	6.57E-05	6.57E-05	0	0	0
C19	30.38812	0	2.21E-05	2.21E-05	0	0	0
C20	28.50182	0	6.27E-06	6.27E-06	0	0	0
C21	26.6446	0	2.22E-06	2.22E-06	0	0	0
C22	24.7716	0	8.60E-07	8.60E-07	0	0	0
C23	23.12728	0	2.32E-07	2.32E-07	0	0	0
C24	21.4577	0	7.24E-08	7.24E-08	0	0	0
C25	19.90057	0	2.57E-08	2.57E-08	0	0	0
C26	18.38008	0	7.58E-09	7.58E-09	0	0	0
C27	17.04279	0	0	0	0	0	0
C28	15.6796	0	0	0	0	0	0
C29	14.43265	0	0	0	0	0	0
C30	13.32845	0	0	0	0	0	0
Total Flow kmol/hr	858.3556	10329.17	1339.855	1339.855	1347.602	1347.602	1347.602
Total Flow kg/hr	27462.21	9.65E+05	32344.99	32344.99	32346.19	32346.19	32346.19
Total Flow L/min	15744.33	1.94E+07	4.73E+05	1.06E+06	1.42E+05	64434.9	39428.64
Vapor Frac	0.9119681	0.1193223	0.6743231	1	1	0.8161554	0.6574456
Liquid Frac	0.0880318	0	0.3256769	0	0	0.1838446	0.3425544
Solid Frac	0	0.8806777	0	0	0	0	0
Density kg/L	0.029071	8.29E-04	1.14E-03	5.07E-04	3.80E-03	8.37E-03	0.0136728
Average MW	31.99398	93.4	24.14067	24.14067	24.00278	24.00278	24.00278

Table B.6.1. Stream Results on a per CR5 Basis.

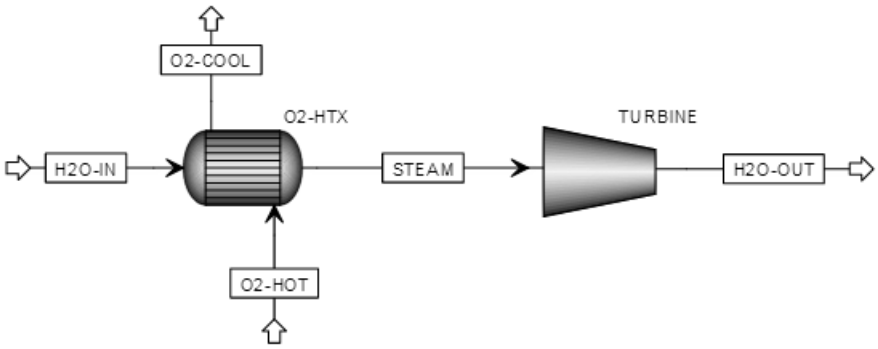
Appendix C – Energy Recovery Options

C.1 Combustion of Light Ends & Hydrogen in GASPURGE Stream

Table C.1.1. Combustion of Light Ends & Hydrogen in GASPURGE Stream: Calculations.

	Mole Flow (kmol/hr)	*MW (kg/kmol)*	*Mass Flow (kg/hr)*	*Mass Flow (kg/s)*	*LHV (MJ/kg)*	*Heat (MW)*	
H2	137.11	2.02	276.96	0.0769	119.96	-1384.34	
C1	0.60	16.04	9.55	0.0027	50.00	-19.90	
C2	0.56	30.07	16.95	0.0047	47.80	-33.77	
C3	0.51	44.10	22.45	0.0062	46.35	-43.36	
C4	0.45	58.12	26.01	0.0072	45.75	-49.58	
						-1530.94	
				$\eta_{\text{combined cycle}}$	0.6	**-918.57**	**MW**

C.2 Heat Recovery from Oxygen Product of CR5 (O2)



O2 Power Recovery						
Stream ID		H2O-IN	H2O-OUT	O2-COOL	O2-HOT	STEAM
From			TURBINE	O2-HTX		O2-HTX
To		O2-HTX			O2-HTX	TURBINE
Phase		LIQUID	MIXED	VAPOR	VAPOR	VAPOR
Substream: MIXED						
Mole Flow	kmol/hr					
WATER		275.0000	275.0000	0.0	0.0	275.0000
O2		0.0	0.0	170.0000	170.0000	0.0
Total Flow	kmol/hr	275.0000	275.0000	170.0000	170.0000	275.0000
Total Flow	kg/hr	4954.202	4954.202	5439.796	5439.796	4954.202
Total Flow	l/min	111.2853	1.28186E+5	8.23652E+5	2.67372E+6	8457.637
Temperature	C	211.6485	102.0834	435.3478	2026.850	211.6485
Pressure	bar	20.00000	1.000000	.2026500	.2026500	20.00000
Vapor Frac		0.0	.9038322	1.000000	1.000000	1.000000
Liquid Frac		1.000000	.0961678	0.0	0.0	0.0
Solid Frac		0.0	0.0	0.0	0.0	0.0
Enthalpy	cal/mol	-64983.22	-58136.85	3051.029	16811.60	-56476.68
Enthalpy	cal/gm	-3607.117	-3227.086	95.34823	525.3822	-3134.932
Enthalpy	cal/sec	-4.9640E+6	-4.4410E+6	1.44076E+5	7.93881E+5	-4.3142E+6
Entropy	cal/mol-K	-30.07597	-11.26718	9.573911	19.63007	-12.91176
Entropy	cal/gm-K	-1.669470	-.6254233	.2991959	.6134626	-.7167115
Density	mol/cc	.0411854	3.57554E-5	3.43996E-6	1.05970E-6	5.41917E-4
Density	gm/cc	.7419668	6.44143E-4	1.10075E-4	3.39091E-5	9.76278E-3
Average MW		18.01528	18.01528	31.99880	31.99880	18.01528
Liq Vol 60F	l/min	82.72917	82.72917	151.7471	151.7471	82.72917

Figure C.2.1. Heat Recovery from Oxygen Product of CR5 (O2): Aspen Process Flow Diagram & Stream Table.

```
BLOCK:  O2-HTX   MODEL: HEATX
 ------------------------------
   HOT SIDE:
   ---------
   INLET STREAM:             O2-HOT
   OUTLET STREAM:            O2-COOL
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE
   COLD SIDE:
   ----------
   INLET STREAM:             H2O-IN
   OUTLET STREAM:            STEAM
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE

                     ***  MASS AND ENERGY BALANCE  ***
                                  IN              OUT        RELATIVE DIFF.
    TOTAL BALANCE
       MOLE(KMOL/HR )            445.000         445.000         0.00000
       MASS(KG/HR   )            10394.0         10394.0         0.00000
       ENTHALPY(CAL/SEC )     -0.417011E+07   -0.417011E+07     0.00000

                     ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E             0.00000      KG/HR
    PRODUCT STREAMS CO2E          0.00000      KG/HR
    NET STREAMS CO2E PRODUCTION   0.00000      KG/HR
    UTILITIES CO2E PRODUCTION     0.00000      KG/HR
    TOTAL CO2E PRODUCTION         0.00000      KG/HR

                        ***  INPUT DATA  ***

   FLASH SPECS FOR HOT SIDE:
   TWO    PHASE      FLASH
   MAXIMUM NO. ITERATIONS                                  30
   CONVERGENCE TOLERANCE                                    0.000100000

   FLASH SPECS FOR COLD SIDE:
   TWO    PHASE      FLASH
   MAXIMUM NO. ITERATIONS                                  30
   CONVERGENCE TOLERANCE                                    0.000100000

   FLOW DIRECTION AND SPECIFICATION:
     COUNTERCURRENT   HEAT EXCHANGER
     SPECIFIED COLD DEG. SUPERHEAT
     SPECIFIED VALUE               C                        0.0000
     LMTD CORRECTION FACTOR                                 1.00000

   PRESSURE SPECIFICATION:
     HOT  SIDE PRESSURE DROP       BAR                      0.0000
     COLD SIDE PRESSURE DROP       BAR                      0.0000

   HEAT TRANSFER COEFFICIENT SPECIFICATION:
     OVERALL COEFFICIENT           CAL/SEC-SQCM-K           0.0203

                       ***  OVERALL RESULTS  ***

   STREAMS:
                    ---------------------------------------
                    |                                     |
   O2-HOT    ----->|               HOT                   |-----> O2-COOL
   T=  2.0268D+03  |                                     |       T=  4.3535D+02
   P=  2.0265D-01  |                                     |       P=  2.0265D-01
   V=  1.0000D+00  |                                     |       V=  1.0000D+00
                    |                                     |
   STEAM     <-----|               COLD                  |<----- H2O-IN
   T=  2.1165D+02  |                                     |       T=  2.1165D+02
   P=  2.0000D+01  |                                     |       P=  2.0000D+01
   V=  1.0000D+00  |                                     |       V=  0.0000D+00
                    ---------------------------------------

   DUTY AND AREA:
     CALCULATED HEAT DUTY          CAL/SEC             649804.6687
     CALCULATED (REQUIRED) AREA    SQM                      4.2106
     ACTUAL EXCHANGER AREA         SQM                      4.2106
```

```
    PER CENT OVER-DESIGN                                        0.0000

  HEAT TRANSFER COEFFICIENT:
    AVERAGE COEFFICIENT (DIRTY)    CAL/SEC-SQCM-K               0.0203
    UA (DIRTY)                     CAL/SEC-K                  854.8294

  LOG-MEAN TEMPERATURE DIFFERENCE:
    LMTD CORRECTION FACTOR                                      1.0000
    LMTD (CORRECTED)               C                          760.1571
    NUMBER OF SHELLS IN SERIES                                   1

  PRESSURE DROP:
    HOTSIDE, TOTAL                 BAR                          0.0000
    COLDSIDE, TOTAL                BAR                          0.0000

BLOCK:  TURBINE  MODEL: COMPR
------------------------------
  INLET STREAM:          STEAM
  OUTLET STREAM:         H2O-OUT
  PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE

                     ***  MASS AND ENERGY BALANCE  ***
                                  IN              OUT        RELATIVE DIFF.
   TOTAL BALANCE
      MOLE(KMOL/HR )            275.000         275.000         0.00000
      MASS(KG/HR   )            4954.20         4954.20         0.00000
      ENTHALPY(CAL/SEC )     -0.431419E+07   -0.444101E+07    0.285562E-01

                     ***  CO2 EQUIVALENT SUMMARY ***
   FEED STREAMS CO2E             0.00000      KG/HR
   PRODUCT STREAMS CO2E          0.00000      KG/HR
   NET STREAMS CO2E PRODUCTION   0.00000      KG/HR
   UTILITIES CO2E PRODUCTION     0.00000      KG/HR
   TOTAL CO2E PRODUCTION         0.00000      KG/HR

                          ***  INPUT DATA  ***

  ISENTROPIC TURBINE
   OUTLET PRESSURE  BAR                                         1.00000
   ISENTROPIC EFFICIENCY                                        0.72000
   MECHANICAL EFFICIENCY                                        1.00000

                          ***  RESULTS  ***

   INDICATED  HORSEPOWER REQUIREMENT  KW                      -530.963
   BRAKE      HORSEPOWER REQUIREMENT  KW                      -530.963
   NET WORK REQUIRED                  KW                      -530.963
   POWER LOSSES                       KW                         0.0
   ISENTROPIC HORSEPOWER REQUIREMENT  KW                      -737.449
   CALCULATED OUTLET TEMP  C                                   102.083
   ISENTROPIC TEMPERATURE  C                                   102.083
   EFFICIENCY (POLYTR/ISENTR) USED                               0.72000
   OUTLET VAPOR FRACTION                                         0.90383
   HEAD DEVELOPED,       M-KGF/KG                           -54,643.7
   MECHANICAL EFFICIENCY USED                                    1.00000
   INLET HEAT CAPACITY RATIO                                     1.43135
   INLET VOLUMETRIC FLOW RATE , L/MIN                          8,457.64
   OUTLET VOLUMETRIC FLOW RATE, L/MIN                        128,186.
   INLET  COMPRESSIBILITY FACTOR                                 0.91561
   OUTLET COMPRESSIBILITY FACTOR                                 0.89646
   AV. ISENT. VOL. EXPONENT                                      1.13210
   AV. ISENT. TEMP EXPONENT                                      1.09351
   AV. ACTUAL VOL. EXPONENT                                      1.10202
   AV. ACTUAL TEMP EXPONENT                                      1.09351
```

Table D.1 Capital Expense table (Years 1-10, 30). Piping at 68% delivered equipment cost, control system at 36% delivered equipment cost, WGS and FT catalysts repurchased every 5 years. Installation cost at 63% total installed cost. Depreciable capital cost includes piping, control system, reactors, catalysts, storage tanks and compressor. All depreciation occurs on a 5 year schedule.

		2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2046
Percent Delivered-Equip Cost		68%										
Piping		**$1,821,723,075**										
Land		**$29,815**										
Percent Delivered-Equip Cost		36%										
Control System		**$964,441,628**										
CR5 Cost		$3,284,081										
WGS Reactor&Catalyst Cost		$1,058,887,716	$0	$0	$0	$0	$1,033,979,650	$0	$0	$0	$0	$0
FT Reactor&Catalyst Cost		$1,317,385,318	$0	$0	$0	$0	$1,303,460,604	$0	$0	$0	$0	$0
Storage Tanks		$11,822,214										
Compressor		$275,322,074										
Decanter		$152,002										
Heat Exchangers		$11,441,424										
Pumps		$709,695										
Yr 1 Installed Cost		**$2,679,004,523**										
Installation Cost		**63%**										
Depreciable Capital Cost		**$7,152,942,076**	**$0**	**$0**	**$0**	**$0**	**$3,810,027,614**	**$0**	0	0	0	0
	Depr Schedule											
Depr Yr 1	0.200	**$1,430,588,415**	**$0**	**$0**	**$0**	**$0**	**$762,005,523**	**$0**	**$0**	**$0**	**$0**	**$0**
Depr Yr 2	0.320		**$2,288,941,464**	**$0**	**$0**	**$0**	**$0**	**$1,219,208,836**	**$0**	**$0**	**$0**	**$0**
Depr Yr 3	0.192			**$1,373,364,879**	**$0**	**$0**	**$0**	**$0**	**$731,525,302**	**$0**	**$0**	**$0**
Depr Yr 4	0.115				**$822,588,339**	**$0**	**$0**	**$0**	**$0**	**$438,153,176**	**$0**	**$0**
Depr Yr 5	0.058					**$414,870,640**	**$0**	**$0**	**$0**	**$0**	**$220,981,602**	**$220,981,602**
Total Acc Depr		$1,430,588,415	$2,288,941,464	$1,373,364,879	$822,588,339	$414,870,640	$762,005,523	$1,219,208,836	$731,525,302	$438,153,176	$220,981,602	$220,981,602
Net PP&E		$5,722,383,476	($2,288,941,464)	($1,373,364,879)	($822,588,339)	($414,870,640)	$3,048,022,091	($1,219,208,836)	($731,525,302)	($438,153,176)	($220,981,602)	($220,981,602)
Total Capital Cost		$7,152,971,891	$0	$0	$0	$0	$3,810,027,614	$0	$0	$0	$0	$0

Table D.2 Expenses (Years 1-10, 30).

		2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2046
COGS (Direct)												
CO2 (kg/yr)		0	0	0	32,720,180	49,080,269	62,168,341	62,168,341	62,168,341	62,168,341	62,168,341	62,168,341
Price ($/kg)		$0.035	$0.035	$0.035	$0.035	$0.035	$0.035	$0.035	$0.035	$0.035	$0.035	$0.035
Carbon Dioxide		**$0**	**$0**	**$0**	**$1,145,206**	**$1,717,809**	**$2,175,892**	**$2,175,892**	**$2,175,892**	**$2,175,892**	**$2,175,892**	**$2,175,892**
Water (kg/yr)		0	0	0	7,147,562	10,721,342	13,580,367	13,580,367	13,580,367	13,580,367	13,580,367	13,580,367
Price ($/kg)		$0.001	$0.001	$0.001	$0.001	$0.001	$0.001	$0.001	$0.001	$0.001	$0.001	$0.001
Water		**$0**	**$0**	**$0**	**$7,148**	**$10,721**	**$13,580**	**$13,580**	**$13,580**	**$13,580**	**$13,580**	**$13,580**
Selling Expense		**$0**	**$0**	**$0**	**$14,236,599**	**$21,354,899**	**$27,049,539**	**$27,049,539**	**$27,049,539**	**$27,049,539**	**$27,049,539**	**$27,049,539**
COGS (DIRECT)		**$0**	**$0**	**$0**	**$15,388,953**	**$23,083,430**	**$29,239,011**	**$29,239,011**	**$29,239,011**	**$29,239,011**	**$29,239,011**	**$29,239,011**
COGS (Indirect)												
Maintenance					**$214,856,163**	**$214,856,163**	**$214,856,163**	**$214,856,163**	**$214,856,163**	**$214,856,163**	**$214,856,163**	**$214,856,163**
Startup/Shutdown					**$145,303,168**	**$217,954,751**	**$276,076,018**	**$276,076,018**	**$276,076,018**	**$276,076,018**	**$276,076,018**	**$276,076,018**
	Wage											
Laborers	$30,000	2	2	2	10	10	10	10	10	10	10	10
Construction Worker	$30,000	10	10	10								
Plumbers	$50,000				5	5	5	5	5	5	5	5
Electricians	$50,000	3	3	3	5	5	5	5	5	5	5	5
Chemical Engineer	$109,000	3	3	3	3	3	3	3	3	3	3	3
Software Developers	$90,500	1	1	1	1	1	1	1	1	1	1	1
Plant Operators	$68,000				20	20	20	20	20	20	20	20
Total Wages (Incl. Operating Supplies & Services: 6%)		**$983,150**	**$927,500**	**$927,500**	**$2,577,500**	**$2,577,500**	**$2,577,500**	**$2,577,500**	**$2,577,500**	**$2,577,500**	**$2,577,500**	**$2,577,500**
Depreciation		**$1,430,588,415**	**$2,288,941,464**	**$1,373,364,879**	**$822,588,339**	**$414,870,640**	**$762,005,523**	**$1,219,208,836**	**$731,525,302**	**$438,153,176**	**$220,981,602**	**$220,981,602**
COGS (INDIRECT)		**$1,431,571,565**	**$2,289,868,964**	**$1,374,292,379**	**$1,185,325,169**	**$850,259,055**	**$1,255,515,204**	**$1,712,718,518**	**$1,225,034,983**	**$931,662,857**	**$714,491,283**	**$714,491,283**
Operating Expenses												
Operating Overhead		**$224,158**	**$211,470**	**$211,470**	**$61,821,676**	**$61,821,676**	**$61,821,676**	**$61,821,676**	**$61,821,676**	**$61,821,676**	**$61,821,676**	**$61,821,676**
Administrative Expense		**$0**	**$0**	**$0**	**$9,491,066**	**$14,236,599**	**$18,033,026**	**$18,033,026**	**$18,033,026**	**$18,033,026**	**$18,033,026**	**$18,033,026**
Mgmt Incentive Comp		**$0**	**$0**	**$0**	**$5,931,916**	**$8,897,875**	**$11,270,641**	**$11,270,641**	**$11,270,641**	**$11,270,641**	**$11,270,641**	**$11,270,641**
Cooling Water		**$0**	**$0**	**$0**	**$2,633,169**	**$3,949,754**	**$5,003,022**	**$5,003,022**	**$5,003,022**	**$5,003,022**	**$5,003,022**	**$5,003,022**
Requirement (kW)		0	0	0	2,245,057,313	3,367,585,969	4,265,608,894	4,265,608,894	4,265,608,894	4,265,608,894	4,265,608,894	4,265,608,894
Turbine + H2 Burn		0	0	0	(1,721,912,250)	(2,582,868,375)	(3,271,633,275)	(3,271,633,275)	(3,271,633,275)	(3,271,633,275)	(3,271,633,275)	(3,271,633,275)
Power Cost ($/kwh)		$0.060	$0.060	$0.060	$0.060	$0.060	$0.060	$0.060	$0.060	$0.060	$0.060	$0.060
Electricity		**$0**	**$0**	**$0**	**$31,388,704**	**$47,083,056**	**$59,638,537**	**$59,638,537**	**$59,638,537**	**$59,638,537**	**$59,638,537**	**$59,638,537**
OPS EXPENSE		**$224,158**	**$211,470**	**$211,470**	**$111,266,532**	**$135,988,960**	**$155,766,903**	**$155,766,903**	**$155,766,903**	**$155,766,903**	**$155,766,903**	**$155,766,903**
EXTRAORDINARY EXPENSE		**$29,815**										
Total Expenses (Incl Inflation)		**$1,431,825,538.71**	**$2,335,882,042.89**	**$1,430,033,804.01**	**$1,392,284,366.50**	**$1,092,532,815.82**	**$1,590,451,712.70**	**$2,137,145,936.73**	**$1,619,693,768.99**	**$1,308,355,440.52**	**$1,074,982,415.15**	**$1,597,367,320.52**

Table D.3 Revenue projections (Years 1-10, 30). Fuel subsidy at $0.38/gal decreasing linearly over 15 years. Carbon credit at $10/ton.

		2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2046
Production Level		0%	0%	0%	50%	75%	95%	95%	95%	95%	95%	95%
FT Fuel Sales		$0	$0	$0	$474,553,316	$711,829,973	$901,651,300	$901,651,300	$901,651,300	$901,651,300	$901,651,300	$901,651,300
TOTAL SALES (Incl Inflation)		$0	$0	$0	$484,044,382	$726,066,573	$919,684,326	$919,684,326	$919,684,326	$919,684,326	$919,684,326	$919,684,326
Renew Fuels (gal)		0	0	0	74,741,837	112,112,756	142,009,490	142,009,490	142,009,490	142,009,490	142,009,490	142,009,490
Subsidy ($/gal)	*$0.38*	$0.00	$0.00	$0.00	$0.38	$0.35	$0.33	$0.30	$0.28	$0.25	$0.23	$0.00
Fuel Subsidy		$0	$0	$0	$28,401,898	$39,762,657	$46,768,459	$43,170,885	$39,573,311	$35,975,738	$32,378,164	$0
Recycled CO2 (ton/yr)		0	0	0	11,773,125	17,659,688	22,368,938	22,368,938	22,368,938	22,368,938	22,368,938	22,368,938
Credit ($/ton)	*$10*	$0	$0	$0	$10	$10	$10	$10	$10	$10	$10	$10
Carbon Credit		$0	$0	$0	$117,731,250	$176,596,875	$223,689,375	$223,689,375	$223,689,375	$223,689,375	$223,689,375	$223,689,375
TOTAL REV (Incl Inflation)		$0	$0	$0	$630,177,530	$942,426,105	$1,190,142,159	$1,186,544,586	$1,182,947,012	$1,179,349,438	$1,175,751,864	$1,143,373,701

Table D.4 Cash flow projections (Years 1-10, 30).

	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2046
Net Earnings	($1,431,825,538.71)	($2,335,882,042.89)	($1,430,033,804.01)	($762,106,836.53)	($150,106,710.68)	($400,309,553.27)	($950,601,351.06)	($436,746,757.07)	($129,006,002.36)	$100,769,449.25	($453,993,619.92)
Depreciation	$1,430,588,415.13	$2,288,941,464.21	$1,373,364,878.53	$822,588,338.70	$414,870,640.39	$762,005,522.73	$1,219,208,836.37	$731,525,301.82	$438,153,175.57	$220,981,601.59	$220,981,601.59
Net Cash from Ops	**($1,237,124)**	**($46,940,579)**	**($56,668,925)**	**$60,481,502**	**$264,763,930**	**$361,695,969**	**$268,607,485**	**$294,778,545**	**$309,147,173**	**$321,751,051**	**($233,012,018)**
Plant & Equipment	$7,152,971,891.04	$0.00	$0.00	$0.00	$0.00	$3,810,027,613.64	$0.00	$0.00	$0.00	$0.00	$0.00
Net Cash from Investing	**($7,152,971,891)**	**$0**	**$0**	**$0**	**$0**	**($3,810,027,614)**	**$0**	**$0**	**$0**	**$0**	**$0**
Increase/(Decrease) in Cash	($7,154,209,014.62)	($46,940,578.68)	($56,668,925.48)	$60,481,502.17	$264,763,929.71	($3,448,331,644.19)	$268,607,485.30	$294,778,544.75	$309,147,173.21	$321,751,050.84	($233,012,018.33)
Net EOY Cash	**($7,154,209,015)**	**($7,201,149,593)**	**($7,257,818,519)**	**($7,197,337,017)**	**($6,932,573,087)**	**($10,380,904,731)**	**($10,112,297,246)**	**($9,817,518,701)**	**($9,508,371,528)**	**($9,186,620,477)**	**($27,792,797,453)**

Table D.5 Earnings projections (Years 1-10, 30).

	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2046
Expenses	$1,431,825,539	$2,335,882,043	$1,430,033,804	$1,392,284,366	$1,092,532,816	$1,590,451,713	$2,137,145,937	$1,619,693,769	$1,308,355,441	$1,074,982,415	$1,597,367,321
Revenue	$0	$0	$0	$630,177,530	$942,426,105	$1,190,142,159	$1,186,544,586	$1,182,947,012	$1,179,349,438	$1,175,751,864	$1,143,373,701
Net Earnings Pretax	($1,431,825,539)	($2,335,882,043)	($1,430,033,804)	($762,106,837)	($150,106,711)	($400,309,553)	($950,601,351)	($436,746,757)	($129,006,002)	$100,769,449	($453,993,620)
Loss Carryforward from Prior Year	0	($1,431,825,539)	($3,767,707,582)	($5,197,741,386)	($5,959,848,222)	($6,109,954,933)	($6,510,264,486)	($7,460,865,837)	($7,897,612,594)	($8,026,618,597)	($24,325,419,801)
Earnings Net of Carryforward	($1,431,825,539)	($3,767,707,582)	($5,197,741,386)	($5,959,848,222)	($6,109,954,933)	($6,510,264,486)	($7,460,865,837)	($7,897,612,594)	($8,026,618,597)	($7,925,849,147)	($24,779,413,421)
Taxable Income	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Taxes	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Net Earnings	($1,431,825,539)	($2,335,882,043)	($1,430,033,804)	($762,106,837)	($150,106,711)	($400,309,553)	($950,601,351)	($436,746,757)	($129,006,002)	$100,769,449	($453,993,620)