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Closing Critical Gaps to Enable a Circular Plastics Economy

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Letter of Transmittal

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This report investigates the various critical issues currently prohibiting a circular plastics economy. There are two main areas of focus included in this work: a design of a pyrolysis oil purification unit in East Java, Indonesia, as well as an analysis of the Bali Sorting Facility to address improvements of its operation. The proposed design for the pyrolysis oil purification unit aims to capture economic value from plastic waste, as this is a critical enabler for achieving the sustainability goal of closing the circular economy. The facility reliably and continuously processes 1.3 million pounds of pyrolysis crude daily. A fractional distillation tower is the main piece of equipment in the purification process, and reliably fractionates the pyrolysis crude into four stream ranging from light vapor to heavy oil. The design effectively manages all high-consequence process safety risks through a highly sophisticated overpressure control system for the distillation tower, minimizing corrosion effects on all processing equipment, and minimizing emissions to the environment throughout the process. The design reliably delivers on-specification feedstock to adjacent Global Petrochemicals ethylene plant without degrading the reliability and economic performance of a downstream ethylene plant through prioritizing high separation in the distillation column, while also implementing accurate and efficient water and contaminant removal systems. The design maximizes economic benefit of the investment by minimizing capital cost and variable operating cost through employing a heat exchange network to limit utility requirements and minimizing equipment pieces. An analysis on the Bali Sorting Facility addresses necessary improvements to increase the throughput of the sorting facility, reduce the contamination level in the sorted flexible plastic waste stream, and lastly to reduce the cost of household collection, sorting operations, or logistics cost for transportation of waste into and out of the sorting facility.

Sincerely,

Melissa Rooney

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Executive Summary

The following report contains a complete design for a pyrolysis oil purification unit along with a "Cold Eyes" review of a plastic waste sorting facility. This report aims to address critical issues currently prohibiting a circular plastics economy. The areas in which this analysis is focused is the chemical recycling of hydrocarbon mixtures, and post use collection of plastic waste at a sorting facility located in Bali, Indonesia.

The purification of pyrolysis crude is a critical aspect of chemical recycling in the plastics cycle. The proposed design aims to capture economic value from plastic waste at the pyrolysis oil purification unit, and is located in East Java, Indonesia. The facility reliably and continuously processes 1.3 million pounds of pyrolysis crude daily. The feedstock to the purification unit is a hydrocarbon liquid mixture sent from a nearby pyrolyzer. The plant reliably delivers 1.2 million pounds of liquid feedstock and 32,000 pounds of vapor feedstock daily to a downstream ethylene steam cracker for further processing. The pyrolysis oil purification unit operates 24 hours a day, 7 days a week, 350 calendar days per year. The goals of this purification unit were to Effectively manage all high-consequence process safety risks, reliably deliver on-specification feedstock to a downstream ethylene plant in order to not degrade the ethylene plant reliability and economic performance, and lastly to maximize economic benefit of the investment by minimizing capital cost and variable operating cost. A process flow diagram is included along with material balances on all processing and utility streams. There are two major aspects to this design: fractional distillation for separation of the hydrocarbon mixture feedstock, and thermal swing adsorption to reliably remove all contaminants from the processing fluid. A complete sized equipment list is included, as well as an economic break down for the estimated annual fixed cost, capital cost, and variable cost. The plant is estimated to have an annual expense of $64.1 MM USD. A piping and instrumentation diagram is illustrated to show the inherent safety of the distillation tower design.

An analysis on the Bali Sorting Facility is included and addresses recommended improvements for its operation. The sorted plastic waste from this facility is the feedstock to an upstream pyrolyzer in which the pyrolysis purification unit is fed from. Therefore, the analysis on this facility addresses necessary improvements to increase the throughput of the sorting facility, reduce the contamination level in the sorted flexible plastic waste stream, and lastly to reduce the cost of household collection, sorting operations, or logistics cost for transportation of waste into and out of the sorting facility.

Process Description

1.3 million pounds of pyrolysis crude are fed from a nearby pyrolyzer and processed daily. The plant reliably delivers 1.2 million pounds of liquid feedstock and 32,000 pounds of vapor feedstock daily to a downstream ethylene steam cracker for further processing. The pyrolysis oil purification unit operates 24 hours a day, 7 days a week, 350 calendar days per year.

Figure 1 illustrates the complete design for this process. The plant is designed for continuous flow and steady state operation. Utilities required for this design include a closed loop nitrogen gas regeneration cycle, thermal fluid, high pressure steam, and utility cooling water. The pyrolysis crude enters the process in stream 1 at 52,432 lb/h and 100°F. There are four product streams: 54 (vapor), 35 (liquid), 48 (liquid), and 52 (liquid), otherwise referred to as pygas, light cut, medium cut, and heavy cut, respectively. There are two major sections included in this process: fractional distillation and contaminant removal. The fractionating of the liquid is carried out in the distillation tower T-100 to separate the hydrocarbon feed into four products ranging from light vapor to heavy oil. The contaminant removal is carried out through thermal swing adsorption in beds TSA-100A, TSA-100B, TSA-101A, and TSA-1001B. The adsorption processing reliably removes chlorides and metals accumulated in the oil throughout the plastics cycle. These processes are equally important, as the viability of the downstream processing is highly reliant on efficient separation of the hydrocarbon feedstock and complete contaminant removal. The pygas, light cut, and medium cut are all feedstocks to a downstream process. The liquid feed and all liquid products are held in pressure vessels designed for one week hold up.

Fractional distillation:

Distillation tower T-100 is designed with 40 baffle trays, a kettle reboiler, and a partial condenser. The tower is designed with two pump-around systems, two side strippers, and a reflux drum with a water decant. Steam is fed at the base of the tower to strip contained liquid of lighter oils, aiding in higher separation with a reduced reboiler duty. The liquid feed is fed through three shell and tube heat exchangers before being fed to the distillation tower at 420°F. The pyrolysis crude feed is first pumped through heat exchanger E-100 upstream of the tower. Stream 3 is partially vaporized by 41,000 lb/h of medium cut at 370 °F in stream 36 passing through the tube side of E-100. Two hot oil streams are drawn at 7000 lbmol/h each from two distinct intermediate stages in the distillation tower and pumped through the ladder two heat exchangers upstream of the tower, E-101 and E-102, to further vaporize the feed. Stream 6 enters T-100 at 19 psig and is fed at tray 29 (tray 1 is at the top of the tower, tray 40 at the base).

Pump-arounds: Stream 10 is drawn from stage 31 at 580 °F and returns to stage 25 at 530°F after passing through E-101. Stream 7 is drawn from stages 10 at 313°F and returns to stage 4 at 383°F after passing through E-102.

Stripper T-102 and is fed 42,000 lb/h of liquid drawn from T-100, and 900 lb/h of stripping steam. The effluent stream 36 from T-101 is the medium cut and leaves the stripper at 41444 lb/h and 370 °F, where it is then utilized as the heating medium in E-100. Stripper T-101 and is fed 17,500 lb/h of liquid drawn from T-100, and 900 lb/h of stripping steam. The effluent stream 24 from T-102 is defined as the light cut and leaves the stripper at 8131 lb/h and 208 °F. Stream 21 leaving the top of the distillation tower passes through condenser E-108 where 66,000 lb/h of vapor are condensed. Uncondensed hydrocarbons are removed from the process as pygas product at 1206 lb/h and 87°F in stream 53 without any further processing. Decanted water is removed from the condensed liquid at 10,400 lb/h in stream 59. Condensed hydrocarbons in stream 23 are returned to the top tray of T-100 at 65,000 lb/h. The bottoms product of T-100 is the heavy cut and is pumped from reboiler E-107 in stream 49 at 2060 lb/h and 685 °F.

Contaminant removal:

The light and medium cuts (streams 24 and 36 respectively) are further processed downstream of the distillation tower to remove all contaminants and entrained water. The light cut is cooled to 100°F in E-104 and pressurized to 85 psia in P-106. The medium cut is cooled to 100°F in E-103 and pressurized to 85 psig in P-107. Streams 26 and 39 define the beginning of the contaminant removal process for the light and medium cut. There are two lead-lag thermal swing adsorption beds in series for the removal of chlorides and metals, respectively. At any time, the lead bed is defined as the bed in which the contaminated hydrocarbon stream is fed, while the lag bed is regenerated with hot nitrogen gas. An alternating system is utilized, where the adsorption beds process one of the cuts at a time while the other cut accumulates in a hold up tank. More detailed description of the regeneration process can be found in the appendix adsorption section. The light and medium cut are both processed in the thermal swing adsorption beds to reliably remove all chlorides and metal contaminants. After all contaminants are removed, both the light and medium cut streams are held in storage tanks V-107 and V-108 before being removed from the process as final products and fed to a downstream process. Hot nitrogen gas is utilized in a continuous closed loop cycle for regeneration of the two lag beds at any time. Nitrogen gas in stream 76 and 78 is fed at the bottom of the lag thermal swing adsorption beds to remove contaminants from the adsorbents. Stream 80 is fed to condenser E-106, and chemical waste is removed from the process in stream 27 from separator V-113. The uncondensed nitrogen gas is reheated in furnace H-100 before returning to the lag beds for regeneration at 400°F.

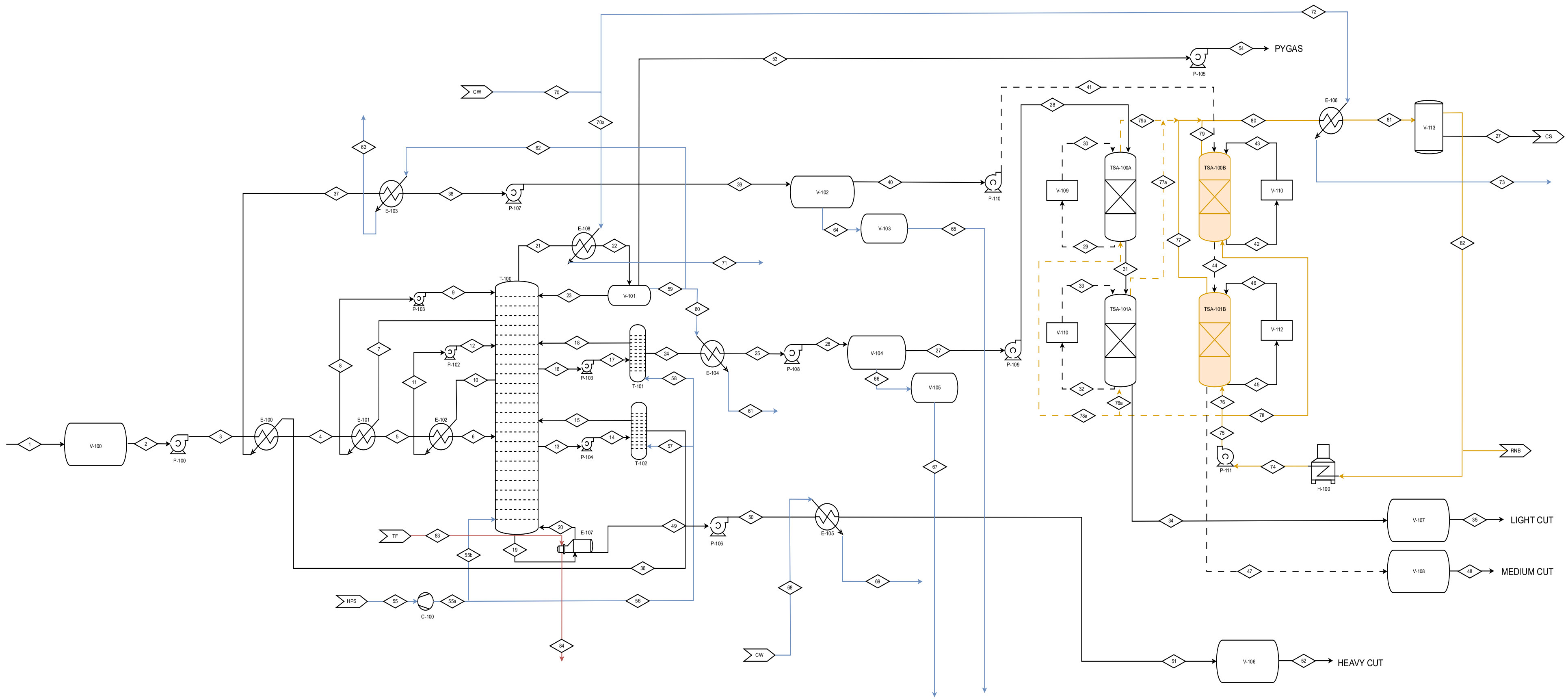

Figure 1 *Process Flow Diagram*

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
T	F	100	100	100	192	320	419	313	283	283	580	550	550	360	360	360	196	196	196	685	685	185	83	83	208	100	100	100	100	100
P	psia	18	18	19	19	19	19	19	19	20	19	19	20	19	19	19	19	19	19	19	19	19	19	19	19	19	85	85	85	85
m	lb/h	52432	52432	52432	52432	52432	52432	100021	100021	100021	194816	194816	194816	41851	41851	407	17532	17532	9402	120100	118040	67697	67697	66491	8131	8131	8131	7749	7749	41444
Pygas		1201	1201	1201	1201	1201	1201	42	42	42	0	0	0	0	0	0	9461	9461	9402	0	0	1141	1141	0	59	59	59	59	59	318
Light cut		8090	8090	8090	8090	8090	8090	57834	57834	57834	85	85	85	3087	3087	407	5345	5345	0	0	0	16688	16688	16623	5345	5345	5345	5345	5345	28588
Medium cut		41654	41654	41654	41654	41654	41654	42086	42086	42086	191703	191703	191703	38697	38697	0	2344	2344	0	35707	35094	49868	49868	49868	2344	2344	2344	2344	2344	12538
Heavy cut		1487	1487	1487	1487	1487	1487	0	0	0	3004	3004	3004	40	40	0	0	0	0	84389	82942	0	0	0	0	0	0	0	0	0
Water		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
Chlorides		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
Metals		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
Thermal fliud		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
Nitrogen gas		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

		30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	55a	55b	56
T	F	100	100	100	100	100	100	370	176	100	100	100	100	100	100	100	100	100	100	100	685	698	100	100	101	101	750	750	750	750
P	psia	85	85	85	85	85	85	19	19	19	85	85	85	85	85	85	85	85	85	85	19	65	65	65	4	4	615	65	65	65
m	lb/h	41444	7749	41444	41444	7749	7749	41444	41444	41444	41444	41417	41417	41417	41417	41417	41417	41417	41417	41417	2060	2060	2060	2060	1206	1206	10800	10800	9000	1800
Pygas		318	59	318	318	59	59	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1141	1141	0	0	0	0
Light cut		28588	5345	28588	28588	5345	5345	2680	2680	2680	2680	2680	2680	2680	2680	2680	2680	2680	2680	2680	0	0	0	0	65	65	0	0	0	0
Medium cut		12538	2344	12538	12538	2344	2344	38697	38697	38697	38697	38697	38697	38697	38697	38697	38697	38697	38697	38697	612	612	612	612	0	0	0	0	0	0
Heavy cut		0	0	0	0	0	0	40	40	40	40	40	40	40	40	40	40	40	40	40	1447	1447	1447	1447	0	0	0	0	0	0
Water		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
Chlorides		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
Metals		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
Thermal fliud		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
Nitrogen gas		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

		57	58	59	60	61	62	63	64	65	66	67	68	69	70	70a	71	72	73	74	75	76	77	78	79	80	81	82	83	84
T	F	750	750	83	83	95	83	0	100	100	100	100	87	107	87	87	107	87	107	400	400	400	400	400	400	400	200	200	752	725
P	psia	65	65	19	19	55	19	19	85	85	85	85	85	55	85	85	55	85	55	45	45	45	45	45	45	45	45	45	245	215
m	lb/h	900	900	10391	5196	5196	5196	5196	27	27	381	381	10000	10000	1160000	1150000	1150000	10000	10000	1135	1135	568	570	568	570	1140	1140	1135	0	0
Pygas		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
Light cut		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
Medium cut		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
Heavy cut		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
Water		0	0	0	0	0	0	0	0	0	0	0	10000	10000	1160000	1150000	1150000	10000	10000	0	0	0	0	0	0	0	0	0	0	0
Chlorides		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	3	3	0	0	0
Metals		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	3	3	0	0	0
Thermal fliud		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	100000	100000
Nitrogen gas		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1135	1135	568	568	568	568	1135	1135	1135	0	0

Table 1 *Material Balances*

Economics

Sized equipment list

***Table 3** Sized equipment list*

Equipment tag	***Equipment type***	***Service***	***Material of construction***	***Total cost***
V-100	Pressure vessel	Feed storage tank	316 Stainless steel	$ 1,578,377
V-101	Reflux drum	Hold up tank for condensed liquid at top of distillation tower	316 Stainless steel	$ 24,000
V-102	Pressure vessel	Medium cut hold up tank	316 Stainless steel	$ 1,183,783
V-103	Floating head tank	Medium cut dewatering tank	316 Stainless steel	$ 24,000
V-104	Pressure vessel	Light cut hold up tank	316 Stainless steel	$ 394,594
V-105	Floating head tank	Light cut dewatering tank	316 Stainless steel	$ 24,000
V-106	Pressure vessel	Heavy cut product storage tank	316 Stainless steel	$ 291,133
V-107	Pressure vessel	Light cut product storage tank	316 Stainless steel	$ 570,510
V-108	Pressure vessel	Medium cut product storage tank	316 Stainless steel	$ 1,475,798
V-109	Floating head tank	Temporary hold up tank for drained liquid from adsorption bed TSA-100A	316 Stainless steel	$ 10,000
V-110	Floating head tank	Temporary hold up tank for drained liquid from adsorption bed TSA-100B	316 Stainless steel	$ 10,000
V-111	Floating head tank	Temporary hold up tank for drained liquid from adsorption bed TSA-101A	316 Stainless steel	$ 10,000
V-112	Floating head tank	Temporary hold up tank for drained liquid from adsorption bed TSA-101B	316 Stainless steel	$ 10,000

V-113	Horizontal gas liquid separator	Contaminant separator from nitrogen regeneration	316 Stainless steel	$ 369,000
V-114	Floating head tank	Distillation tower reflux dewatering tank	316 Stainless steel	$ 258,300
P-100	VFD Centrifugal pump	Move feed into distillation towe	304 Stainless steel	$ 1,080,638
P-101	VFD Centrifugal pump	Move liquid in pump-around system 1	304 Stainless steel	$ 206,800
P-102	VFD Centrifugal pump	Move liquid in pump-around system 2	304 Stainless steel	$ 206,800
P-103	VFD Centrifugal pump	Draw liquid from distillation tower and feed to side stripper one	304 Stainless steel	$ 106,935
P-104	VFD Centrifugal pump	Draw liquid from distillation tower and feed to side stripper two	304 Stainless steel	$ 427,740
P-106	VFD Centrifugal pump	Distillation tower bottoms pump	304 Stainless steel	$ 26,884
P-107	VFD Centrifugal pump	Move medium cut to hold up tank in adsorption section	304 Stainless steel	$ 536,365
P-108	VFD Centrifugal pump	Move light cut to hold up tank in adsorption section	304 Stainless steel	$ 375,456
P-109	VFD Centrifugal pump	Provide required head to move medium cut to the top of the adsorption beds	304 Stainless steel	$ 134,070
P-110	VFD Centrifugal pump	Provide required head to move light cut to the top of the adsorption beds	304 Stainless steel	$ 11,172
P-111	VFD Centrifugal pump	Move nitrogen gas in regeneration cycle	304 Stainless steel	$ 206,800
E-100	Shell and tube heat exchanger	Partially vaporize process feed with medium cut	Carbon steel	$ 199,556

E-101	Shell and tube heat exchanger	Partially vaporize process feed with liquid in pump-around system 1	Carbon steel	$ 199,556
E-102	Shell and tube heat exchanger	Partially vaporize process feed with liquid in pump-around system 2	Carbon steel	$ 199,556
E-103	Shell and tube heat exchanger	Reduce medium cut to adsorption process operating temperature	Carbon steel	$ 337,284
E-104	Shell and tube heat exchanger	Reduce light cut to adsorption process operating temperature	Carbon steel	$ 474,568
E-105	Shell and tube heat exchanger	Cool heavy cut stream	Carbon steel	$ 199,556
E-106	Shell and tube heat exchanger	Condense contaminants in regenerated nitrogen stream	316 Stainless steel	$ 199,556
E-107	Kettle U-tube reboiler	Vaporize liquid held up at bottom of distillation tower	316 Stainless steel	$ 199,556
E-108	Partial condenser	Partially condense top product of distillation tower	316 Stainless steel	$ 199,556
T-100	Distillation tower	Separate pyrolysis crude into four products	316 Stainless steel	$ 8,543,284
T-101	Side stripper	Remove lighter oils from light cut	316 Stainless steel	$ 342,495
T-102	Side stripper	Remove lighter oils from medium cut	316 Stainless steel	$ 626,835
TSA-100A	Thermal swing adsorption bed in service	Reliably remove chloride contaminants from processing stream	316 Stainless steel	$ 555,675

TSA-100B	Thermal swing adsorption bed in regeneration	Regeneration bed for uninterrupted continuous processing	316 Stainless steel	$ 555,675
TSA-101A	Thermal swing adsorption bed in service	Reliably remove chloride contaminants from processing stream	316 Stainless steel	$ 555,675
TSA-101B	Thermal swing adsorption bed in regeneration	Regeneration bed for uninterrupted continuous processing	316 Stainless steel	$ 555,675
H-100	Furnace	Reheat nitrogen to regeneration temperature	Iron chrome aluminum	$ 11,030

Economics

All economic calculations were carried out based on equipment sizing and necessary process assumptions from by Chemical Engineering Design[1.] ChemCAD was used for the sizing of the majority of the equipment and for preliminary cost estimations. A breakdown of the overall capital cost, variable cost, and fixed cost estimates is displayed in figure x.

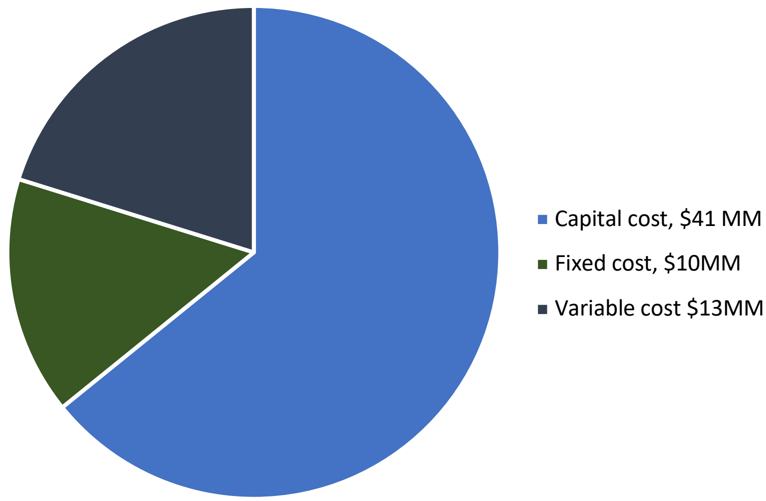

Figure 2 *Annual expenses breakdown*

Capital cost estimate

Table 4 *Capital cost estimate*

ISBL		$	23,508,242
OSBL	40% ISBL	$	9,403,297.00
Engineering	10% ISBL and OSBL	$	3,291,153.95
Contingency	15% ISBL and OSBL	$	4,936,730.92
Capital cost		***$***	***41,139,424***

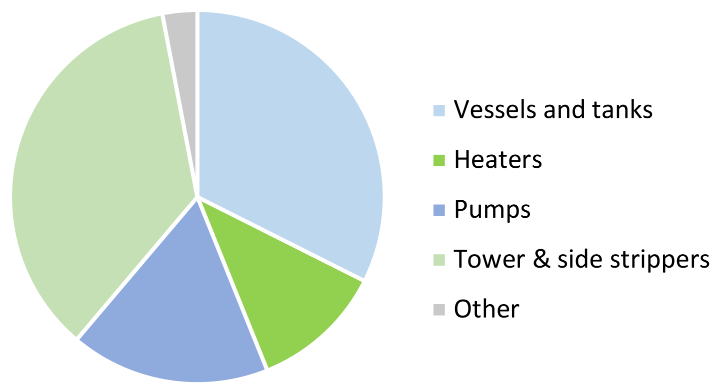

Figure 3 *Equipment cost breakdown*

Variable cost estimate

Table 5 *Variable cost estimate*

Waste disposition	$	728,222
Nitrogen gas	$	4,280,359
Stripping steam	$	942,171
Cooling water	$	4,410,000
Thermal fluid	$	2,460,000
Fuel gas	$	31,689
Electricity	$	7,032
Variable cost	***$***	***12,859,473***

Fixed cost estimate

Table 6 *Fixed cost estimate*

Maintenance	5% ISBL	$	1,175,412
Total operations		$	4,900,000
Operating overhead	65% maintenance and total operations	$	3,949,018
Fixed cost		***$***	***10,024,430***

Process Safety

Minimizing environmental impacts

One of the design goals for the pyrolysis purification unit was to minimize environmental impacts. This pyrolysis oil purification unit processes 1.3 million pounds of liquid hydrocarbon feedstock daily in which hazardous and toxic air pollutants are likely to be emitted at a dangerous rate if safety precautions are not put in place. The air pollutants of most concern in this hydrocarbon processing plant are particulate matter, carbon monoxide, nitrogen oxides, and BTEX compounds: benzene, toluene, ethylbenzene, and xylene. Some of these pollutants are proven or suspected carcinogens and are known to pose significant threats to development and reproductive abilities when exposed to at high concentrations. VOCs are classified as compounds with high vapor pressure, low water solubility, and low boiling points that are emitted into the air throughout the process. Operator exposure to some VOCs can cause a variety of adverse health impacts. As VOCs are emitted into the environment, they can react with other gases to form air pollutants, potentially forming tropospheric ozone and acting as greenhouse gases to further contribute to climate change. Minimizing emissions throughout the pyrolysis purification unit is critical to the feasibility of this design, as they directly lead to adverse impacts on plant operators, the climate and environment, as well as nearby communities exposed to the pollutants.

Thousands of pounds of these emissions are released to the environment throughout the year in typical petroleum refineries through normal emissions, fugitive releases, accidental releases, or plant upsets. In the proposed process design, the most likely and concerning sources of emissions are from the furnaces used to heat the hot oil reboiler fluid and nitrogen gas by firing fuel gas, dewatering systems, the transferring of hydrocarbon products, potential processing fluid leakage from (but not limited to) valves, equipment, or piping, as well as the potential high-temperature combustion of vented material from flare. In order to minimize these emissions and ensure safe plant operator conditions, a number of precautions have been implemented in throughout this design.

An automatic tank dewatering control system is utilized to achieve complete water removal while ensuring safe operator conditions at the facility and minimal hydrocarbons removed in the process. Manual methods to dewater hydrocarbon liquids can result in excessive levels of hydrocarbons ending up in the decanted water removed from the process – essentially leading to high levels of VOC emissions and increased operator exposure to the volatile compounds. In minimizing hydrocarbons removed in the dewatering process, additional environmental fines are avoided from oils ending up in sewer systems. The automated dewatering system accurately detects the presence of hydrocarbons at 5% break through, at which point a motor operated valve is triggered to close and pause the dewatering process. The Micro Motion 2700 Multivariable Flow and Density transmitters operates based on a specific density calculation to identify the limit for 95% water and 5% hydrocarbon breakthrough. The accuracy of this system ensures all water is removed from processing streams, while less than one gallon of hydrocarbon per draw off event is removed from the processing streams. This process ensures mass balances throughout the process are unaffected by this system, corrosion effects on processing equipment are mitigated as water is completely removed, safe operator conditions, and minimal volatile organic compound emissions to the environment.

All streams are pressurized immediately after exiting the distillation tower. High pressure downstream processing limits effectively reduces VOC emissions. All liquid storage tanks are designed as pressure vessels to mitigate evaporative and working losses.

A distillation pressure relief valve is sized assuming an onsite flare is available for the safe and complete combustion of any vented material. The detailed control system illustrated in figure X is designed for inherent safety of the distillation tower, and significantly limits the probability of the pressure relief valve opening. There is also a secondary relief valve designed for 10 psi less than that of the main pressure relief valve. The implementation of the secondary pressure relief valve minimizes the duration of discharge and reduces probability of main pressure relief valve opening.

P&ID w controls and alarms

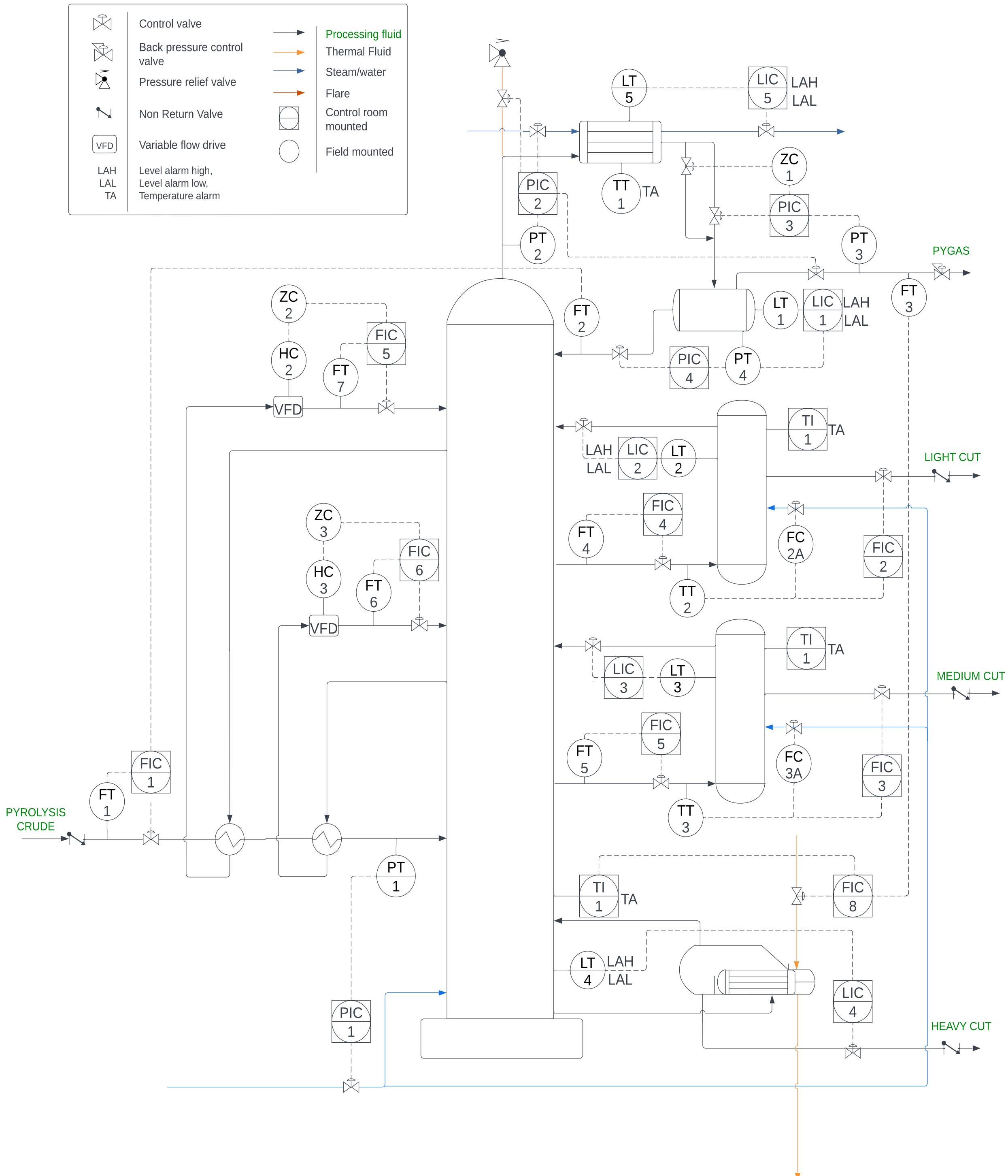

***Figure 4** Distillation tower P&ID*

Personnel exposure risk

Table 7 *Personnel exposure risk I: OSHA PEL and NFPA ratings*[7]

	OSHA PEL		NFPA		
	mg/m3	*ppm*	*Health*	*Flammability*	*Reactivity*
Nitrogen	S/A		1	0	0
Hydrogen	S/A		0	4	0
Carbon monoxide	55	50	4	4	0
Carbon dioxide	9000	5000	2	0	0
Methane	S/A		1	4	0
Ethane	S/A		1	4	0
Ethylene	S/A		1	4	0
Propane	1800	1000	2	4	0
Propylene	S/A		1	4	1
Butane	1200	500	1	4	0
Benzene	1.6	1	2	4	0
1,3-Butadiene	4.4	1	2	4	0
Pentane	2950	1000	2	4	0
Hexane	1800	500	2	4	0
Heptane	1600	400	1	4	0
Octane	1450	300	1	4	0
Nonane	1050	200	1	4	0
Decane	----	----	1	2	0
Undecane	----	----	1	2	0
Dodecane	----	----	1	2	0
Benzene	30	10	2	3	0
Toluene	375	100	2	3	0
Colloidal silica	80	----	2	0	0
Calcium	5	----	1	0	0
Hydrogen chloride	7	5	3	3	1
Chlorobenzene	350	75	2	3	0
Dichlorobenzene	150	25	2	2	1
Benzyl chloride	5	1	3	2	1

__Table 8__ Personnel exposure risk II: Lethal doses and concentrations[7]

	LETHAL LIMITS			
	LD50/LC50	*Dose / Concentration*	*Units*	*Animal*
Nitrogen	----			----
Hydrogen	----			----
Carbon monoxide	LC50 4 hours	1807	ppm	Rat
Carbon dioxide	LC50, 24h 30 days	10000	ppm	Rat
Methane	LC50, 2 hours	326	g/m3	Rat
Ethane	LC50, 4 hours	658	mg/L	Rat
Ethylene	LD50	950,000	ppm	Mouse
Propane	LD50	682	mg/kg	Rat
Propylene	LC50, 4 hours	> 65000	ppm	Rat
Butane	LC50	> 680000	mg/m3	Mouse
Benzene	LD50	930	mg/kg	Rat
1,3-Butadiene	LC50, 4 hours	128000	ppm	Rat
Pentane	LD50	> 2000	mg/kg	Rat
Hexane	LD50	930	mg/kg	Rat
Heptane	LC50, 4 hours	103	g/m3	Rat
Octane	LD50	> 5000	mg/kg	Rat
Nonane	LD50	> 5000	mg/kg	Rat
Decane	LD50	> 5000	mg/kg	Rat
Undecane	LD50	> 5000	mg/kg	Rat
Dodecane	LD50	> 5000	mg/kg	Rat
Benzene	LD50	5970	mg/kg	Rat
Toluene	LD50	12200	mg/kg	Rabbit
Colloidal silica	LD50	7000	mg/kg	Mouse
Calcium	LD50	6450	mg/kg	Rat
Hydrogen chloride	LD50	900	mg/kg	Rabbit
Chlorobenzene	LD50	1100	mg/kg	Rat
Dichlorobenzene	LD50	500	mg/kg	Rat
Benzyl chloride	LD50	1500	mg/kg	Mouse

HAZOP for largest distillation column

***Table 9** HAZOP for distillation tower T-100*

Deviation	***Cause***	***Likelihood***	***Severity***	***Consequence***	***Hazard Control***
No feed	Line blockage valve shut valve failure pump failure	unlikely unlikely unlikely unlikely	5	No operation, no product	Flow monitor, automatic alarm of feed flow
No thermal fluid flow	Pump failure line blockage valve failure valve shut	unlikely unlikely unlikely unlikely	5	No heat supplied to tower, liquid level rapidly increases and pressure builds	Flow monitor, temperature alarm on bottoms product, pressure alarms on distillation column
No cooling water flow to condenser	Pump failure line blockage valve failure valve shut	unlikely unlikely unlikely unlikely	5	Medium and light cut products leave as vapor in distillate top product	Flow monitor, temperature alarm on reflux, pressure alarms on distillation column
No flow in pump-around line	Pump failure line blockage valve failure valve shut	unlikely unlikely unlikely unlikely	5	Feed to tower significantly decreases in temperature, poor separation of products	Flow monitor, control on variable flow drive of return pump, flow automatic alarm
No steam feed	Pump failure line blockage valve failure valve shut	unlikely unlikely unlikely unlikely	2	quality of separation decreases	Flow monitor, decanted water flow automatic alarm
Less feed	Pump corrosion	likely	4	Decrease in column	Flow monitor, automatic alarm of

	line blockage valve failure valve partially shut leakage	unlikely likely unlikely unlikely		pressure, quality of separation decreases	feed flow, pressure alarms on distillation column
Less thermal fluid flow	Pump ware line blockage valve failure valve partially shut leakage	likely unlikely likely unlikely unlikely	4	Not enough heat to distillation column, product streams not properly separated	Flow monitor, temperature alarm on bottoms product, pressure alarms on distillation column
Less cooling water flow to condenser	Pump ware line blockage valve failure valve partially shut leakage	likely unlikely likely unlikely unlikely	4	vapor product contains heavier hydrocarbons, not suitable for steam cracker feed, temperature increases	Flow monitor, temperature alarm on reflux, pressure alarms on distillation column
Less flow in pump-around line	Pump corrosion line blockage valve failure valve partially shut	likely unlikely likely unlikely	2	Feed to tower decreases in temperature, less efficient separation of products, increased pressure in column	Flow monitor, control on variable flow drive of return pump, flow automatic alarm

	leakage	likely			
Less steam fed	Pump ware line blockage valve failure leakage valve partially shut	likely unlikely likely unlikely unlikely	2	quality of separation decreases	Flow monitor, decanted water flow automatic alarm
More thermal fluid flow	increased pump capacity control valve fully open	unlikely likely	2	increase in bottoms temperature	Flow monitor, temperature alarm on bottoms product, pressure alarms on distillation column
More cooling water flow to condenser	increased pump capacity control valve fully open	unlikely likely	2	decrease in distillate product temperature, could potentially decrease pressure top column	Flow monitor, temperature alarm on reflux, pressure alarms on distillation column
More flow in pump-around line	increased pump capacity control valve fully open	unlikely likely	2	heat transferred to feed increases, vapor content rises, could increase pressure of feed	Flow monitor, control on variable flow drive of return pump, flow automatic alarm

More steam feed	increased pump capacity control valve fully open	unlikely likely	2	condenser efficiency decreases	Flow monitor, decanted water flow automatic alarm
Higher pressure in column	steam expander failure high liquid hold up pressure indicator fail PA failure increased vapor pressure bottoms pump failure/corrosion	unlikely somewhat likely likely unlikely somewhat likely likely	4	strain on tower, potential for thermal cracking, vapor condensation and flooding	pressure alarms on distillation column, control valve and pressure control for reflux, control valve and level control for bottoms
No overhead vapor distillate	pressure of column top too low	likely	5	air ingress to process	pressure control top column, automatic alarm top product pressure,
Lower temperature thermal fluid	cold/windy weather conditions	likely	4	Not enough heat to distillation column, product streams not properly separated	temperature control, temperature alarm on bottoms product, pressure alarms on distillation column

Higher temperature water flow to condenser	hot weather conditions	likely	4	vapor product contains heavier hydrocarbons, not suitable for steam cracker feed	temperature control, temperature alarm on reflux, pressure alarms on distillation column
More liquid held in tower bottom	bottoms pump corrosion	likely	3	Increase in pressure and temperature in column, could potentially lead to hydrocracking	level control, bottoms product pump increases
Higher pressure steam feed	turbine failure	unlikely	2	increased pressure in column	pressure control steam feed, pressure alarms on distillation column
No reflux returned to column	valve failure condenser failure	likely unlikely	5		pressure monitor for reflux flow and top vapor product
Less reflux returned to column	valve failure condenser loss in efficiency	likely likely	4		pressure monitor for reflux flow and top vapor product
more reflux returned to column	valve failure increased cooling water sent to condenser	likely unlikely	4		pressure monitor for reflux flow and top vapor product

No bottoms product	pump failure blockage valve failure	unlikely unlikely likely	5	liquid hold up increases, pressure build up, inefficient separation	flow monitor, temperature alarm on bottoms product, pressure alarms on distillation column
more bottoms product	pump increased capacity control valve fully open		4	liquid hold up decreases, quality of separation decreases, pressure decreases	flow monitor, temperature alarm on bottoms product, pressure alarms on distillation column
less bottoms product	pump corrosion blockage valve failure	likely unlikely likely	4	liquid hold up increases, pressure build up, quality of separation decreases	flow monitor, temperature alarm on bottoms product, pressure alarms on distillation column

Recommendations for improvement of Bali sorting facility

Global Petrochemicals (GP) has developed a multi-tiered initiative that results in less waste from and in Negara leaking into the environment while increasing the quantity of waste feedstock available to produce pyoil from a new pyrolysis facility in Surabaya, East Java. The process has been developed with three guiding principles: local collaboration (promoting respect and solidarity), sustainability (contributing to economic development and growth), and transparency (benefiting people and the planet).

The foundation of the initiatives proposed is the successful collaboration within the local community, a collaboration based on respect and solidarity. Mutual respect and understanding of the diverse cultural values while building solidarity of mission is promoted through this work. A sense of common purpose is developed within the program, one that stems from ensuring the celebration and protection of the rich history, culture, and beauty of Bali. The community of action is capitalized on to produce and allow the collaboration to build collective capacity to make things better.

Sustainability is dependent upon the local communities committing to the broader environmental, economic, and social benefits of the program. Common economic interests are emphasized to ensure that the outcomes will inherently benefit the communities. Individual households are anticipated to benefit, as well as the broader communities and beyond. This project ensures that recycling materials that would have become waste actually become a valuable resource and provides a significant contribution to the local economy while safeguarding the quantity of feedstock for our facility. Sustainability is addressed two-fold in this project – economic development that also aims to help protect local natural resources. Transparency is critical in building trust, and a genuine interest in ensuring the outcomes of the project benefit both people and the planet is paramount. The first stage in which progress is built upon is the grassroots work that has already been done in Jembrana. Each community will continue to monitor the progress and participation of their households, as well as track the benefits experienced. Partnering with local schools, villages, and nonprofits in the community will advance our work to build a sustainable recycling network while breaking those habits that may have led to pollution.

The project promotes integrated solutions supported by increased interest and individual responsibility in an effort to systemically change the waste disposal problem within Negara. The solutions connect the economic, social, and environmental benefits to these same individuals and their communities.

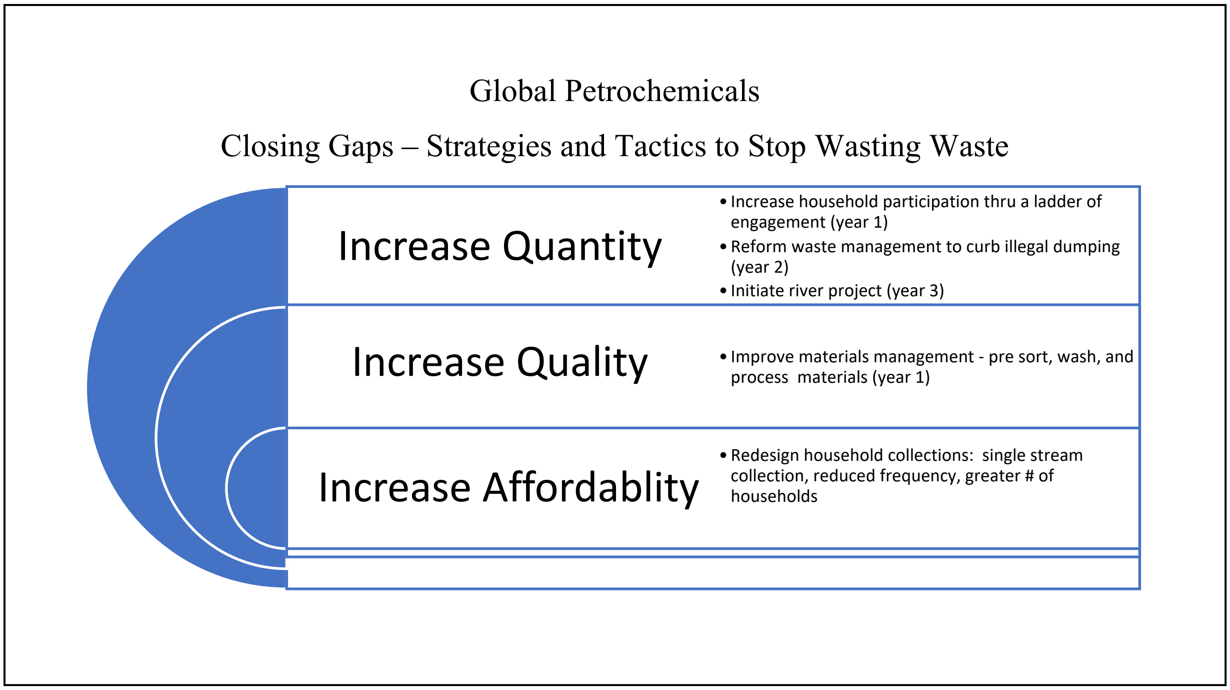

Figure 5 *Bali Sorting Facility improvements*

Increase Quantity

Increase household participation thru a ladder of engagement (year 1): Given that household participation in the current recycling program is less than desired, GP will work closely with individual communities to build upon the work that has been already completed and identify those areas that would benefit from additional education and influence. Through a ladder of engagement, individuals and villages with the lowest levels of interest and participation are addressed while promoting the benefits experienced by those with a more active level of participation and engagement in the recycling program. To keep supporters engaged, no matter where they are on the ladder, collaboration with the local authorities to understand the people of Negara. The program is advocated for while actively working to bring in more supporters. Working with those locals that understand the importance of the program and help them to make the commitment necessary to help sustain their involvement. Volunteers will be sought out to promote the value of the recycling program and ensure that they know how much their help advances the cause. Local successes will be shared with other communities and circle back as the program advances. The cadre training and household education are ensured to be rooted in respect for the local customs, emphasizes common economic interests, and genuinely provides outcomes that benefit both people and the planet. Through this ladder of engagement, PG will work to gradually shift mindsets in waste management, turning passive supporters into active volunteers and advancing participation in the recycling effort.

Reform waste management to curb illegal dumping (year 2): GP will work to be a catalyst for action to reform waste management, working to significantly increase the percentage of Jembrana's total waste that is being recycled. Curbing illegal dumping requires improved waste management and recycling support systems. While solid waste mismanagement is a huge and growing global issue with significant environmental, economic, and social issues, this strategy focuses on local solutions within Bali. GP will work with local governments to advocate for political change and encourage Indonesian lawmakers to allow compulsory municipal waste pick-up. Additionally, in the absence of legal requirements, GP will work with local communities and businesses to advance the expectation that companies, large and small, take back the plastics they bring into the market. GP will assist communities in developing effective recycling and recovery systems that will curb dumping and promote responsibility. The implementation of improved waste management through better collection and disposal practices requires the involvement and buy-in of local manufacturers and businesses. This will happen only with innovation around the litter generation points and improvement of collection systems, facilitating the process for each stakeholder while providing an economic and environmental return on their efforts.

Initiate river project (year 3): While there are river initiatives aimed at preventing the flow of plastic waste into the world's ocean, land-based plastic waste also leaks into the environment from those plastics that never make it to the ocean. Because only a small fraction of plastics that land in river systems are discharged, GP will initiate a river project that extracts those plastics that reside in the waters of Jembrana. Specifically, GP will target those plastics that are retained on riverbeds and floodplains, in the rivers' vegetation, and retained in riverbed sediments.

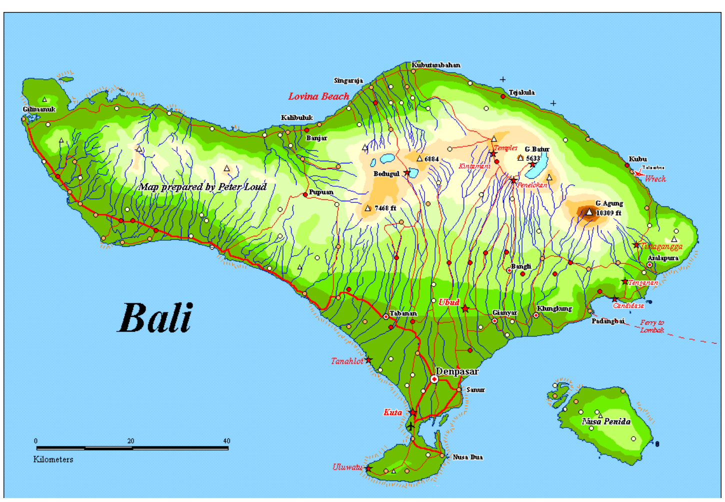

Figure 6 *Map of Bali, Indonesia*

Increase Quality

GP will work with the community to invest in improved materials management where all waste will be pre-sorted more thoroughly and efficiently. Initial screens will continue to separate PVC, metals, and paper from plastics. Greater effort will also be placed on the pre-sorting of plastics, where plastics will be further sorted and separated to ensure that the materials being transported for recycling provide the appropriate products for at-site processing. Correctly segregating the plastics up front will ensure the quality of the recycled plastic while providing efficiencies in the process. The current manual sorting of plastics will be enhanced and supplemented with automated/semi-automated processes. Automated processes require a larger upfront investment in machinery; the return will be realized with the increased certainty of producing higher-quality recycled material. There should be a reduction in the level of contamination in the sorted flexible plastic waste stream that is sent as feedstock to the pyrolysis unit by automating some of the sorting. GP will also engage in the collective work of addressing the concerns regarding additives used in the manufacturing of some plastics. GP will advocate for policy interventions that create restrictions on the use of hazardous additives and better labeling of all additives in plastics manufacturing.

Increase Affordability

A redesign of the current household collections system will increase the affordability of sourcing the flexible plastic waste stream as feedstock for our new facility. Specifically, improvements in the door-to-door collection service of recyclables will contribute to the economic viability of this project. This analysis concluded that there are three areas ready for the redesign: how and when the material is to be sorted, frequency of collection, and level of community participation. The new design will include single-stream collection, reduced frequency of pick-up, and will benefit from the greater number of households participating due to our community efforts mentioned above. Because single-stream is the least costly to collect, endeavors to move the household collection to single-stream. The single-stream collection will allow collection teams to spend less time at each collection site, increase the efficiency of on-site collection, and increase the number of households to be serviced in a day. Costs increase with the number of separately segregated commodities and moving this sorting responsibility to later in the process will save money. The frequency of household waste collection will also be reduced. Currently, households have two inorganic collections per week. Because costs increase with the frequency of collection, the collection will be moved to once per week. As provided above, increased household participation is anticipated by year two, which will decrease the per-household costs as the recycling truck will pass fewer households without set out recyclables.

Conclusions

The pyrolysis oil purification unit reliably and continuously processes 1.3 million pounds of pyrolysis crude daily. The feedstock to the purification unit is a hydrocarbon liquid mixture sent from a nearby pyrolyzer. The plant reliably delivers 1.2 million pounds of liquid feedstock and 32,000 pounds of vapor feedstock daily to a downstream ethylene steam cracker for further processing. The pyrolysis oil purification unit operates 24 hours a day, 7 days a week, 350 calendar days per year. The goals of this purification unit were to effectively manage all high-consequence process safety risks, reliably deliver on-specification feedstock to a downstream ethylene plant in order to not degrade the ethylene plant reliability and economic performance, and lastly to maximize economic benefit of the investment by minimizing capital cost and variable operating cost. A process flow diagram is included along with material balances on all processing and utility streams. There are two major aspects to this design: fractional distillation for separation of the hydrocarbon mixture feedstock, and thermal swing adsorption to reliably remove all contaminants from the processing fluid. A complete sized equipment list is included, as well as an economic break down for the estimated annual fixed cost, capital cost, and variable cost. The plant is estimated to have an annual expense of $64.1 MM USD.

Bali Sorting Facility analysis addresses recommended improvements for its operation. The sorted plastic waste from this facility is the feedstock to an upstream pyrolyzer in which the pyrolysis purification unit is fed from. Therefore, the analysis on this facility addresses necessary improvements to increase the throughput of the sorting facility, reduce the contamination level in the sorted flexible plastic waste stream, and lastly to reduce the cost of household collection, sorting operations, or logistics cost for transportation of waste into and out of the sorting facility. The project promotes integrated solutions supported by increased interest and individual responsibility in an effort to systemically change the waste disposal problem within Negara. The solutions connect the economic, social, and environmental benefits to these same individuals and their communities.

Major Assumptions

- Plant operates 24/7, 350 days per year
- Cost estimations carried out with ChemCAD or constants provided by Chemical Engineering Design[1]
- All pumps operate at 80% efficiency, C-100 operates with 75% efficiency
- No thermal cracking
- Control system provides inherent safety to distillation tower
- Heat exchanger overall heat transfer coefficient calculated with ChemCAD

- Onsite flare available for safe and complete combustion of vented product from pressure relief valves
- OSBL 40% ISBL
- Engineering 10% ISBL and OSBL
- Contingency 15% ISBL and OSBL
- Maintenance 5% equipment cost
- 65% plant overhead

Appendices

Adsorption section detail

Design assumptions:

- BASF adsorbents provide adequate protection against batches with varying chloride content
- Beds are fully regenerated with nitrogen gas
- Fraction of utilized bed is 70%
- The isotherm can be modeled as a linear relationship due to the highly diluted contaminated streams

TSA bed regeneration:

Hot nitrogen gas at 400°F is used to regenerate all adsorption beds in this process and are assumed to be fully regenerated without affects adsorbents loading capacity between lead-lag bed switches. The volume of nitrogen gas used to regenerate each thermal swing adsorption bed is 10 times the bed volume of the adsorbent packing. This ensures full regeneration of the adsorbents to reliably desorb all contaminants remaining in the bed when it is taken out of service. There are two lead-lag thermal swing adsorption beds in series for the removal of chlorides and metals, respectively. At any time, the lead bed is defined as the bed in which the contaminated hydrocarbon stream is fed, while the lag bed is regenerated with hot nitrogen gas. An alternating system is utilized, where the adsorption beds process one of the cuts at a time while the other cut accumulates in a hold up tank. The dashed lines illustrated in figure x indicate closed control valves for the medium cut while the light cut is processed. The lead bed TSA-100A illustrated in figure X is fed the contaminated light cut, while the lag bed TSA-100B is in regeneration. All dashed streams have zero flow at this time, as all medium cut is accumulated in hold up tank V-102. A highly sophisticated control system is utilized for ensuring the proper hydrocarbon stream is fed to the lead bed, and that either cut is fed only for its allotted time before the beds breakpoint is reached. When the breakthrough point in TSA-100A is reached, control valves for the light cut feed are closed and the light cut now accumulates in V-104. The light cut liquid remaining in TSA-100A is drained to temporary storage tank V-109. At this time, TSA-100A is regenerated with hot nitrogen gas and the medium cut is fed to lead bed TSA-100B. When breakthrough occurs in TSA-100B, the system returns to its original operation where the light cut is processed, and the medium cut accumulates in V-102. Before TSA-100A switches from a lag bed back to lead bed, the light cut liquid temporarily held in V-109 is fed back through TSA-100A to bring the temperature of the adsorbents back down to the operating temperature for this process. Hot nitrogen gas is utilized in a continuous closed loop cycle for regeneration of the two lag beds at any time. Nitrogen gas in stream X and X is fed at the bottom of the lag thermal swing adsorption beds to remove contaminants from the adsorbents. Streams x and x are fed to condenser E-106, and chemical waste is removed from the process in stream x from separator V-113. The uncondensed nitrogen gas is reheated in furnace H-100 before returning to the lag beds for regeneration at 400°F. This process allows for the continuous operation of TSA-100A, TSA-100B, TSA-101A, and TSA-101B without interrupting operation of the facility.

Unusual high levels of chloride or metal contamination:

Typical chloride levels in the pyoil products is assumed to be 50 wppm. The adsorption beds is designed with 10% additional adsorbent packing given this contaminant level. The fraction of the bed utilized before being removed from service for regeneration is 70%. The adsorption bed for the removal of chlorides and the removal of metals are designed for the same adsorbent packing. Both the medium and light cut distillation products are stored in hold up tanks prior to being fed to the adsorption beds. Therefore, the contaminant levels in the light and medium cut streams fed to the adsorption beds is an averaged concentration over the time in which the liquid is held up in either tank. This design allows for a distribution of contaminants across multiple loads with varying chloride and metal contaminant levels. For example, in the case of unusually high levels of chloride or metals contamination, the liquid fed to the adsorption beds distribute these contaminants across multiple adsorption cycles. In doing this, the adsorbent packing is capable of reliably removing all chlorides and metals in the processing streams, while ensuring the bed does not become saturated with contaminants before being removed from service for regeneration.

Distillation section detail

Table A 1 *Distillation tower configuration*

tray type	sieve	
tray material	carbon steel	
tray spacing	2	ft
number of trays	40	
hole diameter	0.02	ft
hole pattern	triangular pitch	
hole pitch	0.05	ft
tray thickness	0.0065	ft
tower thickness top	0.0052	ft
tower thickness bottom	0.375	ft
column material*	carbon steel	
column diameter	10	ft
column height	85	ft
reflux ratio	30	
reboiler	kettle u-tube	
condenser	counter current shell and tube	

Table A 2 *Design Considerations*

Beginning T (°F)	Ending T (°F)	Number of points
-46	392	3
392	752	3
752	844	3

Table A 3 *Distillation tower modeling assumptions*

Equilibrium-K	Grayson-Streed-Choa-Seeder
Enthalpy-H	Lee Kessler
Joint efficiency	0.85
Allowable stress	13685 psig
Allowable corrosion	0.003 ft
Flooding	80%

Minimizing overall energy consumption:

The distillation tower is fed stripping steam and utilizes reboiler heat to vaporize liquid accumulating at the bottom of the tower. By designing the tower with essentially two heat sources, the reboiler heaty duty is minimized. The steam fed at the base of the tower aids in separation as it strips lighter oils from the liquid as it flows upward through the tower. This effectively decreases the accumulation lighter oils held up in liquid at the bottom of the tower that would otherwise require additional reboiler heat to vaporize out of the bottoms liquid. Two pump-around systems are implemented in the tower design. These systems effectively minimize condenser heat duty at the top of the column as they remove significant amounts of heat from the hot liquid at two different locations in the tower. By reducing the temperature at the two trays in which the pump-around streams are drawn from, the condenser duty is minimized. Lastly, two side strippers are implemented in the tower design to achieve high separation of the four products. The side strippers operate by using stripping steam to remove lighter oils from the liquid drawn from the tower intended for the medium and light cuts. In using these side strippers, the number of trays in the tower can be reduced effectively minimizing the overall tower height. By minimizing the height, and essentially the volume in which the vapor and liquid streams flow, the reboiler duty is further minimized. Between two pump-around systems, feeding stripping steam to the bottom of the tower, and utilizing two side strippers, the overall energy consumption of this process in minimized by this design. The heat duty of the condenser and reboiler are XXX and XXX, respectively.

Separation:

As aforementioned, the tower is design implements two side strippers and two pump around systems, both of which aid in reliable separation of the liquid feed. The two side strippers essentially act as additional separation units. For example, in the case where the oil drawn from the tower for the medium cut is inclusive of a significant amount of lighter oils that are intended for the light cut or pygas products, the side stripper reliably removes these oils from the medium cut product before being sent to downstream processing. The highly detailed control system illustrated in figure X provides inherent safety to the tower, ensuring the tower operates as intended and the possibility of sending inaccurate cuts to downstream processing is eliminated. The two pump-around systems implemented in this design aid in a consistent temperature profile throughout the tower, and essentially a consistent vapor and liquid profile. In maintain these consistent profiles throughout the operation of the tower, the design ensures the proper cut is drawn from the tower at any given time.

Continuous water removal:

The distillation tower design includes a significant amount of stripping steam fed at the base of the column. This stripping steam removes entrained water droplets suspended in heavy oils. While there are many benefits to this design consideration, the process in which this water is removed from products sent to downstream processing is essential to the viability of this unit. The light and medium cut streams are both drawn from the tower at temperatures greater than the boiling point of water at the operating conditions. Therefore, all water should hypothetically be included in the vapor at the top of the column, and the two side strippers provide further confidence that water is not removed in either the light, medium, or heavy cut products. Also, a water decanting system is implemented at the top of the tower to reliably remove all water from the top product. This dewatering system is an automatic operation through utilizing flow, density, and temperature controls to reliably removed water from the oil products while minimizing operator exposure and emissions to volatile organic compounds. This process utilizing the significant difference in specific gravity between the water and oil to reliably dewater oil products with minimal hydrocarbon liquid wasted throughout the process. This dewatering system is reliable in not disrupting the mass balance of hydrocarbon liquid flowing from feed to product, ensuring minimal oil is removed in the dewatering process. While the dewatering at the location of the tower is reliable and efficient, downstream processes are designed for additional water removal with an identical automatic dewatering system. The automated system ensures the water is removed at the same rate in which it is accumulated in the processing streams, essentially providing a promising continuous water removal process.

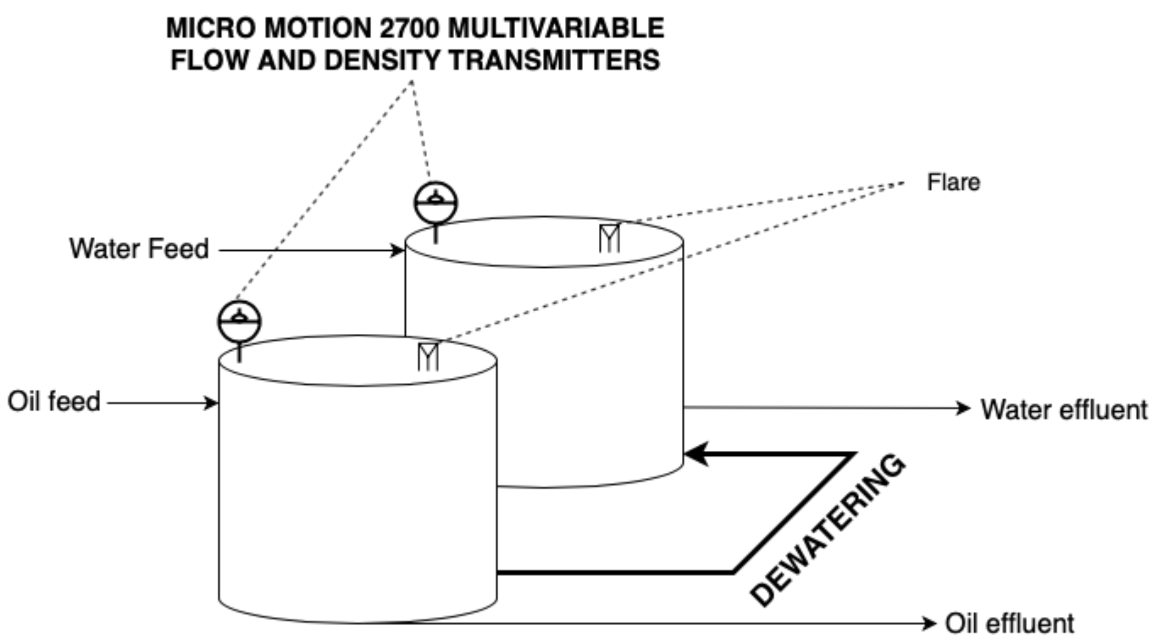

Figure 7 *Micro Motion dewatering control system*

Tray selection:

The distillation tower includes forty sieve trays. Sieve trays were utilized for this design as they are a viable tray selection for the proposed process. The downcomer liquid following through the tower carries heavier continuous liquid phase from one tray to the next moving downward. The light dispersed phase coalesces below the tray and jets upward to the tray above. The sieve trays allow for the lighter liquids to coalesces on the tray above as liquid flows downwards.

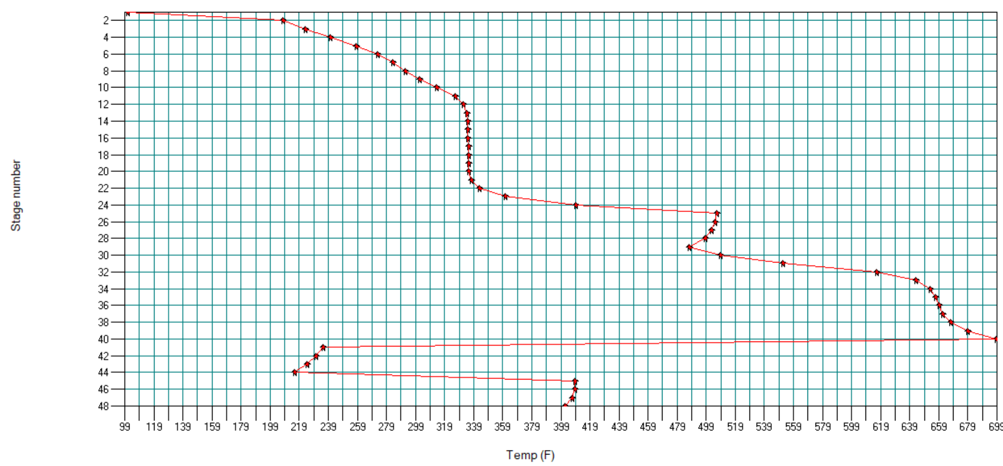

Figure 8 *Distillation tower temperature profile*

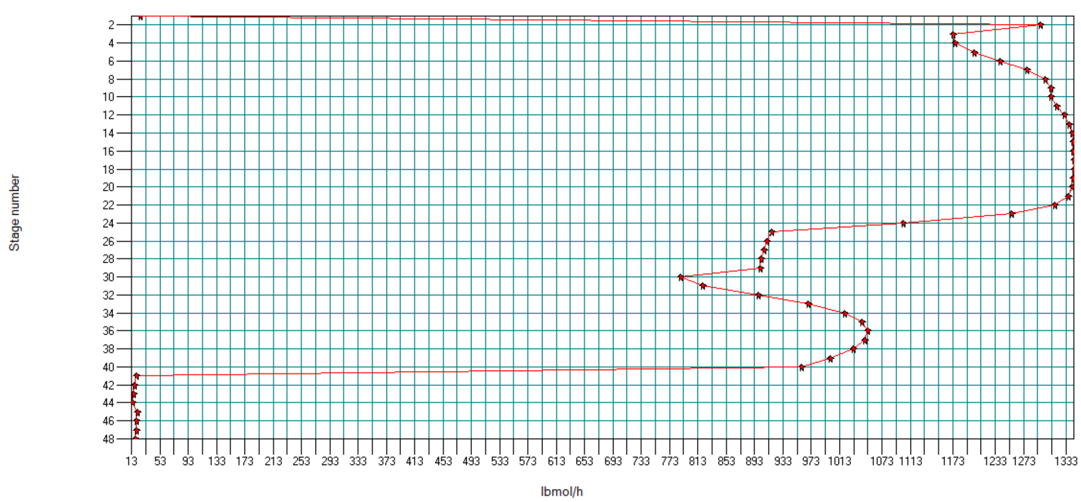

Figure 9 *Distillation tower liquid profile*

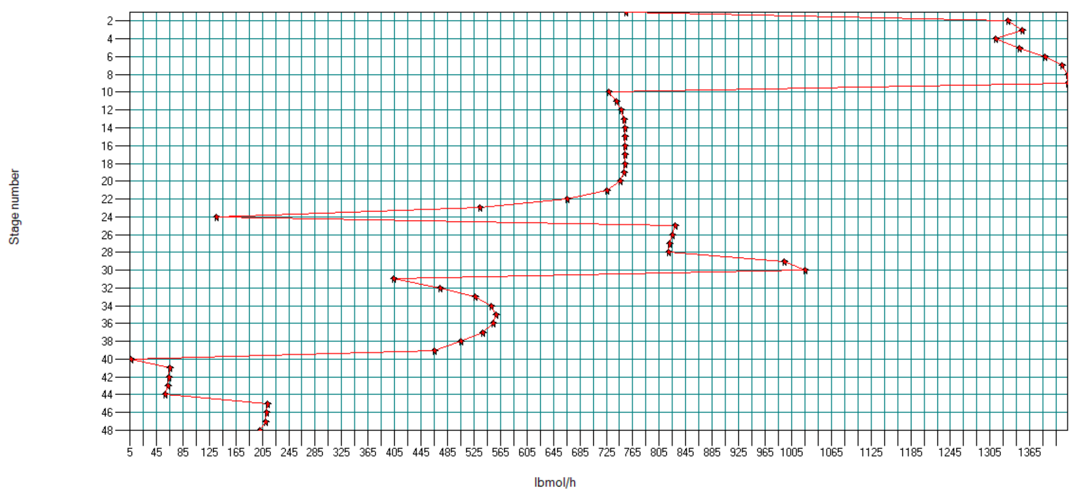

Figure 10 *Distillation tower vapor profile*

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