COST ANALYSIS OF LOCAL BIOPRODUCTS PROCESSING PLANT USING MICROALGAE BIOMASS AS FEEDSTOCK

By

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Abstract

The need to produce bioproducts useful for the human wealth derived from microalgae, such as proteins, lipid and carbohydrates is gaining importance in recent years. In spite of the broad availability of technologies for these kinds of processes there are uncertainties regarding the investment required to build a microalgae processing plant in Puerto Rico. To address this issue, economic analysis for five selected process case scenarios able to produce 222 million pounds of microalgae-derived paste per year were performed. Results indicate that operational costs are predominant in our analysis due primarily to the cost of utilities. In addition, the combination of pond site, dewatering, freeze drying and supercritical CO_2 extraction were the most effective in terms of investment ($80 million) and operational costs with an annual cost of manufacturing of $0.65/lb for the microalgae paste.

Resumen

La necesidad de producir bio-productos para el bienestar humano derivados de microalgas como lo son las proteínas, lípidos y carbohidratos ha cobrado importancia en años recientes. A pesar de la amplia disponibilidad de tecnologías para estos tipos de procesos, aún existen incertidumbres respectó a la inversión requerida para construir una planta de procesamiento de microalgas en Puerto Rico. Para atender este asunto se realizó un estudio económico de cinco casos diseñados para la producción de 222 millones de libra de pasta derivada de microalgas. Nuestros resultados indican que los costos operacionales son predominantes para efectos de nuestro estudio debido primeramente al costo de las utilidades. Además, la combinación de una charca, concentración por desaguado, liofilización y extracción de CO_2 supercrítico demostró ser la más efectiva en términos de inversión ($80 millones) y costos operacionales con un costo de manufactura de $0.65/lb de pasta de microalgas.

Author Right Declaration

Dedication

To my parents Manuel García-Rivera and Altagracia Figueroa-Soto for teaching me the importance to culture a moral philosophy, as well as the rewards of being honest and hard-working. Thank you for teaching me to be determined and consistent in accomplishing my goals.

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Nomenclature

Variable or Term	Description	Unit and Dimensions
$M	Million dollars	1 x 10^6 dollars
Lb	Pound	Pound
Cost	Cost of item in terms of size	$
Capacity	Capacity of item 'i'. Could be mass or energy	Dimensionless
I	Refers to the cost index (**Section LR-6**)	Dimensionless
C_{TPI}	Total permanent investment	$
C_{TCI}	Total Capital investment. Account 15 percent of working capital and 17 percent of general cost over C_{TPI}	$
$C_{p,i}$	Purchase cost of item 'i'	$
f_L	Overall factor of Lang	Dimensionless
COM	Cost of manufacturing	$
DMC	Direct manufacturing cost	$
FMC	Fixed manufacturing cost	$
GMC	General manufacturing cost	$
FCI	Fixed capital investment sometimes referred as capital cost	$
C_{OL} or C_OL	Cost of labors	$/yr
C_{UT} or C_UT	Cost of utilities	$/yr
C_{WT} or C_WT	Cost of waste treatment	$/yr
C_{RM} or C_RM	Cost of raw materials	$/yr
C_i	Cost of item 'i'	$
C_p^0	Bare cost	$
K_i	Constants for bare cost calculation	Dimensionless
F_p	Pressure factor	Dimensionless
F_m	Material factor	Dimensionless
N_{np}	Number of employees who work with non particulate equipments	# of workers
P	Number of employees who work with particulate equipment	# of workers
R	Revenue from sales	$/yr
A, B and C	Constants to calculate the R value (See **Table 17**)	See Table 17
t	Income tax rate	Dimensionless

CHAPTER 1: INTRODUCTION

Microalgae culture has been considered by several research groups as a potential renewable resource production activity to generate useful products for mankind. For instance, it has been estimated that 30-70% of the microalgae dry mass can be used to produce a diversity of commercial bioproducts (Sheenan et al., 1998; Brennan et al., 2010a, 2010b; McKendry et al., 2011). These bioproducts are generally composed of proteins, lipids and carbohydrates. Also, microalgae can be used as a potential feedstock in the cosmetic, pharmaceutical, nutraceutical and fuel industries. **Figure 1.1** summarizes an average composition of the bioproducts obtainable from microalgae.

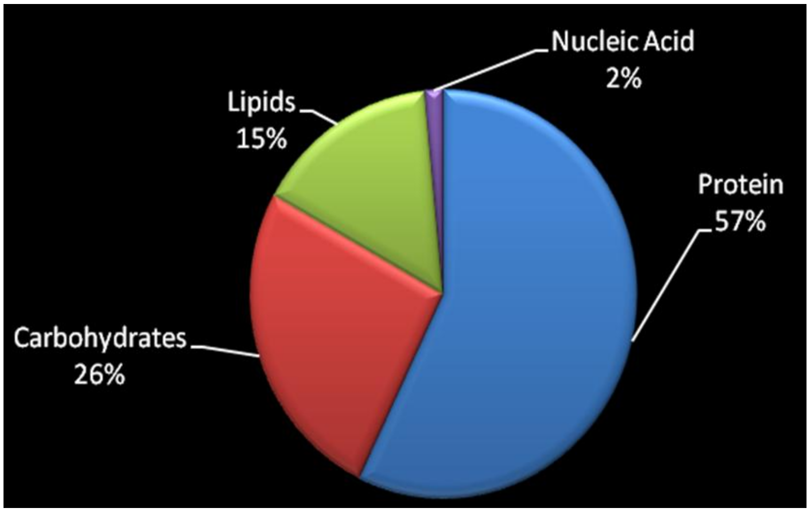


Figure 1.1. Weight composition of microalgae (www.oilalgae.com, 2012).

According to the National Algal Biofuels Technology Roadmap, microalgae technology is attributed to have four main advantages: (1) to produce a high yield of biomass per pond surface area, (2) they can be cultivated in non-arable land, (3) they can be grown in different sources of water, and (4) they can fix CO_2 which is contained at high concentrations in flue emissions from power plants. Finally, microalgae can be used to produce a variety of biofuels and valuable co-products (McKendry et al., 2011).

Moreover, the productivity of microalgae crops for oil production is approximately five times greater than that of palm oil, fifteen times greater than *Jatropha*, and sixty times greater than soybean oil. A representative data is illustrated in **Figure 1.2**.

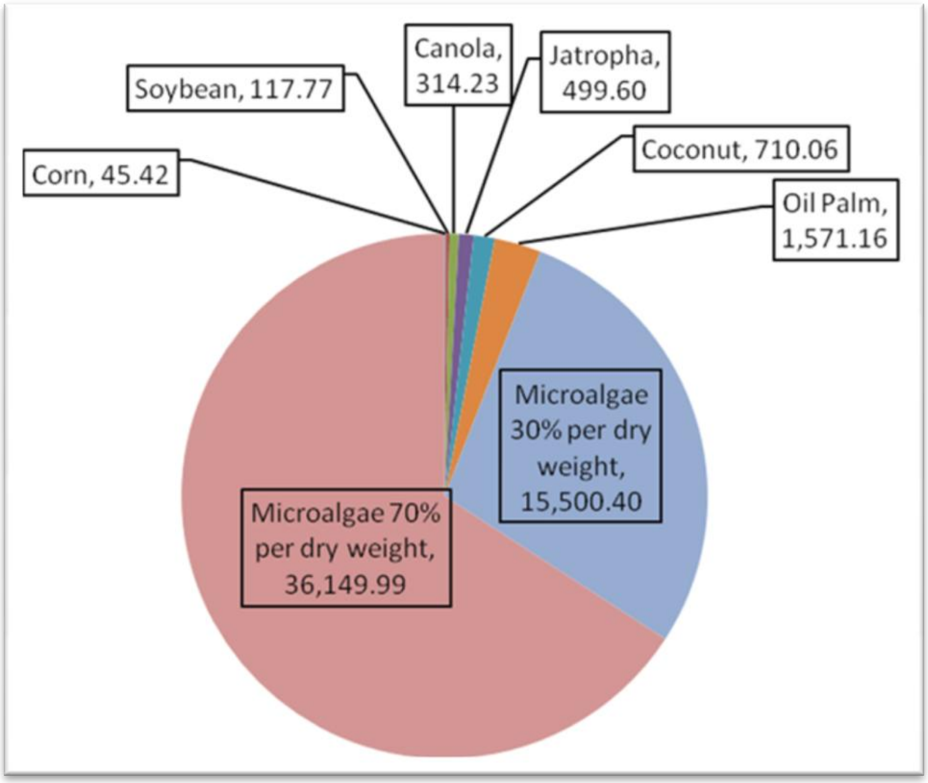


Figure 1.2. United States annual productivity of oil in gallons per hectare using different crops (Chisti et al., 2007).

Several groups believe that the production of biofuel can be obtained using microalgae containing 20% of lipid per dry mass. The bioproducts that are extracted from microalgae also include proteins and carbohydrates that can be used as a potential feedstock to produce high-demand value-added products for the cosmetic, human health, and aquaculture industry (Brennam et al., 2010b).

There are challenges regarding the use of microalgae as feedstock to produce bioproducts. First, there are external factors like potential contamination of bacteria or viruses during the growth stage and even during the harvesting process. Second, steady-state production is still a challenge. Third, there is a need to identify process technologies and schemes that can be implemented and proven to be cost-effective for the culture, harvest, and extraction stages in order to recover high yields of microalgal bio-oil at an industrial scale. An example of the third point is discussed in the article *Algae Plans Bloom* (Bomgardner et al., 2011). In the case of Puerto Rico, an added challenge is to consider local island factors at the time of doing a cost analysis for the production of bioproducts from microalgae.

At present, there are no economic analyses available to accelerate the commercialization of microalgae bioproducts in the island. In response to this, our focus is to perform an economic analysis that would provide a clear understanding of the investment risks and uncertainties as a potential entrepreneurship activity in Puerto Rico. This analysis takes into account microalgae as a biomass feedstock in order to produce 220 million pounds per year of cell paste, which would contain the main bioproducts: lipids, protein, and carbohydrates. The yearly 220 million pounds of cell paste were fixed considering the local availability of culture land for microalgae. In addition, an estimate of the operational and capital costs to build and operate such process in Puerto Rico has been performed as part of this study.

CHAPTER 2: LITERATURE REVIEW

2.1 - The use of microalgae as a feedstock

Microalgae are photosynthetic micro-scale organisms that can grow in aquatic environments using available carbon sources and solar energy in an effective manner. In principle, microalgae's main distinctions are that they store their pigmentation within their cell wall, they have a simple life cycle and a simple cellular structure. The four classes of microalgae are: diatoms (*Bacillariophyceae*), green algae (*Chlorophyceae*), blue-green algae (*Cianophyceae*) and golden algae (*Chrysophyceae*). The literature confirms that the most abundant species are the diatoms and the green algae (Sheenan et al., 1998). They are also known as a third generation crop given that they are not a food or forest based derivative. Microalgae can be cultivated under autotrophic or heterotrophic conditions and are able to grow either in salt water (~70%) or freshwater (~30%) (Singh et al., 2010).

Research literature shows that microalgae biomass is mainly composed of proteins, lipids and carbohydrates as previously shown in **Figure 1.1** (Harun et al., 2010). Moreover, according to the Aquatic Species Program report, microalgae is a potential feedstock to produce the right kind of oil that can be used for the production of fuel (Sheenan et al., 1998). Microalgae have between 30 and 70 percent of bioproduct content; however, several microalgae can reach almost 40 percent of free fatty acids, which are implicitly included in the general matter extracted from the microalgae biomass. This information is consistent with the data of annual oil productivity illustrated in **Figure 1.2** (Mata et al., 2010; Ahmad et al., 2011). In addition, some authors like Brennan and Ahmad showed that oil produced from microalgae is richer in carbon content when it is compared to the oil obtained from wood via fast pyrolysis (refer to **Figures 2.1.1** and **2.1.2**). Most of the properties of biodiesel produced from microalgae are comparable with the properties of biodiesel produced by other different crops, as well as the standardized biodiesel for aviation (**Figure 2.1.1**). This fact was presented by Ahmad and coworkers in 2011.

Microalgae is not a feedstock that can be exclusively and potentially considered for the production of biodiesel only. Natural properties of the oil produced by microalgae make them suitable to produce other added-value chemical compounds instead of biofuels. Most of these chemicals are of great importance in the pharmaceutical, neutraceutical, human care, and fish food industries. **Figure 2.1.2** shows that oil produced from microalgae have favorable properties when compared with oil obtained from other crops (Brenan et al., 2010a; and Ahmad, et al., 2011). Note that oil coming from microalgae as well as wood based sources does not contain sulfur, while petroleum oil contains 0.75-1.0 kg sulfur per liter of fuel (Breenan, 2010a, 2010b).

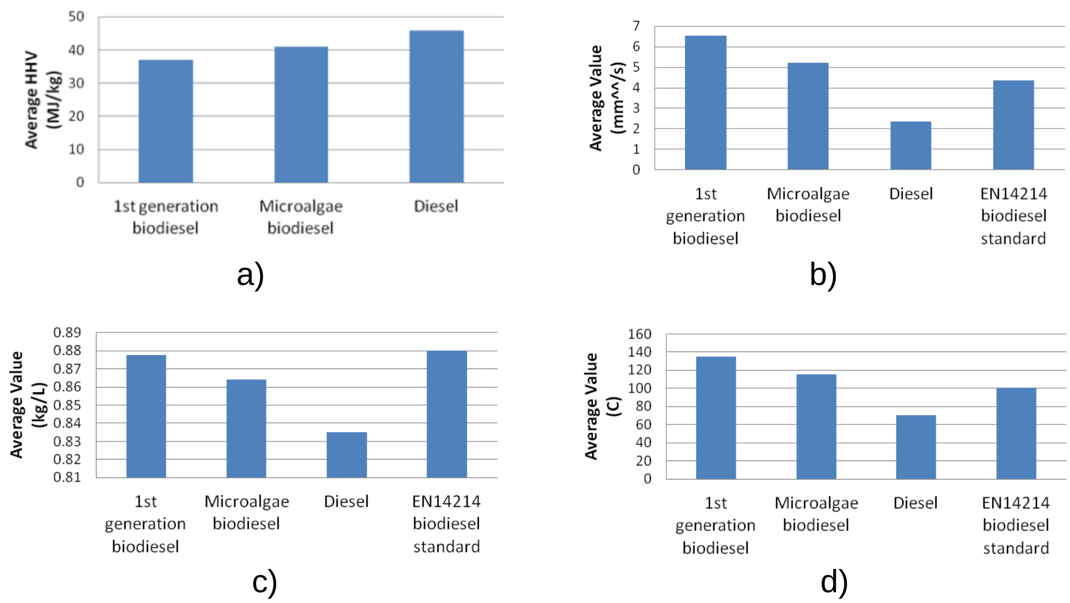


Figure 2.1.1. Physical properties of oil obtained from different crops and standardized biodiesel. a) Average heating value, b) average kinematic viscosity, c) average density, and d) average flash point. (Brennan et al., 2010b).

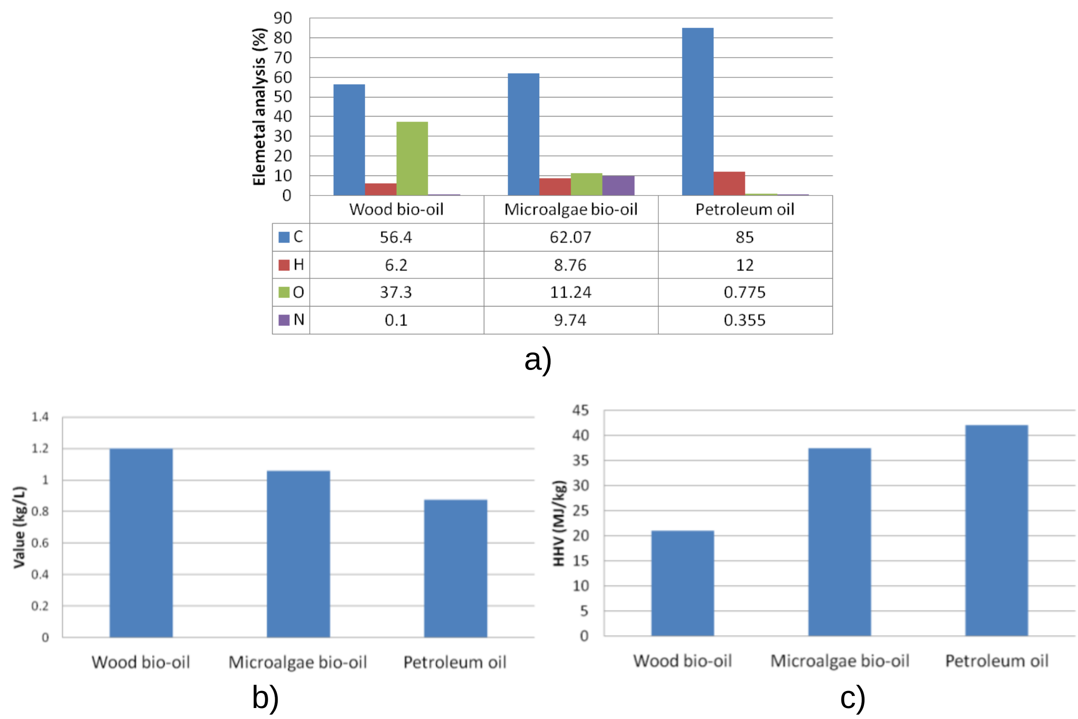


Figure 2.2.2. Properties of oil from different crops. a) Chemical composition analysis, b) density, and c) higher heating value. (Brennan et al., 2010 and Ahmad et al., 2011).

Table 2.1.1 shows common examples of chemicals used for human care, cosmetics, animal nutrition, and neutraceuticals. Among those, high-demand pigments like beta-carotene, docosahexanoic acid (DHA), astaxanthin, lutein, phycocyanin and phycoerythrin can also be obtained *(*Dufosse et al., 2005).

Table 2.1.1. Production by demand of microalgae and derivatives around the world (Brennan et al., 2010b).

Microalgae	Annual Production	Application and Product
Spirulina	3000 tons dry weight	Human nutrition Animal nutrition Cosmetics Phycobiliproteins
Clorella	2000 tons dry weight	Human nutrition Cosmetics Aquaculture
Dunaliela salina	1200 tons dry weight	Human nutrition Cosmetics Betacarotene
Aphanizomenon flas-aquae	500 tons dry weight	Human nutrition
Haematococcus pluvialis	300 tons dry weight	Aquaculture Astaxanthin
Cryptecodinium cohnii	240 tons DHA oil	DHA for omega-3-supplement
shizochytrium	10 tons DHA oil	DHA omega-3-supplement

In agreement with the aforementioned versatility of algae-based products, the idea of using microalgae as raw material to implement a biorefinery industry producing a variety of multiple products is more attractive than just producing bio-fuels only. Furthermore, these products can be sold in their raw form as specialty chemicals or raw materials to produce other specialty products. At the same time, the sales of these specialty chemicals would allow the production of other high-demand products, like commodity chemicals to be sold at a reasonable price in the local markets. Consequently, the potential lower costs of other chemicals by implementing the biorefinery approach may result in the development of a economically feasible microalgae-based industry. A general scheme of the potential products that can be obtained using biomass from microalgae is summarized in **Figure 2.1.3** (Singh et al., 2010).

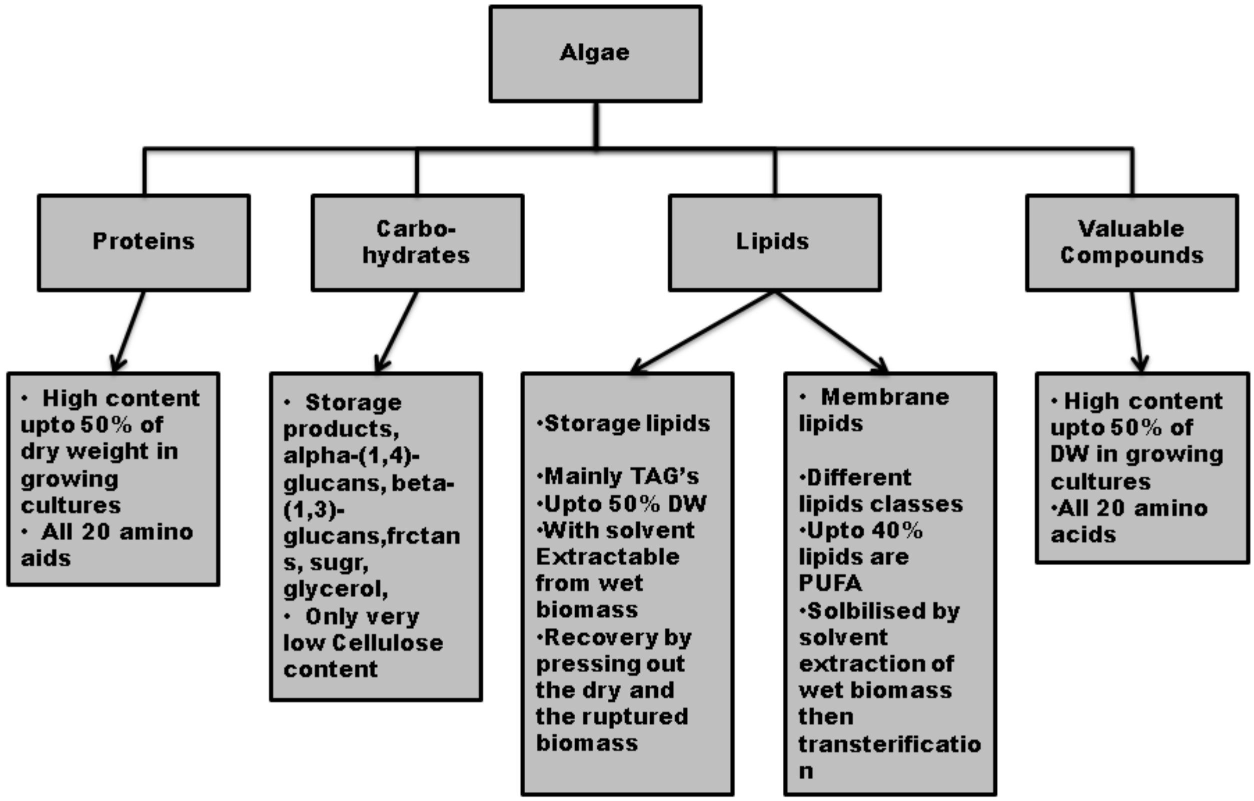


Figure 2.1.3. General potential extracts from microalgae (Singh et al., 2010).

2.2 – Bio-industry from microalgae

One of the earliest efforts of using microalgae as a mass culture was performed by Jorgen Jorgensen and his co-workers in 1968. They patented a procedure that focused on the use of microalgae to produce a wine-like alcoholic beverage via sucrose enzymatic fermentation. Later, Sheehan and co-workers from the National Renewable Energy Laboratories (NREL) prepared a closure report titled "*A Look Back at the U.S. Department of Energy's Aquatic Species Program: Biodiesel from Microalgae*" in 1998. They reported the interesting fact that microalgae have the ability to grow in open ponds using CO_2 under extreme pH and salinity conditions (Sheenan et al., 1998). They suggested three alternatives for the potential use of microalgae: (1) to produce methane via biological or thermal gasification, (2) to produce ethanol via fermentation, and (3) to produce biodiesel via a transesterification reaction.

Even though the report focused on the use of microalgae as a source of alternative and renewable fuels, the interest in using microalgae as a means of producing a new branch of products for the industry of medicine was also discussed. Moreover, the report suggested that building a biotechnology plant to produce non-fuel products as co-products may be more profitable than producing exclusively oil from microalgae. This suggests to conceptualize microalgae processing plants to produce oil as a commodity chemical in addition to generate proteins and carbohydrates as specialty chemicals (Sheenan et al., 1998).

Recently, Singh (2010) proposed the possibility of microalgae as feedstock to produce food supplements and fine chemicals for medicinal purposes and livestock feed. According to the authors, "the main components of a typical algae feedstock are proteins, carbohydrates, lipids, and other valuable components, e.g. pigments, antioxidants, fatty acids, vitamins, etc." This opens an opportunity to explore the possibility of producing biofuels from microalgae on a large-scale basis through a local biorefinery, which can also produce high-demand specialty chemicals (**Figure 2.2.1**).

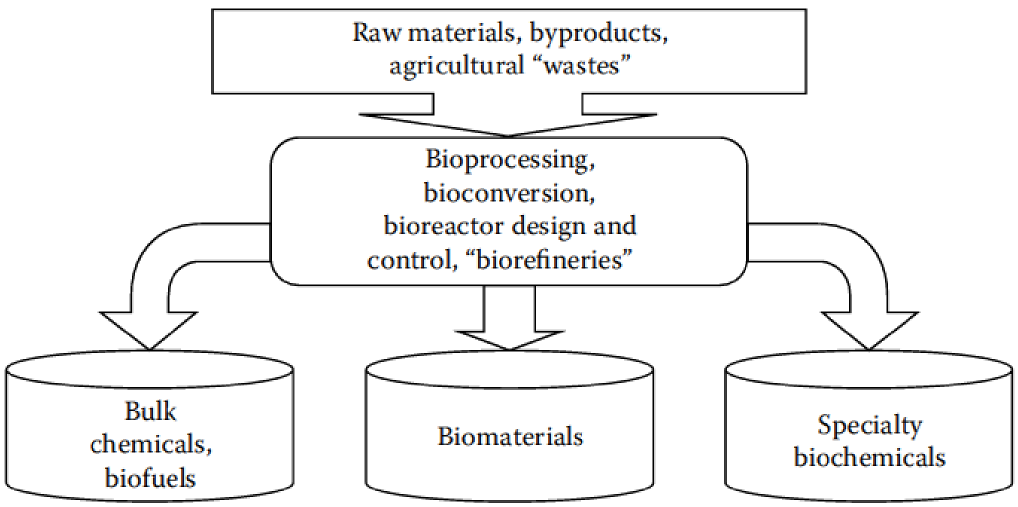


Figure 2.2.1. Biorefinery concept (Patterson et al., 1991; Carotenoids, 2002; Walker et al., 2006; Olivares et al., 2011; www.emergingmarkets.com, 2012).

Figure 2.2.2 shows a general microalgae processing flow diagram. It considers all the possible processes that can be applied to produce biofuels and other bioproducts from microalgae. Although this diagram is very detailed, it is lacking in terms of economical aspects. The reported production rates of oil from microalgae are between ~5,000 gal ac^{-1} yr^{-1} and ~38,000 gal ac^{-1} yr^{-1}. This estimate was obtained based on expected looses, photosynthetic efficiency and other assumptions, like the availability of solar energy consistent with a higher percentage of clear weather conditions and 50% of oil content per microalgae (McKendry et al., 2011).

Moreover, microalgae crops are able to yield between 30% and 70% of lipid content per dry mass. This variability of yields for microalgae is due to the suitability of the selected crop, as well as the nutrients used in the growth process (see Brennam et al., 2010; Moazami et al., 2011; Araujo et al., 2011; Chiu et al., 2008). There is also the need to consider the advantages and operability challenges of using either ponds or photo-bioreactors to design an adequate growth strategy (Scragg et al., 2011).

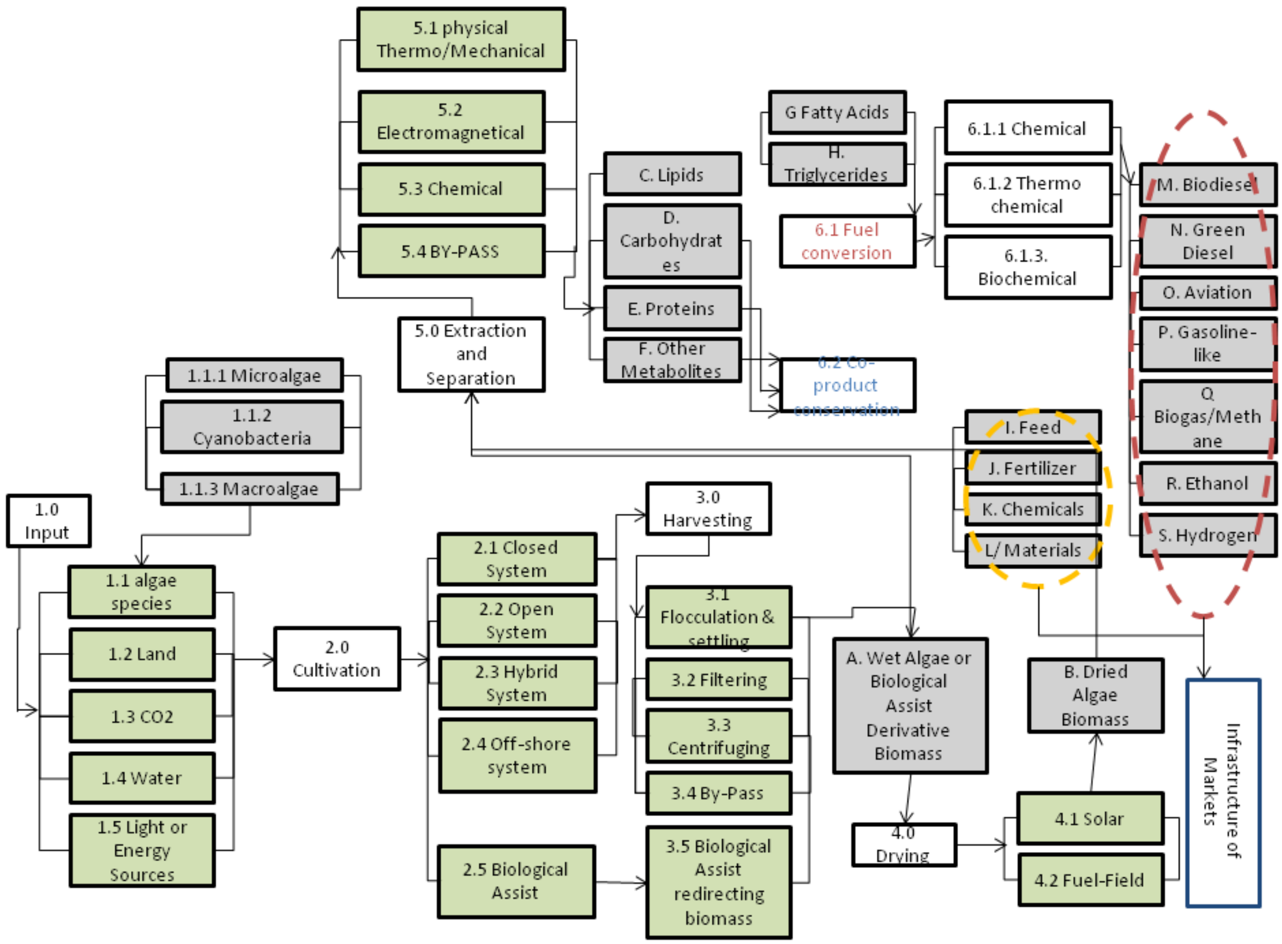
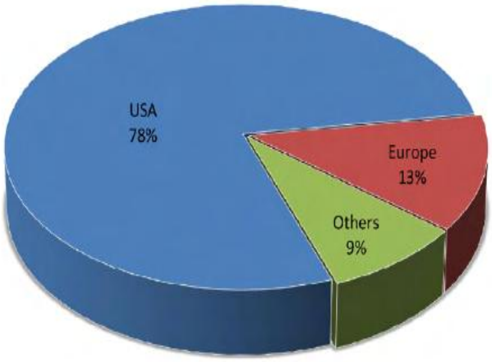


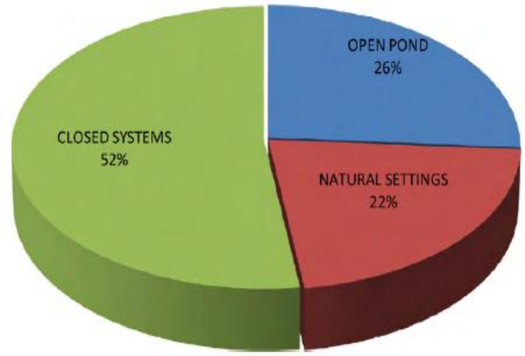
Figure 2.2.2. Multi-process diagram for microalgae processing (McKendry et al., 2011).

2.3 - Growth and harvesting of microalgae

There are several companies around the world dedicated to grow and harvest microalgae. A summary of worldwide distribution of these companies, as well as the main technologies used to grow microalgae are shown in **Figure 2.3.1**.



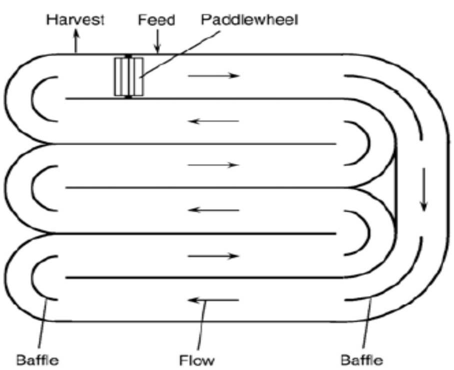
a)



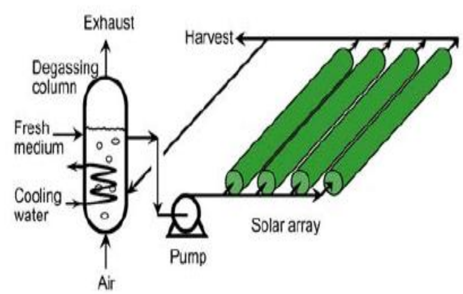
b)

Figure 2.3.1. a) Region wide company distribution and b) technologies used to grow microalgae (Singh et al., 2010).

As shown above, there are two main types of technologies used to grow microalgae: (1) open ponds and (2) photo-bioreactors (closed systems). **Figure 2.3.2** below shows a representative scheme of both technologies: the open ponds (left) and the photo-bioreactors (right).



a)



b)

Figure 2.3.2. Schemes of the two main microalgae culture technologies: a) top view of an open pond and b) a photo-bioreactor (Singh et al., 2010).

Table 2.3.1 shows a comparison of open ponds versus photo-bioreactors. For the objectives of this project, the open pond technology will be considered due to various practical reasons: (1) the process technology is better known than the photo-bioreactor technology, (2) its construction and maintenance appears to be more cost attractive, (3) its operation on a large scale can be more easily manipulated, and (4) the technology is very simple, in terms of operation requirements.

Table 2.3.1. Comparison of open ponds versus photo-bioreactors (Harun et al., 2010; Rattanapoltee et al., 2008; Mata et al., 2010; Chisti et al., 2007).

Fact	Open Pond	Photobioreactor
Capital investment	Low	High
Difficult for scale-up	Good	High
Availability of technology	Available	Not demonstrated for large scale
Downstream processing cost	High	Low
Flexibility to strain selection	Low	High
Water use	High	Low

According to published literature, Jiménez and coworkers (2003) used a model to correlate the growth of microalgae as a function of variables such as pH, dissolved oxygen, temperature, media conductivity and solar irradiance. They reported that dissolved oxygen and pH are the main factors that control the microalgae growth. To support this hypothesis, they observed an increment in the inhibition of microalgae when the dissolved oxygen concentration was greater than 25 mg/L (Mendes et al., 2007). Moreover, the annually averaged microalgae growth rate was 8.2 g of dry weight/m^2•day, yielding approximately 30 tons of microalgae per hectare per year (Jiménez et al., 2003).

Another empirical model developed by Moreno and coworkers in 2003 showed that sodium can inhibit the anaerobic digestion of microalgae. The study was done using Zarouk as growth media. According to Amaro and coworkers (2011), alkaline conditions promote an accelerated adsorption of CO_2, which results in two main products depending on two un-catalyzed reaction paths. These paths are: (1) the hydration of CO_2 followed by subsequent acid-base reactions to form HCO_3^-, and (2) the direct reaction of CO_2 with OH^- to form HCO_3^-. The former is important at a pH lower than 8, where the latter is important at a pH higher than 10. Both reactions compete at pH levels between 8 and 10, respectively.

In addition, studies by Amaro and co-workers showed that lipid content and productivity can be inversely correlated to the nitrogen and phosphate deprivation conditions (Amaro et al., 2011). For example, *Chlorellla sp*. is a microalgae that grows in saline media. Its lipid content can be manipulated between 20% and 50% per algae dry mass by manipulating the nitrogen feed in the media (Brennan et al., 2010b; Li et al., 2007; Feng et al., 2005). A possible explanation for these results was offered by Amaro and coworkers. They suggested that insufficient nitrogen inhibits protein synthesis. Therefore, the excess of carbon that remains in the media is channeled into storage molecules such as triacylglycerols via photosynthesis. Similar results have been found using wastewater as media (Sydney et al., 2011). In summary, the best alternative is to use a species with a higher C/N ratio as the carbon source with the pH between 8 and 10.

Sialve and coworkers (2009) established that the conditions mentioned in the previous paragraph could be employed to obtain microalgae with lipid content of about 40%. Of course, they did not consider the other potential by-products, such as proteins and carbohydrates (**Figure 2.3.3**). Other assumptions included algae steady-state concentration of 0.5 g/L. A factor of 10 for the growth rate was used to determine the initial concentration, 2.5g/m^2. Three-hundred thirty days were established for the pond operation (Davis et al., 2011). The pond dimensions are 12 m wide x 82 m long x 0.3 m deep per each single pond. The calculated pond area available for crop is approximately 8.5 square miles. This is approximately 67 percent of the total area used by the pond site (12.7 square miles). This estimate takes into account other areas needed by the pond site in terms of facilities, in addition to the 8.5 square miles occupied directly by the ponds.

To harvest microalgae after the growth phase is finished requires technologies capable to deliver dry microalgae to the extraction phase. This is due to the fact that harvest of dry algae can achieve a higher fuel-energy ratio and an improvement of the production of valuable bioproducts (Sarada et al., 2009; Jorquera et al., 2010; Xu et al., 2011). The principal techniques considered for the harvesting of microalgae are centrifugation, flocculation, filtration, sedimentation, flotation, and electrophoresis (Brennam et al. 2011). Chitosan or chitosan-based flocculants show to be effective microalgae flocculation agents with concentrations of 40 ppm at pH levels between 7 and 8 (Davis et al., 2011).

It is important to mention that flocculation technology was seen as one of the most efficient and cost attractive means to process microalgae. In addition to flocculation, the processes of flotation, centrifugation, membrane filtration, dewatering and freeze-drying have been identified as alternatives to processing the final microalgae broth (Li et al., 2007; Brennam et al., 2010a, 2010b; Posten et al., 2009). **Table 2.3.2** summarizes the mainly identified harvesting techniques for microalgae-based processes.

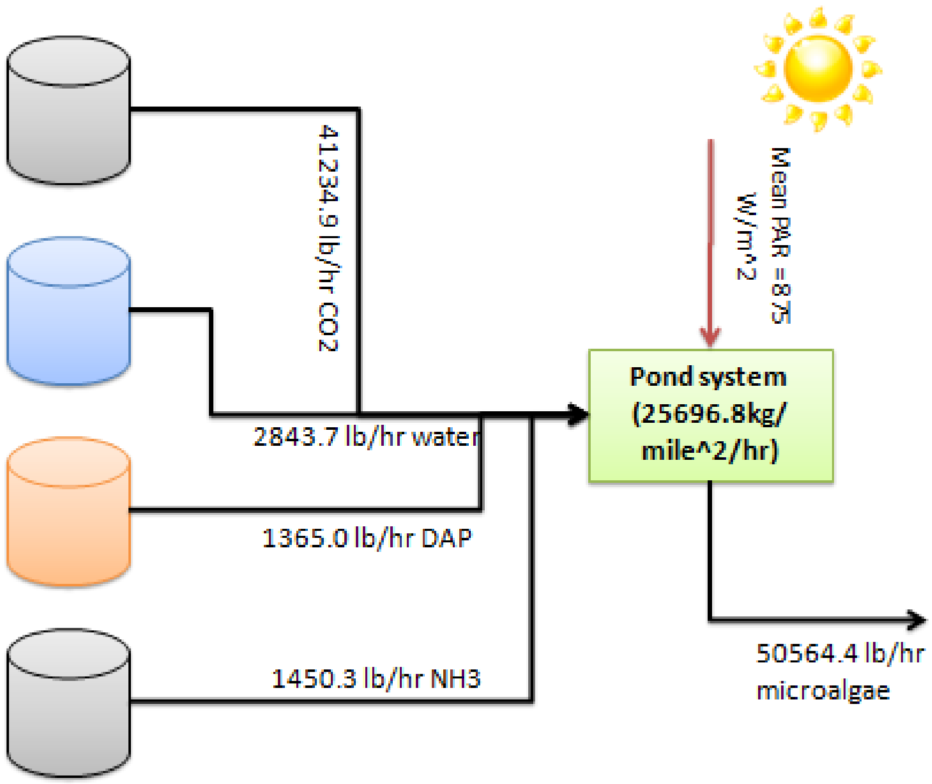


Figure 2.3.3: Propossed formulation and flow diagram to grow microalgae using open pond technology (Chisti et al., 2007; Davis et al, 2011).

Table 2.3.2. Microalgae harvesting technologies.

Harvesting Technology	Uses or application
Centrifuge	Separation of sugar crystals from mother liquid, Measure toll of soil stress, Removal of soil from drilling fluid, Water and wastewater treatment, Oil and sand treatment, Separation of cream from milk.
Flocculation	Colloidal chemistry, Emulsion formation, Separation of clay from slurries, Asexual aggregation of microorganisms, Cheese production, Water treatment from suspended particles.
Drying	Food industry, Preparation of oilseeds for extraction, Prevention of growth of microbial organisms, Reduction of volume and weight in wood based materials.
Dewatering	Aquifer testing, Groundwater drainage, Soil drainage and soil pore size control.
Freeze Drying	Drug preservation and production of tablets, Food preservation, Late state purification procedure in bio-separation, Conservation of bacterial strains, Recovery of paper documentation, Creation of spray slurry in ceramic industry.
Membrane Filtration	Dialysis, Concentration of milk to make cheese, Desalting and solvent exchange of proteins via diafiltration, Fractionation of proteins, Clarification of fruit juice, Recovery of vaccines and antibiotics. Water treatment and or purification.

2.4 - Extraction of oil from microalgae

Herrero and coworkers (2006) presented a conceptual idea on how an oil extraction system from microalgae should be. A summary of different methods that are being contemplated for extraction is shown in **Table 2.4.1**. At the laboratory scale, microwave assisted extraction shows to be an effective technology to extract oil from microalgae (Lee et al., 2010). However, due to the concerns with the control of the microwave technology at a large scale, a solvent extraction strategy promises to be suitable due to the fact that it is a widely used technology at the industrial level. Literature also exposes that the use of a conventional extraction solvent, like hexane, could result in the destruction or degradation of the proteins and carbohydrates of the microalgae. Emergent green solvent technologies, which are able to extract the desired product while preserving the integrity of other constituents should be considered. In that case, supercritical fluid extraction represents an alternative for extracting the oil produced by microalgae.

Table 2.4.1. Comparison of different extraction technologies contemplated to extract oil from microalgae (Revercon et al., 1997; Mendes et al., 2007; Singh et al., 2010; Wang et al., 2011).

Extraction Method	Advantages	Limitations
Oil press	Easy to use. No solvent is involved.	Large amount of sample is required. Time consuming process.
Solvent extraction	Solvent used can be relative inexpensive. The results are reproducible.	Most of the solvents are flammable or toxic. Solvent recovery is expensive and energy intensive. Large volume of solvent is needed.
Super-critical fluid extraction	Results in the non-toxicity or absence of the organic residues in the extracts. The solvent can be considered a green solvent. Solvents for the operation are non-flammable, as well as of simple management.	Need sufficient CO_2 to promote the interaction with the matrix. Need high pressure for operation. Often fails for quantitative extraction technique.
Ultra-sound	Reduced extraction time and solvent consumption. Greater penetration of the solvent into the cellular materials. Improves the release of cell content into the medium.	High power consumption. Difficult to scale-up.

Carbon dioxide supercritical fluid (CO_2-SCF) extraction can be used to extract proteins, lipids and antioxidants from microalgae (Diaz-Reinoso et al., 2007; Wang et al., 2010; Sarada et al., 2011). CO_2-SCF also offers some considerable advantages. First, supercritical fluid extraction can be used instead of traditional organic solvent because it can preserve the extracted by-products. Second, CO_2 has a tunable solvating power, which can be manipulated with pressure and temperature. Third, CO_2 is a low-toxicity solvent and possesses favorable mass transfer rates due to diffusion coefficients in the order around 10^{-8} m^2/s under supercritical conditions. Fourth, the viscosity properties between the solute and the solvent can be thermodynamically manipulated after a critical pressure (P_c) of 72.8 bar and a critical temperature (T_c) of 304.2 K. Finally, the resulting extract from microalgae will be free of solvent (Amaro et al., 2011). Below, **Table 2.5** shows the variation of the dielectric constant and density of CO_2 as a function of temperature under supercritical condition. In summary, when the pressure is increased, the dielectric constant increases, promoting CO_2 to behave as a polar solvent. The fact that the density of CO_2 increases with temperature shows that CO_2 also behaves as a dense solvent, promoting the extraction of desired products by a forced-diffusion mechanism.

Table 2.4.2. Physical properties of CO_2 when it is used as supercritical solvent (Wisniak et al., 2005; Amaro et al., 2011; Halim et al., 2011).

Extraction Pressure (MPa) @ T = 60°C	Density (kg/L)	Dielectric constant
10	0.32	1.17
20	0.73	1.43
30	0.83	1.49

The principal disadvantages of supercritical fluid extraction are that large scale production demands a lot of energy requirements, and it is not cost-attractive due to the fact that it demands high pressure equipment to maintain the CO_2 in the supercritical dense region (Chan et al., 1995; Alvarez et al., 2009; Cooney et al., 2009). Even so, CO_2-SCF shows to be more efficient than Soxhlet extraction apparatus with hexane as a solvent that takes almost six times longer to achieve with a comparable lipid yield (Amaro et al., 2011; Cheng et al., 2011; Halim et al., 2011). This observation is also sustained by Palavra and coworkers (2011), who observed that CO_2 at 313 K and 30 MPa can extract chlorophyll, as well as 60% of hydrocarbons, while Soxhlet hexane extraction yields only around 37% hydrocarbons. Improved hydrocarbon yields greater than or equal to 60% can be achieved at higher pressures.

Moreover, an extensive review regarding the evaluation of supercritical fluid has been done starting with the Natex Company from Australia for the 1980's. It has been determined that the pressure charging stage in a batch process at industrial scale should delay around 45 minutes. The total operation time for extraction is assumed to be 180 minutes (3 hours) on a batch run. At an industrial scale, the main evidence of the extraction of oil from matrixes other than microalgae using CO_2-SCF was separately reported by Rodriguez and co-workers (2010) and Nyam and co-workers (2011). However, Cooney and coworkers showed that a temperature range of 40-50°C and pressures above 379 bars (around 38.4 MPa) are required to efficiently extract oil from microalgae (Cooney et al., 2009).

Other studies by Gamlieli-Bonshtein and coworkers (2002) show that the pressure used to extract most of the oils from microalgae, including the proteins and other by-products is 44.8 MPa and a temperature near to 40ºC. This is also supported by other research articles (Macias-Sanchez et al., 2005; Tang et al., 2011; www.natex.com, 2012). Conveniently, the activity ratio carothenoid/chlorophyl was the best at 200 bar and 60ºC. Therefore, all valuable compounds can be obtained at pressure of above 40 MPa between 35 and 45ºC. **Figure 2.4.1** illustrates a general process scheme for a supercritical fluid extraction system.

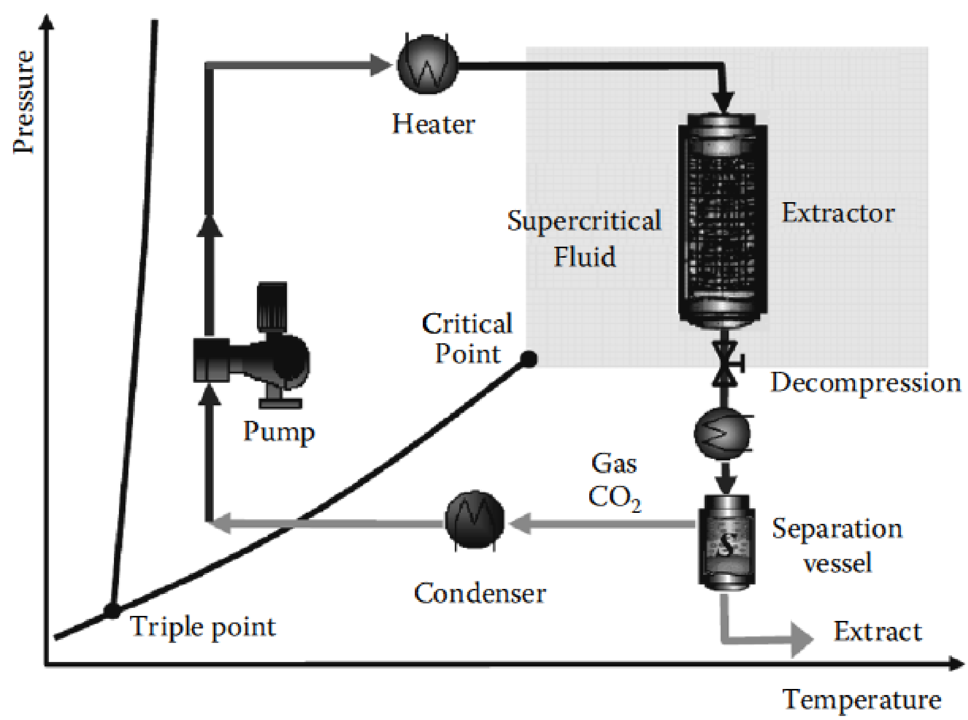


Figure 2.4.1. Operation scheme for supercritical fluid extraction (Mereiles et al, 2008).

Some other alternatives, such as the combination of CO_2 with methanol as a co-solvent and supercritical methanol as a solvent have been proven to achieve a high yield in the oil extraction from microalgae. However, concerns regarding the degradation of valuable by-products such as proteins are still of concern and these alternative solvent approaches need to be further evaluated (Hu et al., 2007; Buit et al., 2011; Liau et al., 2011).

2.5 - Alternative for processing microalgae

Beginning with the use of microalgae to produce alcoholic beverages by Jorgensen, some other researchers claim that microalgae can be used to produce sterols and antioxidants using greener technologies (Patterson, 1991; Rodrigues et al., 2011). Other researchers have proposed that microalgae can be used for CO_2 mitigation and methanation (Jorgensen et al., 1991; Brennen et al., 2010b; Zamalloa et al., 2011). Others, like Khan and coworkers (2009), discussed the composition of microalgae via CO_2 mitigation. Microalgal biomass can be used for either thermochemical or biochemical conversion to energy.

Figure 2.5.1 shows an example of the scheme proposed in the use of microalgae biomass via thermochemical or biochemical conversion. Alternatively, most researchers prefer pyrolysis and catalytic hydrothermal reactions, because their objectives were oriented to using the products for the oil industry (D'Oca et al., 2011; Amin et al., 2009; Biller et al., 2011).

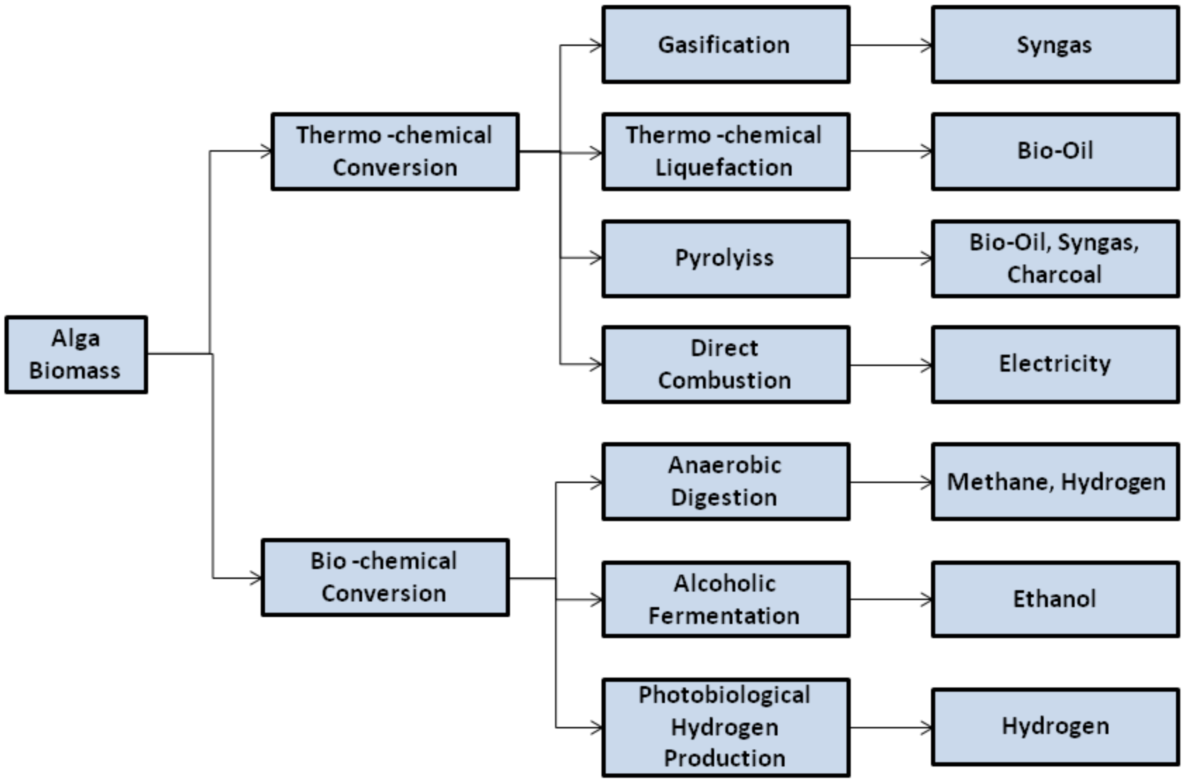


Figure 2.5.1. Summary of techniques available for conversion of microalgae (Brennan et al., 2010a, 2010b).

2.6 - Cost technique used for the analysis

There are different technologies that can be integrated to grow, harvest and extract bioproducts from microalgae. However, an analysis that evaluates how much it will cost to build and operate a microalgae biorefinery plant based in existing technologies and considering local factors remains unrevealed. This uncertainty represents a potential risk that is not acceptable for the investors. In response to this, it is imperative to make an economic analysis based on the evaluation of a preliminary process flow diagram, as well as to take into consideration local cost factors and challenges.

This analysis should involve both operational and capital cost estimates based in the plant layout and unit operations. Accurate capital cost estimates demand detailed equipment cost information. In some cases, the cost value of the units should be adjusted for equipment size, capacity and time (year) as the information is being collected. **Equations 2.6.1** and **2.6.2** are basic relations to make these adjustments. **Equation 2.6.1** is known as the "sixteenths rule." This equation is used to estimate the cost of desired equipment based in capacity. The subscripts 1 and 2 refer to the capacities and costs of the equipment at two scale levels: 1 and 2. The unknown cost of the equipment at its upscale level (for instance, level 2) can be estimated based on the known capacity and cost of the equipment at level 1. **Equation 2.6.2** is used to update the equipment cost based on the year from which its cost is known. The normal index used to get these estimates is the Marshall & Swift (MS) equipment cost index; where I_{base} and I are the base cost and the late or actual cost indexes, respectively.

$$\frac{Cost_1}{Cost_2} = \left(\frac{Capacity_2}{Capacity_1}\right)^{0.6} \qquad \textbf{Eq. 2.6.1}$$

$$Cost = Base\ Cost\left(\frac{I}{I_{base}}\right) \qquad \textbf{Eq. 2.6.2}$$

$$\frac{Cost_1}{Cost_2} = \left(\frac{Capacity_2}{Capacity_1}\right)^{0.6}\left(\frac{I}{I_{base}}\right) \qquad \textbf{Eq. 2.6.3}$$

Equations 2.6.1 and **2.6.2** can be combined in the case that both equipment capacity and year are required for the analysis, obtaining **Equation 2.6.3**. For the equipment where the cost information is missing but the size/capacity information is available, the base cost estimate is required. The base cost can be estimated using equations available in **Appendix B**. **Table 2.6.1** shows the most frequently used data of cost indexes for each year up to 2011, based in commercial-scale processes. **Table 2.6.2** lists the sale price information for different raw materials. It must be pointed out that the equipment cost, as well as the cost index information is substantial to obtain an updated cost estimate. However, the chemical price cost index and labor cost index are two other indexes that should be considered in our cost analysis (**Tables 2.6.3 and 2.6.4**).

Cost estimates can be complemented in order to fine-tune and release a thorough and confident analysis. An approach to do this is to apply the complementary method. For the purpose of this project, the two methods that will be used for cost analysis will be: (1) the Lang factor method integrated with the set of equations of manufacturing costs (shown in **Equations 3.1** to **3.4** on the Research Methodology) and (2) using a computer-based spreadsheet capital and operational costs (CAPCOST) for the analysis developed by Turton and Seider in 2008.

The Lang factor methodology is used to estimate the amount, as well as the contribution in terms of magnitude of the operational costs versus the capital costs to the production costs of a commercial processing plant. This methodology, also known as the “overall factor method of Lang”, developed in 1948 is a tool used to estimate the fixed capital investment of the overall plant. The method requires a plant design diagram, which includes the major equipment with their respective mass and energy balances. The accuracy of the cost estimates will be around plus or minus 35 percent (Seider et al., 2004), depending on the quantity and quality of the technical information available to construct the process flow diagram. **Equations 2.6.4** and **2.6.5** are used to estimate the fixed capital investment (**FCI**) and total capital investment (**TCI**), respectively.

Table 2.6.1. Cost index for industrial processes (Vatavuk et al., 2002; Turton et al., 2009; Economic Indicators, 2011; Lozowski et al., 2011).

Year	Chemical Engineering Plant Cost Index	Marshall and Swift Equipment Cost Index
1991	361	931
1992	358	943
1993	359	964
1994	368	993
1995	381	1028
1996	382	1039
1997	387	1057
1998	390	1062
1999	391	1068
2000	394	1089
2001	394	1094
2002	396	1104
2003	402	1124
2004	444	1179
2005	468	1245
2006	500	1302
2007	525	1373
2008	575	1449
2009	521	1469
2010	550	1457
2011	580	1520

Table 2.6.2. Sale price of different materials required in the microalgae processing plant (Borowitzka et al., 1992; Sialve et al., 1992; Davis et al., 2011).

Material	Cost ($/unit	Year
CO2	$0.02/lb	2011
NH3	$0.18/lb	2011
Diammonium phosphate (DAP)	$0.20/lb	2011
Microalgae	$14.34/lb	2011
Water	$0.006/lb	2012
Flocculant	$4.84/lb	2003
Land	$300/acre/yr	2012

Table 2.6.3. Chemical price cost index (Industrial Chemical Cost index, 2012).

Year	Cost Index
2002	127.3
2003	141.7
2004	162.8
2005	188.5
2006	212.4
2007	226.4
2008	274.6
2009	234.1
2010	269.2
2011	326.3

Table 2.6.4. Annual labor cost index (Employment Cost Index, 2012).

Year	Labor Cost Index	Year	Labor Cost Index
1975	26.9	**1994**	70.2
1976	28.9	**1995**	72.2
1977	30.9	**1996**	74.7
1978	33.2	**1997**	77.6
1979	36.1	**1998**	80.6
1980	39.4	**1999**	83.5
1981	42.8	**2000**	86.7
1982	45.5	**2001**	90.0
1983	47.8	**2002**	92.4
1984	49.8	**2003**	95.2
1985	51.8	**2004**	97.5
1986	53.5	**2005**	100.0
1987	55.2	**2006**	103.2
1988	57.5	**2007**	106.6
1989	59.9	**2008**	109.4
1990	62.3	**2009**	110.8
1991	64.6	**2010**	112.8
1992	66.3	**2011**	114.6
1993	68.3		

$$C_{TPI} = 1.05 f_{L_{TPI}} \sum_i \left(\frac{I_i}{I_{b_i}}\right) C_{P_i}$$ **Eq. 2.6.4**

$$C_{TCI} = 1.05 f_{L_{TCI}} \sum_i \left(\frac{I_i}{I_{b_i}}\right) C_{P_i}$$ **Eq. 2.6.5**

C_{TPI} is the total permanent investment, also known as fixed capital investment. C_{TPI} does not take into account the working capital or additional expenses at exception of mount the equipment. However, C_{TCI} is the total capital investment that includes the 15 percent for the working capital used to operate the equipment from the total capital investment or even a 17.6 percent in additional overhead and other expenses to the total permanent investment. The corresponding Lang factors of the above equations are $f_{L\ TPI}$ and $f_{L\ TCI}$, which are the fixed and the total capital investment Lang factors, respectively. These two factors were obtained based in the original Lang study and were incorporated to the data of fourteen different kinds of chemicals plants.

The CAPCOST analysis can be applied with the purpose to use operational as well as capital cost data to predict the effect of the financing period in the production costs of products at different project time frames. Once the capital and operational costs are obtained, these data can be input to the CAPCOST spreadsheet. CAPCOST then can be used to estimate the effects of the inflation in the production costs of the designed plant at different project time spans that can range from five to twenty years. CAPCOST is also capable to provide estimates of cost data like net present value (NPV), the return of return (ROR**)**, cash flow diagrams, and Monte Carlo analyses (Turton et al., 2009).

The use of these factors depends on the nature of the processing plant (if the plant is designed to process solids, fluids, or a mixture of both), and if the working capital is included or not. **Table 2.6.5** shows the Lang factors corresponding to the mentioned processing plants. I is the late cost index or the cost index corresponding to the current year of analysis. I_{base} is the base cost index, which corresponds to the year in which the equipment was purchased. C_p is the purchase cost which excludes the delivery of the equipment to the plant site. This delivery is taken into account by applying a multiplying factor of 1.05 in the **Equations 2.6.1** and **2.6.2**.

Table 2.6.5. Lang factors of different processes (Seider et al., 2004).

Type of Plant	Original Lang factor (working capital not included)	$f_{L,TPI}$ including working capital	$f_{L,TCI}$ including working capital
Solids processing plant	3.10	3.9	4.8
Solids-fluids processing plant	3.63	4.1	4.9
Fluids processing plant	4.74	4.6	5.7

2.7 - Mass and energy balances, equipment size estimation and energy consumption as tools to complement our analysis

In the previous section we mentioned the necessity to have realistic information of the process to perform a reliable economic analysis. The development of a validated process scheme with realistic conditions, as well as mass and energy balances that correspond to each case scenario is mandatory. This task achieved by hand calculations can be tedious in terms of working as well as time-consuming. Process simulators like ASPEN ONE, developed by ASPEN Tech Inc. (http://www.aspentech.com, 2012) can be used to verify the process reliability and operability conditions. In other words, ASPEN ONE can be used as a validation tool for all process units mass and energy balances.

ASPEN ONE can also provide information that can be used to determine other important design requirements, such as equipment size that at the same time will support our economical analysis in terms of scaling-up. Previous researchers have used ASPEN ONE in an efficient manner to simulate the conversion of oil to biodiesel, as well as a supplementary tool to develop a block diagram to estimate costs of production of diesel using microalgae oil (Sanchez et. al., 2011; Davis et al., 2011). Our project incorporated the ASPEN ONE results to sustain and complement our economic analysis in terms of the production of microalgal paste which contains lipids, proteins and carbohydrates.

CHAPTER 3: RESEARCH METHODOLOGY

Five case scenarios were developed in order to consider potential green technologies (**Figure 3.1**). These technologies were mainly considered because they promote the integrity of the extracted protein, lipids, and carbohydrates. **Table 3.1** shows the path of these scenarios that were summarized in terms of unit steps.

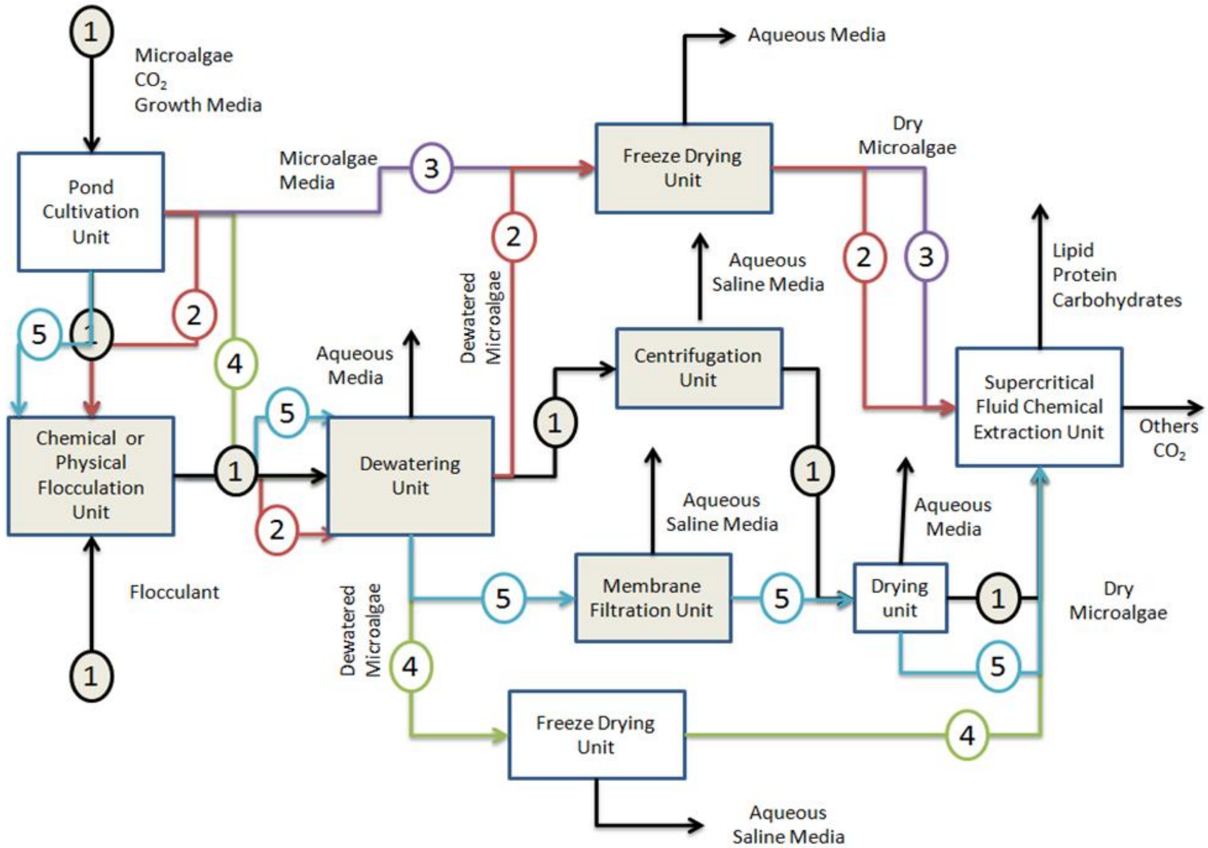


Figure 3.1. Schematic scenario of process diagram for microalgae processing.

All routes in **Figure 3.1** include a pond site to grow the microalgae, as well as a supercritical extraction step to extract the paste from the microalgae. The difference is in the harvesting steps that are between the growth and extraction steps. In Route 1, the microalgae is flocculated and the broth is dewatered. The remaining solid part is centrifuged and conventionally dried before the paste can be extracted. Routes 2 and 5 have the same flocculation and dewatering steps. However, route 2 uses a freeze drying unit to prepare the microalgae, while route 5 uses a combination of membrane filtration followed by a conventional drying unit to prepare the microalgae for the extraction step. Route 4 uses a dewatering unit followed by a freeze drying unit to prepare the microalgae for extraction. Finally, route 3 only uses a freeze drying unit to harvest the microalgae prior to the extraction step.

The reference frameworks provided in **Figure 3.1** were used to generate a mass balance spreadsheet corresponding to the five different possible scenarios using Microsoft Excel 2007 (refer to **Tables 5.1.1 to 5.1.10** of Section 5.1). The generated spreadsheets were used to construct and validate a preliminary process layout for each case scenario using ASPEN ONE. A conversion of microalgae to bulk paste that contains proteins, lipids, and carbohydrates was assumed as 50 percent (according to Sections 2.1 to 2.4). Then, preliminary process flow diagrams for each scenario were obtained (**Figures 5.1.1 to 5.1.5** of Section 5.1**)**. Data gathered from the simulator (**Appendix C)** and balance spreadsheet information were combined to identify appropriate equipment sizes on the plant site (A**ppendix B**), depending on the case scenario.

Table 3.1. Summary of chosen scenarios.

Case Scenario	Unit Operation Sequence
1	Pond → Flocculation → Dewatering → Centrifugation → Drying → SC Extraction
2	Pond → Flocculation → Dewatering → Freeze Drying → SC Extraction
3	Pond → Freeze Drying → SC Extraction
4	Pond → Dewatering → Freeze Drying → SC Extraction
5	Pond → Flocculation → Membrane Filtration → Drying → SC Extraction

Cost of utilities (C_{UT}), labor (C_{OL}), raw materials (C_{RM}), waste treatment (C_{WT}) and fixed capital investment (***FCI***) for plants and ponds were calculated on different basis (see Section 4.1 and 4.2). Cost of manufacture (***COM***) (**Equation 3.1**), direct manufacturing cost (***DMC***) (**Equation 3.2**), fixed manufacturing cost (***FMC***) (**Equation 3.3**), general manufacturing cost (***GMC***) (**Equation 3.4**), fixed capital investment (***FCI***), working capital (***WC***), and cost of land (C_{land}) were calculated and used to obtain the production cost of bulk paste. This was done considering the effect of financing period in the production cost at project terms of: 5, 10, and 20 years. A high-risk annual interest rate of 10% and a taxation of 42% (Hills, 2011) were chosen in conjunction with the Method Accelerated Cost Reduction System (**MACRS**) (Seider et al., 2004) for the cash flow analysis. The construction period was assumed to be two years. The information was used to feed the CAPCOST economic spreadsheet.

$$COM = 0.180FCI + 2.73C_{OL} + 1.23(C_{UT} + C_{WT} + C_{RM}) \quad \textbf{Eq. 3.1}$$

$$DMC = C_{RM} + C_{WT} + C_{UT} + 1.33C_{OL} + 0.03COM_d + 0.069FCI \quad \textbf{Eq. 3.2}$$

$$FMC = 0.708C_{OL} + 0.068FCI + depreciation \quad \textbf{Eq. 3.3}$$

$$GMC = 0.177C_{OL} + 0.009FCI + 0.16COM \quad \textbf{Eq. 3.4}$$

Heat duty as well as power data provided by ASPEN Plus and Excel spreadsheet calculations were used to perform the economic analysis. UNIQUAQ was chosen as the thermodynamic model due to its versatility with respect to the analysis of solid and liquid interaction within processing plants. Examples of other calculations that were relevant to support our economic analysis are shown in Sections 4.1 to 4.3. Finally, the preliminary plant site process flow diagrams (**PFD)**, are shown in **Figures 5.1.6** to **5.1.10** of Section 5.1. The cost analysis information pertinent to building a facility to produce approximately 222.1 million pounds of bulk paste (depending on the five possible scenarios) in an annual basis is also provided in Sections 5.2, and 5.3.

CHAPTER 4: COST ANALYSIS CALCULATIONS

4.1 - Cost related to open pond construction

According to Welssmen and coworkers in 1987, the total cost to build a pond facility of 192 hectares was approximately $4,932,147. Based in the information provided in Section 2.3, the area estimated to grow microalgae for a production of 222.1 million of paste is around of 2,207 hectares. Assuming that a microalgae pond site can be considered as a chemical plant and that the cost index of 1987 value should be close to the cost index of 1991 (with a value of 361), the cost of a pond site in year 2011 (with an index of 580) can be estimated using **Equation 2.6.3**:

$$C_{Pond,2011} = \$4{,}932{,}147x\left(\frac{2207.2\ ha}{192\ ha}\right)^{0.6}\left(\frac{580}{361}\right)$$

$$C_{Pond,2011} = \$34{,}298{,}821.93$$

The cost of land was calculated on basis of the total required land for site construction, instead of the land needed for pond construction, as expressed in the equations of Section 2.3. According to Davis and coworkers (2011), for each 12.71 square miles used for total operation facilities, 8.52 square miles are needed for multiple ponds in the pond site. From data provided in April 13, 2012 by agronomist Cristian Martes Camacho from the 'Autoridad de Tierras de Puerto Rico' (personal communication), a cost of subsidized land rental was estimated as $300 per acre per year. The yearly cost of subsidized land rent is estimated as:

$$C_{land,2011} = 2207.2\ ha\ x\ \left(\frac{1000\ acre}{404.86\ ha}\right)\ x\ \left(\frac{12.71\ sqrt\ miles}{8.52\ sqrt\ miles}\right)\ x\ \$300\frac{1}{acre\ yr}$$

$$C_{land,2011} = \$2{,}439{,}702\ per\ yr$$

The cost of water was calculated using data taken from Section 2.3. Based on Welssmen for 1987, an equivalent volume capacity of 22,430 ponds of 82 m long, 12 m wide and 0.3 m deep should be used to obtain the desired annual production rate. Taking the cost of water provided in Section 2.6, the cost to fill the pond site with water results in:

$$C_{water,2011} = 12\ m\ x82\ m\ x0.3\ m\ \frac{1}{pond\ yr}\left(\frac{3.787gal}{1000\ m^3}\right)22430.73\ pond\ \frac{\$0.00525}{gal}$$

$$C_{water,2011} = \$9{,}140{,}767\ per\ year$$

This result was taken into consideration in the working capital calculation. The annual cost of makeup water based in an evaporation rate of 1,200 m^3 per day was \$606,814 per year. Cost of DAP, NH_3, CO_2 and microalgae were estimated using the sales value and the information provided in Section 2.3.

$$C_{DAP,2011} = 1365.02\frac{lb}{hr}\ x\ \frac{24\ x\ 365.25\ hr}{yr}\ x\ \frac{\$0.20}{lb}$$

$$C_{DAP,2011} = \$\ 2{,}399{,}009\ per\ year$$

$$C_{NH3,2011} = 1450.33\frac{lb}{hr}\ x\ \frac{24\ x\ 365.25\ hr}{yr}\ x\ \frac{\$0.18}{lb}$$

$$C_{NH3,2011} = \$2{,}347{,}108\ per\ year$$

$$C_{CO2,2011} = 41234.88\frac{lb}{yr}\ x\ \frac{24\ x\ 365.25hr}{yr}\ x\ \frac{\$0.02}{lb}$$

$$C_{CO2,2011} = \$6{,}558{,}378\ per\ year$$

$$C_{microalgae,2011} = 121{,}800.3\frac{lb}{yr}\ x\ \frac{\$14.34}{lb}$$

$$C_{microalgae,2011} = \$1{,}747{,}020\ per\ year$$

According to the information from Section 2.3, the amount of CO_2, NH_3 and DAP were assumed as being totally consumed. Adding the cost of the land, makeup water, CO_2, NH_3, DAP, and initial microalgae culture costs for raw materials consumption, $\boldsymbol{C_{RM}}$, is equal to \$**16,098,032** per year. The cost of waste treatment, $\boldsymbol{C_{WT}}$, was assumed \$0 per year in the pond site because we are not disposing any material from over there. The cost of utilities was calculated based on the pond's paddle wheels energy consumption. Welssmen in 1987 established that a pond area of 192 hectares demands 24 paddle wheels. Each paddle wheel has 0.42 of efficiency that results in a shaft power requirement of 8.28 kW. In our case, we need approximately 276 paddle wheels. Assuming that the paddles are operated during the whole year, then a total of 20,021,907 kW-hr per year is required. In Puerto Rico, the electricity cost is around \$0.24/kW-hr for the industrial sector. Therefore, the cost of utilities consumed by the pond ($\boldsymbol{C_{UT}}$) is around \$4,813,647 per year.

Costs of labor were estimated using the data from **Table 4.1.1** and adjusted to the actual salaries and pond area. For the objectives of this project, all the facility workers were counted as operating labors.

Table 4.1.1. Itemization of cost salary work in a 1,000 acre pond site.

Position Title	Quantity	Time (hrs)	Money $/hr	$/yr
Plant Manager	1	2080	25	52000
Shift Supervisor	4	2080	17	35360
Pond Operators	10	2080	10	20800
Centrifuge Operators	5	2080	12	24960
Laboratory Manager	1	2080	17	35360
Laboratory Technicians	2	2080	10	20800
Total ($)				**603200**

$$C_{OL,2011} = \frac{\$603{,}200}{yr}\ x\ \left(\frac{2207.18\ ha}{404.86\ ha}\right)\ x\ \left(\frac{114.6}{55.2}\right)$$

$$C_{OL,2011} = \$6{,}827{,}167.59\ per\ year$$

Note that the pond construction costs were used in **Equations 3.1** to **3.4** to calculate ***COM***, ***DMC***, ***FMC***, and ***GMC***. All of these calculations are summarized in **Table 4.1.2** below.

Table 4.1.2. Summary of manufacturing costs for pond site.

Item	Cost ($)
COM ($/yr)	**50,533,321**
DMC	**33,874,430**
DMC (%)	67.0
FMC	**7,165,955**
FMC (%)	14.18065243
GMC	**9,602,429**
GMC (%)	19.0

4.2 - Cost related to plant construction

Most of the calculations corresponding to this section were done using **Equation 2.6.3** from section 2.6. Tables were constructed to estimate the cost of the equipment or unit operations (**Appendix B)**. For example, the shaft power required for a pumping system, P-103, of Case 1 was estimated as 234.78 kW.

This value exceeds 200 kW, which is the maximum shaft power allowed by the equation of bare/basis cost (**Equation 4.2.1**).

C_p^0 is the bare cost in dollars at standard pressure and temperature conditions; A is the attribute (200 kW) of the system; and K_1, K_2, and K_3 are the constants relative to the chosen equipment. P-103 was analyzed as a centrifugal pump with K_1, K_2, and K_3 equal to 3.3892, 0.0536, and 0.1538, respectively, resulting in a bare cost of $21,226 per pump.

$$C_p^0 = 10^{\left(K_1 + K_2 log_{10}(A) + K_3 (log_{10}(A))^2\right)} \qquad \textbf{Eq. 4.2.1}$$

For this case, the pressure factor F_p and the material factor F_m were set equal to 1. Therefore, the purchase cost in the year 2001 was:

$$C_{p,2001} = C_p^0 \; x \; F_p \; x \; F_m$$

$$C_{p,2001} = \$21{,}226 \; x \; 1 \; x \; 1 = \$21{,}226$$

Using this value, the cost for the actual size and year is an amount of:

$$C_{p,2011} = \$21{,}226 \; x \; \left(\frac{234..78kW}{200kW}\right)^{0.6} \; x \; \frac{1520}{1094}$$

$$C_{p,2011} = \$32{,}469$$

Table 4.2.1 shows the summary of units considered to calculate the capital cost of plant for case scenario 1 using **Equation 2.6.5**. Adding the purchase cost of the equipment and multiplying it by 1.05 and 4.1 to account an adjustment of the cost index relation from plant and equipment, a capital cost (C_{TCI}) of **$67,463,816** was estimated.

Table 4.2.1. Summary of purchase cost for equipment in Case Scenario 1.

Item	Description	$C_{p,2011}$ ($)
P-101	Pump or Pump System	21,463
P-102	Pump or Pump System	28,652
P-103	Pump or Pump System	32,469
P-104	Pump or Pump System	8,756
P-105	Pump or Pump System	12,830
P-106	Pump or Pump System	6,835
P-107	Pump or Pump System	8,126
P-108	Pump or Pump System	5,279
P-109	Pump or Pump System	9,071
P-110	Pump or Pump System	80,318
Tk-101	Flocculation Tank	78,747
Z-101	Dewatering system	43,249
Z-102	Centrifuge System	1,200,886
Z-103	Drying System	4,015,288
Z-104	CO2 Compressor	1,680,936
Z-105	SCF - Extraction Vessel	17,879
Z-106	SCF - Separation Vessel	7,951,428
Z-108	CO2 - Stripping System	468,825

Continuing with case scenario 1, **Table 4.2.2** shows a summary of utility costs and number of operators used for each unit. This information was used to estimate the cost of utilities for the plant site in Case 1. Overall, the electricity consumed by the plant was calculated taking the sum the electricity of all individual equipments (~19,700 kW) and multiplied by 24 hours per day of operation, and using the factor of 365.25 days per year. This gave an energy consumption of 1.73 x 10^8 kW-hr per year. In Puerto Rico, the actual electricity cost was approximately $0.24 per year for the industrial sector in 2011. Therefore the annual electricity cost amount was determined as:

$$C_{electricity} = \frac{1.73\ x\ 10^8 kWhr}{yr}\ x\ \frac{\$0.24}{kWhr}$$

$$C_{electricity} = \$\ 41{,}600{,}000\ per\ year$$

Table 4.2.2. Amount of utilities and of labors per system in Case Scenario 1.

Item	Utility: Electricity (kW)	Utility: Water (kg/s)	# of Labors
P-101	129.6	----	----
P-102	192.3	----	----
P-103	234.78	----	----
P-104	12.58	----	----
P-105	58.77	----	----
P-106	6.916	----	----
P-107	25.28	----	----
P-108	3.14	----	----
P-109	31.51	----	----
P-110	303.83	----	----
Tk-101	----	----	1
Z-101	13.1	----	1
Z-102	2,644.94	----	1
Z-103	3.15	----	1
Z-104	16,082.52	----	1
Z-105	----	250.61	1
Z-106	----	----	----
Z-108	----	----	1

Water consumption was estimated around 552.48 lb/s, which equals to 17.4 x 10^9 pounds per year. The price of water was assumed to be $0.0006 per pound of water. The annual cost of water is therefore $10,948,445 per year. This analysis makes a total cost of utilities (***C_{UT}***), of approximately $52,600,000 per year. The cost of labor was estimated from **Equation 4.2.2**.

$$C_{OL} = \frac{\$39{,}931.73}{yr}\, x\ Int\left\{4.5(6.29 + 31.7P^2 + 0.23N_{np})^{0.5}\right\} \qquad \textbf{Eq. 4.2.2}$$

The amount of $39,931.73 is the annual salary for regular operators during 2011. **4.5** is the shift number factor per work per each year, *Int* is the integer number, ***P*** is the number of operators who are assumed to work with solids or solid particles and fluids, and ***N_{np}*** is the number of operators that work with powder or particulate material. For Case 1, ***P*** is equal to 7 and N_{np} is equal to 0. Then, the cost of operating labor is approximately to $9,330,030 per year. The cost of waste disposal was estimated as $36 per ton for the year 2001. Assuming that half of microalgae mass is being disposed as a non-hazardous waste, the cost for waste disposal is:

$$C_{WT} = \frac{22.98293\ Ton}{hr} x\ \frac{24\ x\ 365.25\ hr}{yr}\ x \frac{\$36}{Ton} x \frac{580}{397}$$

$$C_{WT} = \$5{,}298{,}060\ per\ year$$

The cost of CO_2 was estimated at $2,647,660 per year using a similar methodology as described to calculate the amount of water for the pond site. The makeup CO_2 was based in the loss of one day with an equivalent cost of $794,298 per year. The cost of flocculant is about $1,980,129 per year. Adding these values to the cost of land, the total cost of raw materials was estimated as $5,214,130 per year. Cost of manufacturing for case scenario 1 was calculated and is summarized below.

Table 4.2.3. Summary for cost of manufacturing in Case Scenario 1.

Item	Cost ($)
COM ($/yr)	**109,340,080**
DMC	74,144,485
DMC (%)	**75.16**
FMC	7,480,437
FMC (%)	**7.6**
GMC	17,283,807
GMC (%)	**17.52**

4.3 - Adjusted value and the use of CAPCOST

In addition to the chemical plant cost index value required in CAPCOST, some other values from the 'user options' spreadsheet of each case were modified. This section explains how these values were obtained. The electricity cost in $/GJ amount calculated by **Equation 4.3.1** is:

$$Electricity\ Cost = \frac{\$0.24}{kWhr} x \frac{1hr}{3600s}\ x\ \frac{1x10^6 kJ}{1GJ} \qquad \textbf{Eq. 4.3.1}$$

$$Electricity\ Cost = \frac{\$66.78}{GJ}$$

The cost of water in **$/GJ** was calculated by dividing the value of the annual utility cost between the needed heat duty for the extraction vessel of Case 1, Z-105, from APEN ONE simulator (**Appendix C**), resulting in a value of **$16.60/GJ**. In 2001, the cost for waste treatment was $36/ton for non-hazardous waste. Using the chemical plant cost index, the actual cost for waste disposal was determined to be $52.59/ton for non-hazardous waste.

The pump efficiency was adjusted to a justifiable normal minimum of 0.6 and the average operator salary was estimated to be $16/hr. Assuming that one operator works 40 hours per week and 49 weeks per year, the annual salary would have been $31,360 in 2001. Using this and the labor cost index, the annual salary for labor would be $39,931 in 2011. The time for production was considered to be 8,766 hours annually.

Working capital was estimated based on the materials needed to start up the plant for the first month of operation. For Case scenario 1, the sum of $9.14 million to fill the ponds with water, $2.65 million for CO_2, and $2.18 million for raw materials $\boldsymbol{C_{RM}}$, of $5.88 million in utilities, $0.54 million in waste treatment and $3.19 million for labor, $\boldsymbol{C_{OL}}$, are needed to start the project during the first month. The addition of all these values gives an estimated working capital of approximately $23.6 million. Fixed capital investment (***FCI***) is the sum of the capital cost of the processing plant and pond site. The cost of land was estimated based on two years of construction. To obtain the production costs of bulk microalgae paste, the revenue from sales value ***R***, was calculated assuming a break-even scenario for each case using **Equation 4.3.2**.

$$R = COM + AC_{Land} + B\,FCI - Ct \qquad \textbf{Eq. 4.3.2}$$

The parameter ***t*** is known as the taxation rate, which is equal to 0.42 in this analysis. The annual interest or discount rate was assumed to be 10 percent which is normally considered a high risk for purposes of investment. **Table 4.3.1** shows the respective values of ***A***, ***B***, and ***C*** in order to calculate the production costs, ***R*** value, in 2011 for each case scenario, as well as for considering effects in production costs at three different financing periods: 5, 10, and 20 years.

Table 4.3.1. Summary of *A*, *B*, and *C* to calculate the *R* value.

Case Scenario	5 years			10 years			20 years		
	A	B	C (1 x 10^6)	A	B	C (1 x 10^6)	A	B	C (1 x 10^6)
Case 1	0.268	0.511	38.519	0.231	0.330	23.764	0.215	0.249	17.151
Case 2	0.268	0.519	30.544	0.231	0.338	18.844	0.215	0.256	13.600
Case 3	0.268	0.526	33.498	0.231	0.345	20.666	0.215	0.264	14.916
Case 4	0.268	0.519	30.568	0.231	0.338	18.859	0.215	0.257	13.611
Case 5	0.268	0.513	36.626	0.231	0.332	22.596	0.215	0.250	16.308

Factor ***A*** accounts for the project life, the income tax rate and the depreciation. Factor ***B*** accounts for the income tax, annual interest and the working capital. Factor ***C*** accounts for the annual interest, the income tax rate and the depreciation. For example, the production cost value of microalgae oil for five years of project life using case scenario 1 was calculated. Land should be rented for two years during the construction period. Using the values of ***COM*** **Equation 4.3.2**, an ***R*** value of $198,327,942 per year was obtained. The calculated density of microalgae (as shown in **Appendix A**) was assumed to be 1.33 kg/L. Then, the ***R*** value means that for a production of 222.1 million pounds of bioproducts per year, the break-even sale value based on revenue from sales should be $0.89 per pound. These results were used to feed CAPCOST and perform the cash flow and uncertainty analyses for projects of 5, 10, and 20 years for each case scenario. The values used for case scenario 1 are shown as an example in **Table 4.3.2**.

Table 4.3.2. Values used in CAPCOST for Case Scenario 1.

Item	Cost ($)
Cost of Land	9,758,808
Fixed Capital Investment	101,76,2638
Working Capital	23,584,681
COM	159873401.4
Salvage Value	0
Taxation Rate	0.42
Annual Interest Rate	0.10

CHAPTER 5: RESULTS AND DISCUSSION

5.1 - General process description, ASPEN ONE complementary information and plant site process flow diagram

Five different case scenarios were designed and analyzed in this project. Each case scenario process scheme is described in this section. ASPEN ONE was used to generate the plant site simulation diagrams shown in **Figures 5.1.1**, **5.1.3**, **5.1.5**, **5.1.7**, and **5.1.9** below (see **Appendix C)**. Also, **Figures 5.1.2**, **5.1.4**, **5.1.6**, **5.1.8**, and **5.1.10** shown below are the process flow diagrams obtained for each of the five case scenarios that were analyzed. Finally, process stream conditions and equipment specifications and costs for each case scenario results are summarized in **Tables 5.1.1** to **5.1.10**.

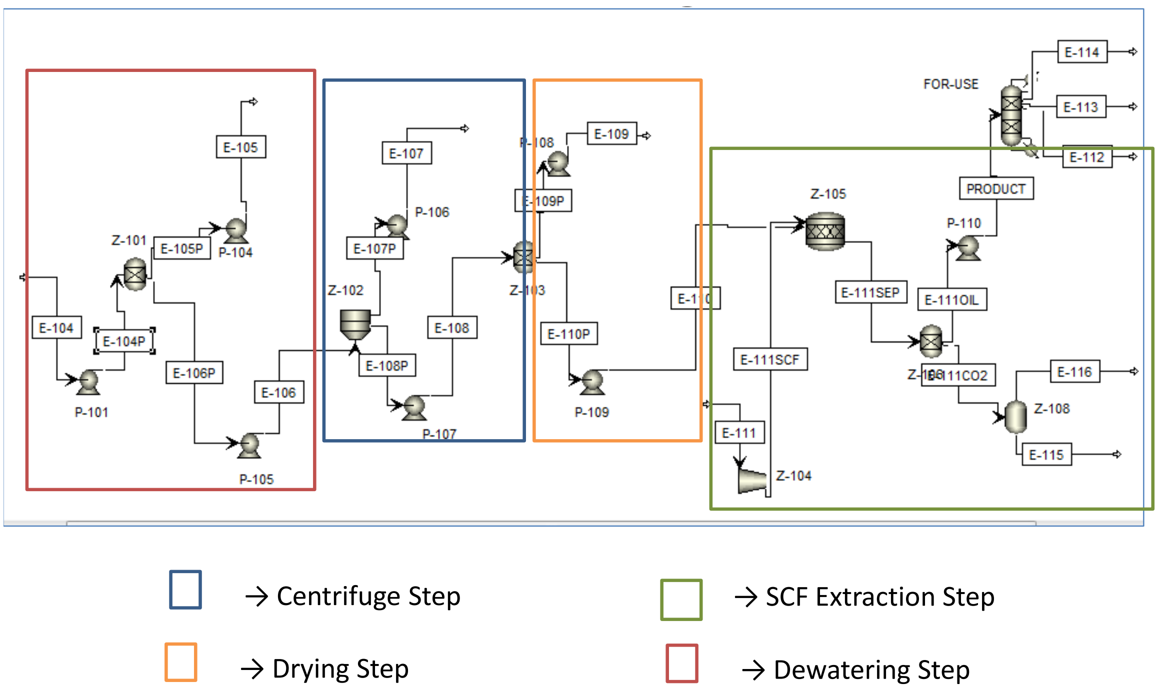


Figure 5.1.1. Simulation diagram for Case Scenario 1 using ASPEN ONE.

Case Scenario 1 – Process Description

Microalgae broth of approximately 9.1% wt. biomass is pumped from the pond site to flocculation tank **Tk-101**. In **Tk-101,** part of the water is recycled to the pond thorough **E-103** increasing the microalgae concentration up to 50% wt. Then the microalgae mixture flows to the dewatering system **Z-101.** In **Z-101** more water is recycled to the pond site, achieving a concentration of approximately 33% wt. water. Then, water is removed in the centrifugation unit **Z-102**, concentrating the microalgae broth to approximately 10% wt. water. This residual water is removed using a drying system **Z-103** before entering the cell paste to the supercritical fluid extraction unit (**SC-Extraction**). In the **SC-Extraction**, 50% of microalgae composed by lipid, proteins and carbohydrates (bulk paste, as mentioned in Section LR-1), is extracted at an operating pressure of 40 MPa and temperature of 121°F in **Z-105** using supercritical CO_2. Bulk paste extracted from the **SC-Extraction** is transported to storage for sale or to be used (**FOR USE**) through **Z-106** at approximately 870 psia and 80°F. The carbon dioxide and the remaining biomass are separated in **Z-108**, where carbon dioxide is recycled to the extraction unit and the residual biomass is sent to a waste treatment plant.

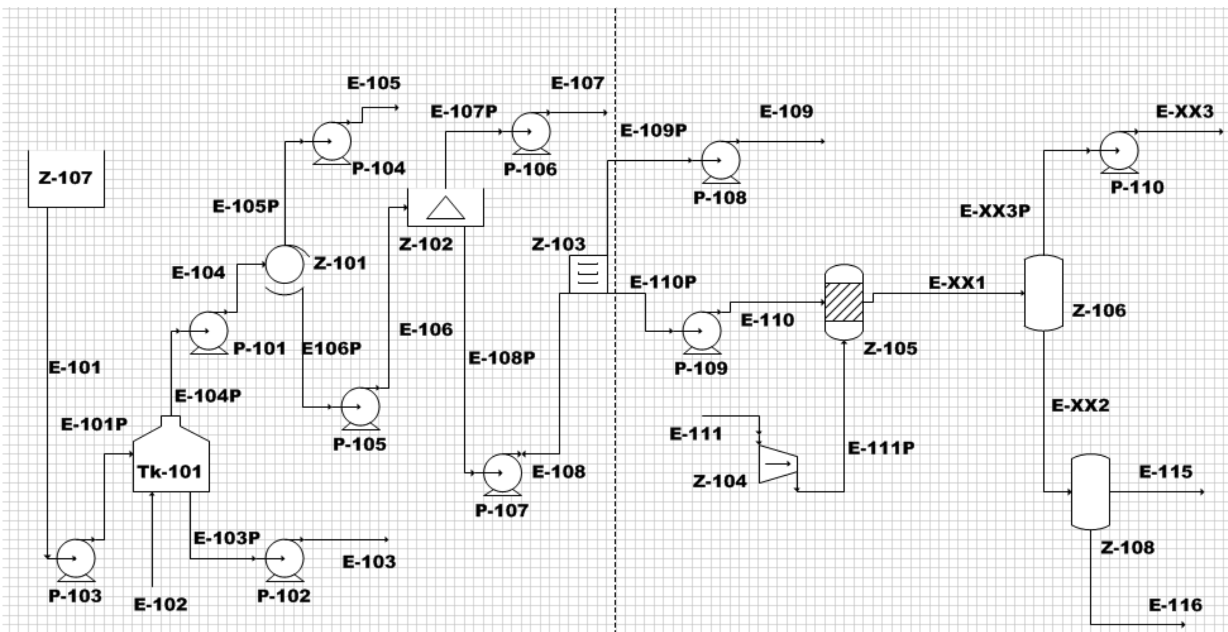


Figure 5.1.2. Preliminary process flow diagram for Case Scenario 1.

Table 5.1.1. Process stream conditions for Case Scenario 1.

Stream ID	E-101	E-102	E-103	E-104	E-105	E-106
From	Pond	----	Flocculation Tank	Flocculation Tank	Dewatering System	Dewatering System
To	Flocculation Tank	Flocculation Tank	----	Dewatering System	----	Centrifuge system
T (F)	76.9	76.9	76.9	76.9	76.7	76.9
P (psia)	30.0	----	30.0	90.0	30.0	30.0
Microalgae (LB/HR)	50668.7	----	----	50668.7	----	50668.7
Water (LB/HR)	506686.9	----	456018.2	50668.7	30401.0	20267.7
Chitosan Base (LB/HR)	----	20.3	18.2	2.0	1.2	0.8
C6H12 (CARB) (LB/HR)	----	----	----	----	----	----
C2H5N (PROTEIN) (LB/HR)	----	----	----	----	----	----
C3H8O (LIPID)(LB/HR)	----	----	----	----	----	----
OTHER (LB/HR)	----	----	----	----	----	----
CO2 (LB/HR)	----	----	----	----	----	----
TOTAL (LB/HR)	557355.6	20.3	456036.4	101339.4	30402.2	70937.2

Table 5.1.1. Continued

STREAM ID	E-107	E-108	E-109	E-110	E-111	E-112
From	Centrifuge System	Centrifuge System	Dryer	Dryer	----	SC Extraction System
To	----	Dryer	----	SC - Extraction System	SC Extraction system	For use
T (F)	76.9	76.9	76.9	76.9	80.5	121.9
P (psia)	30.0	30.0	45.0	45.0	870.2	870.2
Microalgae(LB/HR)	----	50668.7	----	50668.7	----	----
Water (LB/HR)	15201.0	5066.7	5066.7	----	----	----
Chitosan Base (LB/HR)	0.6	0.2	0.2	----	----	----
C6H12 (CARB) (LB/HR)	----	----	----	----	----	6662.9
C2H5N (PROTEIN) (LB/HR)	----	----	----	----	----	----
C3H8O (LIPID) (LB/HR)	----	----	----	----	----	----
OTHER (LB/HR)	----	----	----	----	----	----
CO2 (LB/HR)	----	----	----	----	2026747.5	
TOTAL (LB/HR)	15201.6	55735.6	5066.9	50668.7	2026747.5	6662.9

Table 5.1.1 Continued

STREAM ID	E-113	E-114	E-115	E-116
From	SC Extraction system	SC Extraction System	SC Extraction System	SC Extraction system
To	For use	For use	Waste Treatment Plant	----
T (F)	121.9	121.9	121.3	121.6
P (psia)	870.2	870.2	870.2	870.2
Microalgae (LB/HR)	----	----	----	----
Water (LB/HR)	----	----	----	----
Chitosan Base (LB/HR)	----	----	----	----
C6H12 (CARB) (LB/HR)	----	----	----	----
C2H5N (PROTEIN) (LB/HR)	14719.3	----	----	----
C3H8O (LIPID) (LB/HR)	----	3952.2	----	----
OTHER (LB/HR)	----	----	25334.3	----
CO2 (LB/HR)				2026747.5
TOTAL (LB/HR)	14719.3	3952.2	25334.3	2026747.5

Table 5.1.2. Equipment specifications and costs for Case Scenario 1.

Equipment ID	Specification	Purchase Cost ($)
P-101	Centrifugal pump system of129.6kW	21,462
P-102	Centrifugal Pump system of 192.53kW	28,651
P-103	Centrifugal Pump system of 234.78kW	32,469
P-104	Positive displacement pump system 12.58kW	8,755
P-105	Centrifugal Pump system of 58.77kW	12,830
P-106	Positive displacement pump system 6.916kW	6,834
P-107	Centrifugal pump system of 25.28kW	8,125
P-108	Positive displacement pump system of 3.14kW	5,278
P-109	Centrifugal pump system of 31.51kW	9,071
P-110	Centrifugal pump system of 303.83kW	80,318
Tk-101	Flocculation Tank of 300m^3	78,747
Z-101	Dewatering Press Filter of cake volume 3764m^3	43,249
Z-102	Centrifuge system of process capacity 70,937.19lb/hr	1,200,886
Z-103	Drying unit with capacity of 25282 kg	4,015,288
Z-104	CO2 Compressor of 16082.52kW	1,680,936
Z-105	Supercritical Extraction Vessel of 6092.24m^3	17,879
Z-106	SC Separation Vessel unit of 1581.21m^3	7,951,428
Z-108	SC trip Tank with capacity of 8695.76m^3	468,825

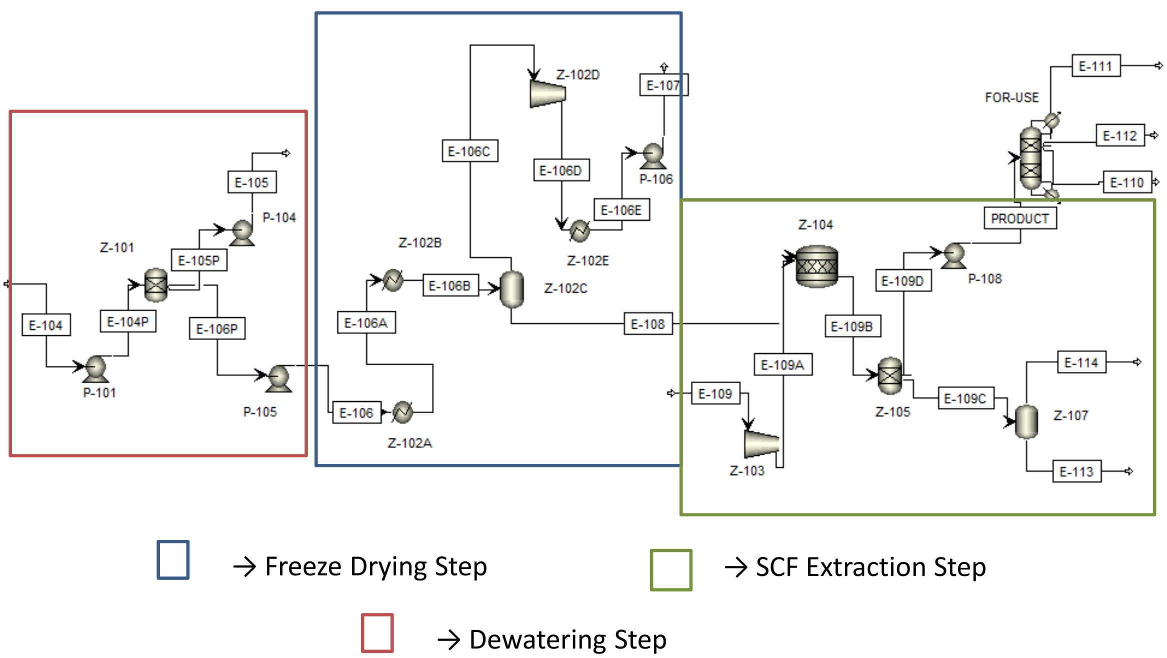


Figure 5.1.3. Simulation diagram for Case Scenario 2 using ASPEN ONE.

Case Scenario 2 – Process Description

Microalgae broth with approximately 10% wt. biomass is sent from the pond site to the flocculation tank (**Tk-101**), where part of the water is recycled to the pond through **E-103**. The microalgae mixture of approximately 50% wt. water content goes to the dewatering system **Z-101**, where broth is concentrated up to 33% wt. water. Then the excess water is extracted using a freeze dryer system, **Z-102,** operated at a temperature range between -40ºC to -50ºC and 1.45 psia before it enters the supercritical fluid extraction unit (**SC-Extraction**). In the **SC-Extraction** unit, 50% of the microalgae, composed by lipid, proteins and carbohydrates, is extracted at 40 MPa and 121.9°F in unit **Z-104** using supercritical CO_2. The bulk paste extracted from the supercritical fluid extraction unit is stored for sale or can be used (**FOR USE),** through **Z-106**. Carbon dioxide and residual biomass are separated in **Z-107**, where the biomass is disposed as waste.

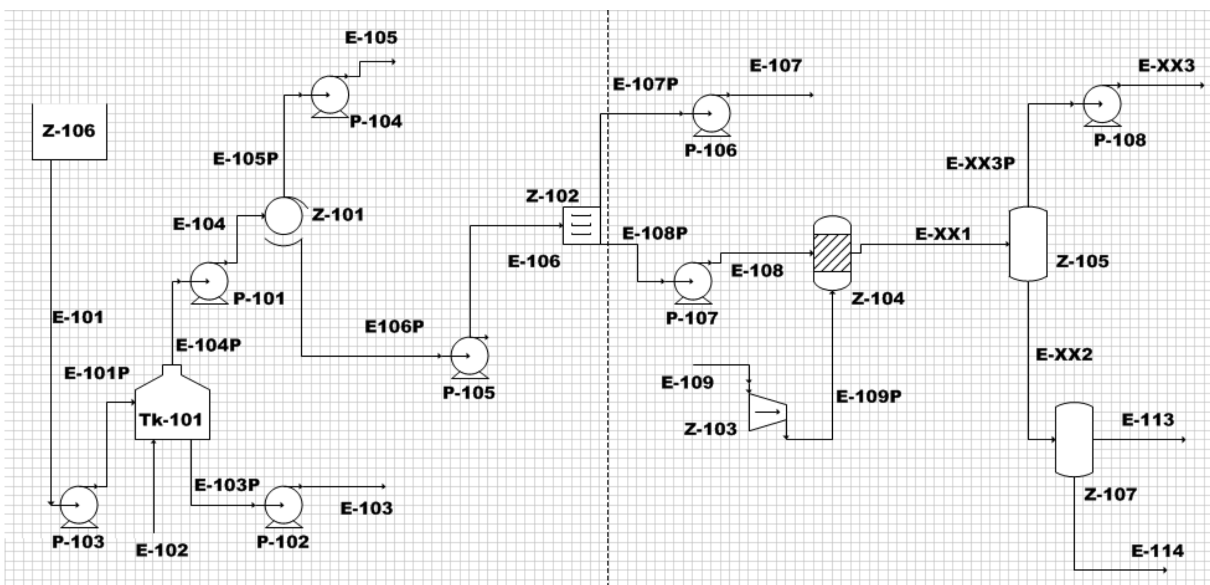


Figure 5.1.4. Preliminary process flow diagram for Case Scenario 2.

Table 5.1.3: Process stream conditions for Case Scenario 2.

STREAM ID	E-101	E-102	E-103	E-104	E-105	E-106
From	Pond	----	Flocculation Tank	Flocculation Tank	Dewatering Unit	Dewatering Unit
To	Flocculation Tank	Flocculation Tank	----	Dewatering Unit	----	Freeze Dryer
T (F)	76.9	76.9	76.9	76.9	76.8	76.9
P (psia)	30.0	----	30.0	90.0	30.0	60.0
Microalgae (LB/HR)	50668.7	----	----	50668.7	----	50668.7
Water (LB/HR)	506686.9	----	456018.2	50668.7	30401.0	20267.7
Chitosan Base (LB/HR)	----	20.3	18.2	2.0	1.2	0.8
C6H12 (CARB) (LB/HR)	----	----	----	----	----	----
C2H5N (PROTEIN) (LB/HR)	----	----	----	----	----	----
C3H8O (LIPID) (LB/HR)	----	----	----	----	----	----
OTHER (LB/HR)	----	----	----	----	----	----
CO2 (LB/HR)	----	----	----	----	----	----
TOTAL (LB/HR)	557355.6	20.3	456036.4	101339.4	30402.2	70937.2

Table 5.1.3 Continued.

STREAM ID	E-107	E-108	E-109	E-110	E-111	E-112
From	Freeze Dryer	Freeze Dryer	----	SC Extraction	SC Extraction	SC Extraction
To	----	SC Extraction	SC Extraction	For use	For use	For use
T (F)	86.1	----	80.5	121.9	121.9	121.9
P (psia)	45.0	1.5	870.2	870.2	870.2	870.2
Microalgae (LB/HR)	----	50668.7	----	----	----	----
Water (LB/HR)	20267.7	----	----	----	----	----
Chitosan Base (LB/HR)	0.8	----	----	----	----	----
C6H12 (CARB) (LB/HR)	----	----	----	6662.9	----	----
C2H5N (PROTEIN) (LB/HR)	----	----	----	----	14719.3	----
C3H8O (LIPID) (LB/HR)	----	----	----	----	----	3952.2
OTHER (LB/HR)	----	----	----	----	----	----
CO2 (LB/HR)	----	----	2026747.5			
TOTAL (LB/HR)	20268.5	50668.7	2026747.5	6662.9	14719.3	3952.2

Table 5.1.3. Continued.

STREAM ID	E-113	E-114
From	SC Extraction	SC Extraction
To	Waste Treatment	----
T (F)	121.9	121.9
P (psia)	870.2	870.2
Microalgae (LB/HR)	----	----
Water (LB/HR)	----	----
Chitosan Base (LB/HR)	----	----
C6H12 (CARB) (LB/HR)	----	----
C2H5N (PROTEIN) (LB/HR)	----	----
C3H8O (LIPID) (LB/HR)	----	----
OTHER (LB/HR)	25334.3	----
CO2 (LB/HR)		2026747.5
TOTAL (LB/HR)	25334.3	2026747.5

Table 5.1.4. Equipment specifications and costs for Case Scenario 2.

Equipment ID	Specification	Purchase Cost ($)
P-101	Centrifugal pump system of 129.6kW	21,462
P-102	Centrifugal Pump system of 192.53kW	28,651
P-103	Centrifugal Pump system of 234.78kW	32,469
P-104	Positive displacement pump system 12.58kW	8,755
P-105	Centrifugal Pump system of 58.77kW	12,830
P-106	Positive displacement pump system 12.56kW	8,749
P-107	Centrifugal pump system of 31.51kW	9,071
P-108	Centrifugal pump system of 303.83kW	80,318
Tk-101	Flocculation Tank of 300m^3	78,747
Z-101	Dewatering Press Filter of cake volume 1605.07ft^3/hr	43,249
Z-102	Freeze Dryer for 8200kg of ice capacity	333,670
Z-103	CO2 Compressor of 16082.52kW	1,680,936
Z-104	Supercritical Extraction Vessel of 6092.24m^3	17,879
Z-105	SC Separation Vessel unit of 1581.21m^3	7,951,428
Z-107	SC trip Tank with capacity of 8695.76m^3	468,825

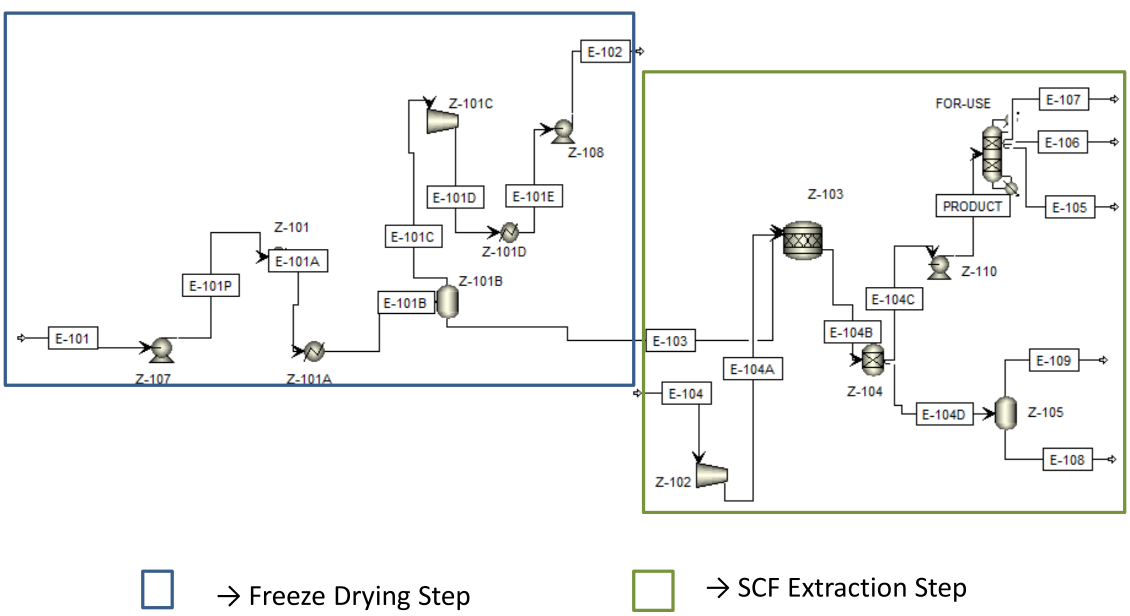


Figure 5.1.5. Simulation diagram for Case Scenario 3 using ASPEN ONE.

Case Scenario 3 – Process Description

Microalgae broth of approximately 9% wt. biomass is directly fed into a Freeze Dryer **Z-101** operated between -40.9°C and -50°C with a pressure of 1.45 psia. All the water from the dryer is recycled to the pond. Dry microalgae enters the supercritical fluid extraction unit (**SC-Extraction**), were 50% of the microalgae is extracted at 40 MPa and 121.9°F (**Z-103)** using dense supercritical CO_2. The bulk paste extracted from the supercritical fluid extraction unit is stored for sale or to be used (**FOR USE**) through **Z-104**. Carbon dioxide and the residual biomass are separated in **Z-105**, where the biomass is disposed as waste.

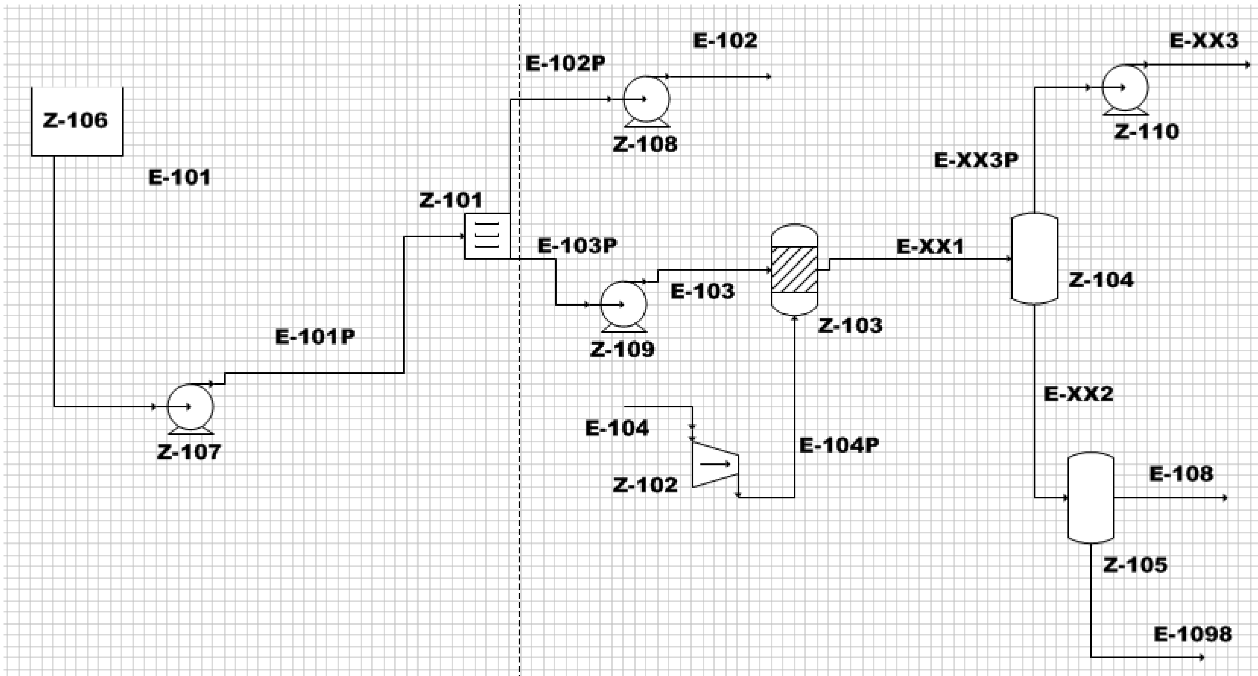


Figure 5.1.6. Preliminary process flow diagram for Case Scenario 3.

Table 5.1.5. Process stream conditions for Case Scenario 3.

STREAM ID	E-101	E-102	E-103	E-104	E-105	E-106
From	Pond	Freeze Dryer	Freeze Dryer		SC Extraction	SC Extraction
To	Freeze Dryer	----	SC Extraction	SC Extraction	For use	For use
T (F)	76.90	86.10	86.10	121.91	121.91	121.91
P (psia)	45.00	45.00	1.45	870.23	870.23	870.23
Microalgae (LB/HR)	50668.69	----	50668.69	----	----	----
Water (LB/HR)	506686.87	506686.87	----	----	----	----
Chitosan Base (LB/HR)	----	----	----	----	6662.93	----
C6H12 (CARB) (LB/HR)	----	----	----	----	----	14719.25
C2H5N (PROTEIN) (LB/HR)	----	----	----	----	----	----
C3H8O (LIPID) (LB/HR)	----	----	----	----	----	----
OTHER (LB/HR)	----	----	----	2026747.50		
CO2 (LB/HR)	557355.56	506686.87	50668.69	2026747.50	6662.93	14719.25
TOTAL (LB/HR)	20268.5	50668.7	2026747.5	6662.9	14719.3	3952.2

Table 5.1.5. Continued.

STREAM ID	E-107	E-108	E-109
From	SC Extraction	SC Extraction	SC Extraction
To	For use	Waste Treatment	----
T (F)	121.91	121.91	121.91
P (psia)	870.23	870.23	870.23
Microalgae (LB/HR)	----	----	----
Water (LB/HR)	----	----	----
Chitosan Base (LB/HR)	----	----	----
C6H12 (CARB) (LB/HR)	----	----	----
C2H5N (PROTEIN) (LB/HR)	3952.16	----	----
C3H8O (LIPID) (LB/HR)	----	25334.34	----
OTHER (LB/HR)			2026747.50
CO2 (LB/HR)	3952.16	25334.34	2026747.50
TOTAL (LB/HR)	20268.5	50668.7	2026747.5

Table 5.1.6. Equipment specifications and costs for Case Scenario 3.

Equipment ID	Specification	Purchase Cost ($)
Z-107	Centrifugal pump system of 463.53kW	40,950
Z-108	Centrifugal Pump system of 323.90kW	39,384
Z-109	Centrifugal Pump system of 28.73kW	8,600
Z-101	Freeze Dryer for 229,832 kg of ice capacity	2,301,808
Z-102	CO2 Compressor of 16082.52kW	1,680,936
Z-103	Supercritical Extraction Vessel of 6092.24m^3	17,879
Z-104	SC Separation Vessel unit of 1581.21m^3	7,951,428
Z-105	SC trip Tank with capacity of 8695.76m^3	468,825
Z-110	Centrifugal Pump system of 303.83kW	80,318

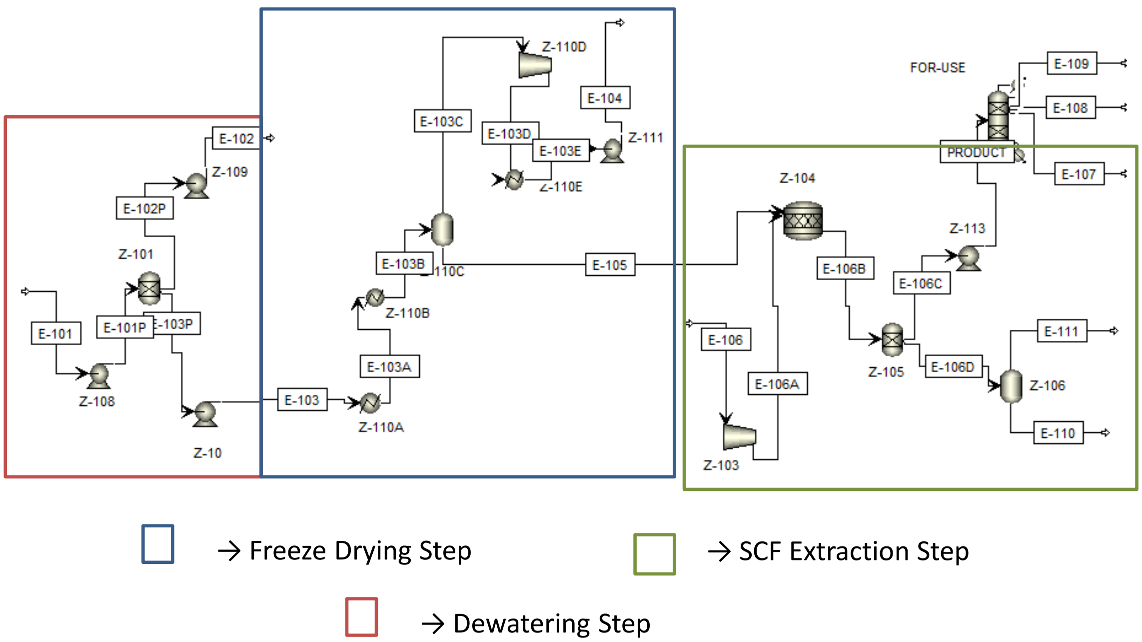


Figure 5.1.7. Simulation diagram for Case Scenario 4 using ASPEN ONE.

Case 4 – Process Description

Microalgae broth of approximately 9% wt. biomass is collected from the pond site and moved thorough **E-103** to the dewatering system **Z-101**, where broth is concentrated to 33% wt. water. Then, microalgae is moved to the freeze dryer system operated at a range between -40.9°C and -50°C at 1.45 psia, where the balance of the water is removed. Then, dry microalgae is fed to the supercritical fluid extraction unit (**SC-Extraction**) where 50% of microalgae extracted at a pressure of 40 MPa and a temperature of 121.9°F (**Z-104**) using dense supercritical CO_2. Bulk paste extracted from the supercritical fluid unit is stored for sale or to be used (**FOR USE**) through **Z-105**. Carbon dioxide and residual biomass are separated in **Z-106**, where the biomass is disposed as waste.

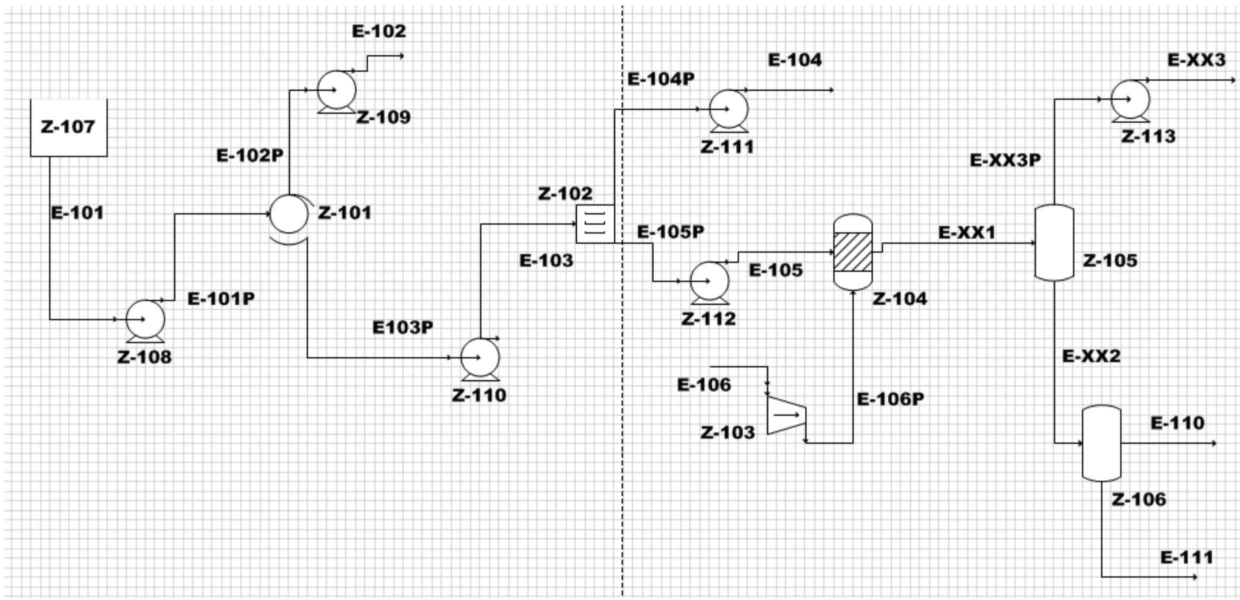


Figure 5.1.8. Preliminary process flow diagram for Case Scenario 4.

Table 5.1.7. Process stream conditions for Case Scenario 4.

STREAM ID	E-101	E-102	E-103	E-104	E-105	E-106
From	Pond	Dewatering system	Dewatering System	Freeze Dryer	Freeze Dryer	----
To	Dewatering System	----	Freeze Dryer	----	SC Extraction	SC Extraction
T (F)	76.9	76.9	76.9	86.1	86.1	121.9
P (psia)	90.0	30.0	45.0	45.0	1.5	870.2
Microalgae (LB/HR)	50668.7	----	50668.7	----	50668.7	----
Water (LB/HR)	506686.9	486419.2	20267.7	20267.7	----	----
Chitosan Base (LB/HR)	----	----	----	----	----	----
C6H12 (CARB) (LB/HR)	----	----	----	----	----	----
C2H5N (PROTEIN) (LB/HR)	----	----	----	----	----	----
C3H8O (LIPID) (LB/HR)	----	----	----	----	----	----
OTHER (LB/HR)	----	----	----	----	----	2026747.5
CO2 (LB/HR)	557355.6	486419.2	70936.4	20267.7	50668.7	2026747.5
TOTAL (LB/HR)	20268.5	50668.7	2026747.5	6662.9	14719.3	3952.2

Table 5.1.7. Continued.

STREAM ID	E-107	E-108	E-109	E-110	E-111
From	SC Extraction	SC Extraction	SC Extraction	SC Extraction	SC Extraction
To	For use	For use	For use	Waste Treatment	----
T (F)	121.9	121.9	121.9	121.9	121.9
P (psia)	870.2	870.2	870.2	870.2	870.2
Microalgae (LB/HR)	----	----	----	----	----
Water (LB/HR)	----	----	----	----	----
Chitosan Base (LB/HR)	6662.9	----	----	----	----
C6H12 (CARB) (LB/HR)	----	14719.3	----	----	----
C2H5N (PROTEIN) (LB/HR)	----	----	3952.2	----	----
C3H8O (LIPID) (LB/HR)	----	----	----	25334.3	----
OTHER (LB/HR)					2026747.5
CO2 (LB/HR)	6662.9	14719.3	3952.2	25334.3	2026747.5
TOTAL (LB/HR)	20268.5	50668.7	2026747.5	6662.9	14719.3

Table 5.1.8. Equipment specifications and costs for Case Scenario 4.

Equipment ID	Specification	Purchase Cost ($)
Z-108	Centrifugal pump system of 690.05KW	62,001
Z-109	Positive displacement pump system 201.44 kW	49,410
Z-110	Centrifugal Pump system of 44.08kW	10,863
Z-111	Positive displacement pump system 12.56kW	8,749
Z-112	Centrifugal Pump system of 31.46kW	9,064
Z-113	Centrifugal pump system 30k3.83kW	80318
Z-101	Dewatering Press Filter of cake volume 8667.72ft^3/hr	180,889
Z-102	Freeze Dryer for 8200kg of ice capacity	333,670
Z-103	CO2 Compressor of 16082.52kW	1,680,936
Z-104	Supercritical Extraction Vessel of 6092.24m^3	17,879
Z-105	SC Separation Vessel unit of 1581.21m^3	7,951,428
Z-106	SC trip Tank with capacity of 8695.76m^3	468,825

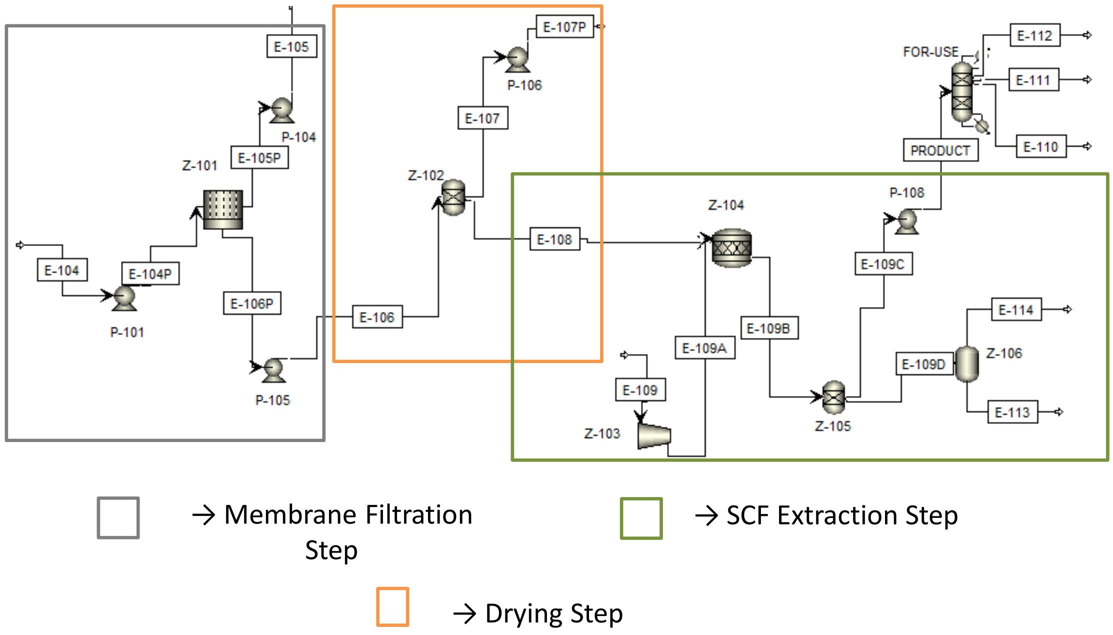


Figure 5.1.9. Simulation diagram for Case Scenario 5 using ASPEN ONE.

Case 5 – Process Description

Microalgae broth of approximately 9% wt. biomass is collected from the pond site through **E-104** to a flocculation tank **Tk-101**, where the broth is concentrated up to 50% wt. of biomass. The remaining broth is pumped to a membrane filtration system **Z-101**, where it is concentrated up to 10% wt. water content. Then microalgae is totally dried in a fluidized dryer system, **Z-102** and moved to the supercritical fluid extraction unit (**SC-Extraction**) where 50% of microalgae is extracted at a pressure of 40 MPa and a temperature of 121.9°F in **Z-104** using dense supercritical CO_2. The bulk paste extracted from the supercritical fluid extractor is stored for sale or to be used (**FOR USE**) through **Z-105**. Carbon dioxide and residual biomass are separated in **Z-106**, where the biomass is disposed as waste.

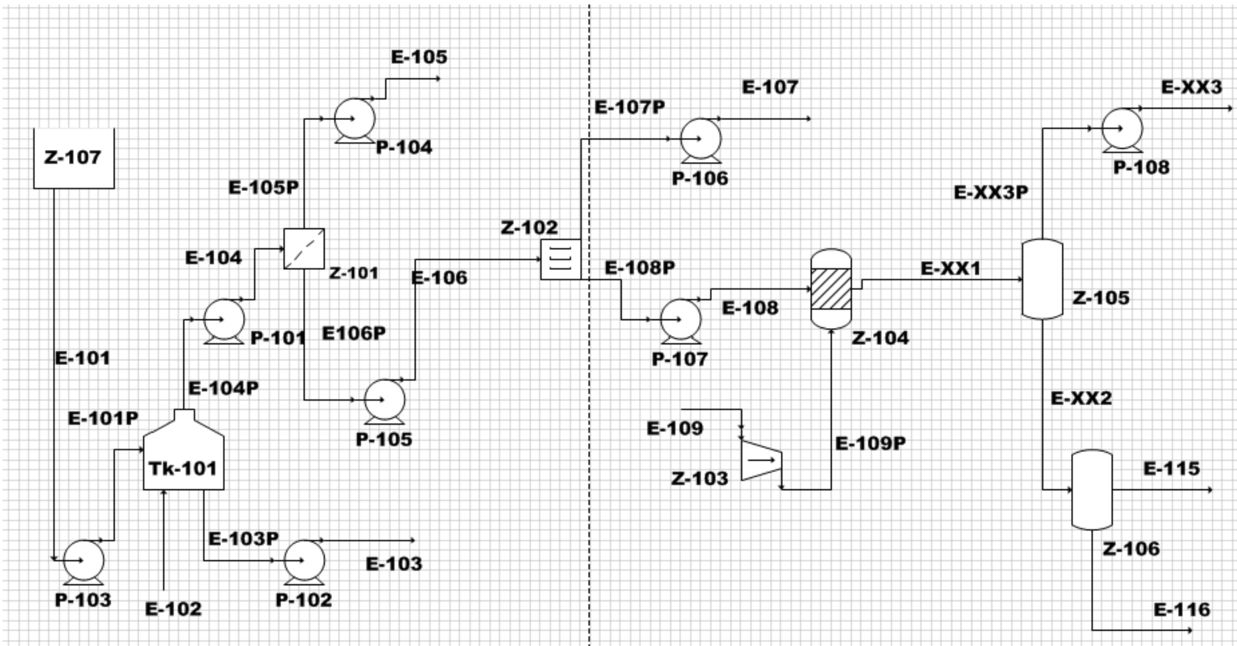


Figure 5.1.10: Preliminary process flow diagram for Case Scenario 5.

Table 5.1.9. Process stream conditions for Case Scenario 5.

STREAM ID	E-101	E-102	E-103	E-104	E-105	E-106
From	Pond	----	Flocculation Tank	Flocculation Tank	Membrane Filtration	Membrane Filtration
To	Flocculation Tank	Flocculation Tank	----	Membrane Filtration	----	Dryer
T (F)	76.90	76.90	76.90	76.90	77.00	76.90
P (psia)	30.00	----	30.00	90.00	100.00	45.00
Microalgae (LB/HR)	50668.69	----	----	50668.69	----	50668.69
Water (LB/HR)	506686.87	----	456018.19	50668.69	45601.82	5066.87
Chitosan Base (LB/HR)	----	20.27	18.24	2.03	1.82	0.20
C6H12 (CARB) (LB/HR)	----	----	----	----	----	----
C2H5N (PROTEIN) (LB/HR)	----	----	----	----	----	----
C3H8O (LIPID) (LB/HR)	----	----	----	----	----	----
OTHER (LB/HR)	----	----	----	----	----	----
CO2 (LB/HR)	----	----	----	----	----	----
TOTAL (LB/HR)	557355.56	20.27	456036.43	101339.40	45603.64	55735.76

Table 5.1.9. Continued.

STREAM ID	E-107	E-108	E-109	E-110	E-111	E-112
From	Dryer	Dryer		SC Extraction	SC Extraction	SC Extraction
To	----	SC Extraction	SC Extraction	For use	For use	For use
T (F)	76.90	76.90	121.91	121.91	121.91	121.91
P (psia)	45.00	45.00	870.23	870.23	870.23	870.23
Microalgae (LB/HR)	----	50668.69	----	----	----	----
Water (LB/HR)	5066.87	----	----	----	----	----
Chitosan Base (LB/HR)	0.20	----	----	----	----	----
C6H12 (CARB) (LB/HR)	----	----	----	6662.93	----	----
C2H5N (PROTEIN) (LB/HR)	----	----	----	----	14719.25	----
C3H8O (LIPID) (LB/HR)	----	----	----	----	----	3952.16
OTHER (LB/HR)	----	----	----	----	----	----
CO2 (LB/HR)	----	----	2026747.50			
TOTAL (LB/HR)	5067.07	50668.69	2026747.50	6662.93	14719.25	3952.16

Table 5.1.9. Continued.

STREAM ID	E-113	E-114
From	SC Extraction	SC Extraction
To	Waste Treatment	----
T (F)	121.91	121.91
P (psia)	870.23	870.23
Microalgae (LB/HR)	----	----
Water (LB/HR)	----	----
Chitosan Base (LB/HR)	----	----
C6H12 (CARB) (LB/HR)	----	----
C2H5N (PROTEIN) (LB/HR)	----	----
C3H8O (LIPID) (LB/HR)	----	----
OTHER (LB/HR)	25334.34	----
CO2 (LB/HR)		2026747.50
TOTAL (LB/HR)	25334.34	2026747.50

Table 5.1.10. Equipment specifications and costs for Case Scenario 5.

Equipment ID	Specification	Purchase Cost ($)
P-101	Centrifugal pump system of 129.6kW	21,462
P-102	Centrifugal Pump system of 192.53kW	28,651
P-103	Centrifugal Pump system of 234.78kW	32,469
P-104	Positive displacement pump system 628.93kW	58,645
P-105	Centrifugal Pump system of 34.63kW	9528
P-106	Positive displacement pump system 6.29kW	6598
P-107	Centrifugal pump system of 31.46kW	9,064
P-108	Centrifugal pump system of 303.83kW	80,318
Tk-101	Flocculation Tank of 300m^3	78,747
Z-101	Membrane Filtration of 2490.39gal/min	31,915
Z-102	Drying unit with capacity of 25282 kg	4,015,295
Z-103	CO2 Compressor of 16082.52kW	1,680,936
Z-104	Supercritical Extraction Vessel of 6092.24m^3	17,879
Z-105	SC Separation Vessel unit of 1581.21m^3	7,951,428
Z-106	SC trip Tank with capacity of 8695.76m^3	468,825

5.2 - Economic analysis for each case scenario

Costs of manufacturing (**COM**) that are equivalent to the operational costs for the five different case scenarios to obtain the bioproducts from the microalgae growth process to the paste extraction phase are displayed in **Table 5.2.1**. These **COM** are divided in direct manufacturing costs (**DMC**) that depend on the associated facts, and fixed manufacturing costs (**FMC**) regarding the direct processing of microalgae (see **Tables 5.2.2** and **5.2.3**), such like the costs of raw materials, labor and utilities. General manufacturing costs (**GMC**) (**Table 5.2.4**) include costs of distribution, selling, research and development.

Table 5.2.1. Breakdown of manufacturing costs in terms of direct, fixed and general manufacturing costs.

Case Scenario	Case 1	Case 2	Case 3	Case 4	Case 5
DMC ($/yr)	114,437,700	108,018,916	164,342,105	105,530,851	108,338,952
FMC ($/yr)	16,842,394	14,646,392	13,791,843	14,028,801	15,740,526
GMC ($/yr)	28,976,242	26,886,237	37,084,342	26,111,730	27,327,981
COM ($/yr)	**159,873,401**	**149,188,692**	**214,652,352**	**145,316,237**	**151,044,518**

Table 5.2.2. Breakdown of direct manufacturing costs (**DMC**) in $/yr.

Case Scenario	Case 1	Case 2	Case 3	Case 4	Case 5
DMC	114,437,700	108,018,916	164,342,105	105,530,851	108,338,952
Raw Materials	21,312,162	21,312,162	19,332,032	19,332,032	21,312,162
Waste Treatment	5,298,060	5,298,060	5,298,060	5,298,060	5,298,060
Utilities	57,369,864	54,159,306	112,562,498	54,931,497	53,313,443
Operating Labor	14,014,880	12,936,723	10,980,068	12,058,225	12,936,723
Direct Supervisor and clerical labor	2,522,678	2,328,610	1,976,412	2,170,480	2,328,610
Maintenance and repairs	6,105,758	4,841,640	5,309,960	4,845,510	5,807,052
Operating supplies	915,864	726,246	796,494	726,826	871,057
Laboratory Charges	2,102,232	1,940,508	1,647,010	1,808,734	1,940,508
Patent & Royalties	4,796,202	4,475,661	6,439,571	4,359,487	4,531,335

Table 5.2.3. Breakdown of fixed manufacturing costs (**FMC**) in $/yr.

Case Scenario	Case 1	Case 2	Case 3	Case 4	Case 5
FMC	16,842,394	14,646,392	13,791,843	14,028,801	15,740,526
Local Taxes and insurance	3,256,404	2,582,208	2,831,979	2,584,272	3,097,094
Plant Overhead	13,585,990	12,064,184	10,959,864	11,444,529	12,643,431

Table 5.2.4. Breakdown of general manufacturing costs (**GMC**) in $/yr.

Case Scenario	Case 1	Case 2	Case 3	Case 4	Case 5
GMC	28,976,242	26,886,237	37,084,342	26,111,730	27,327,981
Administration	3,396,497	3,016,046	2,739,966	2,861,132	3,160,858
Distribution and selling	17,586,074	16,410,756	23,611,759	15,984,786	16,614,897
Research and Development	7,993,670	7,459,435	10,732,618	7,265,812	7,552,226

Table 5.2.5 shows the costs of manufacturing divided into the costs associated to the fixed capital investment, the operating labor, raw materials, utilities, and waste treatment. The factor 0.18 accounts for all contingencies associated to equipment in the facilities, such as equipment tax insurance and maintenance operations over the equipment used to manufacture the product. The factor 2.73 accounts for influence of all additional labor efforts required in addition

to operating labor such as overhead, and marketing over the cost of the estimated labor to manufacture the products. The factor 1.23 accounts for additional costs of other materials. Notice in **Table 5.2.5** and **Table 5.2.1** to **Table 5.2.4** that the breakeven operational cost is dominated by the cost of utilities.

Table 5.2.5. Summary for cost of manufacturing in terms of operating labor, raw materials, utilities, waste treatment, and fixed capital investment.

Case Scenario	Case 1	Case 2	Case 3	Case 4	Case 5
0.18FCI ($/yr)	18,317,275	14,524,920	15,929,881	14,536,529	17,416,928
2.73C_OL ($/yr)	38,260,621	35,317,253	29,975,585	32,918,953	35,317,253
1.23C_RM ($/yr)	26,213,960	26,213,960	23,778,399	23,778,399	26,213,960
1.23C_WT ($/yr)	6,516,613	6,516,613	6,516,613	6,516,613	6,516,613
1.23C_UT ($/yr)	70,564,932	66,615,946	138,451,872	67,565,740	65,575,535
COM ($/yr)	**159,873,401**	**149,188,692**	**214,652,352**	**145,316,237**	**151,044,518**

For any case scenario, the supercritical extraction unit shows high consumption in terms of utilities (**Table 5.2.6**) due to the water required in the extraction vessel (**Figure 5.2.1**) and a great amount of energy associated to the CO_2 compression system (**Figure 5.2.2**). The pond site requires 126 operation personnel for all the cases. **Figure 5.2.3** shows the variability in the number of operating personnel required in the plant site. These results of direct impact in costs of operating labor are shown in **Figure 5.2.4** below.

Table 5.2.6. Breakdown for utilities per unit in $/yr.

Case Scenario	Case 1	Case 2	Case 3	Case 4	Case 5
Flocculation	1,443,644	1,443,645	2,114,750	----	1,411,138
Dewatering	218,795	214,272	----	2,607,961	----
Centrifugation	6,939,771	3,093,286	----	----	----
Membrane Filtration	----	----	----	----	2,188,203
Drying	97,977	----	----	----	111,450
Freeze Drying	----	3,093,286	2,114,750	3,093,037	----
SC Extraction	42,477,369	42,477,370	42,477,370	42,477,370	42,477,370
Subtotal Energy	51,177,558	47,228,572	44,592,120	48,178,367	46,188,161
Pond Energy	5,920,785	5,920,786	5,920,786	5,920,786	5,920,786
Water for SC Extraction	13,466,587	13,466,588	13,466,588	13,466,588	13,466,588
Total Utilities	**70,564,932**	**66,615,946**	**63,979,493**	**67,565,741**	**65,575,535**

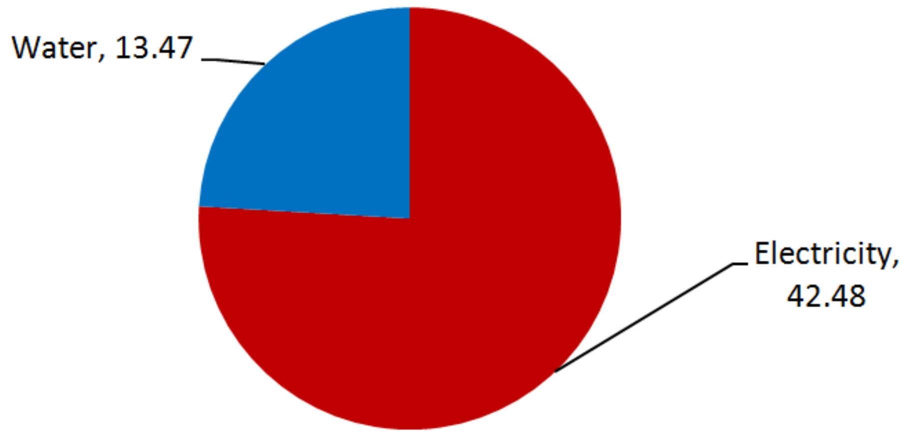


Figure 5.2.1. Cost of utilities consumed by the supercritical fluid extraction unit.

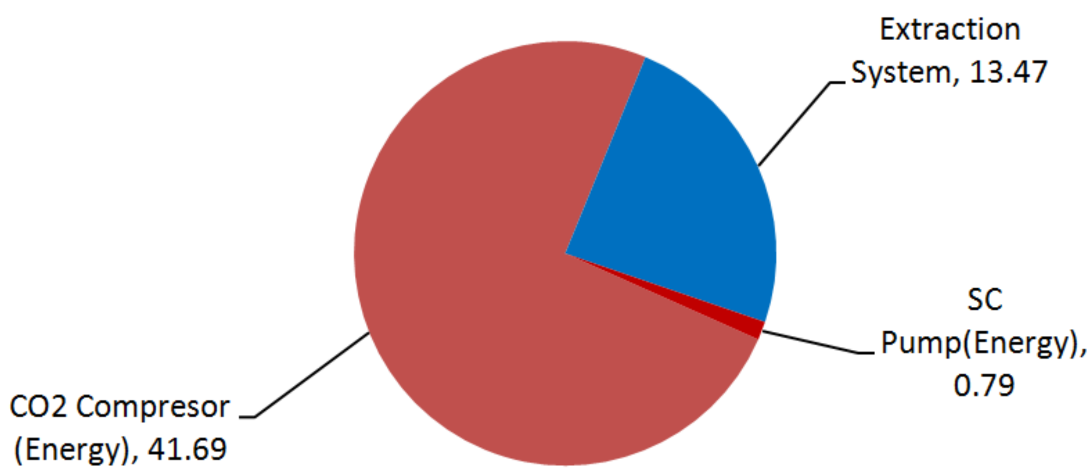


Figure 5.2.2. Breakdown of cost of utilities used by the supercritical extraction unit.

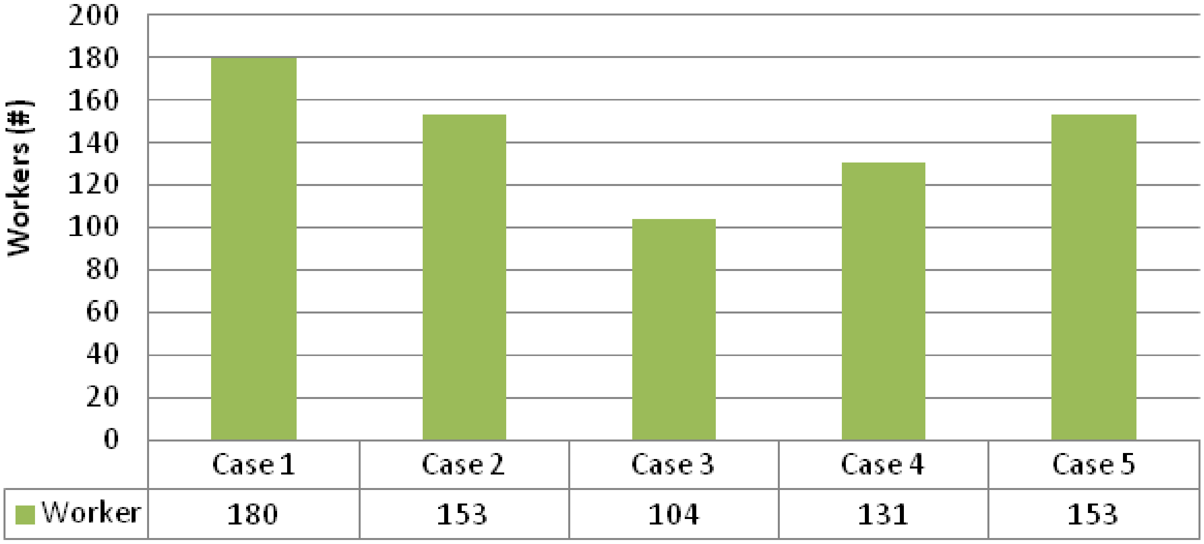


Figure 5.2.3. Operating labor workers required in the plant site.

Table 5.2.7. Breakdown of labor workers in percent effort.

Case Scenario	Case 1	Case 2	Case 3	Case 4	Case 5
Flocculation (%)	8.40	9.14	----	----	9.14
Dewatering (%)	8.40	9.14	----	10.19	----
Centrifugation (%)	8.40	----	----	----	----
Membrane Filtration (%)	----	----	----	----	9.14
Drying (%)	8.40	----	----	----	9.14
Freeze Drying (%)	----	9.14	11.30	10.19	----
SC Extraction (%)	25.21	27.42	33.91	30.58	27.42
Subtotal Energy (%)	58.82	54.84	45.22	50.97	54.84
Pond (%)	41.18	45.16	54.78	49.03	45.16
Total Workers	**306**	**279**	**230**	**257**	**279**

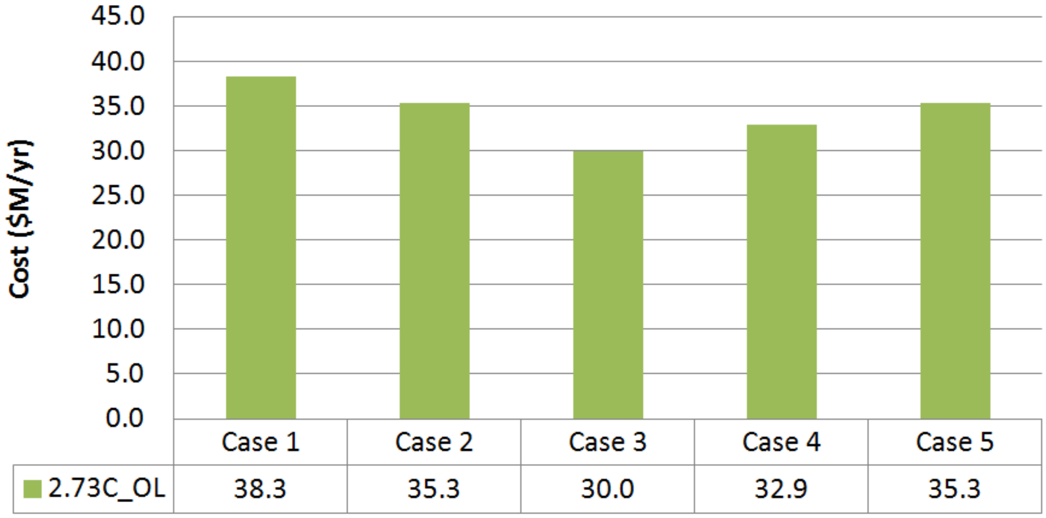


Figure 5.2.4. Cost of operating labor workers in million dollars per year.

In summary, the costs of manufacturing for a production of 222.1 million pounds of bulk paste is in the range of $0.65/lb to $0.97/lb, which are equivalent to $4.92/gal oil to $7.26/gal oil (**Table 5.2.8**). In terms of the needed investment, **Table 5.2.9** is divided in cost of land, working capital and the fixed capital investment. Fixed capital investment refers to the capital cost of the plant and pond sites. Land costs were assumed the same for all cases. Working capital (**Table 5.2.10**) is the quantity needed to operate the plant during the first month of operation.

Table 5.2.8. Production cost of 222.1 million pounds of bulk paste and equivalence in oil gallon.

Case Scenario	Case 1	Case 2	Case 3	Case 4	Case 5
Bulk Paste ($/lb)	0.72	0.67	0.97	0.65	0.68
Oil ($/gal)	5.41	5.05	7.26	4.92	5.11

Table 5.2.9. Breakdown of total investment in terms of fixed capital investment, land and working capital.

Item	Case 1	Case 2	Case 3	Case 4	Case 5
FCI ($M)	101.76	80.69	88.50	80.76	96.76
Land ($M)	9.76	9.76	9.76	9.76	9.76
Working Capital ($M)	23.58	23.01	28.35	22.69	22.92
Total Investment ($M)	**135.11**	**113.46**	**126.61**	**113.20**	**129.47**

Table 5.2.10. Breakdown of working capital for each case scenario.

Case Scenario	Water for pond ($M)	CO_2 of SCE ($M)	RM ($M)	UT ($M)	WT ($M)	OL ($M)	Working Capital ($M)	% in FCI (%)	Equivalent startup days @ 15% FCI
Case 1	9.14	2.65	2.18	5.88	0.54	3.19	23.58	23.18	20
Case 2	9.14	2.65	2.18	5.55	0.54	2.94	23.01	28.52	16
Case 3	9.14	2.65	1.98	11.54	0.54	2.50	28.35	32.03	14
Case 4	9.14	2.65	1.98	5.63	0.54	2.74	22.69	28.09	16
Case 5	9.14	2.65	2.18	5.46	0.54	2.94	22.92	23.69	19

According to the 2011Puerto Rico Tax Guide, taxation rates vary from 20% to 40.95%, plus minor uncertainties due to the volume of production scale (Hills et al., 2011). This makes a rate of 42% appropriate as the income tax rate. Production costs of bulk paste considering a project life of 5, 10 and 20 years at an annual interest of 10% are shown in **Figure 5.2.5**. **Figure 5.2.6** shows the equivalent cost of the oil in terms of dollars per gallon. Breakdown for production costs of bulk paste for 5, 10 and 20 years (**Table 5.2.11** to **5.2.13)** shows that costs of manufacturing remain the same. However, as expected, the fixed capital contribution decreases with time.

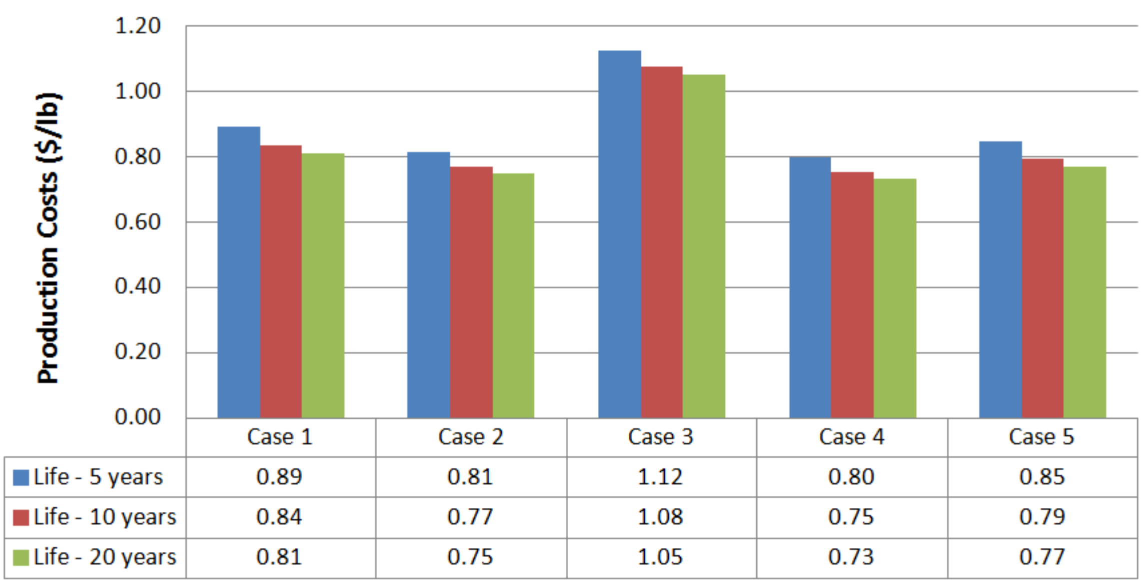


Figure 5.2.5. Production costs of bulk microalgal paste for each case scenario.

Figure 5.2.6. Production costs in equivalence of oil gallon for each case scenario.

Table 5.2.11. Breakdown of production costs for a 5-year project in $/lb.

Case Scenario	Case 1	Case 2	Case 3	Case 4	Case 5
Production cost	0.89	0.81	1.12	0.80	0.85
COM	0.72	0.67	0.96	0.65	0.68
Land	0.01	0.01	0.01	0.01	0.01
Fixed Capital	0.16	0.13	0.15	0.14	0.16

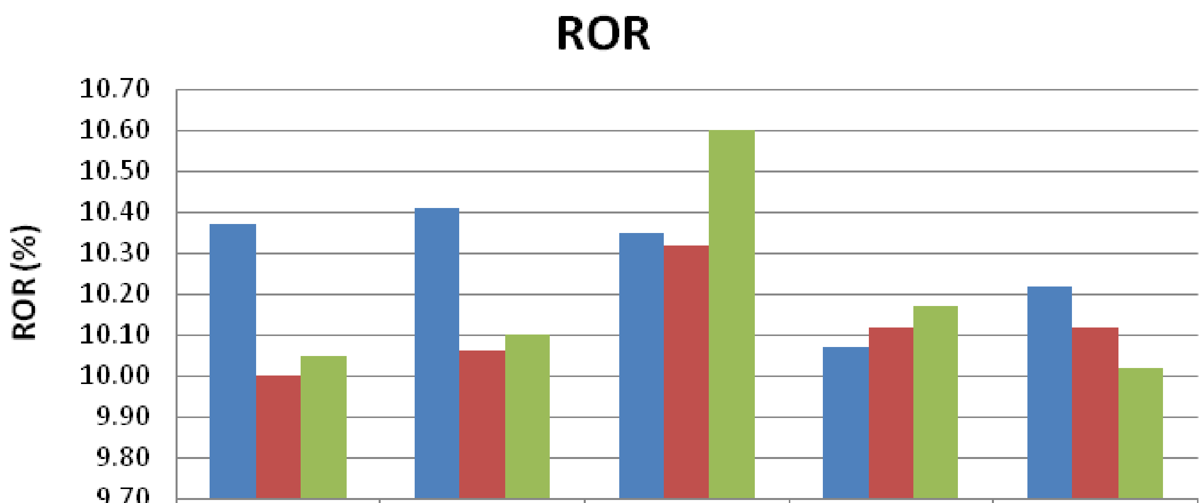
Table 5.2.12. Breakdown of production costs for a 10-year project in $/lb.

Case Scenario	Case 1	Case 2	Case 3	Case 4	Case 5
Production cost	0.84	0.77	1.08	0.75	0.79
COM	0.72	0.67	0.96	0.65	0.68
Land	0.01	0.01	0.01	0.01	0.01
Fixed Capital	0.11	0.09	0.11	0.09	0.10

Table 5.2.13. Breakdown of production costs for a 20-year project in $/lb.

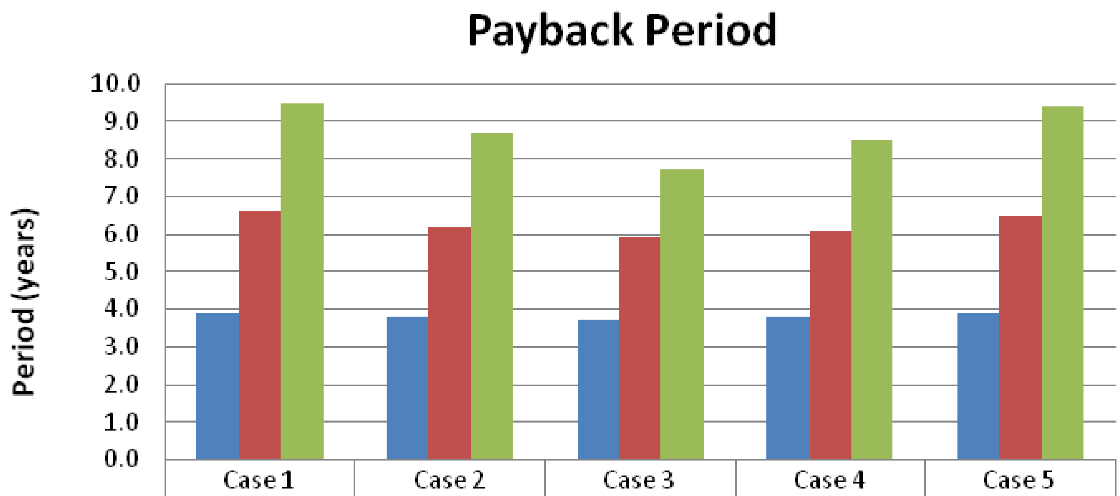
Case Scenario	Case 1	Case 2	Case 3	Case 4	Case 5
Production cost	0.81	0.75	1.05	0.73	0.77
COM	0.72	0.67	0.96	0.65	0.68
Land	0.01	0.01	0.01	0.01	0.01
Fix Capital	0.08	0.07	0.08	0.07	0.08

The estimated rate of return (**Figure 5.2.7**) validates our analysis due to its proximity to a 10%, that is equal to the annual interest used for the analysis assuming breakeven situation. It is important to remember that 10% is a fair value for investment. However, the payback period (**Figure 5.2.8**) shows to have a lower value than the value that was expected, which should approximate a value close to the project life. An explanation for this is that the payback period only considers the time to pay a loan for the fixed capital investment. Payback period does not consider the cash flow movement or the effect of the operational costs. This results in a shorter payback period than the one expected, that should be the closest to the project life.



	Case 1	Case 2	Case 3	Case 4	Case 5
Life - 5 years	10.37	10.41	10.35	10.07	10.22
Life - 10 years	10.00	10.06	10.32	10.12	10.12
Life - 20 years	10.05	10.10	10.60	10.17	10.02

Figure 5.2.7. Rate of return (**ROR**) for each case scenario using CAPCOST.



	Case 1	Case 2	Case 3	Case 4	Case 5
Life - 5 years	3.9	3.8	3.7	3.8	3.9
Life - 10 years	6.6	6.2	5.9	6.1	6.5
Life - 20 years	9.5	8.7	7.7	8.5	9.4

Figure 5.2.8. Payback period for each case scenario using CAPCOST.

5.3 - Facts and recommendations based in our economic analysis

The economic analysis results displayed in Section 5.2 show that our preferences in terms of investment should be in the following order: Case 4 → Case 2 → Case 5 → Case 1 → Case 3. Case 4 is the preferred due to low fixed capital investment and costs of operating labor, as well as a lower cost of raw materials and a considerable cost of utilities. Case 2 has a lower cost of utilities and fixed capital cost, but a higher cost of raw materials and operating labor as compared to Case 4. Case 5 has the same cost of operating labor and raw materials as Case 2, and a lower cost of utilities. However, the fixed capital investment for Case 5 shows to be higher than Cases 2 and 4. Cases 1 and 3 were shown to have the higher costs of utilities, operating labor and raw materials, as well as fixed capital, which is equivalent to higher capital and operational costs. According to these observations, as the fixed capital investment becomes higher; the higher will be the added-value production costs due to income tax and annual interest rates.

According to this project, the cost of disposing the remaining microalgal biomass is \$0.03/lb from our cost of manufacturing. The remaining biomass still has properties that make it suitable to use as fertilizer, fish food, as well as for other emerging applications. Actually, urea- and phosphate-based fertilizers have prices between \$0.30/lb to \$0.33/lb (fertilizer cost, 2012). If the remaining biomass can be sold at a value of $0.30/lb as fertilizer, this could have a positive effect of $0.30/lb, or at least a reduction of $0.03/lb waste in the actual manufacturing costs.

Supercritical fluid extraction increases considerably the operational cost, especially in utilities and operating labor. The process also requires at least 45 minutes to pressurize the extraction chamber and three additional hours to extract the paste per each batch. At least, this will cause an increment in the utilities needed to operate the plant. Thereupon, it is imperative that a detailed design study be done in order to: 1) optimize the use of resources, such as utilities and equipment operation, considering the schedule effect in the annual cost of manufacturing, and 2) determine if it is reasonable to produce the paste using supercritical fluid extraction or by implementing another emerging technology that preserves the integrity of proteins, lipids and carbohydrates in the extracted paste.

According to the Lang factor technique, the additional unit composed of one centrifugation system, one separation tank and five centrifugal pumps to separate lipids, proteins and carbohydrates will add around $3,175,455 to the capital investment (**Appendix B**). This is equivalent to the addition of $0.04 per pound each year to the actual cost of manufacturing the paste, which also will influence the operational costs (**Table 5.3.1**). However, note that the added value to produce proteins relative to the actual manufacturing cost may not be too high. Moreover, the sale value of proteins, lipids and carbohydrates could be $653/lb, $0.24/lb and $0.06/lb, respectively (Lever1diet, 2012; Monthly Data – Monthly Lactose Price, 2012; Arifeen et al., 2007; Haas et al., 2006). If this is true, maybe the cost production can be justified based in the production of proteins from microalgae, instead of from the paste itself. A much better idea would be the sale of proteins in little quantities and sell the remaining of bulk paste as supplement compounds for the food industry as well as feedstock to produce biofuels or fuel derivatives.

Table 5.3.1. Breakdown of costs of manufacturing for an additional separation unit for the proteins, lipids and carbohydrates contained in the microalgal biomass.

Unit	PLC Separation
COM ($/yr)	90,053,93
COM ($/lb)	0.04
0.18*FCI	571,581.9
2.73*C_OL	5,886,736
1.23*C_RM	0
1.23*C_UT	2,547,075
1.23*C_WT	0

CHAPTER 6: FINDINGS AND RECOMMENDATIONS

An economic analysis was performed for five different case scenarios maintaining a fixed pond site, a supercritical extraction unit, with various technologies to harvest the bioproduct for a design of an annual production of 222.1 million pounds of bulk paste with a high protein content from microalgae. Flocculation, dewatering, drying, centrifugation, freeze-drying and membrane filtration were the considered technologies. Case 4, which considers the use of pond → dewatering → freeze dryer → supercritical fluid extraction shows to be the most attractive in terms of investment due to a low cost of fixed capital (80 million dollars), as well as lower annual operational costs (132.5 million dollar). This results in a production cost of $0.74/lb, $0.69/lb and $0.67/lb to produce the bulk paste equivalent to $5.56/gal, $5.22/gal and $5.06/gal of oil considering an annual interest of 10% and an income tax of 42% at 5, 10 and 20 years of financing, respectively.

In all the cases, operational costs were the predominant factor due to the high costs associated to the operating labor, raw materials and utilities required to operate the supercritical fluid extraction unit. It is recommended to perform a detailed analysis in order to find strategies to reduce the associated operational costs to this unit, as well as to identify emerging technologies to replace the supercritical fluid extraction without affecting the yield and integrity of the proteins, lipids and carbohydrates contained by the paste.

Selling the residual microalgal biomass as a bio-fertilizer or fish food versus disposing it as a waste could result in a positive effect in terms of the production costs of $0.30/lb to our analysis. In summary, our results indicate that microalgae-based production facility requires a biorefinery operation philosophy. Especially, a variety of products must be produced efficiently and sold in a wide variety of markets such as commodities (biofuels) and value-added specialties (proteins, lipids). A single product approach will not justify either the investment or operational costs of similar processing plants.

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APPENDIX

APPENDIX A: YIELD CALCULATIONS FOR POND SITE

TO PRODUCE MICROALGAE

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A.1 - Yield calculations for pond site to produce microalgae

Chisti reported in 2007, that microalgae cultured using a photobioreactor system can yield 30-70% of bio-oil, equivalent to 15,500-36,150 gallons of oil per hectare (ha) in an annual basis. Assuming that an annual production of 20 million gallons of oil with a specific gravity of 0.85 is desired, an area between 1,290-553 ha should be used, depending if oil content is either 30 or 70 percent. Chisti also showed that the equivalence in terms of a growth area of 5,681 m^2 of photobioreactor equals 7,828 m^2 of an open raceway pond site. Therefore, the area of pond site should be between 1,778-762 ha, with an average area of 1,270 ha (5 square miles), considering oil with a specific gravity of 0.85, which represents an annual biomass of 153,283,333 kg microalgae.

Literature shows that microalgae biomass is composed of lipids, proteins and carbohydrates with a characteristic specific gravity around 1.2. We chose a monomer of protein (glycine), lipid (glycerol) and carbohydrate (glucose derivative) to simulate our sample with an average paste bulk specific gravity of 1.33, assuming a microalgae conversion of 50 percent (refer to Introduction). To produce 20 million gallons of bulk paste per year, the production of microalgae was estimated to be 201,468,400 kg microalgae per year. This tells us that we need 22,982.93 kg of microalgae per hour to obtain 20 million gallons of bulk paste per year (222 lb/yr). Details of recipe are given in **Section A.1**.

Section A.2 - General aspects for microalgae broth formulation

Christenson in 2011 showed the N/P ratio is not a significant parameter for microalgae growth (**Figure A.2.1**). However, the C/N ratio shows to be an important factor to grow microalgae (**Section 2.3**).

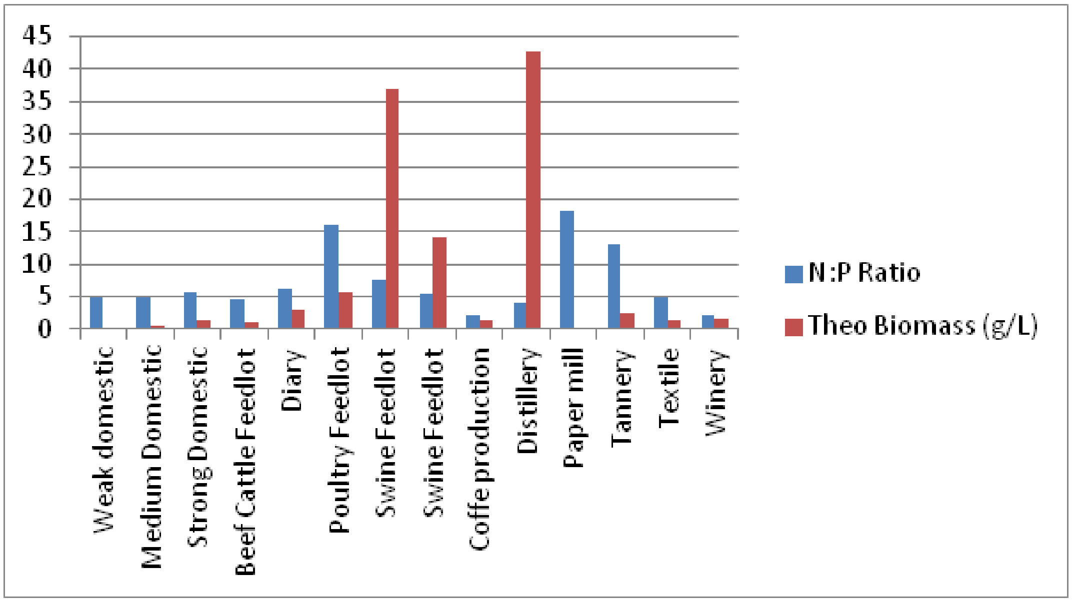

Figure A.2.1. Microalgae growth using different source media (analysis of data from Xu et al., 2011).

A microalgae growth medium was formulated using the data of Welssmen, et al., 1987; Chisti et al., 2007; and Davis et al., 2011 (**Tables A.2.1** and **A.2.2**). PAR-radiation data was assumed by this author based on empirical data. Pond dimensions (**Table A.02)**, as well as complimentary data of required labor workers and energy consumed from paddle wheels was reported by Welssmen et al., 1987 and Davis et al., 2011 (**Figures A.2.2 to A.2.5**).

Table A.2.1. Medium composition for growth of microalgae (adjusted from Chisti et al., 2007; Davis et al., 2011).

Parameter	Value	Unit
Algae production rate	50,654.37772	lb/hr
Land use	2207.184114	ha
Land use	8.522451515	$mile^2$
Total land use	12.71295153	$mile^2$
Net water Demand	2,843.785114	lb/hr
Fresh CO_2 demand	41,234.88416	lb/hr
Fresh NH_3 Demand	1,450.330408	lb/hr
Fresh DAP required	1,365.016855	lb/hr
Reported algae productivity	2,696.751042	$kg/mile^2/hr$
Initial algae	2.5031104	g/m^2
PAR-Radiation (400-700 nm)	2.32 -04 - 4.44 -04	($W/mile^2$)
Incident solar power	2.65858E-05	(W)
Radiation time	8 – 12	(hr/day)
Operating days	330	Days
Year	2011	Year

Table A.2.2. Pond dimensions (adjusted from Welssmen et al., 1987).

Parameter	Value	Units
Long	269.0256	ft
Wide	39.3696	ft
Deep	0.981435897	ft
Area	0.000380087	$mile^2$
Needed ponds	22,422.37073	No ponds
Needed area	2207.1841	ha
Cost to build a pond	32,300,798	$

LABOR REQUIRED PER 1000 ACRE												FROM 128 PAGE 110
POSITION TITLE	QUANTITY		Time	Salary								
			HR/YR	$/hr	$/yr							
Plant Manager	1		2080	25	52000			Total Labor	23		1000 acre	
Shift Supervisors	4		2080	17	35360			Total Labor	126			
Pond Operators	10		2080	10	20800							
Centrifuge Operators	5		2080	12	24960							
Laboratory Manager	1		2080	17	35360							
Laboratory Technicians	2		2080	10	20800							
Total ($)					189280							
Area (acre)	1000											
Area (ha)	404.86											
Required Arrea (ha)	2207.1841											
Needed Labor Cost ($)	1031901.9					Cost for the year 1987			look on 129 for the labor cost indexes on Dec of each year			
Updated Labor Cost ($)	2142318.1					Cost for the Year 2011			look on 129			

Figure A.2.2. Labor information for pond site (adjusted from Welssmen et al., 1987).

WATER COST FOR ALGAE GROWTH				
Needed Water (gal)	1.744E+09		Evap (m^3/day)	1200
Cost of Water ($/gal)	0.0052427		Cost of make up ($/yr)	606815
Cost of Water ($)	9140676.3	Esto lo necesitas solo para llenar las charcas		
LAND COST				
Required Land (acre)	8132.3403			
Cost of Land ($/acre/yr	300			
Cost of Land ($/yr)	2439702.1			

Figure A.2.3. Water and land information for pond site (adjusted from Welssmen et al., 1987 and Davis et al., 2011).

RAW MATERIALS				
	CO2	NH3	DAP	MICROALGAE
	(1/yr)	(1/yr)	(1/yr)	1/yr
Needed (lb)	361464995	1.3E+07	11965738	121800
Class	Variable	Variable	Variable	Variable
Material Cost ($/lb)	0.0181439	0.18461	0.20049	14.3433
Cost ($)	6558377.8	2347108	2399009	1747020

Figure A.2.4. Raw materials information for pond site (adjusted from Davis et al., 2011).

UTILITIES	
Pilot area (ha)	192
Pilot Paddle Wells (#)	24
Efficiency of Paddle well	0.42
Hydraulic Power per Paddle well (kW)	3.477
Shaft Power per Paddle well (kW)	8.278571
Our Area (ha)	2207.184
Needed Paddle Wells (#)	275.898
Power of Paddle Wells (kW)	2284.041
Operation Time (hr)	24
Electricity Demand (kWh/day)	54816.99
Electricity per Year (kWh/yr)	20021907
Electricity Cost ($/kWhr)	0.240419
Utility Cost ($/yr)	4813647

Figure A.2.5. Utilities information for pond site (adjusted from Welssmen et al., 1987).

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APPENDIX B: TABULATED INFORMATION FOR PLANT SITE USING EXCEL SPREASHEETS

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List of Tables

B.1 – Introduction to equipment cost information tables

Tables B.1.1 to **B.1.5** show the relevant information regarding the equipment involved for each case scenario considered in this project. Parameters for pumps, turbines and compressors were calculated using the hydraulic equation and the turbine equation. Parameters for other specialized equipment, such as freeze dryers, fluidized bed dryers, supercritical fluid extraction systems (SC-Extraction), dewatering, and centrifugation systems were determined according to related literature.

Table B.1.1. Equipment and cost information of plant site for Case Scenario 1.

Equipment	Unit	Description	Description Value	Cost ($) (year)
Flocculation tank (Tk-101) 1 Labor	Flocculation	SS or CS Tank P = ambient pressure T = ambient or near Tank Capacity (lb) Volume (m^3) Used volume (m^3)	---- ---- ---- 557375.8288 247.1250204 300	56677.47 (2001) 78747.49 (2011)
CLTALGAE Pump (P-101) 129.6kW	Flocculation	Fluid density kg/L Flow capacity (m^3/h) Gravity constant (m/s^2) Differential head (m) Pump efficiency Calculated hydraulic power (kW) Calculated hydraulic power (bph) Calculated shaft power (kW) Calculated shaft power (bph) Centrifugal pump	1.030345212 45.45214893 9.81 602.0868184 0.6 77.76 104.28 129.6 173.8 ----	15447.58 (2001) 21462.81 (2011)
RE-WATER Pump system (P-102) 192.53kW	Flocculation	Fluid density kg/L Flow capacity (m^3/h) Specific gravity (m/s^2) Differential head (m) Pump efficiency Calculated hydraulic power (kW) Calculated hydraulic power (bph) Calculated shaft power (kW) Calculated shaft power (bph) Centrifugal pump	1.030345212 204.5478511 9.81 200.6956061 0.6 115.53 154.91 192.53 258.18 ----	20621.54 (2001) 28651.49 (2011)

Table B.1.1. Continued.

Equipment	Unit	Description	Description Value	Cost ($) (year)
PONDFEED Pump system P-103) 234.78kW	Flocculation	Fluid density (kg/L) Flow capacity (m^3/h) Gravity constant (m/s^2) Differential head (m) Pump efficiency Calculated hydraulic power (kW) Calculated hydraulic power (bph) Calculated shaft power (kW) Required shaft power (kW) Calculated shaft power (bph) Ratio of required/pilot capacity Centrifugal pump	1.030345212 250 9.81 200.6956061 0.6 140.87 188.9 200 234.78 314.83 1.1739 ----	21225.9 (2001) 23369.25 (2001) 32469.16 (2011)
Dewatering press filter (Z-101) 1 Labor 13.1kW	Dewatering	Filter presses system - Pressure leaf Operating pressure Operating temperature (°F) Initial estimated capacity (ft^3/hr) Total volume feed batch (gal) Solid concentration product feed (%) Specific gravity of process solid Mass of the cake (lb/hr) Volume of the cake (ft^3/hr) Weight of cake (lb/ft^3) Percent of dry solids in cake (%) Desired cycles per day of filter Estimated time for one batch (day) Cake required volume (ft^3) Application volume requirement (ft^3) Cake thickness (m) Estimated filter area (ft^2) Quote index for the current year	---- 90 76.9 1605.068937 12002.15182 49.99900002 1.33 70937.1855 934.905853 75.87628772 71.4275412 24 0.042 3763.63 156.81795 1.5 31.86579493 394	11210.68 (2001) 43249.31 (2011)
DEWAT Pump system (P-104)123.58kW	Dewatering	Fluid density (kg/L) Flow capacity (m^3/h) Gravity (m/s^2) Differential head (m) Pump efficiency Calculated hydraulic power (kW) Calculated hydraulic	1.00E+00 1.38E+01 9.81 200.6956061 0.6 7.55	6301.644 (2001) 8755.484 (2011)

Equipment	Unit	Description	Description Value	Cost ($) (year)
		power (bph) Calculated shaft power (kW) Calculated shaft power (bph) Positive displacement	10.12 12.58 16.87 ----	

Table B.1.1. Continued.

Equipment	Unit	Description	Description Value	Cost ($) (year)
WETALGAE Pump system 58.77kW	Dewatering	Fluid density (kg/L) Flow capacity (m^3/h) Gravity constant (m/s^2) Differential head (m) Pump efficiency Calculated hydraulic power (kW) Calculated hydraulic power (bph) Calculated shaft power (kW) Calculated shaft power (bph) Centrifugal pump	1.24E+00 2.60E+01 9.81 401.3912122 0.6 35.26 47.29 58.77 78.81 ----	9234.368 (2001) 12830.2 (2011)
Centrifuge system (Z-102) 1 Labor 2644.94kW	Centrifugation	Perforated Basket Centrifuge Type solid bowl with motor Speed (rpm) Diameter (inch) Drum height (inch) Electrical supply Capacity (lb) Process capacity (lb) Ratio of required/pilot capacity	---- ---- 1020-4000 20 14 460 VAC with 3ph 60 70937.1855 1182.286425	16500 (2001) 1151112 (2001) 1200886 (2011)
Water Pump (P-106) 6.92kW	Centrifugation	Fluid density (kg/L) Flow capacity (m^3/h) Gravity constant (m/s^2) Differential head (m) Pump efficiency Calculated hydraulic power (kW) Calculated hydraulic power (bph) Calculated shaft power (kW) Calculated shaft power (bph) Positive displacement	1.00E+00 6.90E+00 9.81 200.6956061 0.6 4.15 5.565 6.916 9.274 ----	4919.383 (2001) 6834.975 (2011)

Table B.1.1. Continued.

Equipment	Unit	Description	Description Value	Cost ($) (year)
CNTMATTER Pump system (P-107) 25.28kW	Centrifugation	Fluid density (kg/L) Flow capacity (m^3/h) Gravity constant (m/s^2) Differential head (m) Pump efficiency Calculated hydraulic power (kW) Calculated hydraulic power (bph) Calculated shaft power (kW) Calculated shaft power (bph) Centrifugal pump	1.30E+00 1.94E+01 9.81 200.6956061 0.6 15.17 20.34 25.28 33.9 ----	5848.358 (2001) 8125.689 (2011)
Dryer (Z-103) 1 Labor 3.15kW	Drying	Model from International Process Plants Type Fluid Bed Dryer SS Model capacity (kg) Speed (rpm) Det. Pressure Range (psia) Model drum deep (in) Model drum diameter (in) Surface area (m^2) Required capacity (kg) Ratio of required/pilot capacity	---- ---- 70 1725 50 -80 16 34 0.350975576 25281.49209 361.1641727	84385.45 (2001) 2889950 (2001) 4015288 (2011)
Water Pump system (P-108) 3.14kW	Drying	Fluid density (kg/L) Flow capacity (m^3/h) Gravity constant (m/s^2) Differential head (m) Pump efficiency Calculated Hydraulic power (kW) Calculated hydraulic power (bph) Calculated shaft power (kW) Calculated shaft power (bph) Positive displacement	1.00E+00 2.30E+00 9.81 301.0434092 0.6 1.89 2.53 3.14 4.22 ----	3799.228 (2001) 5278.635 (2011)

Table B.1.1. Continued.

Equipment	Unit	Description	Description Value	Cost ($) (year)
DRYMATTER Pump system (P-109) 31.46kW	Drying	Fluid density (kg/L) Flow capacity (m^3/h) Gravity constant (m/s^2) Differential head (m) Pump efficiency Calculated hydraulic power (kW) Calculated hydraulic power (bph) Calculated shaft power (kW) Calculated shaft power (bph) Centrifugal pump	1.33 17.28058 9.81 301.0434 0.6 18.88 25.31 31.46 42.19 ----	6523.738 (2001) 9064.06 (2011)
CO_2 Compression system (Z-104) 1 Labor 16082.52kW	SC-Extraction	Axial gas compressor Inlet pressure (psia) Inlet temperature (°F) Outlet pressure (psia) Outlet temperature (°F) Mass capacity (kg/hr) Pressure change (kPa) CO_2 density (lb/ft^3) CO_2 density (kg/m^3) Volumetric flow rate (m^3/s) Fluid power (kW) Pilot turbine fluid power (kW) Ratio of required/pilot capacity	---- 870.23 80.51 1450.37 169.92 919326.6 3998.822 6.6067 105.8264 2.413089 9649.513 3000 3.216504	600198 (2001) 1209832 (2001) 1680936 (2011)
Extraction system (Z-105) 1 Labor 250 kg/s	SC-Extraction	Jacketed non agitated Operating pressure (MPa) Range of temperature (°F) Algae density (kg/L) Algae density (kg/m^3) CO_2 density (lb/ft^3) CO_2 density (kg/m^3) SC volume capacity (m^3) Pilot reactor volume (m^3) Ratio of required/pilot capacity	---- 40 95 - 131 1.33 1330 9.4475 151.3305 6092.241 54 112.8193	755.2593 (2001) 12868.45 (2001) 17879.38 (2011)

Table B.1.1. Continued.

Equipment	Unit	Description	Description Value	Cost ($) (year)
Separation vessel (Z-106)	SC-Extraction	Process Vessel - Vertical Pressure inlet (psia) Temperature inlet (°F) Pressure outlet (psia) Temperature outlet (°F) Algae density (kg/L) Algae density (kg/m^3) CO_2 density (lb/ft^3) CO_2 density (kg/m^3) Volume capacity (m^3) Pilot vessel volume ($m^3$3) Ratio of required/pilot capacity	---- 5801.51 121.9 870.23 130.9 1.33 1330 36.6995 587.8542 1581.208 520 3.040784	2936483 (2001) 5722936 (2001) 7951428 (2011)
Material Pump system (P-110) 303.83kW	SC-Extraction	Fluid density (kg/L) Flow capacity (m^3/h) Gravity constant (m/s^2) Differential head (m) Pump efficiency Calculated hydraulic power (kW) Calculated hydraulic power (bph) Calculated shaft power (kW) Calculated shaft power (bph) Centrifugal pump	1.33 8.640288 9.81 5821.711 0.6 182.3 244.46 303.83 407.44 ----	57808.08 (2001) 80318.36 (2011)
CO_2 Strip vessel (Z-108) 1 Labor	SC-Extraction	Storage - Tank area Pressure inlet (psia) Temperature inlet (°F) Pressure outlet (psia) Temperature outlet (°F) Algae density (kg/L) Algae density (kg/m^3) CO_2 density (lb/ft^3) CO_2 density (kg/m^3) Volume capacity (m^3) Pilot vessel volume (m^3) Ratio of required/pilot capacity	--- 870.23 121.9 870.23 121.9 1.33 1330 6.6067 105.8264 8695.76 8695.76 1	337430.9 (2001) 337430.9 (2001) 468825.4 (2011)

Table B.1.2. Technical equipment and cost information of plant site for Case Scenario 2.

Equipment	Unit	Description	Description Value	Cost ($) (year)
Flocculation tank (TK-101) 1 Labor	Flocculation	SS or CS Tank P = ambient pressure T = ambient or near Temperature Capacity (lb) Volume (m^3) Used volume (m^3)	---- ---- ---- 557375.8 247.1276 300	56677.47 (2001) 78747.49 (2011)
CLTALGAE Pump system (P-101) 129.6kW	Flocculation	Fluid density (kg/L) Flow capacity (m^3/h) Gravity constant (m/s^2) Differential head (m) Pump efficiency Calculated hydraulic power (kW) Calculated hydraulic power (bph) Calculated shaft power (kW) Calculated shaft power (bph) Centrifugal pump	1.33 39.45725 9.81 602.0868 0.6 77.76 104.28 129.6 173.8 ----	15447.58 (2001) 21462.81 (2011)

Table B.1.2. Continued.

Equipment	Unit	Description	Description Value	Cost ($) (year)
RE-WATER Pump system (P-102) 192.53kW	Flocculation	Fluid density (kg/L)	0.999984	20621.54 (2001) 28651.49 (2011)
		Flow capacity (m^3/h)	210.5427	
		Gravity constant (m/s^2)	9.81	
		Differential head (m)	200.6956	
		Pump efficiency	0.6	
		Calculated hydraulic power (kW)	115.53	
		Calculated hydraulic power (bph)	154.91	
		Calculated shaft power (kW)	192.53	
		Calculated shaft power (bph)	258.18	
		Centrifugal pump	----	
PONDFEED Pump system (P-103) 234.78kW	Flocculation	Fluid density (kg/L)	1.03	21225.9 (2001) 23369.25 (2001) 32469.16 (2011)
		Flow capacity (m^3/h)	250	
		Gravity constant (m/s^2)	9.81	
		Differential head (m)	200.6956	
		Pump efficiency	0.6	
		Calculated hydraulic power (kW)	140.87	
		Calculated hydraulic Power (bph)	188.9	
		Calculated shaft power (kW)	200	
		Required shaft power (kW)	234.78	
		Calculated shaft power (bph)	314.83	
		Ratio of required/pilot capacity	1.1739	
		Centrifugal pump	----	
Dewatering Press Filter (Z-101) 1 Labor 11.31kW	Dewatering	Filter presses system - Pressure leaf	----	11210.68 (2001) 43249.31 (2011)
		Operating pressure (psia)	90	
		Operating temperature (°F)	76.9	
		Initial estimated capacity (ft^3/hr)	1605.069	
		Total volume feed batch (gal)	12002.15	
		Solid concentration product feed (%)	49.999	
		Specific gravity of process solid	1.33	
		Mass of the cake (lb/hr)	70937.19	
		Volume of the cake (ft^3/hr)	934.9059	
		Weight of cake (lb/ft^3)	75.87629	
		Percent of dry solids in cake (%)	71.42754	
		Desired cycles per day of filter	24	
		Estimated time for one batch	0.042	
		Cake required volume (ft^3)	3763.63	
		Application volume requirement (ft^3)	156.818	

Equipment	Unit	Description	Description Value	Cost ($) (year)
		Cake thickness (m) Estimated filter area (ft^2) Quote index for the current year	1.5 31.86579 394	

Table B.1.2. Continued.

Equipment	Unit	Description	Description Value	Cost ($) (year)
WETALGAE Pump system (P-104) 12.58kW	Dewatering	Fluid density (kg/L) Flow capacity (m^3/h) Gravity constant (m/s^2) Differential head (m) Pump efficiency Calculated hydraulic power (kW) Calculated hydraulic power (bph) Calculated shaft power (kW) Calculated shaft power (bph) Centrifugal pump	1.24E+00 2.60E+01 9.81 401.3912 0.6 35.26 47.29 58.77 78.81 ----	9234.368 (2001) 12830.2 (2011)
Freeze Dryer system (Z-102) 1 Labor 1169.26kW	Freeze Drying	Assumed Drum Dryer Model area capacity (m^2) 304SS VAC freeze dryer Number of shelves Shelve wide (m) Shelve long (m) Shelve distance (mm) Temperature range (°C) Shell dimensions, h w deep, (m) Ice capacity (kg) Ratio of required/pilot capacity	---- 3.8 ---- 5 0.81 0.79 80 -40 to 60 1.2 x 1.0 x0.95 80 114.9216	13939.62 (2001) 240155.2 (2001) 333670.9 (2011)
Water Pump (P-106) 12.56kW	Freeze Drying	Fluid density (kg/L) Flow capacity (m^3/h) Gravity constant (m/s^2) Differential head (m) Pump efficiency Calculated hydraulic power (kW) Calculated hydraulic power (bph) Calculated shaft power (kW) Calculated shaft power (bph) Positive displacement pump	1.00E+00 9.19E+00 9.81 301.0434 0.6 7.54 10.11 12.56 16.85 ----	6297.122 (2001) 8749.201 (2011)

Table B.1.2. Continued.

Equipment	Unit	Description	Description Value	Cost ($) (year)
DRYMATTER Pump system (P-107) **31.46kW**	Freeze Drying	Fluid density (kg/L) Flow capacity (m^3/h) Gravity constant (m/s^2) Differential head (m) Pump efficiency Calculated hydraulic power (kW) Calculated hydraulic power (bph) Calculated shaft power (kW) Calculated shaft power (bph) Centrifugal pump	1.33 17.28058 9.81 301.0434 0.6 18.88 25.31 31.46 42.19 ----	6523.738 (2001) 9064.06 (2011)
CO_2 Compression system (Z-103) **1 Labor** **16082.52kW**	SC-Extraction	Axial gas compressor Inlet pressure (psia) Inlet temperature (°F) Outlet pressure (psia) Outlet temperature (°F) Mass capacity (kg/hr) Pressure change (kPa) CO_2 density (lb/ft^3) CO_2 density (kg/m^3) Volumetric flow rate (m^3/s) Fluid power (kW) Pilot turbine fluid power (kW) Ratio of required/pilot capacity	---- 870.23 80.51 1450.37 169.92 919326.6 3998.822 6.6067 105.8264 2.413089 9649.513 3000 3.216504	600198 (2001) 1209832 (2001) 1680936 (2011)
Extraction system (Z-104) **1 Labor** **250 kg/s**	SC-Extraction	Jacketed non agitated Operation pressure (MPa) Range of temperature (°F) Algae density (kg/L) Algae density (kg/m^3) CO_2 density (lb/ft^3) CO_2 density (kg/m^3) SC volume capacity (m^3) Pilot reactor volume (m^3) Ratio of required/pilot capacity	---- 40 95 - 131 1.33 1330 9.4475 151.3305 6092.241 54 112.8193	755.2593 (2001) 12868.45 (2001) 17879.38 (2011)

Table B.1.2. Continued.

Equipment	Unit	Description	Description Value	Cost ($) (year)
Separation vessel (Z-105)	SC-Extraction	Process Vessel – Vertical Pressure inlet (psia) Temperature inlet (°F) Pressure outlet (psia) Temperature outlet (°F) Algae density (kg/L) Algae density (kg/m^3) CO_2 density (lb/ft^3) CO_2 density (kg/m^3) Volume capacity (m^3) Pilot vessel volume (m^3) Ratio of required/pilot capacity	---- 5801.51 121.9 870.23 130.9 1.33 1330 36.6995 587.8542 1581.208 520 3.040784	2936483 (2001) 5722936 (2001) 7951428 (2011)
Material Pump system (P-108) 303.83kW	SC-Extraction	Fluid density (kg/L) Flow capacity (m^3/h) Gravity constant (m/s^2) Differential head (m) Pump efficiency Calculated hydraulic power (kW) Calculated hydraulic power (bph) Calculated shaft power (kW) Calculated shaft power (bph) Centrifugal pump	1.33 8.640288 9.81 5821.711 0.6 182.3 244.46 303.83 407.44 ----	57808.08 (2001) 80318.36 (2011)
CO_2 Strip vessel (Z-107) 1 Labor	SC-Extraction	Storage - Tank Area Pressure inlet (psia) Temperature inlet (°F) Pressure outlet (psia) Temperature outlet (°F) Algae density (kg/L) Algae density (kg/m^3) CO_2 density (lb/ft^3) CO_2 density (kg/m^3) Volume Capacity (m^3) Pilot vessel volume (m^3) Ratio of required/pilot capacity	---- 870.23 121.9 870.23 121.9 1.33 1330 6.6067 105.8264 8695.76 8695.76 1	337430.9 (2001) 337430.9 (2001) 468825.4 (2011)

Table B.1.3. Technical equipment and cost information of plant site for Case Scenario 3.

Equipment	Unit	Description	Description Value	Cost ($) (year)
CLTALGAE Pump system (Z-107) 345.66Kw	Freeze Drying	Fluid density (kg/L) Flow capacity (m^3/h) Gravity constant (m/s^2) Differential head (m) Pump efficiency Calculated hydraulic Power (kW) Calculated hydraulic power (bph) Calculated shaft power (kW) Required shaft power (kW) Calculated shaft power (bph) Ratio required/pilot centrifugal pump	1.03+00 245 9.81 301.04 0.6 207.39 278.12 200 345.66 464 1.73 ----	21225.89797 (2001) 29473.89624 (2001) 40950.93444 (2011)
Freeze Dryer system (Z-101) 1 Labor 28728.96Kw	Freeze Drying	Assumed Drum Dryer Model area capacity (m^2) 304SS VAC freeze dryer number of shelves Shelve wide (m) Shelve long (m) Shelve distance (mm) Temperature range (°C) Shell dimensions , h w deep, (m) Ice capacity (kg) Ratio of required/pilot capacity	---- 3.8 ---- 5 0.81 0.79 80 -40 to 60 1.2 x 1.0 x0.95 80 2872.895729	13939.62149 (2001) 1656696.289 (2001) 2301808.373 (2011)
Water Pump (Z-108) 323.9Kw	Freeze Drying	Fluid density (kg/L) Flow capacity (m^3/h) Gravity constant (m/s^2) Differential head (m) Pump efficiency Calculated hydraulic power (kW) Calculated hydraulic power (bph) Calculated shaft power (kW) Required shaft power (kW) Calculated shaft power (bph) Ratio required/pilot Positive displacement pump	1.00E+00 2.30E+02 9.81 301.0434092 0.6 194.34 260.61 200 323.9 434.35 1.6195 ----	21225.89797 (2001) 28346.18673 (2001) 39384.09856 (2011)

Table B.1.3. Continued.

Equipment	Unit	Description	Description Value	Cost ($) (year)
DRYMATTER Pump system (Z-109) 31.46kW	Drying	Fluid density (kg/L) Flow capacity (m^3/h) Gravity constant (m/s^2) Differential head (m) Pump efficiency Calculated hydraulic power (kW) Calculated hydraulic power (bph) Calculated shaft power (kW) Calculated shaft power (bph) Centrifugal pump	1.33 17.28058 9.81 301.0434 0.6 18.88 25.31 31.46 42.19 ----	6523.738 (2001) 9064.06 (2011)
CO_2 Compression system (Z-102) 1 Labor 16082.52kW	SC-Extraction	Axial gas compressor Inlet pressure (psia) Inlet temperature (°F) Outlet pressure (psia) Outlet temperature (°F) Mass capacity (kg/hr) Pressure change (kPa) CO_2 density (lb/ft^3) CO_2 density (kg/m^3) Volumetric flow rate (m^3/s) Fluid power (kW) Pilot turbine fluid Power (kW) Ratio of required/pilot capacity	---- 870.23 80.51 1450.37 169.92 919326.6 3998.822 6.6067 105.8264 2.413089 9649.513 3000 3.216504	600198 (2001) 1209832 (2001) 1680936 (2011)
Extraction system (Z-103) 1 Labor 250 kg/s	SC-Extraction	Jacketed non agitated Operating pressure (MPa) Range of temperature (°F) Algae density (kg/L) Algae density (kg/m^3) CO_2 density (lb/ft^3) CO_2 density (kg/m^3) SC volume capacity (m^3) Pilot reactor volume (m^3) Ratio of required/pilot capacity	---- 40 95 - 131 1.33 1330 9.4475 151.3305 6092.241 54 112.8193	755.2593 (2001) 12868.45 (2001) 17879.38 (2011)

Table B.1.3. Continued.

Equipment	Unit	Description	Description Value	Cost ($) (year)
Separation vessel (Z-104)	SC-Extraction	Process Vessel - Vertical Pressure inlet (psia) Temperature inlet (°F) Pressure outlet (psia) Temperature outlet (°F) Algae density (kg/L) Algae density (kg/m^3) CO_2 density (lb/ft^3) CO_2 density (kg/m^3) Volume capacity (m^3) Pilot vessel volume (m^3) Ratio of required/pilot capacity	---- 5801.51 121.9 870.23 130.9 1.33 1330 36.6995 587.8542 1581.208 520 3.040784	2936483 (2001) 5722936 (2001) 7951428 (2011)
Material Pump system (Z-110) 303.83kW	SC-Extraction	Fluid density (kg/L) Flow capacity (m^3/h) Gravity constant (m/s^2) Differential head (m) Pump efficiency Calculated hydraulic power (kW) Calculated hydraulic power (bph) Calculated shaft Power (kW) Calculated shaft power (bph) Centrifugal pump	1.33 8.640288 9.81 5821.711 0.6 182.3 244.46 303.83 407.44 ----	57808.08 (2001) 80318.36 (2011)
CO_2 Strip vessel (Z-105) 1 Labor	SC-Extraction	Storage - Tank Area Pressure inlet (psia) Temperature inlet (°F) Pressure outlet (psia) Temperature outlet (°F) Algae density (kg/L) Algae density (kg/m^3) CO_2 density (lb/ft^3) CO_2 density (kg/m^3) Volume capacity (m^3) Pilot vessel volume (m^3) Ratio of required/pilot capacity	--- 870.23 121.9 870.23 121.9 1.33 1330 6.6067 105.8264 8695.76 8695.76 1	337430.9 (2001) 337430.9 (2001) 468825.4 (2011)

Table B.1.4. Technical equipment and cost information of plant site for Case Scenario 4.

Equipment	Unit	Description	Description Value	Cost ($) (year)
PONPFEED Pump system (Z-108) 690.05W	Flocculation	Fluid density (kg/L) Flow capacity (m^3/h) Gravity constant (m/s^2) Differential head (m) Pump efficiency Calculated hydraulic power (kW) Calculated hydraulic power (bph) Calculated shaft power (kW) Required shaft power (kW) Calculated shaft power (bph) Ratio required/pilot centrifugal pump	1.03 245 9.81 602.08 0.6 414.03 555.21 200 690.05 925.35 3.45 ----	21225.90 (2001) 44624.81 (2001) 62001.57 (2011)
DEWAT Pump system (Z-109) 201.44kW	Dewatering	Fluid density (kg/L) Flow capacity (m^3/h) Gravity constant (m/s^2) Differential head (m) Pump efficiency Calculated hydraulic power (kW) Calculated hydraulic power (bph) Calculated shaft power (kW) Required shaft power (kW) Calculated shaft power (bph) Ratio of required/pilot capacity Centrifugal pump	1.00 221 9.81 200.6956 0.6 120.86 162.08 200 201.44 270.13 1.0072 ----	35409.72 (2001) 35562.47 (2001) 49410.38 (2011)
Dewatering Press Filter (Z-101) 1 Labor 70.49kW	Dewatering	Filter presses system - Pressure leaf Operating pressure (psia) Operating temperature (°F) Initial estimated capacity (ft^3/hr) Total volume feed batch (gal) Solid concentration product feed (%) Specific gravity of process solid Mass of the cake (lb/hr) Volume of the cake (ft^3/hr) Weight of cake (lb/ft^3) Percent of dry solids in cake (%) Desired cycles per day of filter	---- 90 76.9 8668 64814 9.10 1.33 70936.19 919.50 77.14 71.43 24	46888.43 (2001) 180889.4 (2011)

Equipment	Unit	Description	Description Value	Cost ($) (year)
		Estimated time for one batch Cake required volume (ft^3) Application volume requirement (ft^3) Cake thickness (m) Estimated filter area (ft^2) Quote index for the current year	0.042 1186.1 1176.7 1.5 239.1 394	

Table B.1.4. Continued.

Equipment	Unit	Description	Description Value	Cost ($) (year)
WETALGAE Pump system (Z-110) 44.08kW	Dewatering	Fluid density (kg/L) Flow capacity (m^3/h) Gravity constant (m/s^2) Differential head (m) Pump efficiency Calculated hydraulic power (kW) Calculated hydraulic power (bph) Calculated shaft power (kW) Calculated shaft power (bph) Centrifugal pump	1.24E+00 2.60E+01 9.81 301.04 0.6 26.45 35.47 44.08 59.11 ----	7818.696 (2001) 10863.27 (2011)
Freeze Dryer system (Z-102) 1 Labor 1169.26kW	Freeze Drying	Assumed Drum Dryer Model area capacity (m^2) 304SS VAC freeze dryer Number of shelves Shelve wide (m) Shelve long (m) Shelve distance (mm) Temperature range (°C) Shell dimensions, h w deep, (m) Ice capacity (kg) Ratio of required/pilot capacity	---- 3.8 ---- 5 0.81 0.79 80 -40 to 60 1.2 x 1.0 x0.95 80 114.9216	13939.62 (2001) 240155.2 (2001) 333670.9 (2011)
Water Pump (Z-111) 12.56kW	Freeze Drying	Fluid density (kg/L) Flow capacity (m^3/h) Gravity constant (m/s^2) Differential head (m) Pump efficiency Calculated hydraulic power (kW) Calculated hydraulic power (bph) Calculated shaft power (kW) Calculated shaft power (bph) Positive displacement pump	1.00E+00 9.19E+00 9.81 301.0434 0.6 7.54 10.11 12.56 16.85 ----	6297.122 (2001) 8749.201 (2011)

Table B.1.4. Continued.

Equipment	Unit	Description	Description Value	Cost ($) (year)
DRYMATTER Pump system (Z-112) 31.46kW	Drying	Fluid density (kg/L) Flow capacity (m^3/h) Gravity constant (m/s^2) Differential head (m) Pump efficiency Calculated hydraulic power (kW) Calculated hydraulic power (bph) Calculated shaft power (kW) Calculated shaft power (bph) Centrifugal Pump	1.33 17.28058 9.81 301.0434 0.6 18.88 25.31 31.46 42.19 ----	6523.738 (2001) 9064.06 (2011)
CO_2 Compression system (Z-103) 1 Labor 16082.52kW	SC-Extraction	Axial gas compressor Inlet pressure (psia) Inlet temperature (°F) Outlet pressure (psia) Outlet temperature (°F) Mass capacity (kg/hr) Pressure change (kPa) CO_2 density (lb/ft^3) CO_2 density (kg/m^3) Volumetric flow rate (m^3/s) Fluid power (kW) Pilot turbine fluid Power (kW) Ratio of required/pilot capacity	---- 870.23 80.51 1450.37 169.92 919326.6 3998.822 6.6067 105.8264 2.413089 9649.513 3000 3.216504	600198 (2001) 1209832 (2001) 1680936 (2011)
Extraction system (Z-104) 1 Labor 250 kg/s	SC-Extraction	Jacketed non agitated Operating pressure (MPa) Range of temperature (°F) Algae density (kg/L) Algae density (kg/m^3) CO_2 density (lb/ft^3) CO_2 density (kg/m^3) SC volume capacity (m^3) Pilot reactor volume (m^3) Ratio of required/pilot capacity	---- 40 95 - 131 1.33 1330 9.4475 151.3305 6092.241 54 112.8193	755.2593 (2001) 12868.45 (2001) 17879.38 (2011)

Table B.1.4. Continued.

Equipment	Unit	Description	Description Value	Cost ($) (year)
Separation vessel (Z-105)	SC-Extraction	Process Vessel - Vertical Pressure inlet (psia) Temperature inlet (°F) Pressure outlet (psia) Temperature outlet (°F) Algae density (kg/L) Algae density (kg/m^3) CO_2 density (lb/ft^3) CO_2 density (kg/m^3) Volume capacity (m^3) Pilot vessel volume (m^3) Ratio of required/pilot capacity	---- 5801.51 121.9 870.23 130.9 1.33 1330 36.6995 587.8542 1581.208 520 3.040784	2936483 (2001) 5722936 (2001) 7951428 (2011)
Material Pump system (Z-113) 303.83kW	SC-Extraction	Fluid density (kg/L) Flow capacity (m^3/h) Gravity constant (m/s^2) Differential head (m) Pump efficiency Calculated hydraulic power (kW) Calculated hydraulic power (bph) Calculated shaft power (kW) Calculated shaft power (bph) Centrifugal pump	1.33 8.640288 9.81 5821.711 0.6 182.3 244.46 303.83 407.44 ----	57808.08 (2001) 80318.36 (2011)
CO_2 Strip vessel (Z-106) 1 Labor	SC-Extraction	Storage - Tank Area Pressure inlet (psia) Temperature inlet (°F) Pressure outlet (psia) Temperature outlet (°F) Algae density (kg/L) Algae density (kg/m^3) CO_2 density (lb/ft^3) CO_2 density (kg/m^3) Volume capacity (m^3) Pilot vessel volume (m^3) Ratio of required/pilot capacity	--- 870.23 121.9 870.23 121.9 1.33 1330 6.6067 105.8264 8695.76 8695.76 1	337430.9 (2001) 337430.9 (2001) 468825.4 (2011)

Table B.1.5. Technical equipment and cost information of plant site for Case Scenario 5.

Equipment	Unit	Description	Description Value	Cost ($) (year)
Flocculation Tank (Tk-101) 1 Labor	Flocculation	SS or CS Tank P = ambient pressure T = ambient or near temperature Capacity (lb) Volume (m^3) Used volume (m^3)	---- ---- ---- ---- 557375.8 245.4639 300	56677.47 (2001) 78747.49 (2011)
CLTALGAE Pump System (P-101) 126.15kW	Flocculation	Fluid density (kg/L) Flow capacity (m^3/h) Gravity constant (m/s^2) Differential head (m) Pump efficiency Calculated hydraulic power (kW) Calculated hydraulic power (bph) Calculated shaft power (kW) Calculated shaft power (bph) Centrifugal pump	1.164989 39.45725 9.81 602.0868 0.6 75.69 101.5 126.15 169.17 ---	15157.89 (2001) 21060.33 (2011)
RE-WATER Pump System (P-102) 187.77kW	Flocculation	Fluid density (kg/L) Flow capacity (m^3/h) Gravity constant (m/s^2) Differential head (m) Pump efficiency Calculated hydraulic power (kW) Calculated hydraulic power (bph) Calculated shaft power (kW) Calculated shaft power (bph) Centrifugal pump	1.00 206.0067 9.81 200.6956 0.6 112.66 151.08 187.77 251.8 ----	33681.84 (2001) 46797.44 (2011)

Table B.1.5. Continued.

Equipment	Unit	Description	Description Value	Cost ($) (year)
PONDFEED Pump System (P-103) 230.45kW	Flocculation	Fluid density (kg/L) Flow capacity (m^3/h) Gravity constant (m/s^2) Differential head (m) Pump efficiency Calculated hydraulic power (kW) Calculated hydraulic power (bph) Calculated shaft power (kW) Required shaft power (kW) Calculated shaft power (bph) Ratio required/pilot centrifugal pump	1.03 245.4639 9.81 200.6956 0.6 138.27 185.42 200 230.45 309.03 1.15225 ----	21225.9 (2001) 23109.69 (2001) 32108.53 (2011)
Membrane Filtration system 1 Labor (Z-101) 180.58kW	Membrane Filtration	Ultra filtration Membrane Model Operation Pressure (psia) Capacity (gal/min) Bed length (inch) Diameter (inch) Diameter (m) Area (m^2) Required capacity (gal/min) Ratio plant/pilot	 100 28 96 30 0.762009 0.455817 2490.386 88.94236 1	560 (2000) 8272.813 (2000) 31915.42 (2011)
DEWAT Pump system (P-104) 628.93kW	Membrane Filtration	Fluid density (kg/L) Flow capacity (m^3/h) Gravity constant (m/s^2) Differential head (m) Pump efficiency Calculated hydraulic power (kW) Calculated hydraulic power (bph) Calculated shaft power (kW) Required shaft power (kW) Calculated shaft power (bph) Ratio required/pilot centrifugal pump	1.00E+00 2.07E+01 9.81 668.9854 0.6 377.36 506.04 200 628.93 843.39 3.14465	21225.9 0(2001) 42209.43 (2001) 58645.64 (2011)

Table B.1.5. Continued.

Equipment	Unit	Description	Description Value	Cost ($) (year)
FILTRATE Pump system (P-105) 34.63kW	Membrane Filtration	Fluid density (kg/L) Flow capacity (m^3/h) Gravity constant (m/s^2) Differential head (m) Pump efficiency Calculated hydraulic power (kW) Calculated hydraulic power (bph) Calculated shaft power (kW) Calculated shaft power (bph) Centrifugal pump	1.299997 19.4474 9.81 301.0434 0.6 20.78 27.87 34.63 46.44 ----	6858.157 (2001) 9528.701 (2011)
Dryer (Z-102) 1 Labor 5.24kW	Drying	Model from International Process Plants Type fluid bed dryer SS type drum Model capacity (kg) Speed (rpm) Pressure range (psia) Model drum deep (in) Model drum diameter (in) Surface area (m^2) Required capacity (kg) Ratio of required/pilot capacity	---- ---- 70 1725 50 -8 16 34 0.350976 25281.57 361.1653	84385.45 (2001) 2889956 (2001) 4015295 (2011)
Water Pump System (P-106) 6.29kW	Drying	Fluid density (kg/L) Flow capacity (m^3/h) Gravity constant (m/s^2) Differential head (m) Pump efficiency Calculated hydraulic power (kW) Calculated hydraulic power (bph) Calculated shaft power (kW) Calculated shaft power (bph) Positive displacement	1 2.298409 9.81 602.0868 0.6 3.77 5.06 6.29 8.43 ----	4749.41 (2001) 4749.41 (2011)

Table B.1.5. Continued.

Equipment	Unit	Description	Description Value	Cost ($) (year)
DRYMATTER Pump system (P-107) 31.46kW	Drying	Fluid density (kg/L) Flow capacity (m^3/h) Gravity constant (m/s^2) Differential head (m) Pump efficiency Calculated hydraulic power (kW) Calculated hydraulic power (bph) Calculated shaft power (kW) Calculated shaft power (bph) Centrifugal pump	1.33 17.28058 9.81 301.0434 0.6 18.88 25.31 31.46 42.19 ----	6523.738 (2001) 9064.06 (2011)
CO_2 Compression system (Z-103) 1 Labor 16082.52kW	SC-Extraction	Axial gas compressor Inlet pressure (psia) Inlet temperature (°F) Outlet pressure (psia) Outlet temperature (°F) Mass capacity (kg/hr) Pressure change (kPa) CO_2 density (lb/ft^3) CO_2 density (kg/m^3) Volumetric flow rate (m^3/s) Fluid power (kW) Pilot turbine fluid Power (kW) Ratio of required/pilot capacity	---- 870.23 80.51 1450.37 169.92 919326.6 3998.822 6.6067 105.8264 2.413089 9649.513 3000 3.216504	600198 (2001) 1209832 (2001) 1680936 (2011)
Extraction system (Z-104) 1 Labor 250 kg/s	SC-Extraction	Jacketed non agitated Operating pressure (MPa) Range of temperature (°F) Algae density (kg/L) Algae density (kg/m^3) CO_2 density (lb/ft^3) CO_2 density (kg/m^3) SC volume capacity (m^3) Pilot reactor volume (m^3) Ratio of required/pilot capacity	---- 40 95 - 131 1.33 1330 9.4475 151.3305 6092.241 54 112.8193	755.2593 (2001) 12868.45 (2001) 17879.38 (2011)

Table B.1.5. Continued.

Equipment	Unit	Description	Description Value	Cost ($) (year)
Separation vessel (Z-105)	SC-Extraction	Process vessel - vertical Pressure inlet (psia) Temperature inlet (°F) Pressure outlet (psia) Temperature outlet (°F) Algae density (kg/L) Algae density (kg/m^3) CO_2 density (lb/ft^3) CO_2 density (kg/m^3) Volume capacity (m^3) Pilot vessel volume (m^3) Ratio of required/pilot capacity	---- 5801.51 121.9 870.23 130.9 1.33 1330 36.6995 587.8542 1581.208 520 3.040784	2936483 (2001) 5722936 (2001) 7951428 (2011)
Material pump system (P-108) 303.83kW	SC-Extraction	Fluid density (kg/L) Flow capacity (m^3/h) Gravity constant (m/s^2) Differential head (m) Pump efficiency Calculated hydraulic power (kW) Calculated hydraulic power (bph) Calculated shaft power (kW) Calculated shaft power (bph) Centrifugal pump	1.33 8.640288 9.81 5821.711 0.6 182.3 244.46 303.83 407.44 ----	57808.08 (2001) 80318.36 (2011)
CO_2 Strip vessel (Z-106) 1 Labor	SC-Extraction	Storage - tank area Pressure inlet (psia) Temperature inlet (°F) Pressure outlet (psia) Temperature outlet (°F) Algae density (kg/L) Algae density (kg/m^3) CO_2 density (lb/ft^3) CO_2 density (kg/m^3) Volume capacity (m^3) Pilot vessel volume (m^3) Ratio of required/pilot capacity	--- 870.23 121.9 870.23 121.9 1.33 1330 6.6067 105.8264 8695.76 8695.76 1	337430.9 (2001) 337430.9 (2001) 468825.4 (2011)

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APPENDIX C: ASPEN SIMULATION EXAMPLE - CASE SCENARIO 3 AND SIMULATIONS OUTPUT

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C.1 – Example: Simulating Case Scenario 3 using ASPEN ONE version 7.3

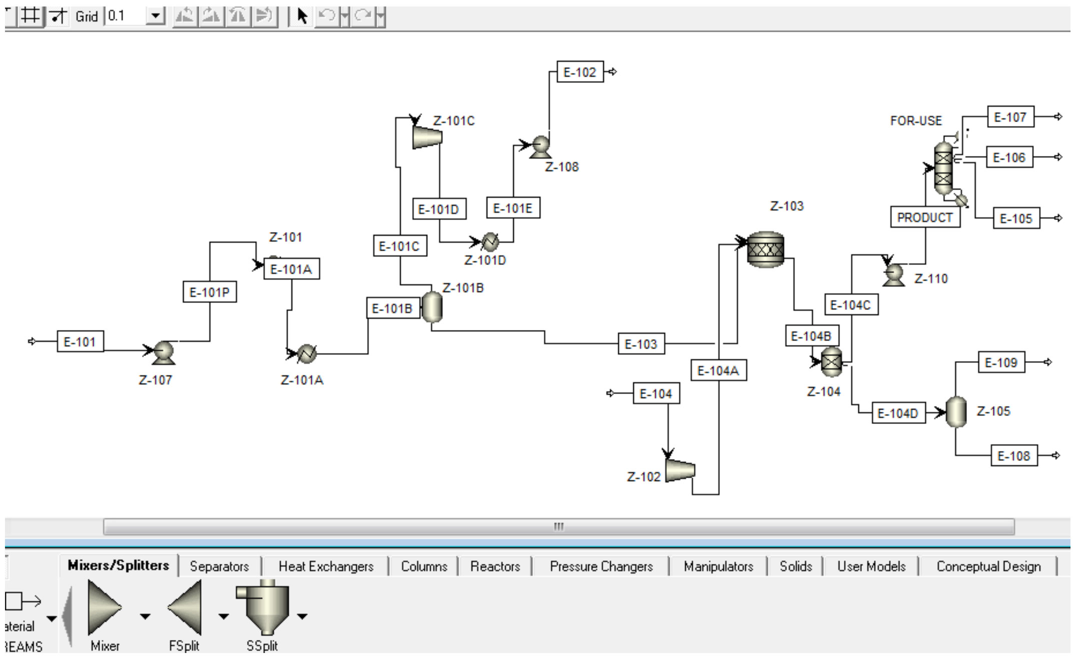


Figure C.1.1. Case 3 process flow diagram window (after building the diagram click the next icon).

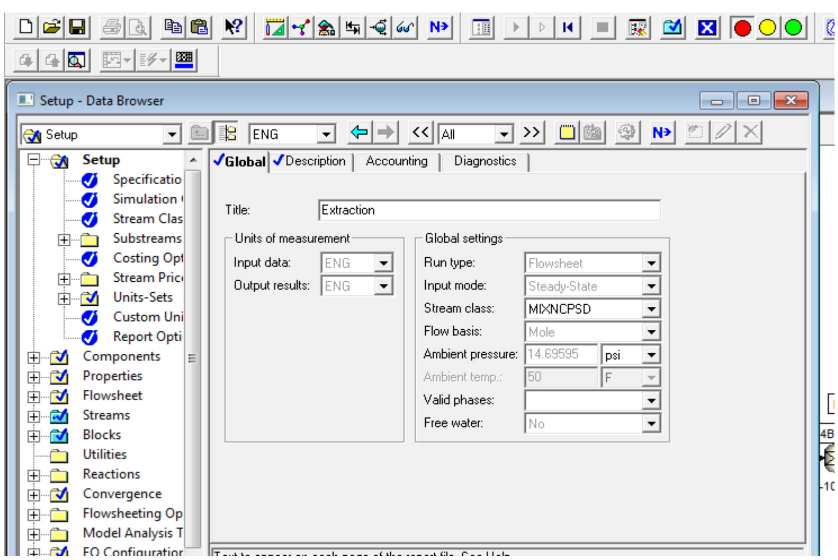


Figure C.1.2. Setup window.

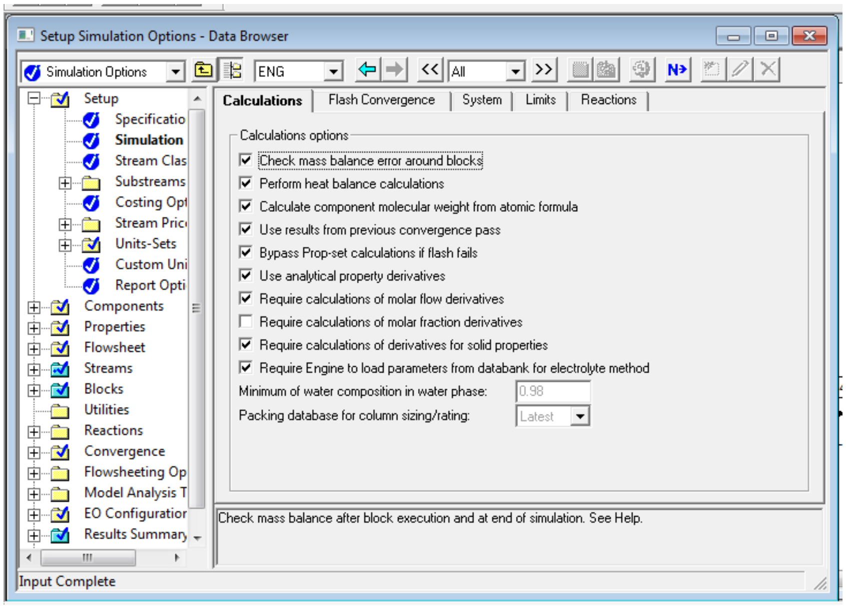


Figure C.1.3. Simulation window.

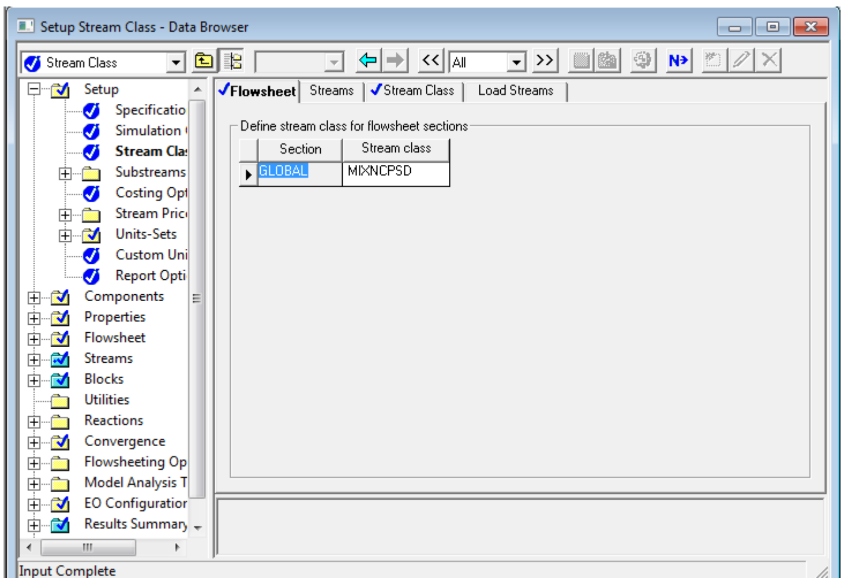


Figure C.1.4. Stream class window (define mixture with non conventional solid with particle size distribution).

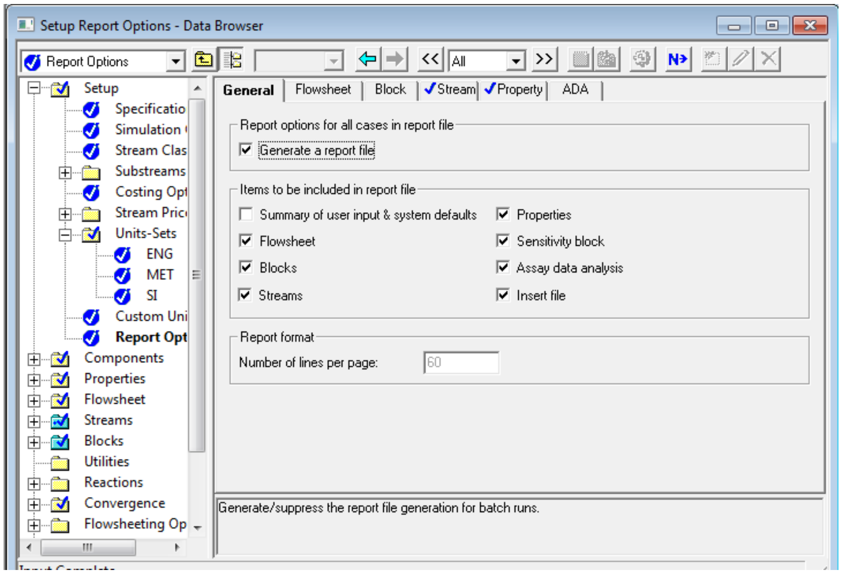


Figure C.01.05. Report Options window (choose the options that you which to be displayed in the report output).

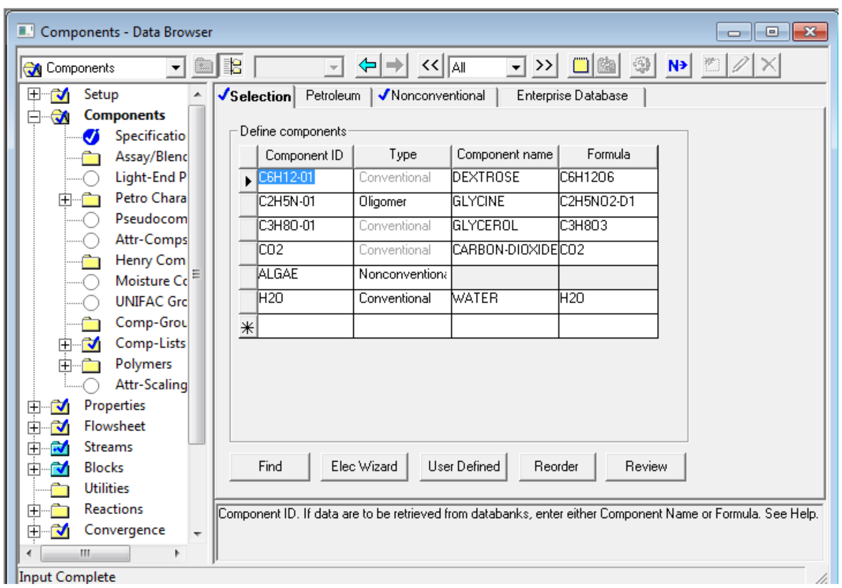


Figure C.1.6. Components window (all the components that will be used in the simulation were specified).

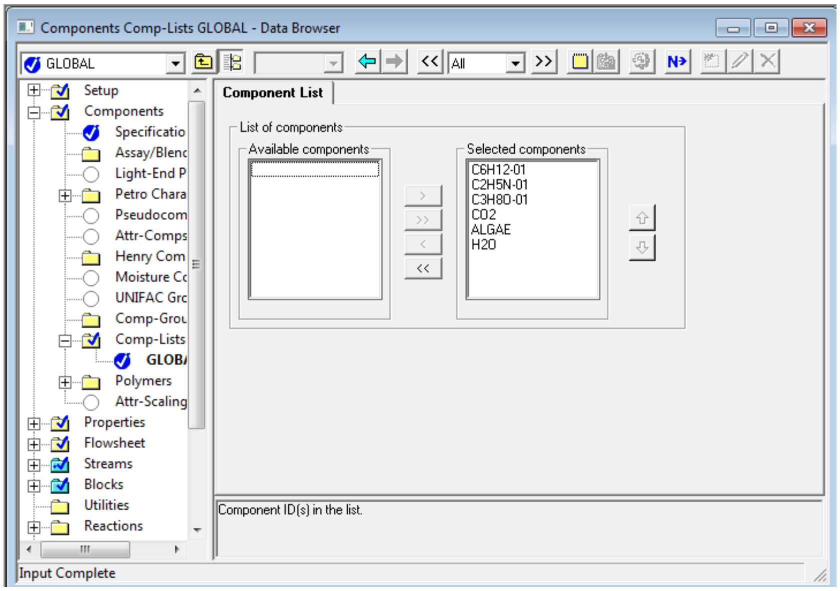


Figure C.1.7. Global component list window (verify that all the components were included in the global section).

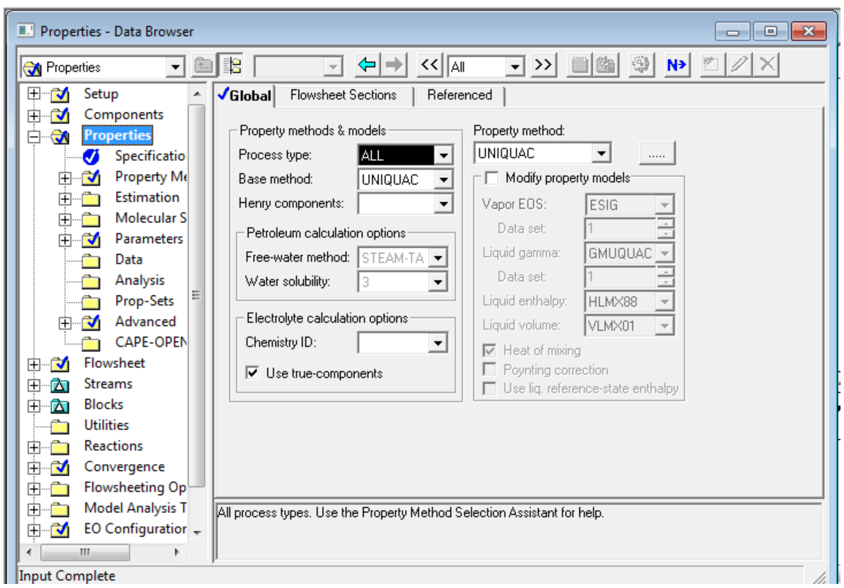


Figure C.1.8. Properties Specification window (make sure that you choose UNIQUAC as base method).

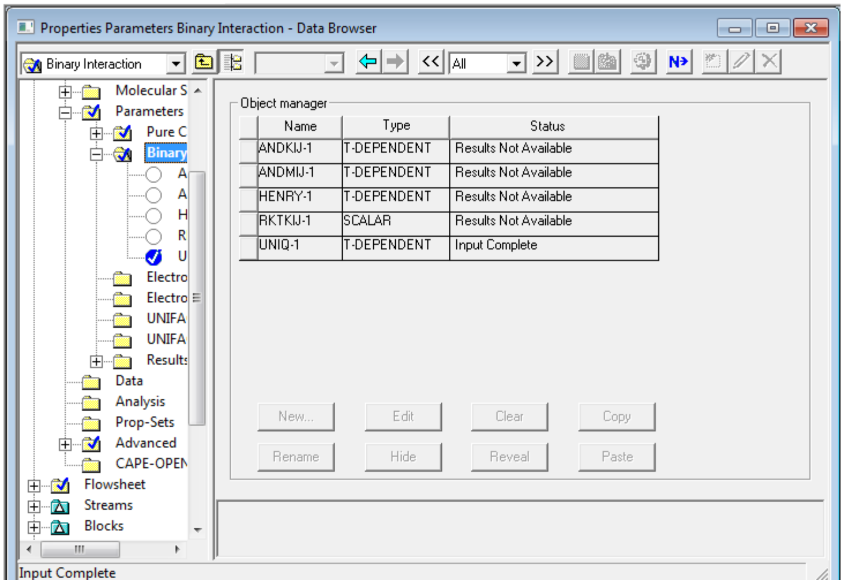


Figure C.1.9: Binary window in parameters tab.

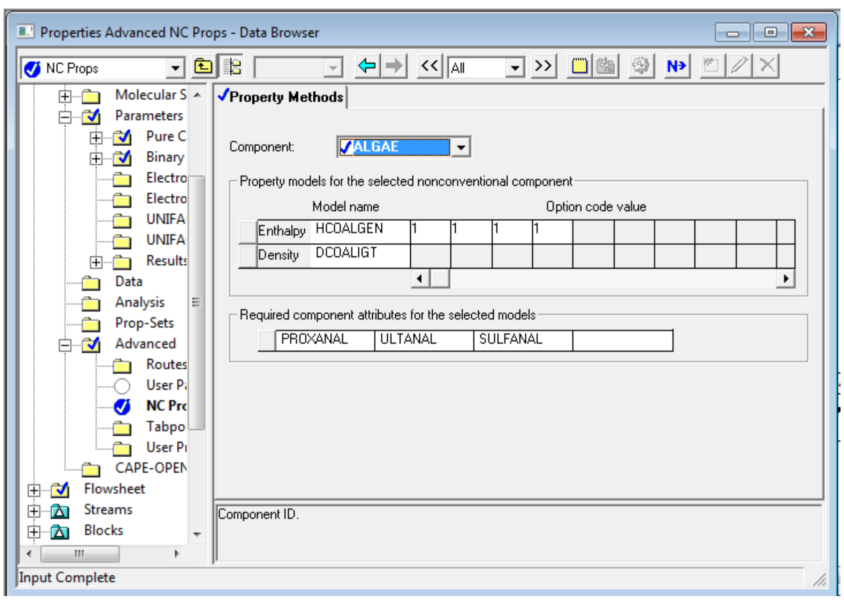


Figure C.1.10. Advance section in properties window (choose the methods of enthalpy and density calculation).

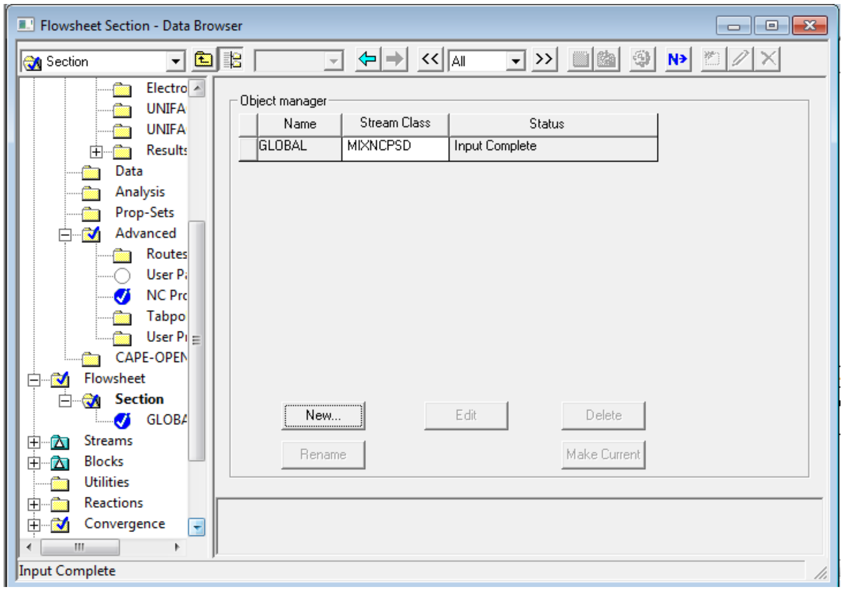


Figure C.1.11. Flowsheet window.

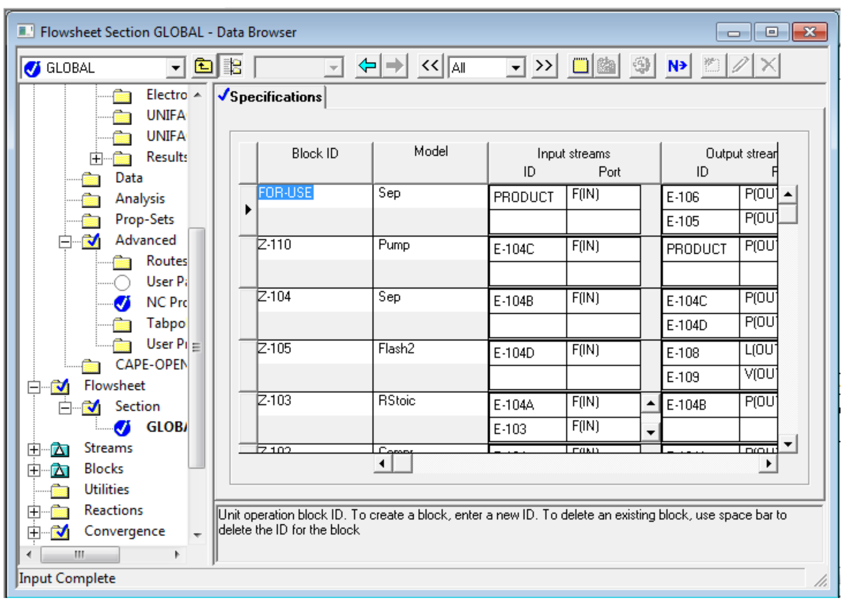


Figure C.1.12. Global Flowsheet window (here the connectivity can be verified).

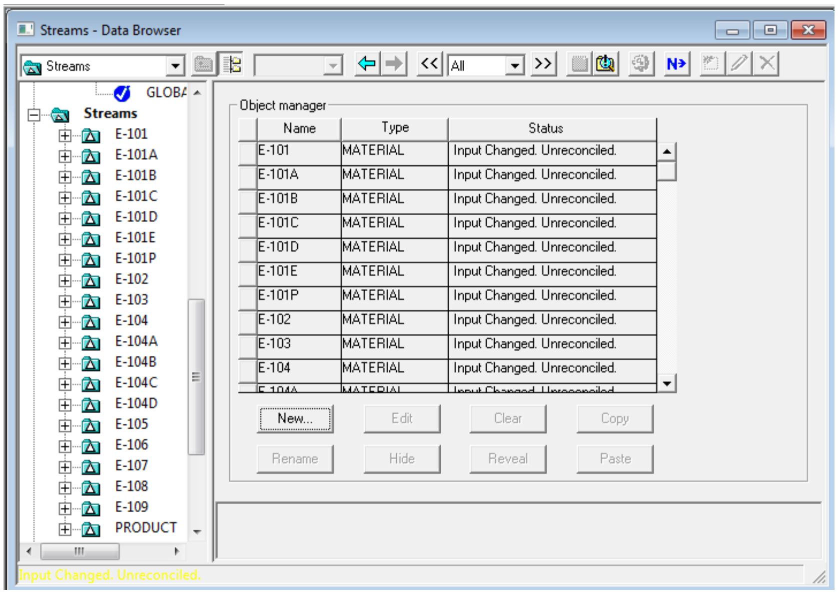


Figure C.1.13. Streams window (here are all the streams already named according to Case 3).

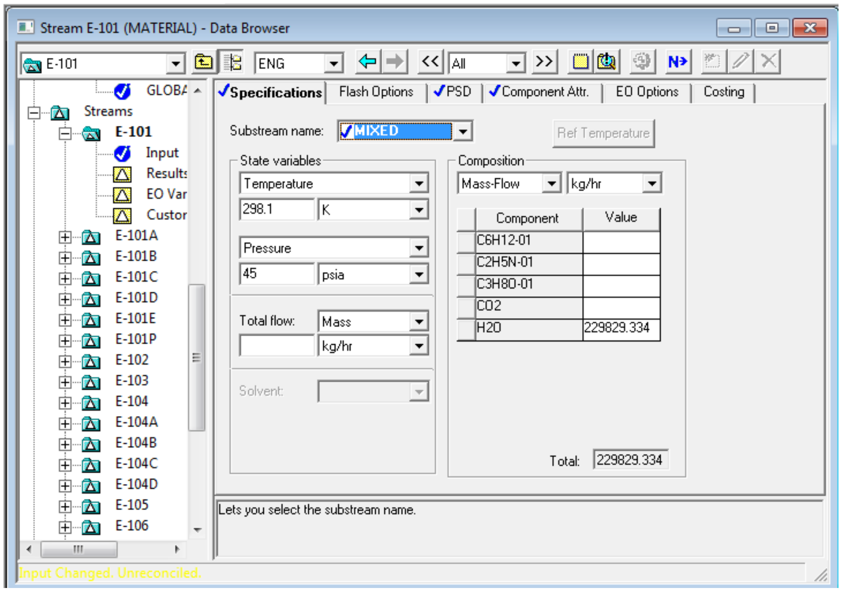


Figure C.1.14. E-101 mixed tab (inlet stream should be the only one defined).

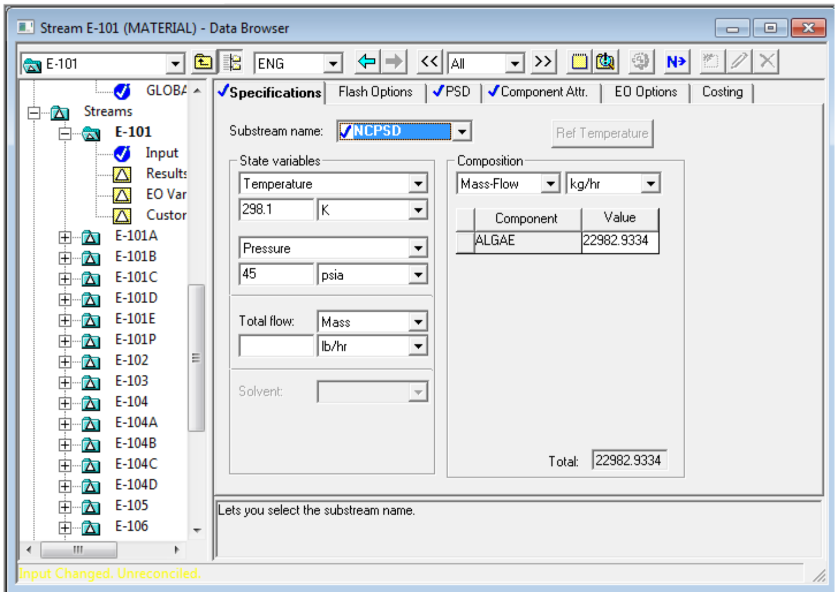
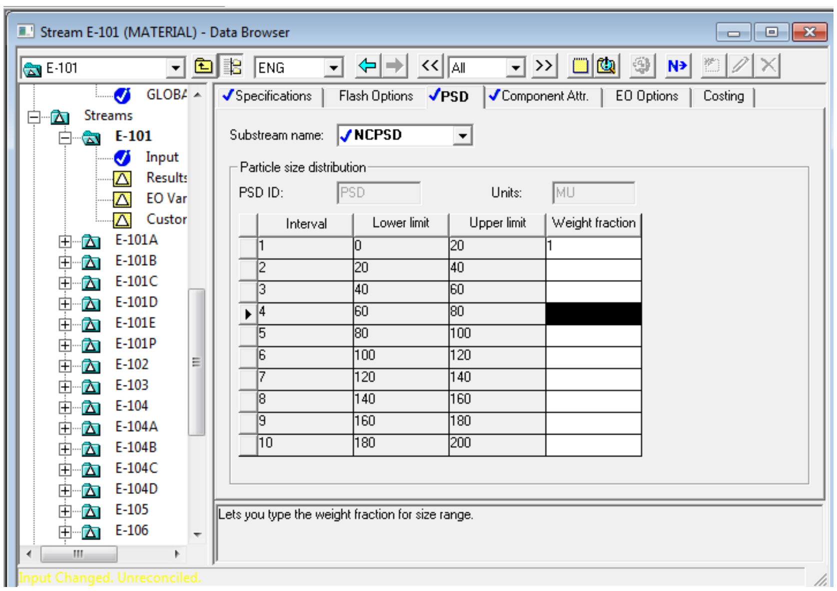


Figure C.1.15. E-101 nonconventional compound tab for microalgae (inlet stream should be the only one defined).



Interval	Lower limit	Upper limit	Weight fraction
1	0	20	1
2	20	40	
3	40	60	
4	60	80	
5	80	100	
6	100	120	
7	120	140	
8	140	160	
9	160	180	
10	180	200	

Figure C.1.16. Particle size distribution in E-101 (microalgae has between 10 µm to 30 µm).

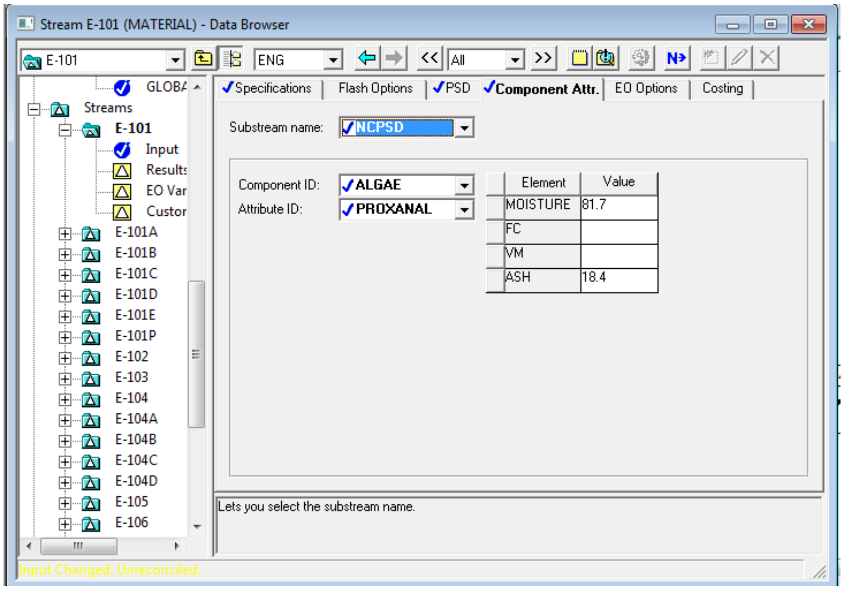


Figure C.1.17. E-101 Proxanal component properties for microalgae based on literature (sulfanal and ultanal component properties should be entered).

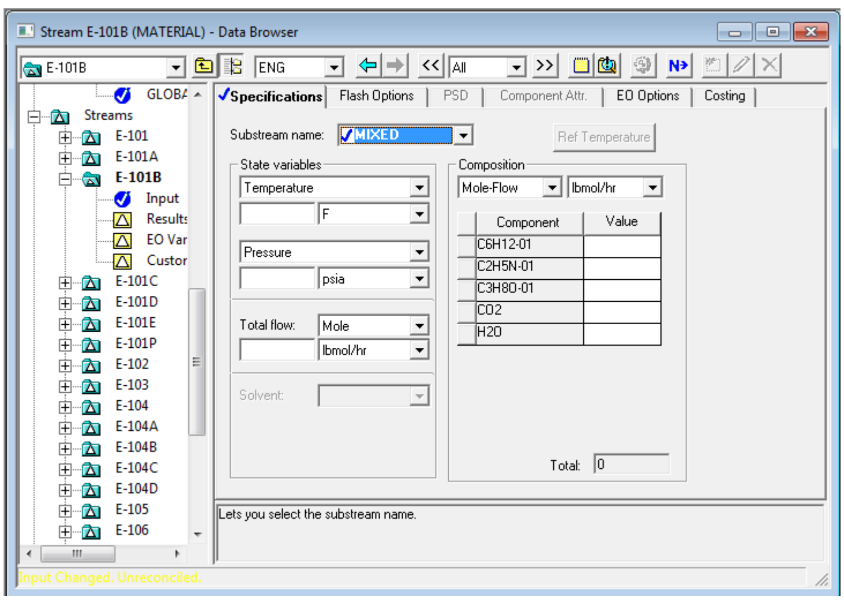


Figure C.1.18. Examples of other streams in the input (input should not be done).

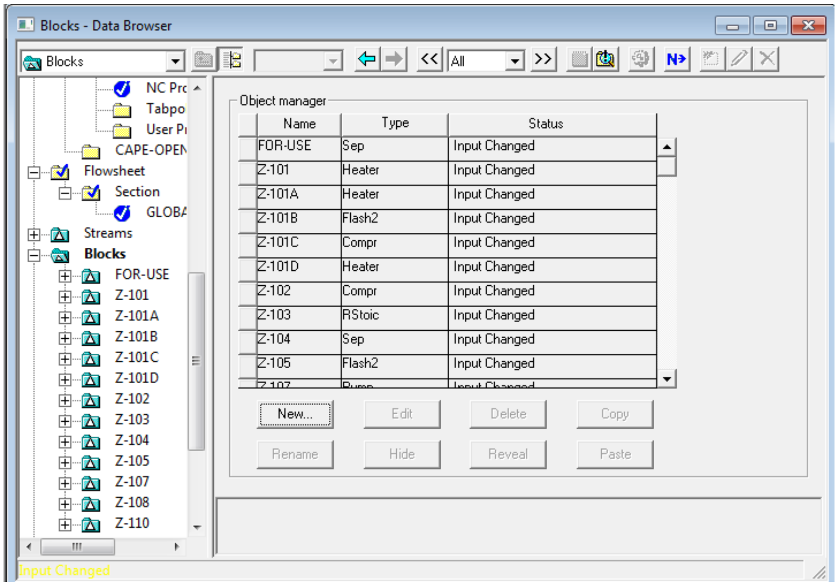


Figure C.1.19. Block window.

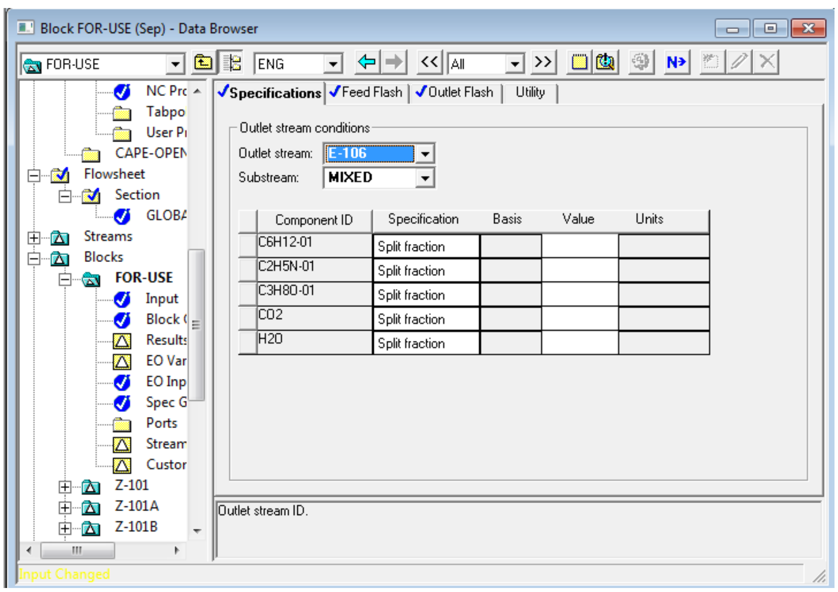


Figure C.1.20. FOR-USE Specification window for E-106.

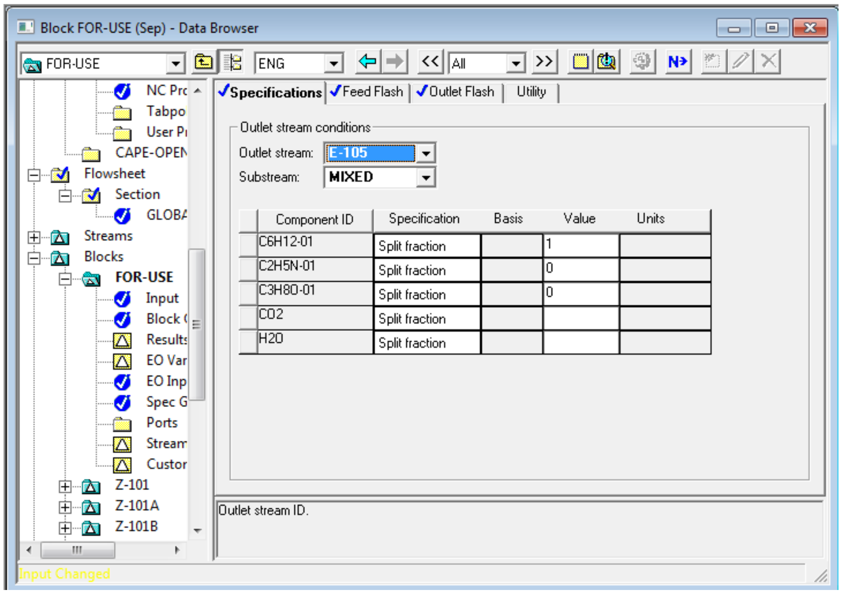


Figure C.1.21. FOR-USE Specification window for E-105.

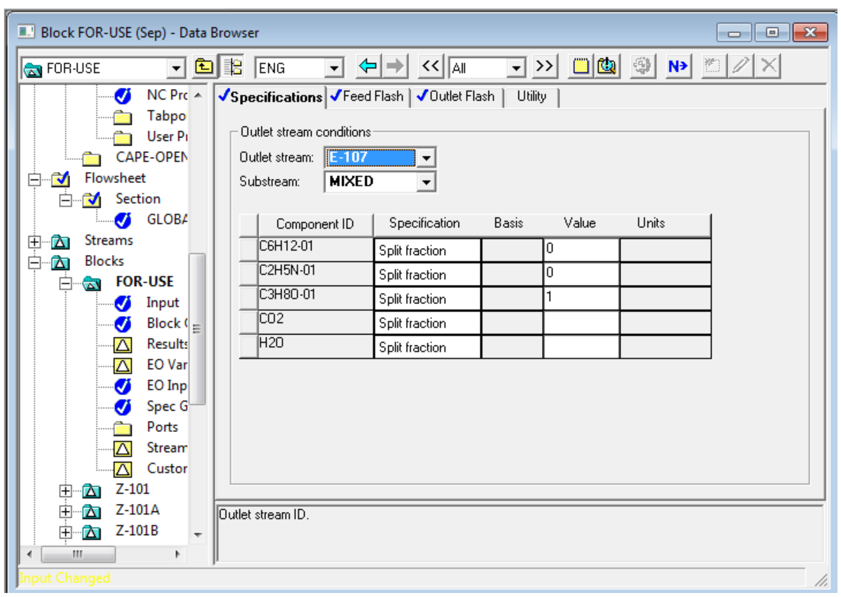


Figure C.1.22. FOR-USE Specification window for E-107.

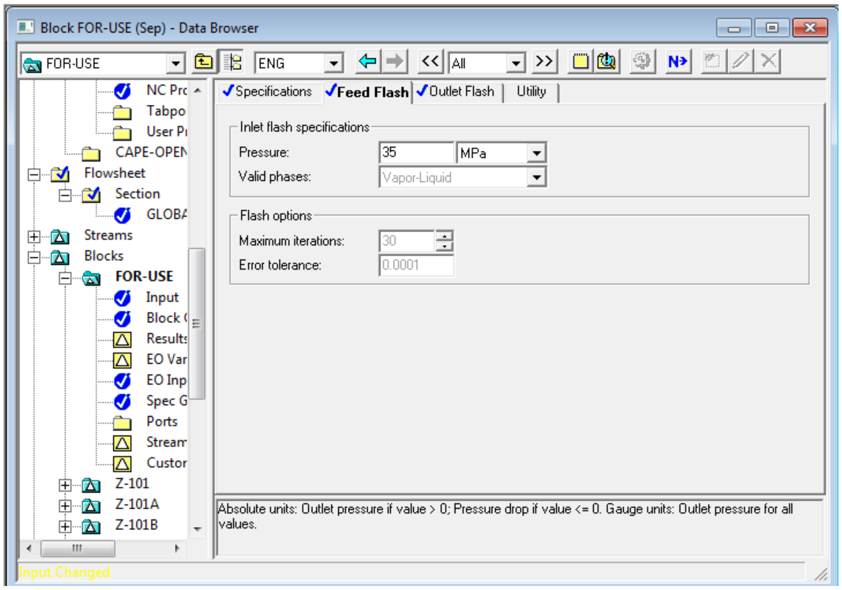


Figure C.1.23. FOR-USE feed flash window.

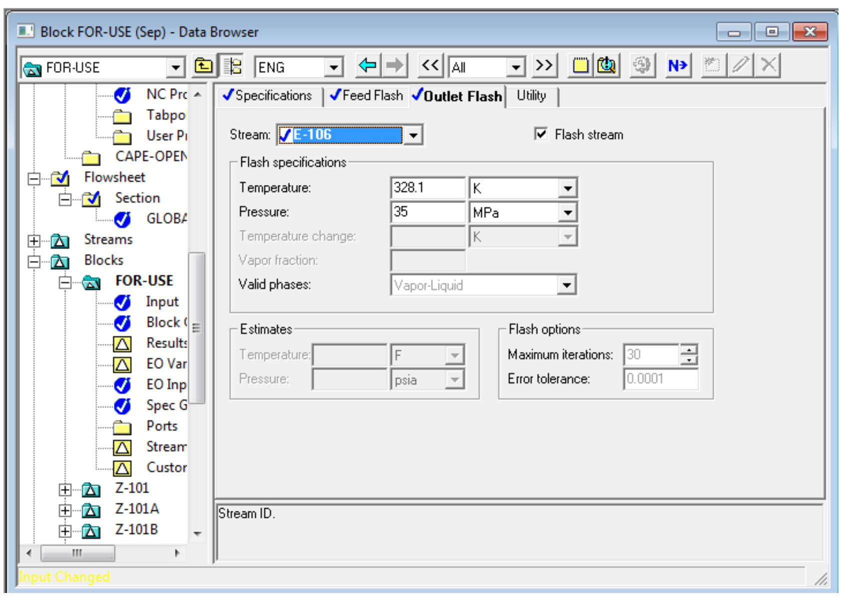


Figure C.1.24. FOR-USE outlet flash window for E-106.

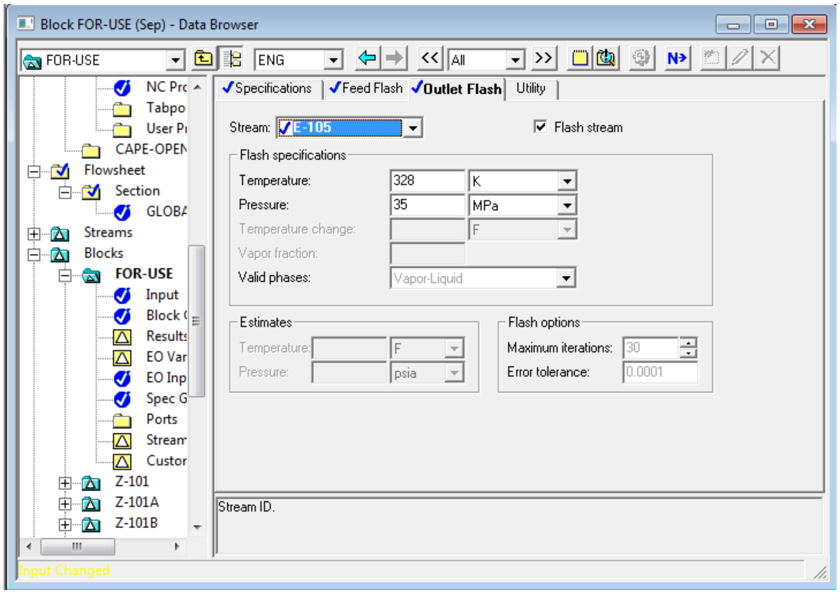


Figure C.1.25. FOR-USE outlet flash window for E-105.

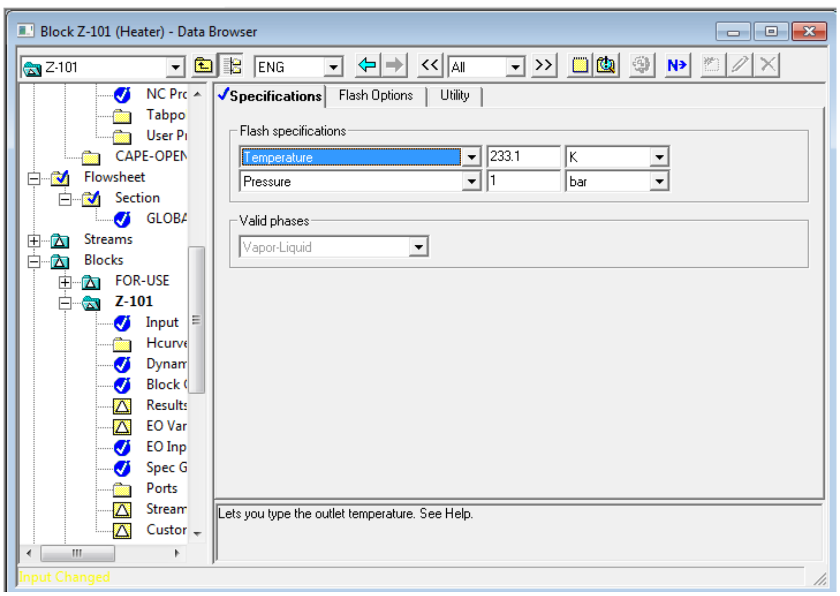


Figure C.1.26: Z-101 Specifications window.

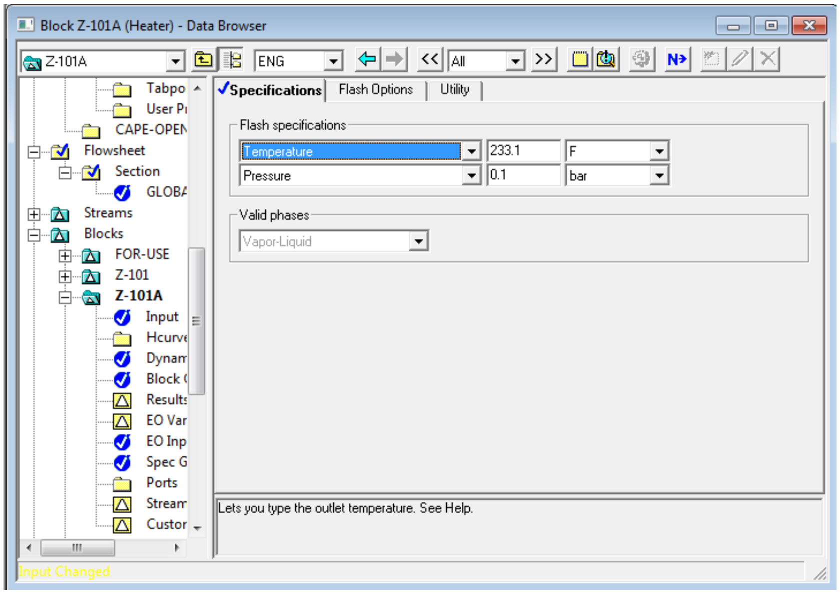


Figure C.1.27. Z-101A Specifications window.

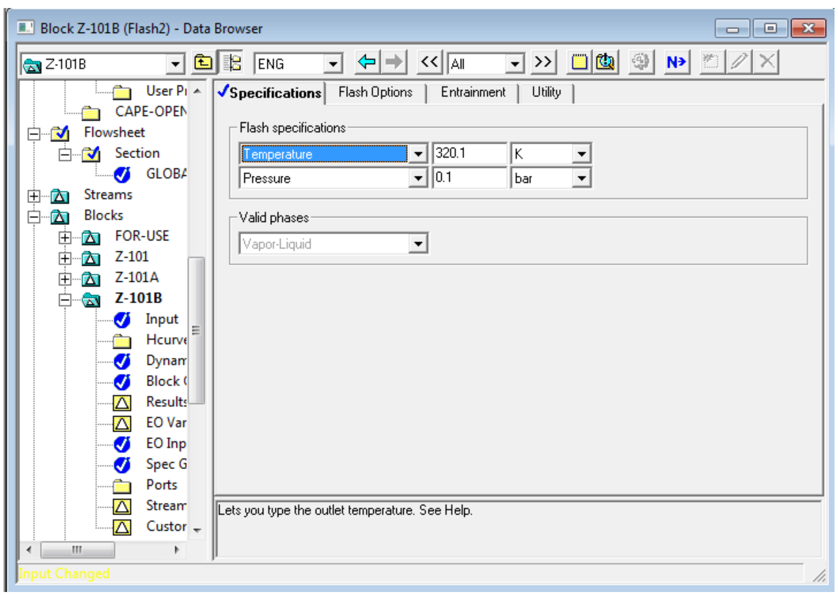


Figure C.1.28. Z-101B Specifications window.

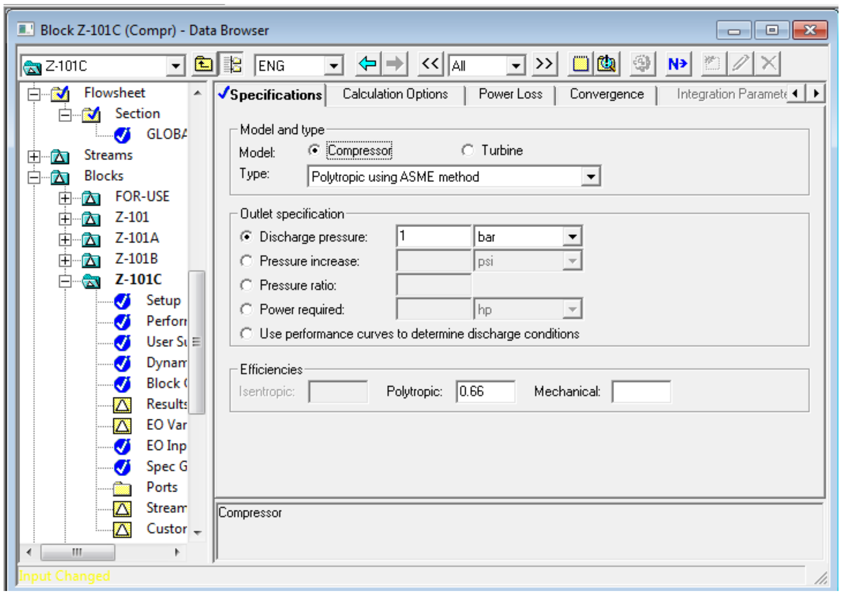


Figure C.1.29. Z-101C Specifications window.

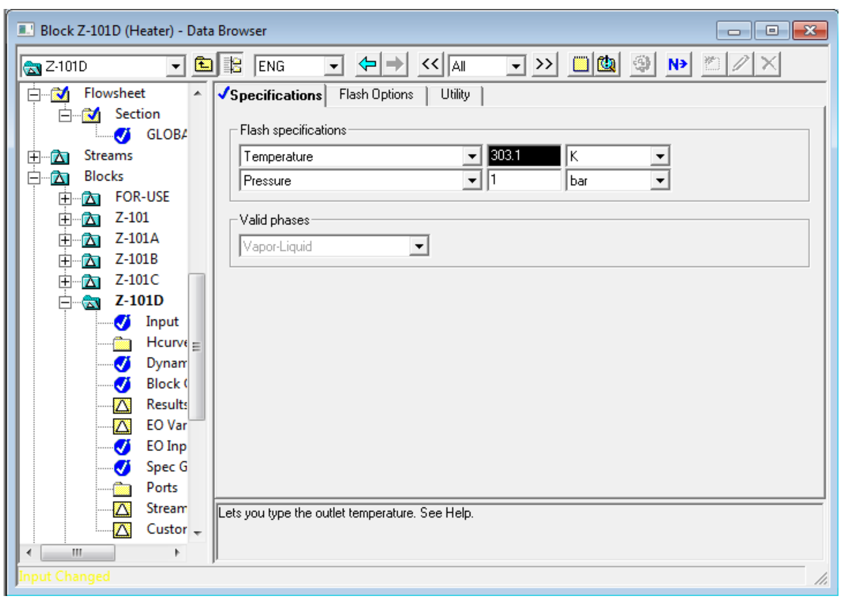


Figure C.1.30. Z-101D Specifications window.

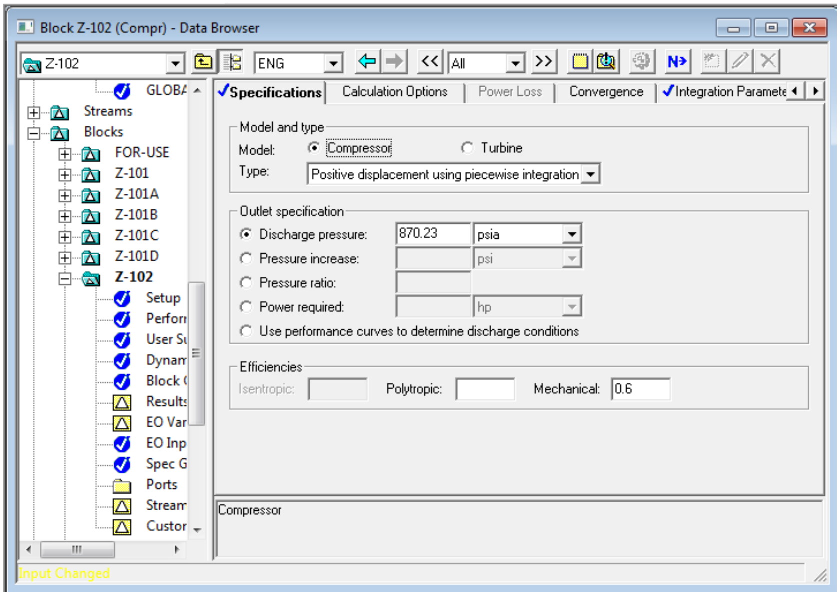


Figure C.1.31. Z-102 Specifications window.

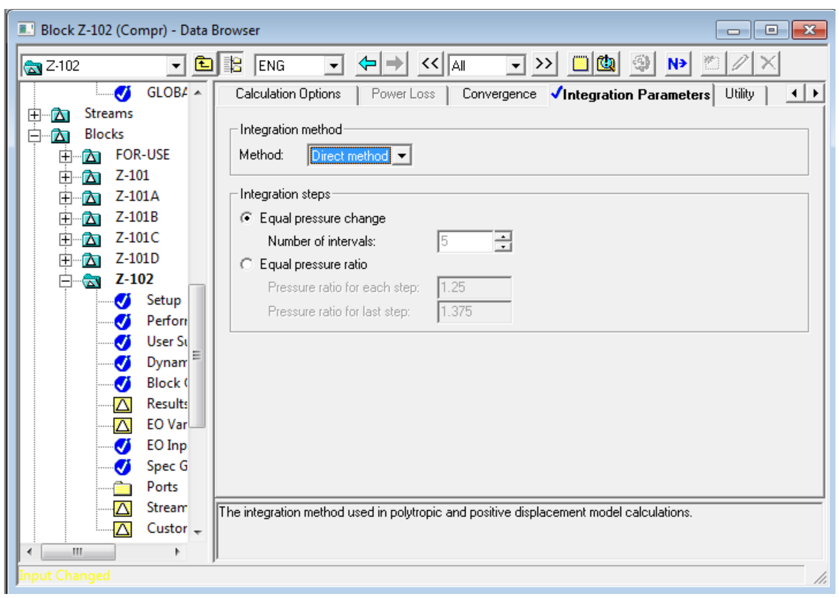


Figure C.1.32. Z-101 Integration parameters window.

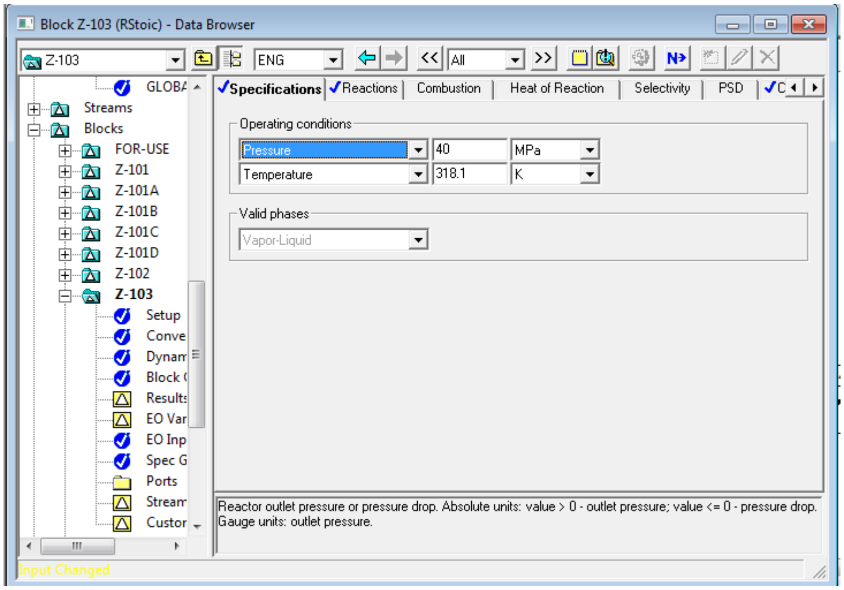


Figure C.1.33. Z-103 Specifications window.

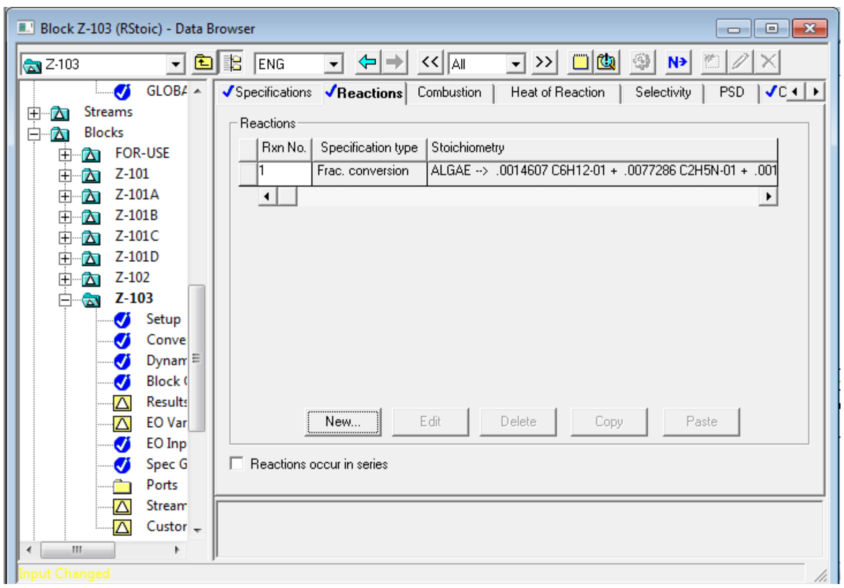


Figure C.1.34. Z-103 Reaction parameters window.

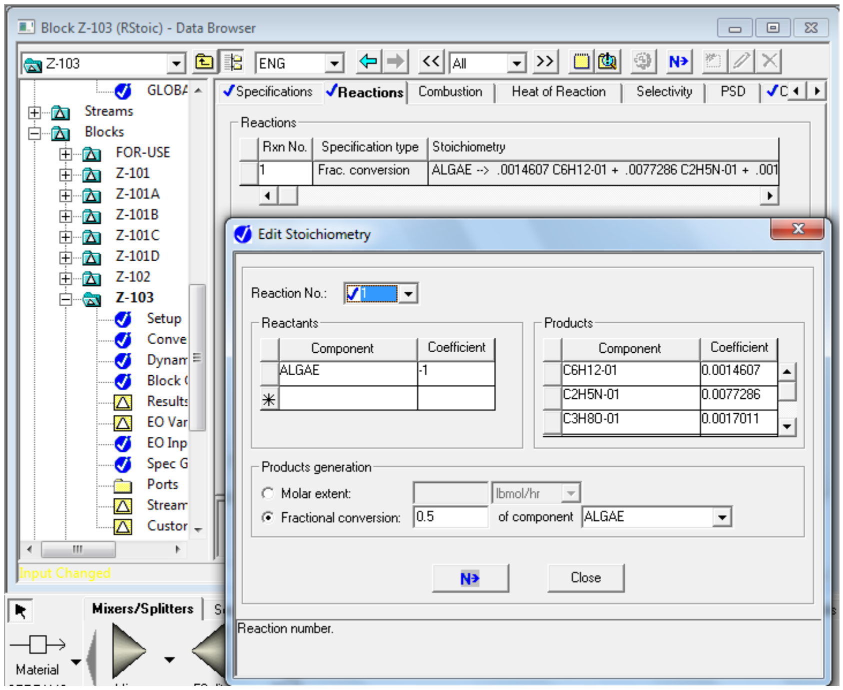


Figure C.1.35. Z-103 reaction editor window (all parameters are based on Appendix A using the molecular weights provided by ASPEN).

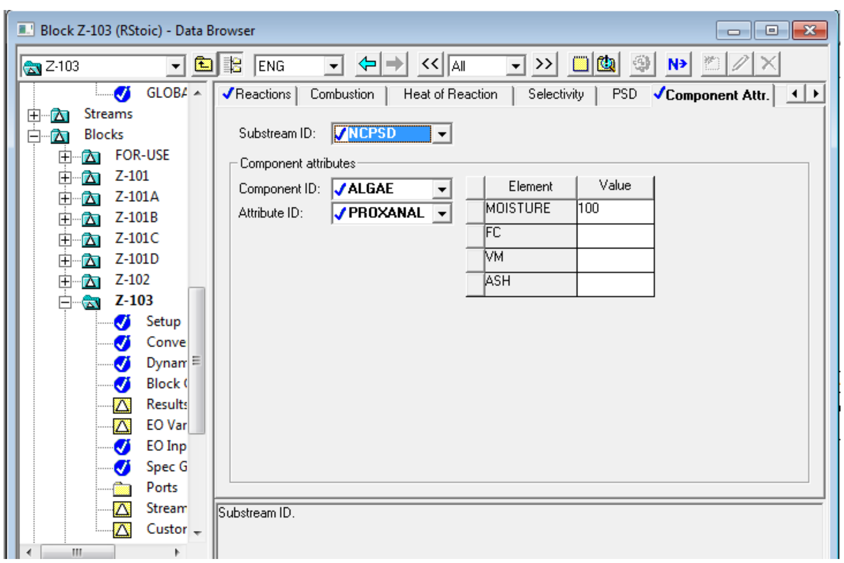


Figure C.1.36. Z-103 Component attributes window

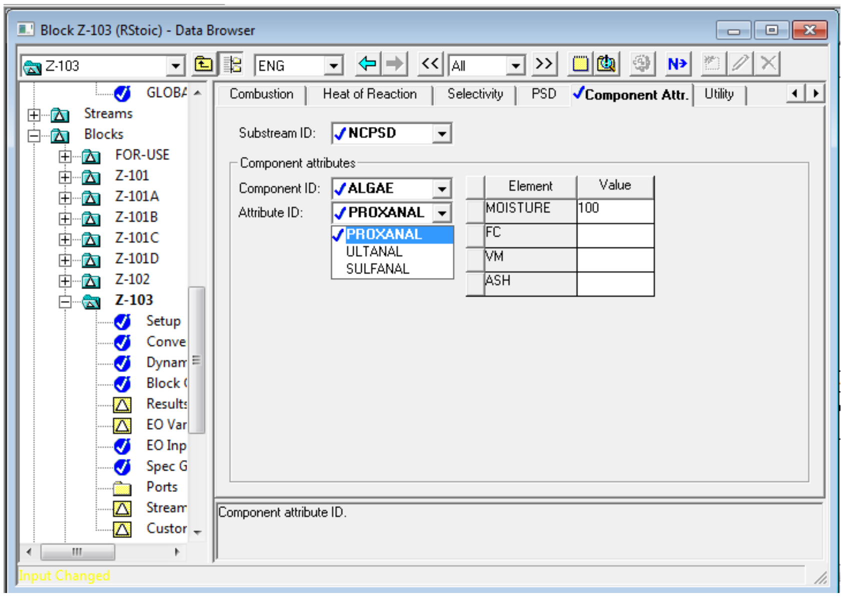


Figure C.1.37. Z-103 Component attribute window (ultanal and sulfanal need not to be specified).

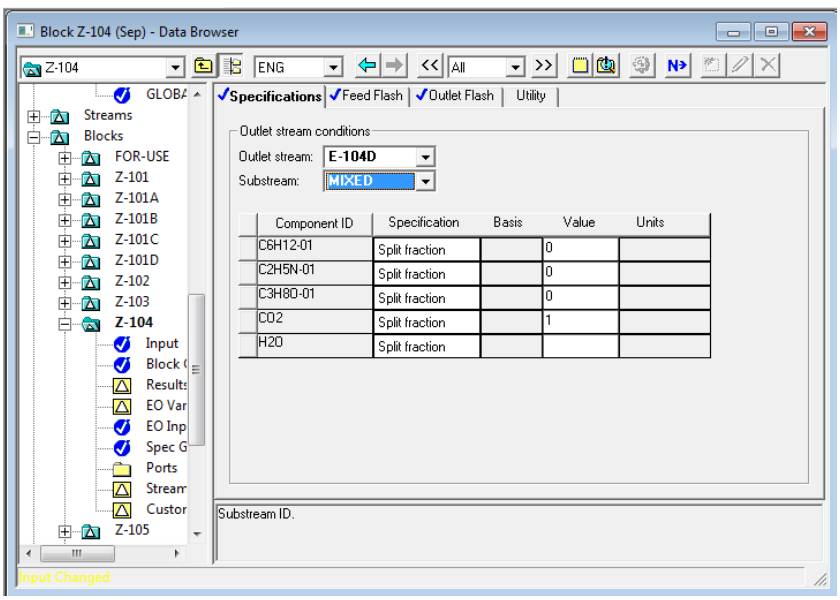


Figure C.1.38. Z-104 Specifications window for E-104D.

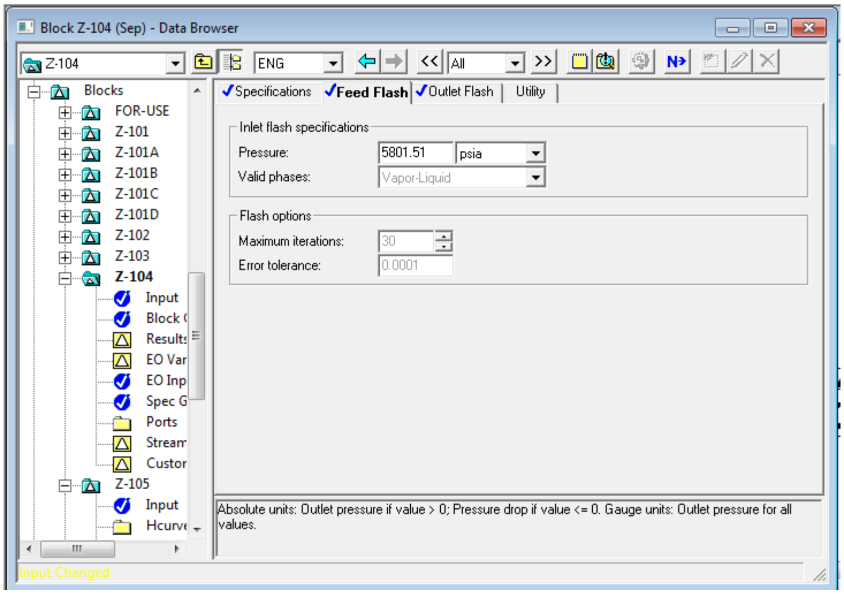


Figure C.1.39. Z-104 feed flash window.

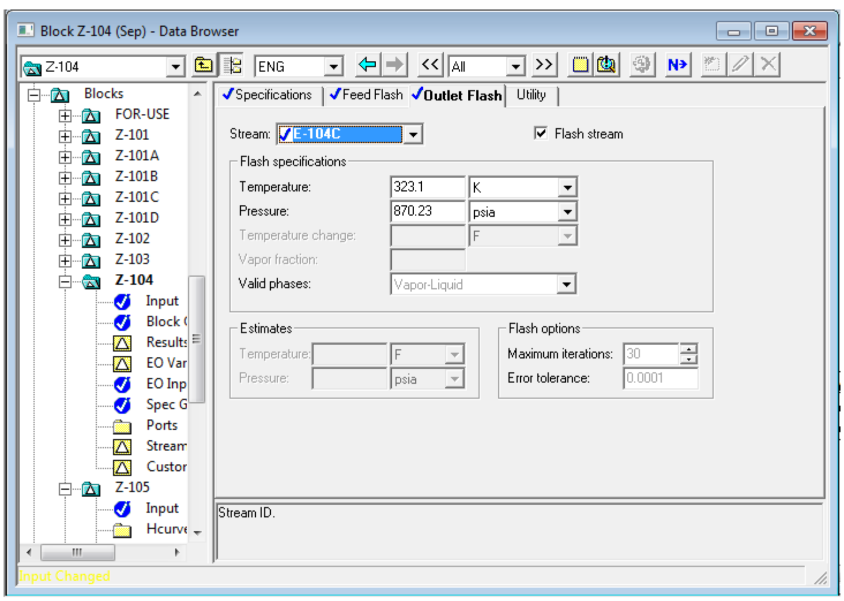


Figure C.1.40. Z-104 outlet window for E-104C.

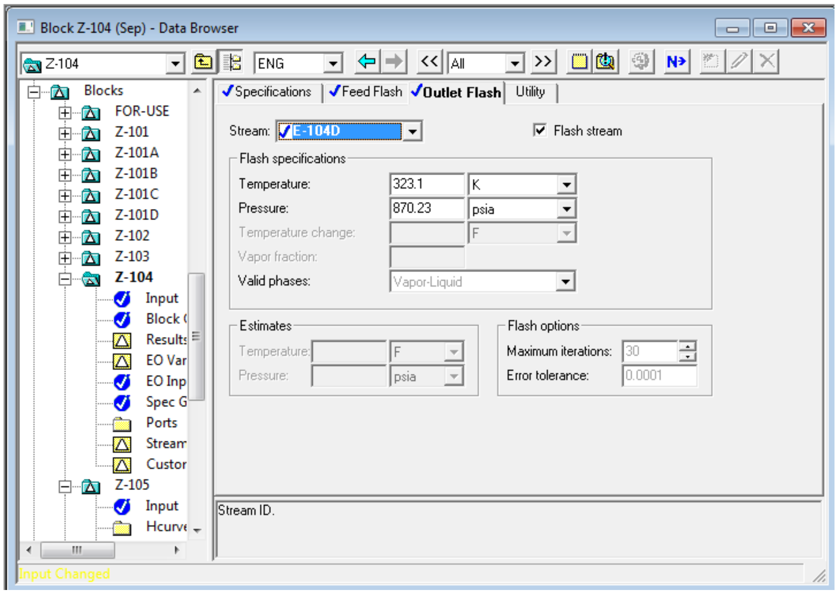


Figure C.1.41. Z-104 outlet window for E-104D.

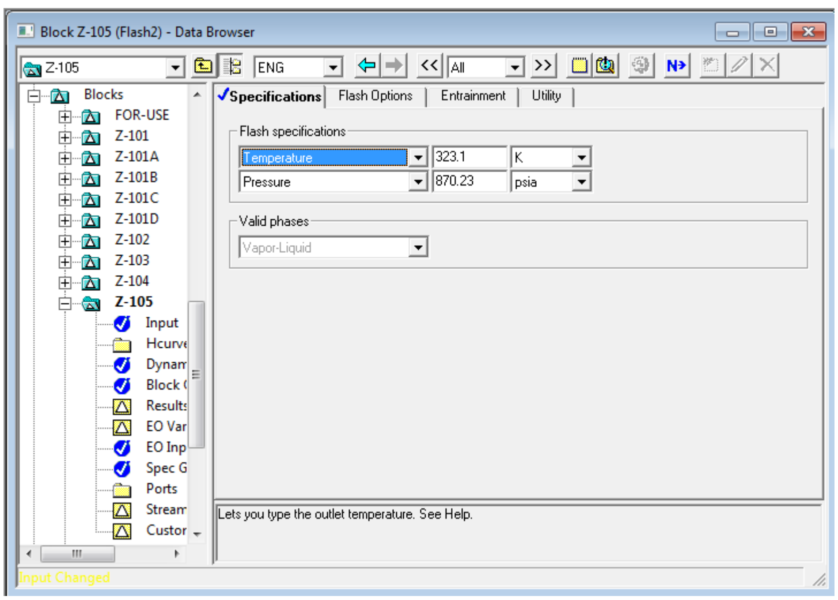


Figure C.1.42. Z-105 Specification window.

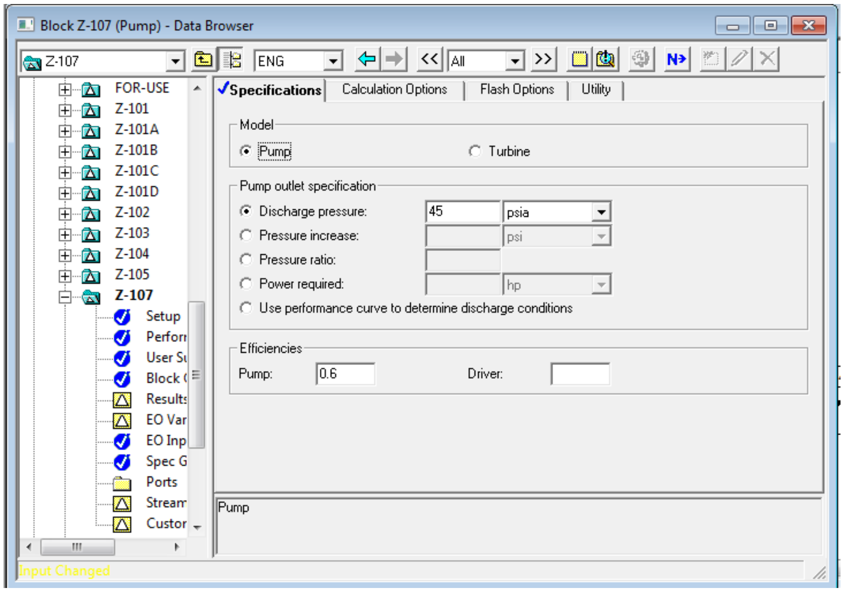


Figure C.1.43. Z-107 Specification window.

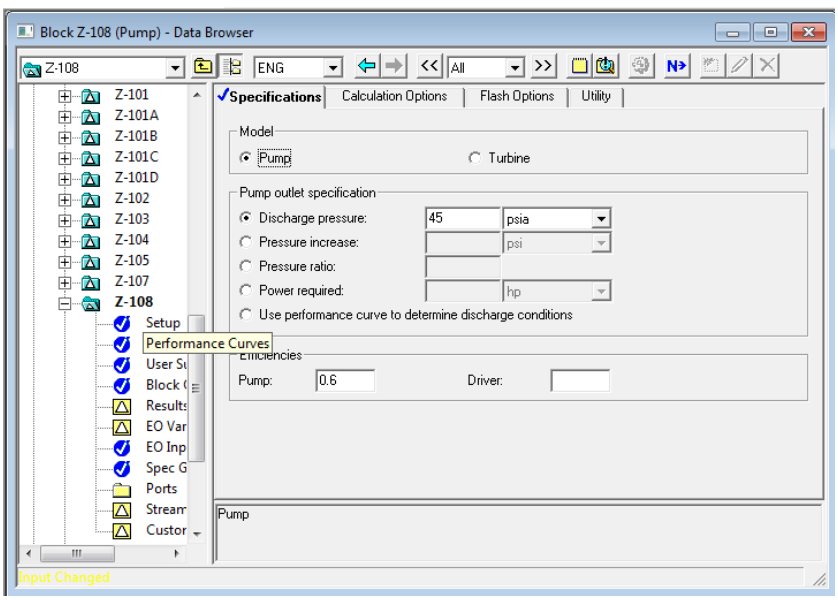


Figure C.1.44. Z-108 Specification window.

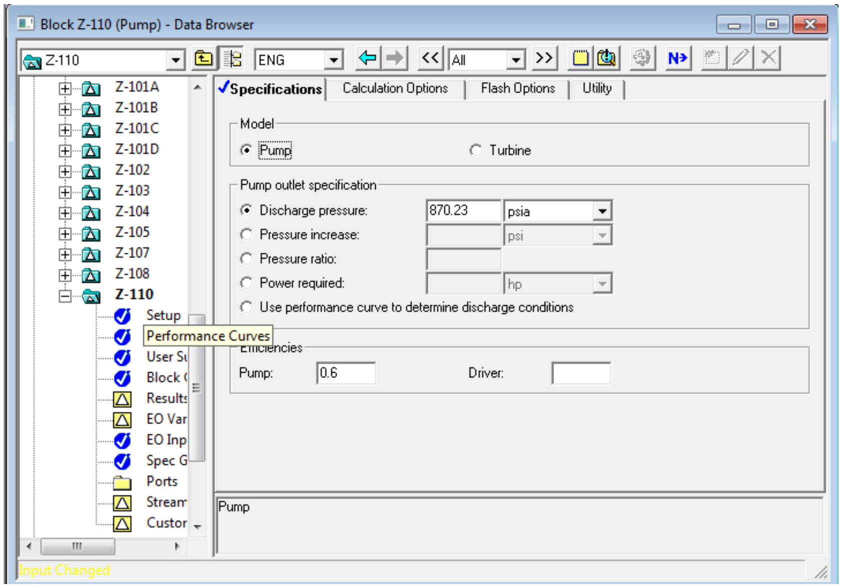


Figure C.1.45. Z-110 Specification window.

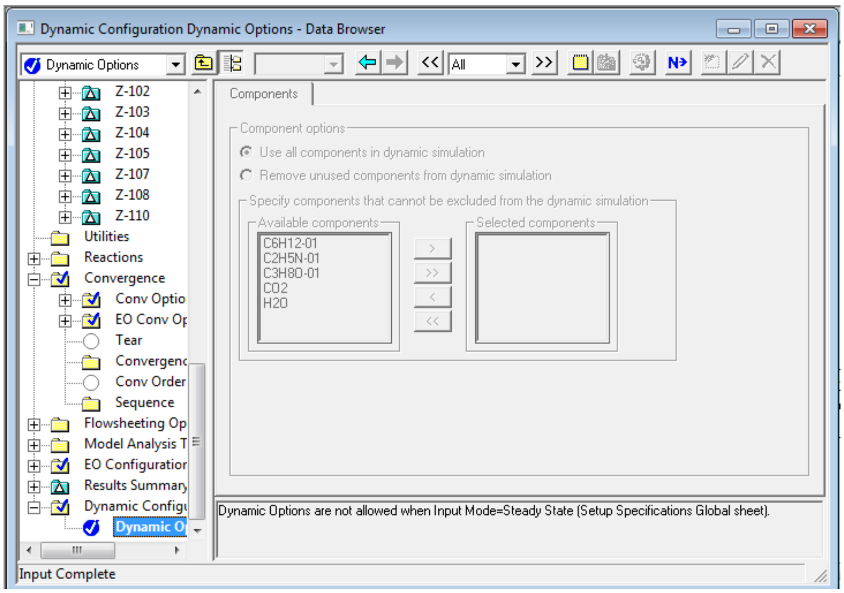


Figure C.1.46. Dynamic window.

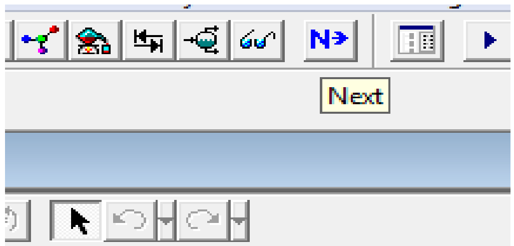


Figure C.1.47. Next icon (use next after overall or section input is completed, to run the simulation click next).

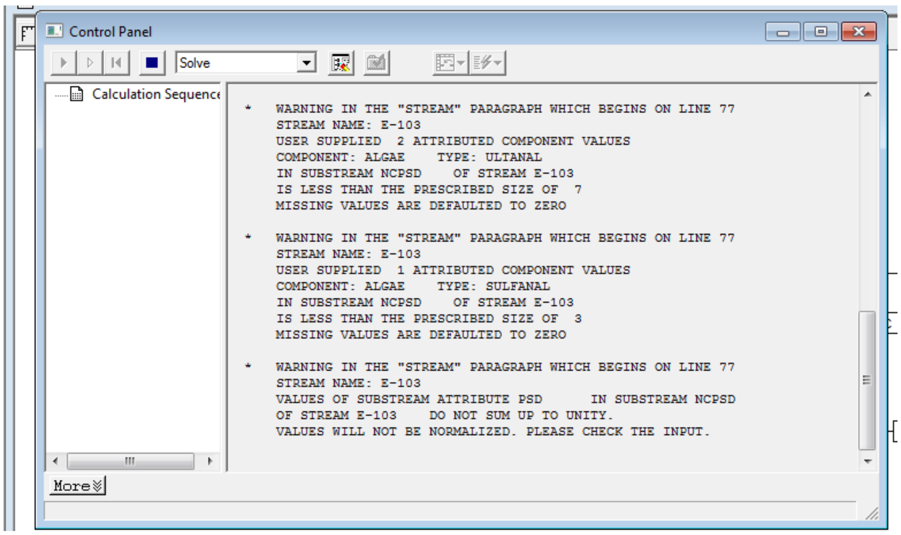


Figure C.1.48. Normal warning (ASPEN advices that some parameters were not specified. This is more at the discretion of the person doing the simulation).

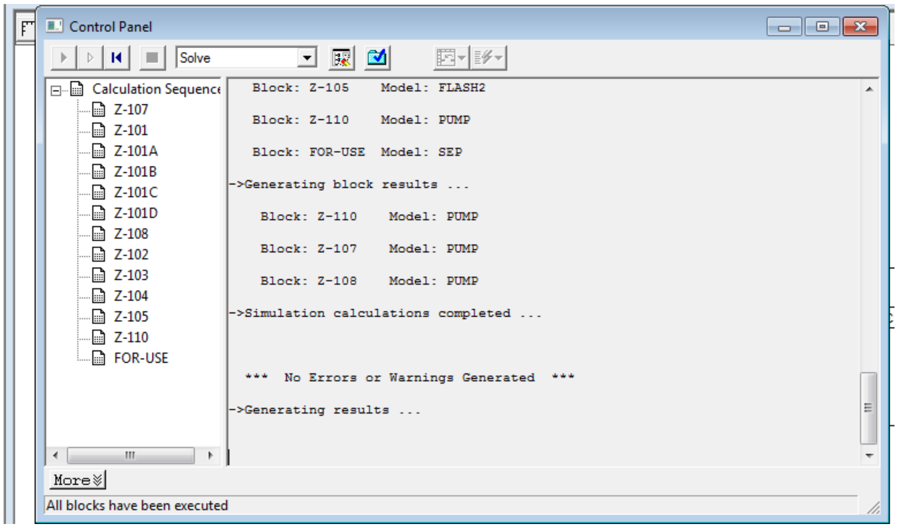


Figure C.1.49. Final output (this is normal output indicating that simulations wre run with errors or warnings. Errors or warning should be corrected).

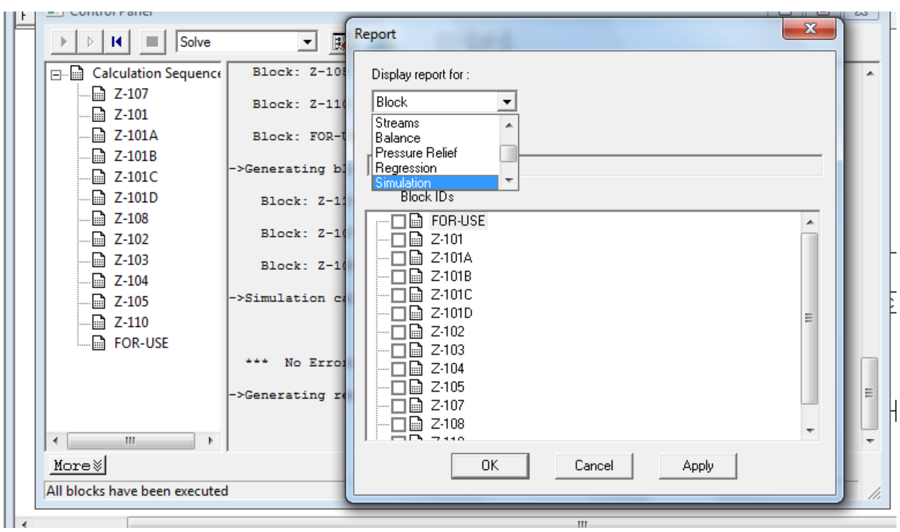


Figure C.1.50. Report generation window (after simulation runs, press Crlt, Alt, Delete and choose simulation).

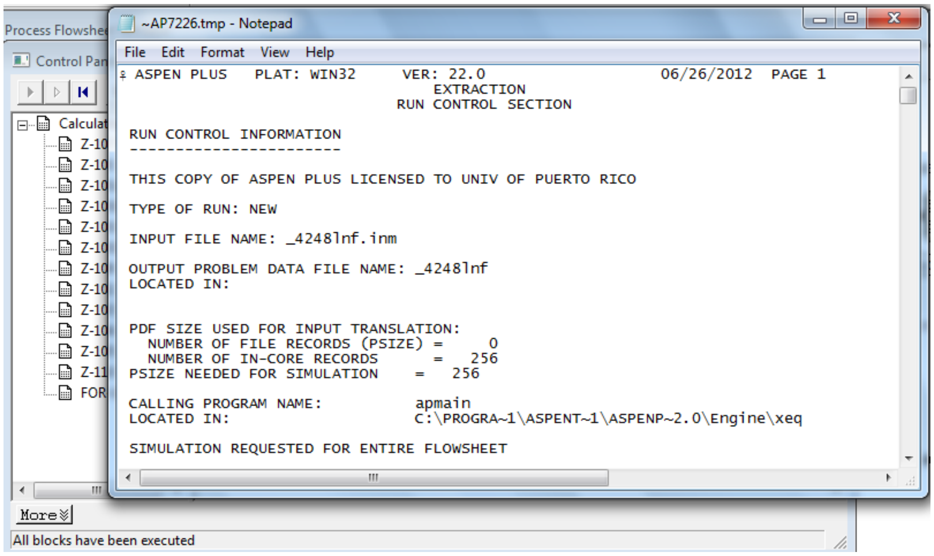


Figure C.1.51. ASPEN simulation report (where the information is used for validation purposes).

C.2 - ASPEN simulation outputs

Figures C.2.1 to C.2.5 are the summary output obtained from ASPEN ONE simulator. For illustrative purposes, the figures appear separated in different sub-sections C.2.1 to C.2.5.

C.2.1 - APEN Plus simulator output for Case Scenario 1

```
ASPEN PLUS   PLAT: WIN32     VER: 22.0                  06/01/2012   PAGE 1
                                  EXTRACTION
                              RUN CONTROL SECTION

 RUN CONTROL INFORMATION
 -----------------------

 THIS COPY OF ASPEN PLUS LICENSED TO UNIV OF PUERTO RICO

 TYPE OF RUN: NEW

 INPUT FILE NAME: _1218zrm.inm

 OUTPUT PROBLEM DATA FILE NAME: _5138nrg
 LOCATED IN:


 PDF SIZE USED FOR INPUT TRANSLATION:
   NUMBER OF FILE RECORDS (PSIZE) =     0
   NUMBER OF IN-CORE RECORDS      =   256
 PSIZE NEEDED FOR SIMULATION      =     1

 CALLING PROGRAM NAME:          apmain
 LOCATED IN:                    C:\PROGRA~1\ASPENT~1\ASPENP~2.0\Engine\xeq

 SIMULATION REQUESTED FOR ENTIRE FLOWSHEET

 DESCRIPTION
 -----------

        VESION ANTERIOR 19 WAS SIMULATED WITH THREE LITTLE
        REPREESENTATIVES. TOD AY A MASS OF ALGAE WILL BE ADJUSTED TO RUN
        WITH NORMALIZED THESE COMPOUN S. THIS APPLIES CASE 1-5. (14688.34
        TO 2982.93)
ASPEN PLUS   PLAT: WIN32     VER: 22.0                  06/01/2012   PAGE 2
                                  EXTRACTION
                              FLOWSHEET SECTION
```

Figure C.2.1. ASPEN print out for Case Scenario 1

```
ASPEN PLUS   PLAT: WIN32     VER: 22.0                  06/01/2012   PAGE 2
                                  EXTRACTION
                              FLOWSHEET SECTION

 FLOWSHEET CONNECTIVITY BY STREAMS
 ---------------------------------

   STREAM     SOURCE     DEST           STREAM     SOURCE     DEST
   E-111      ----       Z-104          E-104      ----       P-101
   E-113      FOR-USE    ----           E-112      FOR-USE    ----
   E-114      FOR-USE    ----           PRODUCT    P-110      FOR-USE
   E-111OIL   Z-106      P-110          E-111CO2   Z-106      Z-108
   E-116      Z-108      ----           E-115      Z-108      ----
   E-111SEP   Z-105      Z-106          E-111SCF   Z-104      Z-105
   E-106P     Z-101      P-105          E-105P     Z-101      P-104
   E-106      P-105      Z-102          E-107P     Z-102      P-106
   E-108P     Z-102      P-107          E-109P     Z-103      P-108
   E-110P     Z-103      P-109          E-104P     P-101      Z-101
   E-105      P-104      ----           E-107      P-106      ----
   E-108      P-107      Z-103          E-109      P-108      ----
   E-110      P-109      Z-105

 FLOWSHEET CONNECTIVITY BY BLOCKS
 --------------------------------

   BLOCK        INLETS                         OUTLETS
   FOR-USE      PRODUCT                        E-113 E-112 E-114
   P-110        E-111OIL                       PRODUCT
   Z-106        E-111SEP                       E-111OIL E-111CO2
   Z-108        E-111CO2                       E-116 E-115
   Z-105        E-111SCF E-110                 E-111SEP
   Z-104        E-111                          E-111SCF
   Z-101        E-104P                         E-106P E-105P
   P-105        E-106P                         E-106
   Z-102        E-106                          E-107P E-108P
   Z-103        E-108                          E-109P E-110P
   P-101        E-104                          E-104P
   P-104        E-105P                         E-105
   P-106        E-107P                         E-107
   P-107        E-108P                         E-108
   P-108        E-109P                         E-109
   P-109        E-110P                         E-110
```

(*Figure C.2.1: Continue*)

```
COMPUTATIONAL SEQUENCE
----------------------

SEQUENCE USED WAS:
   P-101 Z-101 P-105 Z-102 P-106 P-107 Z-103 P-108 P-104 P-109 Z-104 Z-105
   Z-106 Z-108 P-110 FOR-USE

OVERALL FLOWSHEET BALANCE
-------------------------
ASPEN PLUS    PLAT: WIN32      VER: 22.0                     06/01/2012   PAGE 3
                                  EXTRACTION
                               FLOWSHEET SECTION

OVERALL FLOWSHEET BALANCE (CONTINUED)

                     ***  MASS AND ENERGY BALANCE   ***
                                          IN              OUT          RELATIVE DIFF.
   CONVENTIONAL COMPONENTS (LBMOL/HR)
      C6H12-01                        0.00000         37.0059         -1.00000
      C2H5N-01                        0.00000         195.799         -1.00000
      C3H8O-01                        0.00000         43.0963         -1.00000
      CO2                             20904.4         20904.4          0.00000
      H2O                             2812.54         2812.54          0.161686E-15
   SUBTOTAL(LBMOL/HR)                 23717.0         23992.9         -0.114993E-01
           (LB/HR    )                970669.         996003.         -0.254356E-01
   NON-CONVENTIONAL COMPONENTS (LB/HR    )
      ALGAE                           50668.7         25334.3          0.500000
   SUBTOTAL(LB/HR    )                50668.7         25334.3          0.500000
   TOTAL BALANCE
      MASS(LB/HR    )               0.102134E+07    0.102134E+07     0.413688E-06
      ENTHALPY(BTU/HR   )          -0.420976E+10   -0.411995E+10    -0.213328E-01
ASPEN PLUS    PLAT: WIN32      VER: 22.0                     06/01/2012   PAGE 4
                                  EXTRACTION
                           PHYSICAL PROPERTIES SECTION
```

(*Figure C.2.1: Continue*)

```
COMPONENTS
----------

 ID         TYPE  FORMULA        NAME OR ALIAS                          REPORT NAME
  C6H12-01 C      C6H12O6          C6H12O6                                C6H12-01
  C2H5N-01 C      C2H5NO2-D1       C2H5NO2-D1                             C2H5N-01
  C3H8O-01 C      C3H8O3           C3H8O3                                 C3H8O-01
  CO2       C     CO2              CO2                                    CO2
  ALGAE     NC                     MISSING                                ALGAE
  H2O       C     H2O              H2O                                    H2O

 ID               ATTRIBUTE TYPES
  ALGAE            PROXANAL ULTANAL SULFANAL
ASPEN PLUS    PLAT: WIN32      VER: 22.0                     06/01/2012   PAGE 5
                                  EXTRACTION
                               U-O-S BLOCK SECTION

BLOCK:  FOR-USE  MODEL: SEP
---------------------------
  INLET STREAM:           PRODUCT
  OUTLET STREAMS:         E-113       E-112       E-114
  PROPERTY OPTION SET:    UNIQUAC     UNIQUAC / IDEAL GAS

                     ***  MASS AND ENERGY BALANCE   ***
                                          IN              OUT          RELATIVE DIFF.
     CONV. COMP.(LBMOL/HR)            275.901         275.901          0.00000
                (LB/HR    )           25333.9         25333.9          0.00000
     NONCONV. COMP(LB/HR    )         0.00000         0.00000          0.00000
   TOTAL BALANCE
     MASS(LB/HR    )                  25333.9         25333.9          0.00000
     ENTHALPY(BTU/HR   )           -0.742263E+08   -0.741089E+08    -0.158168E-02
```

(*Figure C.2.1: Continue*)

```
                        ***  INPUT DATA  ***

  INLET PRESSURE   PSIA                                     5,076.32

  FLASH SPECS FOR STREAM E-113
  TWO    PHASE  TP  FLASH
  SPECIFIED TEMPERATURE F                                  130.910
  SPECIFIED PRESSURE    PSIA                             5,076.32
  MAXIMUM NO. ITERATIONS                                    30
  CONVERGENCE TOLERANCE                                      0.000100000

  FLASH SPECS FOR STREAM E-112
  TWO    PHASE  TP  FLASH
  SPECIFIED TEMPERATURE F                                  130.730
  SPECIFIED PRESSURE    PSIA                             5,076.32
  MAXIMUM NO. ITERATIONS                                    30
  CONVERGENCE TOLERANCE                                      0.000100000

  FLASH SPECS FOR STREAM E-114
  TWO    PHASE  TP  FLASH
  SPECIFIED TEMPERATURE F                                  130.910
  SPECIFIED PRESSURE    PSIA                             5,076.32
  MAXIMUM NO. ITERATIONS                                    30
  CONVERGENCE TOLERANCE                                      0.000100000
ASPEN PLUS   PLAT: WIN32     VER: 22.0                    06/01/2012   PAGE 6
                                 EXTRACTION
                             U-O-S BLOCK SECTION

BLOCK:  FOR-USE  MODEL: SEP (CONTINUED)

  FRACTION OF FEED
    SUBSTREAM= MIXED
      STREAM= E-112     CPT= C6H12-01  FRACTION=           1.00000
                             C2H5N-01                      0.0
                             C3H8O-01                      0.0
      STREAM= E-114     CPT= C6H12-01  FRACTION=           0.0
                             C2H5N-01                      0.0
                             C3H8O-01                      1.00000
```

(*Figure C.2.1: Continue*)

```
                           ***  RESULTS  ***

  HEAT DUTY              BTU/HR                                  0.11740E+06

 COMPONENT = C6H12-01
   STREAM      SUBSTREAM     SPLIT FRACTION
   E-112       MIXED                  1.00000

 COMPONENT = C2H5N-01
   STREAM      SUBSTREAM     SPLIT FRACTION
   E-113       MIXED                  1.00000

 COMPONENT = C3H8O-01
   STREAM      SUBSTREAM     SPLIT FRACTION
   E-114       MIXED                  1.00000

BLOCK:  P-101    MODEL: PUMP
-----------------------------
  INLET STREAM:             E-104
  OUTLET STREAM:            E-104P
  PROPERTY OPTION SET:      UNIQUAC   UNIQUAC / IDEAL GAS

                    ***  MASS AND ENERGY BALANCE  ***
                                 IN              OUT         RELATIVE DIFF.
     CONV. COMP.(LBMOL/HR)      2812.54        2812.54          0.00000
                (LB/HR    )     50668.7        50668.7          0.00000
     NONCONV. COMP(LB/HR   )    50668.7        50668.7          0.00000
   TOTAL BALANCE
     MASS(LB/HR    )            101337.        101337.          0.00000
     ENTHALPY(BTU/HR  )      -0.673825E+09  -0.673825E+09       0.00000
ASPEN PLUS   PLAT: WIN32     VER: 22.0                    06/01/2012   PAGE 7
                                 EXTRACTION
                             U-O-S BLOCK SECTION
```

(*Figure C.2.1: Continue*)

```
BLOCK:  P-101    MODEL: PUMP (CONTINUED)

                         ***  INPUT DATA  ***
   OUTLET PRESSURE  PSIA                                  90.0000
   PUMP EFFICIENCY                                         0.60000
   DRIVER EFFICIENCY                                       1.00000

   FLASH SPECIFICATIONS:
   LIQUID PHASE CALCULATION
   NO FLASH PERFORMED
   MAXIMUM NUMBER OF ITERATIONS                            30
   TOLERANCE                                               0.000100000

                          ***  RESULTS  ***
   VOLUMETRIC FLOW RATE  CUFT/HR                         816.529
   PRESSURE CHANGE  PSI                                    0.0
   NPSH AVAILABLE   FT-LBF/LB                            207.787
   FLUID POWER  HP                                         0.0
   BRAKE POWER  HP                                         0.0
   ELECTRICITY  KW                                         0.0
   PUMP EFFICIENCY USED                                    0.60000
   NET WORK REQUIRED  HP                                   0.0
   HEAD DEVELOPED FT-LBF/LB                                0.0

BLOCK:  P-104    MODEL: PUMP
----------------------------
  INLET STREAM:           E-105P  |
  OUTLET STREAM:          E-105
  PROPERTY OPTION SET:    UNIQUAC   UNIQUAC / IDEAL GAS

                   ***  MASS AND ENERGY BALANCE  ***
                                 IN              OUT          RELATIVE DIFF.
      CONV. COMP.(LBMOL/HR)    1687.52         1687.52          0.00000
                 (LB/HR   )    30401.2         30401.2          0.00000
      NONCONV. COMP(LB/HR   )  0.00000         0.00000          0.00000
   TOTAL BALANCE
      MASS(LB/HR   )           30401.2         30401.2          0.00000
      ENTHALPY(BTU/HR  )     -0.207267E+09  -0.207270E+09     0.157463E-04
 ASPEN PLUS   PLAT: WIN32      VER: 22.0                     06/01/2012   PAGE 8
                                    EXTRACTION
                                U-O-S BLOCK SECTION
```

(*Figure C.2.1: Continue*)

```
BLOCK:  P-104    MODEL: PUMP (CONTINUED)

                         ***  INPUT DATA  ***
   OUTLET PRESSURE  PSIA                                  30.0000
   PUMP EFFICIENCY                                         0.60000
   DRIVER EFFICIENCY                                       1.00000

   FLASH SPECIFICATIONS:
   LIQUID PHASE CALCULATION
   NO FLASH PERFORMED
   MAXIMUM NUMBER OF ITERATIONS                            30
   TOLERANCE                                               0.000100000

                          ***  RESULTS  ***
   VOLUMETRIC FLOW RATE  CUFT/HR                         489.918
   PRESSURE CHANGE  PSI                                  -60.0000
   NPSH AVAILABLE   FT-LBF/LB                            207.787
   FLUID POWER  HP                                        -2.13782
   BRAKE POWER  HP                                        -1.28269
   ELECTRICITY  KW                                        -0.95650
   PUMP EFFICIENCY USED                                    0.60000
   NET WORK REQUIRED  HP                                  -1.28269
   HEAD DEVELOPED FT-LBF/LB                             -139.234

BLOCK:  P-105    MODEL: PUMP
----------------------------
  INLET STREAM:           E-106P
  OUTLET STREAM:          E-106
  PROPERTY OPTION SET:    UNIQUAC   UNIQUAC / IDEAL GAS

                   ***  MASS AND ENERGY BALANCE  ***
                                 IN              OUT          RELATIVE DIFF.
      CONV. COMP.(LBMOL/HR)    1125.02         1125.02          0.00000
                 (LB/HR   )    20267.5         20267.5          0.00000
      NONCONV. COMP(LB/HR   )  50668.7         50668.7          0.00000
   TOTAL BALANCE
      MASS(LB/HR   )           70936.2         70936.2          0.00000
      ENTHALPY(BTU/HR  )     -0.466558E+09  -0.466560E+09     0.466301E-05
 ASPEN PLUS   PLAT: WIN32      VER: 22.0                     06/01/2012   PAGE 9
                                    EXTRACTION
                                U-O-S BLOCK SECTION
```

(*Figure C.2.1: Continue*)

```
BLOCK:  P-105    MODEL: PUMP (CONTINUED)

                      ***  INPUT DATA  ***
   OUTLET PRESSURE  PSIA                                  30.0000
   PUMP EFFICIENCY                                         0.60000
   DRIVER EFFICIENCY                                       1.00000

   FLASH SPECIFICATIONS:
   LIQUID PHASE CALCULATION
   NO FLASH PERFORMED
   MAXIMUM NUMBER OF ITERATIONS                            30
   TOLERANCE                                               0.000100000

                       ***  RESULTS  ***
   VOLUMETRIC FLOW RATE  CUFT/HR                         326.612
   PRESSURE CHANGE  PSI                                  -60.0000
   NPSH AVAILABLE    FT-LBF/LB                           207.787
   FLUID POWER   HP                                       -1.42522
   BRAKE POWER   HP                                       -0.85513
   ELECTRICITY   KW                                       -0.63767
   PUMP EFFICIENCY USED                                    0.60000
   NET WORK REQUIRED  HP                                  -0.85513
   HEAD DEVELOPED FT-LBF/LB                             -139.234

BLOCK:  P-106    MODEL: PUMP
----------------------------
  INLET STREAM:           E-107P
  OUTLET STREAM:          E-107
  PROPERTY OPTION SET:    UNIQUAC    UNIQUAC / IDEAL GAS

                  ***  MASS AND ENERGY BALANCE  ***
                                IN            OUT         RELATIVE DIFF.
     CONV. COMP.(LBMOL/HR)   843.762        843.762         0.00000
                 (LB/HR   )  15200.6        15200.6         0.00000
     NONCONV. COMP(LB/HR   )  0.00000        0.00000         0.00000
   TOTAL BALANCE
     MASS(LB/HR    )          15200.6        15200.6         0.00000
     ENTHALPY(BTU/HR  )    -0.103634E+09  -0.103633E+09   -0.111590E-04
± ASPEN PLUS    PLAT: WIN32      VER: 22.0                  06/01/2012   PAGE 10
                                     EXTRACTION
                                 U-O-S BLOCK SECTION
```

(*Figure C.2.1: Continue*)

```
BLOCK:  P-106    MODEL: PUMP (CONTINUED)

                      ***  INPUT DATA  ***
   OUTLET PRESSURE  PSIA                                  30.0000
   PUMP EFFICIENCY                                         0.60000
   DRIVER EFFICIENCY                                       1.00000

   FLASH SPECIFICATIONS:
   LIQUID PHASE CALCULATION
   NO FLASH PERFORMED
   MAXIMUM NUMBER OF ITERATIONS                            30
   TOLERANCE                                               0.000100000

                       ***  RESULTS  ***
   VOLUMETRIC FLOW RATE  CUFT/HR                         244.952
   PRESSURE CHANGE  PSI                                   15.3077
   NPSH AVAILABLE    FT-LBF/LB                            33.0315
   FLUID POWER   HP                                        0.27270
   BRAKE POWER   HP                                        0.45450
   ELECTRICITY   KW                                        0.33892
   PUMP EFFICIENCY USED                                    0.60000
   NET WORK REQUIRED  HP                                   0.45450
   HEAD DEVELOPED FT-LBF/LB                               35.5216

BLOCK:  P-107    MODEL: PUMP
----------------------------
  INLET STREAM:           E-108P
  OUTLET STREAM:          E-108   |
  PROPERTY OPTION SET:    UNIQUAC    UNIQUAC / IDEAL GAS

                  ***  MASS AND ENERGY BALANCE  ***
                                IN            OUT         RELATIVE DIFF.
     CONV. COMP.(LBMOL/HR)   281.254        281.254         0.00000
                 (LB/HR   )  5066.87        5066.87         0.00000
     NONCONV. COMP(LB/HR   )  50668.7        50668.7         0.00000
   TOTAL BALANCE
     MASS(LB/HR    )          55735.6        55735.6         0.00000
     ENTHALPY(BTU/HR  )    -0.362926E+09  -0.362926E+09   -0.106214E-05
± ASPEN PLUS    PLAT: WIN32      VER: 22.0                  06/01/2012   PAGE 11
                                     EXTRACTION
```

(*Figure C.2.1: Continue*)

```
BLOCK:  P-107    MODEL: PUMP (CONTINUED)

                         ***  INPUT DATA  ***
   OUTLET PRESSURE  PSIA                                       30.0000
   PUMP EFFICIENCY                                              0.60000
   DRIVER EFFICIENCY                                            1.00000

   FLASH SPECIFICATIONS:
   LIQUID PHASE CALCULATION
   NO FLASH PERFORMED
   MAXIMUM NUMBER OF ITERATIONS                                 30
   TOLERANCE                                                    0.000100000

                          ***  RESULTS  ***
   VOLUMETRIC FLOW RATE  CUFT/HR                               81.6507
   PRESSURE CHANGE  PSI                                        15.3077
   NPSH AVAILABLE   FT-LBF/LB                                  33.0315
   FLUID POWER  HP                                              0.090901
   BRAKE POWER  HP                                              0.15150
   ELECTRICITY  KW                                              0.11297
   PUMP EFFICIENCY USED                                         0.60000
   NET WORK REQUIRED  HP                                        0.15150
   HEAD DEVELOPED FT-LBF/LB                                    35.5216

BLOCK:  P-108    MODEL: PUMP
------------------------------
  INLET STREAM:           E-109P
  OUTLET STREAM:          E-109
  PROPERTY OPTION SET:    UNIQUAC   UNIQUAC / IDEAL GAS

                    ***  MASS AND ENERGY BALANCE  ***
                                   IN            OUT         RELATIVE DIFF.
      CONV. COMP.(LBMOL/HR)     281.251        281.251         0.00000
                 (LB/HR    )    5066.82        5066.82         0.00000
      NONCONV. COMP(LB/HR    )  0.00000        0.00000         0.00000
   TOTAL BALANCE
      MASS(LB/HR     )          5066.82        5066.82         0.00000
      ENTHALPY(BTU/HR   )     -0.345443E+08  -0.345445E+08   0.524572E-05
 ASPEN PLUS   PLAT: WIN32     VER: 22.0                   06/01/2012   PAGE 12
                                 EXTRACTION
                             U-O-S BLOCK SECTION
```

(*Figure C.2.1: Continue*)

```
BLOCK:  P-108    MODEL: PUMP (CONTINUED)

                         ***  INPUT DATA  ***
   OUTLET PRESSURE  PSIA                                       45.0000
   PUMP EFFICIENCY                                              0.60000
   DRIVER EFFICIENCY                                            1.00000

   FLASH SPECIFICATIONS:
   LIQUID PHASE CALCULATION
   NO FLASH PERFORMED
   MAXIMUM NUMBER OF ITERATIONS                                 30
   TOLERANCE                                                    0.000100000

                          ***  RESULTS  ***
   VOLUMETRIC FLOW RATE  CUFT/HR                               81.6505
   PRESSURE CHANGE  PSI                                       -20.0000
   NPSH AVAILABLE   FT-LBF/LB                                 149.771
   FLUID POWER  HP                                             -0.11876
   BRAKE POWER  HP                                             -0.071259
   ELECTRICITY  KW                                             -0.053138
   PUMP EFFICIENCY USED                                         0.60000
   NET WORK REQUIRED  HP                                       -0.071259
   HEAD DEVELOPED FT-LBF/LB                                   -46.4105

BLOCK:  P-109    MODEL: PUMP
------------------------------
  INLET STREAM:           E-110P
  OUTLET STREAM:          E-110
  PROPERTY OPTION SET:    UNIQUAC   UNIQUAC / IDEAL GAS

                    ***  MASS AND ENERGY BALANCE  ***
                                   IN            OUT         RELATIVE DIFF.
      CONV. COMP.(LBMOL/HR)    0.281254E-02   0.281254E-02    0.00000
                 (LB/HR    )   0.506687E-01   0.506687E-01    0.00000
      NONCONV. COMP(LB/HR    )  50668.7        50668.7        0.00000
   TOTAL BALANCE
      MASS(LB/HR     )          50668.7        50668.7        0.00000
      ENTHALPY(BTU/HR   )     -0.328382E+09  -0.328382E+09  0.552390E-11
 ASPEN PLUS   PLAT: WIN32     VER: 22.0                   06/01/2012   PAGE 13
                                 EXTRACTION
                             U-O-S BLOCK SECTION
```

(*Figure C.2.1: Continue*)

```
BLOCK:  P-109    MODEL: PUMP (CONTINUED)

                   ***  INPUT DATA  ***
   EQUIPMENT TYPE: TURBINE
   OUTLET PRESSURE  PSIA                                    45.0000
   PUMP EFFICIENCY                                           0.60000
   DRIVER EFFICIENCY                                         1.00000

   FLASH SPECIFICATIONS:
   LIQUID PHASE CALCULATION
   NO FLASH PERFORMED
   MAXIMUM NUMBER OF ITERATIONS                              30
   TOLERANCE                                                 0.000100000

                   ***  RESULTS  ***
   VOLUMETRIC FLOW RATE  CUFT/HR                             0.00081651
   PRESSURE CHANGE  PSI                                    -20.0000
   NPSH AVAILABLE   FT-LBF/LB                              149.771
   FLUID POWER  HP                                          -0.118766-05
   BRAKE POWER  HP                                          -0.712593-06
   ELECTRICITY  KW                                          -0.531381-06
   PUMP EFFICIENCY USED                                      0.60000
   NET WORK REQUIRED  HP                                    -0.712593-06
   HEAD DEVELOPED FT-LBF/LB                                -46.4105

BLOCK:  P-110    MODEL: PUMP
----------------------------
  INLET STREAM:          E-111OIL
  OUTLET STREAM:         PRODUCT
  PROPERTY OPTION SET:   UNIQUAC   UNIQUAC / IDEAL GAS

                 ***  MASS AND ENERGY BALANCE  ***
                               IN            OUT         RELATIVE DIFF.
     CONV. COMP.(LBMOL/HR)    275.901       275.901        0.00000
                (LB/HR   )    25333.9       25333.9        0.00000
     NONCONV. COMP(LB/HR   )  0.00000       0.00000        0.00000
   TOTAL BALANCE
     MASS(LB/HR   )           25333.9       25333.9        0.00000
     ENTHALPY(BTU/HR  )     -0.742263E+08  -0.742263E+08  0.103601E-06
‡ ASPEN PLUS   PLAT: WIN32    VER: 22.0                  06/01/2012  PAGE 14
                                EXTRACTION
                             U-O-S BLOCK SECTION
```

(*Figure C.2.1: Continue*)

```
BLOCK:  P-110    MODEL: PUMP (CONTINUED)

                   ***  INPUT DATA  ***
   EQUIPMENT TYPE: PUMP
   OUTLET PRESSURE  PSIA                                   870.000
   PUMP EFFICIENCY                                           0.60000
   DRIVER EFFICIENCY                                         0.60000

   FLASH SPECIFICATIONS:
   LIQUID PHASE CALCULATION
   NO FLASH PERFORMED
   MAXIMUM NUMBER OF ITERATIONS                              30
   TOLERANCE                                                 0.000100000

                   ***  RESULTS  ***
   VOLUMETRIC FLOW RATE  CUFT/HR                           295.307
   PRESSURE CHANGE  PSI                                     -0.23000
   NPSH AVAILABLE   FT-LBF/LB                            1,460.72
   FLUID POWER  HP                                          -0.0049397
   BRAKE POWER  HP                                          -0.0029638
   ELECTRICITY  KW                                          -0.0013261
   PUMP EFFICIENCY USED                                      0.60000
   NET WORK REQUIRED  HP                                    -0.0017783
   HEAD DEVELOPED FT-LBF/LB                                 -0.38607

BLOCK:  Z-101    MODEL: SEP
---------------------------
  INLET STREAM:          E-104P
  OUTLET STREAMS:        E-106P      E-105P  |
  PROPERTY OPTION SET:   UNIQUAC   UNIQUAC / IDEAL GAS

                 ***  MASS AND ENERGY BALANCE  ***
                               IN            OUT         RELATIVE DIFF.
     CONV. COMP.(LBMOL/HR)    2812.54       2812.54        0.00000
                (LB/HR   )    50668.7       50668.7        0.00000
     NONCONV. COMP(LB/HR   )  50668.7       50668.7        0.00000
   TOTAL BALANCE
     MASS(LB/HR   )           101337.       101337.        0.00000
     ENTHALPY(BTU/HR  )     -0.673825E+09  -0.673825E+09 -0.424417E-12
```

(*Figure C.2.1: Continue*)

```
                         ***  INPUT DATA  ***

  INLET PRESSURE    PSIA                                        90.0000
 ASPEN PLUS   PLAT: WIN32       VER: 22.0                    06/01/2012  PAGE 15
                                   EXTRACTION
                                U-O-S BLOCK SECTION

 BLOCK:  Z-101     MODEL: SEP (CONTINUED)

  FLASH SPECS FOR STREAM E-106P
  TWO    PHASE   TP  FLASH
  PRESSURE DROP           PSI                                 0.0
  MAXIMUM NO. ITERATIONS                                     30
  CONVERGENCE TOLERANCE                                       0.000100000

  FLASH SPECS FOR STREAM E-105P
  TWO    PHASE   TP  FLASH
  PRESSURE DROP           PSI                                 0.0
  MAXIMUM NO. ITERATIONS                                     30
  CONVERGENCE TOLERANCE                                       0.000100000

  FRACTION OF FEED
    SUBSTREAM= MIXED
      STREAM= E-105P    CPT= H2O       FRACTION=           0.60000
    SUBSTREAM= NCPSD
      STREAM= E-105P    CPT= ALGAE     FRACTION=           0.0

                          ***  RESULTS  ***

  HEAT DUTY               BTU/HR                              0.28595E-03

 COMPONENT = H2O
   STREAM     SUBSTREAM     SPLIT FRACTION
   E-106P     MIXED                0.40000
   E-105P     MIXED                0.60000

 COMPONENT = ALGAE
   STREAM     SUBSTREAM     SPLIT FRACTION
   E-106P     NCPSD                1.00000
```

(*Figure C.2.1: Continue*)

```
 BLOCK:  Z-102     MODEL: CFUGE
 -----------------------------
   INLET STREAM:           E-106
   OUTLET STREAMS:         E-107P      E-108P
   PROPERTY OPTION SET:    UNIQUAC    UNIQUAC / IDEAL GAS
 ASPEN PLUS   PLAT: WIN32       VER: 22.0                    06/01/2012  PAGE 16
                                   EXTRACTION
                                U-O-S BLOCK SECTION

 BLOCK:  Z-102     MODEL: CFUGE (CONTINUED)

                    ***  MASS AND ENERGY BALANCE  ***
                                    IN             OUT        RELATIVE DIFF.
      CONV. COMP.(LBMOL/HR)      1125.02         1125.02          0.00000
                 (LB/HR    )      20267.5         20267.5          0.00000
      NONCONV. COMP(LB/HR    )    50668.7         50668.7          0.00000
    TOTAL BALANCE
      MASS(LB/HR    )              70936.2         70936.2          0.00000
      ENTHALPY(BTU/HR  )        -0.466560E+09   -0.466560E+09    0.292675E-09

                          ***  INPUT DATA  ***
   RATIO OF LIQ RADIUS TO RADIUS OF BOWL                         0.73800
   RATIO OF CAKE RADIUS TO RADIUS OF BOWL                        0.79000
   RATIO OF HEIGHT TO RADIUS OF BOWL                             0.95450
   CAKE RESISTANCE   FT/LB                                       0.00032174
   FILTER MEDIUM RESISTANCE  1/FT                                0.38100
   MOISTURE CONTENT                                              0.100000
   POROSITY OF CAKE                                              0.45000
   PARTICLE SPHERICITY                                           0.75000
   AVERAGE PARTICLE DIAMETER  FT                                 0.328084-04
   SURFACE TENSION   DYNE/CM                                    72.8293
   AVERAGE SOLID DENSITY  LB/CUFT                              141.979
   DRY SOLIDS FEED MASS FLOW RATE   LB/HR                    50,668.7

                          ***  RESULTS  ***
   CALCULATED PARTICLE DIAMETER  FT                             0.328084-04
   RESULTED MOISTURE CONTENT                                    0.100000
   SELECTED BOWL RADIUS   FT                                  688.976
   REVOLUTION SPEED    RPM                                  1,210.00
   BASKET HEIGHT  FT                                          657.628
```

(*Figure C.2.1: Continue*)

```
BLOCK:  Z-103    MODEL: SEP
----------------------------
  INLET STREAM:            E-108
  OUTLET STREAMS:          E-109P      E-110P
  PROPERTY OPTION SET:     UNIQUAC    UNIQUAC / IDEAL GAS

                     ***  MASS AND ENERGY BALANCE  ***
                                    IN               OUT          RELATIVE DIFF.
      CONV. COMP.(LBMOL/HR)      281.254          281.254           0.00000
                 (LB/HR    )     5066.87          5066.87           0.00000
      NONCONV. COMP(LB/HR    )   50668.7          50668.7           0.00000
‡ ASPEN PLUS   PLAT: WIN32     VER: 22.0                        06/01/2012  PAGE 17
                                 EXTRACTION
                             U-O-S BLOCK SECTION

BLOCK:  Z-103    MODEL: SEP (CONTINUED)
   TOTAL BALANCE
      MASS(LB/HR    )             55735.6          55735.6          0.00000
      ENTHALPY(BTU/HR  )       -0.362926E+09    -0.362926E+09   -0.148997E-09

                         ***  INPUT DATA  ***

  INLET PRESSURE   PSIA                                         65.0000

  FLASH SPECS FOR STREAM E-109P
  TWO    PHASE  TP  FLASH
  PRESSURE DROP          PSI                                  0.0
  MAXIMUM NO. ITERATIONS                                     30
  CONVERGENCE TOLERANCE                                       0.000100000

  FLASH SPECS FOR STREAM E-110P
  TWO    PHASE  TP  FLASH
  PRESSURE DROP          PSI                                  0.0
  MAXIMUM NO. ITERATIONS                                     30
  CONVERGENCE TOLERANCE                                       0.000100000

  FRACTION OF FEED
    SUBSTREAM= MIXED
      STREAM= E-110P    CPT= H2O       FRACTION=          0.100000-04
    SUBSTREAM= NCPSD
      STREAM= E-110P    CPT= ALGAE     FRACTION=          1.00000
```

(*Figure C.2.1: Continue*)

```
                         ***  RESULTS  ***

  HEAT DUTY              BTU/HR                                0.54075E-01

 COMPONENT = H2O
   STREAM      SUBSTREAM    SPLIT FRACTION
   E-109P      MIXED                 0.99999
   E-110P      MIXED                 0.100000-04

 COMPONENT = ALGAE
   STREAM      SUBSTREAM    SPLIT FRACTION
   E-110P      NCPSD                 1.00000

BLOCK:  Z-104    MODEL: COMPR
----------------------------
  INLET STREAM:            E-111
  OUTLET STREAM:           E-111SCF
  PROPERTY OPTION SET:     UNIQUAC    UNIQUAC / IDEAL GAS
‡ ASPEN PLUS   PLAT: WIN32     VER: 22.0                        06/01/2012  PAGE 18
                                 EXTRACTION
                             U-O-S BLOCK SECTION

BLOCK:  Z-104    MODEL: COMPR (CONTINUED)

                     ***  MASS AND ENERGY BALANCE  ***
                                    IN               OUT          RELATIVE DIFF.
      CONV. COMP.(LBMOL/HR)      20904.4          20904.4           0.00000
                 (LB/HR    )     920000.          920000.           0.00000
      NONCONV. COMP(LB/HR    )   0.00000          0.00000           0.00000
   TOTAL BALANCE
      MASS(LB/HR    )             920000.          920000.          0.00000
      ENTHALPY(BTU/HR  )       -0.353593E+10    -0.351873E+10   -0.486696E-02

                         ***  INPUT DATA  ***

  POLYTROPIC POSITIVE DISPLACEMENT COMPRESSOR          USING PIECEWISE INTEGRATION
   OUTLET PRESSURE  PSIA                                1,450.37
   POLYTROPIC EFFICIENCY                                    0.72000
   MECHANICAL EFFICIENCY                                    0.60000
   CLEARANCE FRACTION                                       0.50000
```

(*Figure C.2.1: Continue*)

```
                        ***  RESULTS  ***

 INDICATED  HORSEPOWER REQUIREMENT  HP                  6,763.49
 BRAKE      HORSEPOWER REQUIREMENT  HP                 11,272.5
 NET WORK REQUIRED                  HP                 11,272.5
 POWER LOSSES                       HP                  4,508.99
 ISENTROPIC HORSEPOWER REQUIREMENT  HP                  4,763.68
 CALCULATED OUTLET TEMP  F                                169.918
 ISENTROPIC TEMPERATURE  F                                144.034
 EFFICIENCY (POLYTR/ISENTR) USED                            0.72000
 VOLUMETRIC EFFICIENCY                                      0.76835
 DISPLACEMENT              CUFT/HR                    181,235.
 OUTLET VAPOR FRACTION                                      1.00000
 HEAD DEVELOPED,        FT-LBF/LB                      10,480.5
 MECHANICAL EFFICIENCY USED                                 0.60000
 INLET HEAT CAPACITY RATIO                                  1.28678
 INLET VOLUMETRIC FLOW RATE , CUFT/HR                 139,251.
 OUTLET VOLUMETRIC FLOW RATE, CUFT/HR                  97,380.6
 INLET  COMPRESSIBILITY FACTOR                              1.00000
 OUTLET COMPRESSIBILITY FACTOR                              1.00000
 AV. ISENT. VOL. EXPONENT                                   1.27821
 AV. ISENT. TEMP EXPONENT                                   1.27821
 AV. ACTUAL VOL. EXPONENT                                   1.42824
 AV. ACTUAL TEMP EXPONENT                                   1.42824
‡ ASPEN PLUS    PLAT: WIN32      VER: 22.0                 06/01/2012   PAGE 19
                               EXTRACTION
                           U-O-S BLOCK SECTION

 BLOCK:  Z-105    MODEL: RSTOIC
 ------------------------------
   INLET STREAMS:          E-111SCF    E-110
   OUTLET STREAM:          E-111SEP
   PROPERTY OPTION SET:    UNIQUAC    UNIQUAC / IDEAL GAS

                      ***  MASS AND ENERGY BALANCE  ***
                              IN           OUT        GENERATION    RELATIVE DIFF.
 CONV. COMP.(LBMOL/HR)     20904.4       21180.3        275.901       0.161027E-16
            (LB/HR    )    920000.       945334.                     -0.267989E-01
 NONCONV COMP(LB/HR    )   50668.7       25334.3                      0.500000
   TOTAL BALANCE
      MASS(LB/HR    )      970669.       970668.                      0.435283E-06
      ENTHALPY(BTU/HR   )-0.384711E+10 -0.377578E+10                 -0.185415E-01
```

(*Figure C.2.1: Continue*)

```
                        ***  INPUT DATA  ***
 STOICHIOMETRY MATRIX:

  REACTION #    1:
   SUBSTREAM MIXED    :
   C6H12-01  0.146E-02C2H5N-01  0.773E-02C3H8O-01  0.170E-02
   SUBSTREAM NCPSD    :
   ALGAE      -1.00


 REACTION CONVERSION SPECS: NUMBER=     1
   REACTION #    1:
   SUBSTREAM:NCPSD     KEY COMP:ALGAE     CONV FRAC: 0.5000



 TWO    PHASE  TP  FLASH
 SPECIFIED TEMPERATURE F                                116.330
 SPECIFIED PRESSURE      PSIA                         5,801.51
 MAXIMUM NO. ITERATIONS                                   30
 CONVERGENCE TOLERANCE                                     0.000100000
 SIMULTANEOUS REACTIONS
 GENERATE COMBUSTION REACTIONS FOR FEED SPECIES          NO
‡ ASPEN PLUS    PLAT: WIN32      VER: 22.0               06/01/2012   PAGE 20
                               EXTRACTION
                           U-O-S BLOCK SECTION

 BLOCK:  Z-105    MODEL: RSTOIC (CONTINUED)

                          ***  RESULTS  ***
 OUTLET TEMPERATURE      F                                116.33
 OUTLET PRESSURE         PSIA                             5801.5
 HEAT DUTY               BTU/HR                          0.71329E+08
 VAPOR FRACTION                                           0.0000
```

(*Figure C.2.1: Continue*)

```
 REACTION EXTENTS:

    REACTION           REACTION
    NUMBER             EXTENT
                       LBMOL/HR
    1                   25334.

 V-L PHASE EQUILIBRIUM :

    COMP             F(I)          X(I)          Y(I)          K(I)
    C6H12-01        0.17472E-02   0.17472E-02   0.22531E-16   0.32789E-14
    C2H5N-01        0.92444E-02   0.92444E-02   0.26078E-12   0.71726E-11
    C3H8O-01        0.20347E-02   0.20347E-02   0.29753E-10   0.37180E-08
    CO2             0.98697       0.98697        1.0000       0.25762
    H2O             0.13279E-06   0.13279E-06   0.22627E-09   0.43325E-03

BLOCK:  Z-106    MODEL: SEP
----------------------------
  INLET STREAM:            E-111SEP
  OUTLET STREAMS:          E-111OIL     E-111CO2
  PROPERTY OPTION SET:     UNIQUAC    UNIQUAC / IDEAL GAS

                   ***  MASS AND ENERGY BALANCE  ***
                                    IN               OUT        RELATIVE DIFF.
    CONV. COMP.(LBMOL/HR)      21180.3          21180.3         0.00000
               (LB/HR    )     945334.          945334.        -0.123147E-15
    NONCONV. COMP(LB/HR    )   25334.3          25334.3         0.00000
   TOTAL BALANCE
    MASS(LB/HR    )            970668.          970668.        -0.119933E-15
    ENTHALPY(BTU/HR   )     -0.377578E+10    -0.377454E+10    -0.326944E-03


                       ***  INPUT DATA  ***

  INLET PRESSURE    PSIA                                  5,801.51
 ASPEN PLUS    PLAT: WIN32      VER: 22.0                06/01/2012   PAGE 21
                                   EXTRACTION
                                U-O-S BLOCK SECTION
```

(*Figure C.2.1: Continue*)

```
                                U-O-S BLOCK SECTION

BLOCK:  Z-106    MODEL: SEP (CONTINUED)

  FLASH SPECS FOR STREAM E-111OIL
  TWO    PHASE   TP  FLASH
  SPECIFIED TEMPERATURE F                                   121.910
  SPECIFIED PRESSURE    PSIA                                870.230
  MAXIMUM NO. ITERATIONS                                     30
  CONVERGENCE TOLERANCE                                       0.000100000

  FLASH SPECS FOR STREAM E-111CO2
  TWO    PHASE   TP  FLASH
  SPECIFIED TEMPERATURE F                                   122.000
  SPECIFIED PRESSURE    PSIA                                870.230
  MAXIMUM NO. ITERATIONS                                     30
  CONVERGENCE TOLERANCE                                       0.000100000

  FRACTION OF FEED
    SUBSTREAM= MIXED
      STREAM= E-111CO2   CPT= C6H12-01   FRACTION=          0.0
                              C2H5N-01                      0.0
                              C3H8O-01                      0.0
                              CO2                           1.00000
```

(*Figure C.2.1: Continue*)

```
  HEAT DUTY              BTU/HR                                 0.12345E+07

 COMPONENT = C6H12-01
   STREAM     SUBSTREAM     SPLIT FRACTION
   E-111OIL   MIXED                 1.00000

 COMPONENT = C2H5N-01
   STREAM     SUBSTREAM     SPLIT FRACTION
   E-111OIL   MIXED                 1.00000

 COMPONENT = C3H8O-01
   STREAM     SUBSTREAM     SPLIT FRACTION
   E-111OIL   MIXED                 1.00000

 COMPONENT = CO2
   STREAM     SUBSTREAM     SPLIT FRACTION
   E-111CO2   MIXED                 1.00000

 COMPONENT = H2O
   STREAM     SUBSTREAM     SPLIT FRACTION
   E-111CO2   MIXED                 1.00000

 COMPONENT = ALGAE
   STREAM     SUBSTREAM     SPLIT FRACTION
   E-111CO2   NCPSD                 1.00000
 ASPEN PLUS    PLAT: WIN32      VER: 22.0                     06/01/2012   PAGE 22
                                     EXTRACTION
                                 U-O-S BLOCK SECTION
```

(*Figure C.2.1: Continue*)

```
 BLOCK:  Z-108     MODEL: FLASH2
 ------------------------------
   INLET STREAM:           E-111CO2
   OUTLET VAPOR STREAM:    E-116
   OUTLET LIQUID STREAM:   E-115
   PROPERTY OPTION SET:    UNIQUAC   UNIQUAC / IDEAL GAS

                    ***  MASS AND ENERGY BALANCE  ***
                                   IN             OUT          RELATIVE DIFF.
       CONV. COMP.(LBMOL/HR)     20904.4         20904.4         0.00000
                  (LB/HR   )     920000.         920000.         0.126538E-15
       NONCONV. COMP(LB/HR   )   25334.3         25334.3         0.00000
    TOTAL BALANCE
       MASS(LB/HR    )           945334.         945334.         0.123147E-15
       ENTHALPY(BTU/HR  )      -0.370032E+10   -0.370040E+10     0.221840E-04

                        ***  INPUT DATA  ***
   TWO    PHASE   TP  FLASH
   SPECIFIED TEMPERATURE F                                  121.600
   SPECIFIED PRESSURE    PSIA                               870.230
   MAXIMUM NO. ITERATIONS                                    30
   CONVERGENCE TOLERANCE                                      0.000100000

                         ***  RESULTS  ***
   OUTLET TEMPERATURE    F                                    121.60
   OUTLET PRESSURE       PSIA                                 870.23
   HEAT DUTY             BTU/HR                              -82090.
   VAPOR FRACTION                                              1.0000


   V-L PHASE EQUILIBRIUM :

      COMP              F(I)           X(I)            Y(I)           K(I)
      CO2               1.0000         0.99993         1.0000         1.8205
      H2O               0.13454E-06    0.73099E-04     0.13454E-06    0.33505E-02
 ASPEN PLUS    PLAT: WIN32      VER: 22.0               06/01/2012   PAGE 23
                                  EXTRACTION
                                STREAM SECTION
```

(*Figure C.2.1: Continue*)

```
SUBSTREAM ATTR PSD TYPE: PSD
----------------------------

INTERVAL      LOWER LIMIT            UPPER LIMIT
    1           0.0      FT         6.5617-05  FT
    2         6.5617-05  FT         1.3123-04  FT
    3         1.3123-04  FT         1.9685-04  FT
    4         1.9685-04  FT         2.6247-04  FT
    5         2.6247-04  FT         3.2808-04  FT
    6         3.2808-04  FT         3.9370-04  FT
    7         3.9370-04  FT         4.5932-04  FT
    8         4.5932-04  FT         5.2493-04  FT
    9         5.2493-04  FT         5.9055-04  FT
   10         5.9055-04  FT         6.5617-04  FT

ASPEN PLUS   PLAT: WIN32     VER: 22.0                  06/01/2012   PAGE 24
                               EXTRACTION
                             STREAM SECTION

E-104 E-104P E-105 E-105P E-106
-------------------------------
```

(*Figure C.2.1: Continue*)

E-106P E-107 E-107P E-108 E-108P

STREAM ID	E-104	E-104P	E-105	E-105P	E-106	E-106P	E-107	E-107P	E-108	E-108P
FROM :	----	P-101	P-104	Z-101	P-105	Z-101	P-106	Z-102	P-107	Z-102
TO :	P-101	Z-101	----	P-104	Z-102	P-105	----	P-106	Z-103	P-107
CLASS:	MIXNCPSD	MIXNCPSD	MIXNCPSD	MIXNCPSD	MIXNCPSD	MIXNCPSD	MIXNCPSD	MIXNCPSD	MIXNCPSD	MIXNCPSD
TOTAL STREAM:										
LB/HR	1.0134+05	1.0134+05	3.0401+04	3.0401+04	7.0936+04	7.0936+04	1.5201+04	1.5201+04	5.5736+04	5.5736+04
BTU/HR	-6.7383+08	-6.7383+08	-2.0727+08	-2.0727+08	-4.6656+08	-4.6656+08	-1.0363+08	-1.0363+08	-3.6293+08	-3.6293+08
SUBSTREAM: MIXED										
PHASE:	LIQUID	LIQUID	LIQUID	LIQUID	LIQUID	LIQUID	LIQUID	LIQUID	LIQUID	LIQUID
COMPONENTS: LBMOL/HR										
C6H12-01	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C2H5N-01	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C3H8O-01	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CO2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
H2O	2812.5396	2812.5396	1687.5237	1687.5237	1125.0158	1125.0158	843.7618	843.7618	281.2540	281.2540
COMPONENTS: LB/HR										
C6H12-01	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C2H5N-01	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C3H8O-01	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CO2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
H2O	5.0669+04	5.0669+04	3.0401+04	3.0401+04	2.0267+04	2.0267+04	1.5201+04	1.5201+04	5066.8695	5066.8695
COMPONENTS: MASS FRAC										
C6H12-01	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C2H5N-01	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C3H8O-01	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CO2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
H2O	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
TOTAL FLOW:										
LBMOL/HR	2812.5396	2812.5396	1687.5237	1687.5237	1125.0158	1125.0158	843.7618	843.7618	281.2540	281.2540
LB/HR	5.0669+04	5.0669+04	3.0401+04	3.0401+04	2.0267+04	2.0267+04	1.5201+04	1.5201+04	5066.8695	5066.8695
CUFT/HR	816.5294	816.5294	489.8869	489.9177	326.6027	326.6118	244.9629	244.9520	81.6513	81.6507
STATE VARIABLES:										
TEMP F	76.9100	76.9100	76.7934	76.9100	76.8587	76.9100	76.9413	76.8587	76.8723	76.8587
PRES PSIA	90.0000	90.0000	30.0000	90.0000	30.0000	90.0000	30.0000	14.6923	30.0000	14.6923
VFRAC	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
LFRAC	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
SFRAC	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

(*Figure C.2.1: Continue*)

```
 ENTHALPY:
   BTU/LBMOL          -1.2282+05 -1.2282+05 -1.2282+05 -1.2282+05 -1.2282+05 -1.2282+05 -1.2282+05 -1.2282+05 -1.2282+05 -1.2282+05
   BTU/LB             -6817.7136 -6817.7136 -6817.8210 -6817.7136 -6817.7609 -6817.7136 -6817.6848 -6817.7609 -6817.7484 -6817.7609
   BTU/HR             -3.4544+08 -3.4544+08 -2.0727+08 -2.0727+08 -1.3818+08 -1.3818+08 -1.0363+08 -1.0363+08 -3.4545+07 -3.4545+07
 ENTROPY:
   BTU/LBMOL-R          -38.8595   -38.8595   -38.8631   -38.8595   -38.8611   -38.8595   -38.8586   -38.8611   -38.8607   -38.8611
   BTU/LB-R              -2.1570    -2.1570    -2.1572    -2.1570    -2.1571    -2.1570    -2.1570    -2.1571    -2.1571    -2.1571
 DENSITY:
   LBMOL/CUFT             3.4445     3.4445     3.4447     3.4445     3.4446     3.4445     3.4444     3.4446     3.4446     3.4446
   LB/CUFT               62.0537    62.0537    62.0576    62.0537    62.0554    62.0537    62.0527    62.0554    62.0550    62.0554
 AVG MW                  18.0153    18.0153    18.0153    18.0153    18.0153    18.0153    18.0153    18.0153    18.0153    18.0153

 ASPEN PLUS   PLAT: WIN32     VER: 22.0                   06/01/2012  PAGE 25
                                EXTRACTION
                               STREAM SECTION

 E-104 E-104P E-105 E-105P E-106

 E-106P E-107 E-107P E-108 E-108P (CONTINUED)

 STREAM ID               E-104      E-104P     E-105      E-105P     E-106      E-106P     E-107      E-107P     E-108      E-108P

 SUBSTREAM: NCPSD        STRUCTURE: NON CONVENTIONAL
 COMPONENTS: LB/HR
   ALGAE                5.0669+04  5.0669+04   0.0        0.0       5.0669+04  5.0669+04   0.0        0.0       5.0669+04  5.0669+04
 COMPONENTS: MASS FRAC
   ALGAE                   1.0000     1.0000   0.0        0.0          1.0000     1.0000   0.0        0.0          1.0000     1.0000
 TOTAL FLOW:
   LB/HR                5.0669+04  5.0669+04   0.0        0.0       5.0669+04  5.0669+04   0.0        0.0       5.0669+04  5.0669+04
 STATE VARIABLES:
   TEMP    F              76.9100    76.9100   MISSING    MISSING     76.8587    76.9100   MISSING    MISSING     76.8723    76.8587
   PRES    PSIA           90.0000    90.0000   30.0000    90.0000     30.0000    90.0000   30.0000    14.6923     30.0000    14.6923
   VFRAC                  0.0        0.0       MISSING    MISSING     0.0        0.0       MISSING    MISSING     0.0        0.0
   LFRAC                  0.0        0.0       MISSING    MISSING     0.0        0.0       MISSING    MISSING     0.0        0.0
   SFRAC                  1.0000     1.0000    MISSING    MISSING     1.0000     1.0000    MISSING    MISSING     1.0000     1.0000
 ENTHALPY:
   BTU/LB             -6480.9341 -6480.9341    MISSING    MISSING -6480.9581 -6480.9341    MISSING    MISSING -6480.9518 -6480.9581
   BTU/HR             -3.2838+08 -3.2838+08    MISSING    MISSING -3.2838+08 -3.2838+08    MISSING    MISSING -3.2838+08 -3.2838+08
 DENSITY:
   LB/CUFT               141.9785   141.9785   MISSING    MISSING    141.9785   141.9785   MISSING    MISSING    141.9785   141.9785
 AVG MW                    1.0000     1.0000    1.0000     1.0000     1.0000     1.0000    1.0000     1.0000     1.0000     1.0000
```

(*Figure C.2.1: Continue*)

```
 COMPONENT ATTRIBUTES:
 ALGAE     PROXANAL
             MOISTURE     81.7000     81.7000     MISSING     MISSING     81.7000     81.7000     MISSING     MISSING     81.7000     81.7000
             FC            0.0         0.0        MISSING     MISSING      0.0         0.0        MISSING     MISSING      0.0         0.0
             VM            0.0         0.0        MISSING     MISSING      0.0         0.0        MISSING     MISSING      0.0         0.0
             ASH          18.4000     18.4000     MISSING     MISSING     18.4000     18.4000     MISSING     MISSING     18.4000     18.4000
           ULTANAL
             ASH           0.0         0.0        MISSING     MISSING      0.0         0.0        MISSING     MISSING      0.0         0.0
             CARBON        0.0         0.0        MISSING     MISSING      0.0         0.0        MISSING     MISSING      0.0         0.0
             HYDROGEN      0.0         0.0        MISSING     MISSING      0.0         0.0        MISSING     MISSING      0.0         0.0
             NITROGEN      0.0         0.0        MISSING     MISSING      0.0         0.0        MISSING     MISSING      0.0         0.0
             CHLORINE      0.0         0.0        MISSING     MISSING      0.0         0.0        MISSING     MISSING      0.0         0.0
             SULFUR        0.0         0.0        MISSING     MISSING      0.0         0.0        MISSING     MISSING      0.0         0.0
             OXYGEN        0.0         0.0        MISSING     MISSING      0.0         0.0        MISSING     MISSING      0.0         0.0
           SULFANAL
             PYRITIC       0.0         0.0        MISSING     MISSING      0.0         0.0        MISSING     MISSING      0.0         0.0
             SULFATE       0.0         0.0        MISSING     MISSING      0.0         0.0        MISSING     MISSING      0.0         0.0
             ORGANIC       0.0         0.0        MISSING     MISSING      0.0         0.0        MISSING     MISSING      0.0         0.0
 SUBSTREAM ATTRIBUTES:
 PSD
   FRAC1                   0.0         0.0         0.0         0.0         0.0         0.0        MISSING     MISSING      0.0         0.0
   FRAC2                   0.0         0.0         0.0         0.0         0.0         0.0        MISSING     MISSING      0.0         0.0
   FRAC3                   0.0         0.0         0.0         0.0         0.0         0.0        MISSING     MISSING      0.0         0.0
   FRAC4                   0.0         0.0         0.0         0.0         0.0         0.0        MISSING     MISSING      0.0         0.0
   FRAC5                   0.0         0.0         0.0         0.0         0.0         0.0        MISSING     MISSING      0.0         0.0
   FRAC6                   0.0         0.0         0.0         0.0         0.0         0.0        MISSING     MISSING      0.0         0.0
   FRAC7                   0.0         0.0         0.0         0.0         0.0         0.0        MISSING     MISSING      0.0         0.0
   FRAC8                   0.0         0.0         0.0         0.0         0.0         0.0        MISSING     MISSING      0.0         0.0
   FRAC9                   0.0         0.0         0.0         0.0         0.0         0.0        MISSING     MISSING      0.0         0.0
   FRAC10                  0.0         0.0         0.0         0.0         0.0         0.0        MISSING     MISSING      0.0         0.0
 ASPEN PLUS   PLAT: WIN32     VER: 22.0                   06/01/2012  PAGE 26
                                EXTRACTION
                               STREAM SECTION

 E-109 E-109P E-110 E-110P E-111
 -------------------------------
```

(*Figure C.2.1: Continue*)

```
E-111CO2 E-111OIL E-111SCF E-111SEP E-112
-----------------------------------------

STREAM ID               E-109     E-109P    E-110     E-110P    E-111     E-111CO2  E-111OIL  E-111SCF  E-111SEP  E-112
FROM :                  P-108     Z-103     P-109     Z-103     ----      Z-106     Z-106     Z-104     Z-105     FOR-USE
TO   :                  ----      P-108     Z-105     P-109     Z-104     Z-108     P-110     Z-105     Z-106     ----
CLASS:                  MIXNCPSD  MIXNCPSD  MIXNCPSD  MIXNCPSD  MIXNCPSD  MIXNCPSD  MIXNCPSD  MIXNCPSD  MIXNCPSD  MIXNCPSD
TOTAL STREAM:
  LB/HR                5066.8188 5066.8188 5.0669+04 5.0669+04 9.2000+05 9.4533+05 2.5334+04 9.2000+05 9.7067+05 6666.8937
  BTU/HR              -3.4544+07 -3.4544+07 -3.2838+08 -3.2838+08 -3.5359+09 -3.7003+09 -7.4226+07 -3.5187+09 -3.7758+09 -1.9832+07
SUBSTREAM: MIXED
PHASE:                  LIQUID    LIQUID    LIQUID    LIQUID    VAPOR     VAPOR     LIQUID    VAPOR     LIQUID    LIQUID
COMPONENTS: LBMOL/HR
  C6H12-01               0.0       0.0       0.0       0.0       0.0       0.0      37.0059    0.0      37.0059   37.0059
  C2H5N-01               0.0       0.0       0.0       0.0       0.0       0.0     195.7990    0.0     195.7990    0.0
  C3H8O-01               0.0       0.0       0.0       0.0       0.0       0.0      43.0963    0.0      43.0963    0.0
  CO2                    0.0       0.0       0.0       0.0     2.0904+04 2.0904+04   0.0     2.0904+04 2.0904+04   0.0
  H2O                  281.2512  281.2512  2.8125-03 2.8125-03   0.0     2.8125-03   0.0       0.0     2.8125-03   0.0
COMPONENTS: LB/HR
  C6H12-01               0.0       0.0       0.0       0.0       0.0       0.0     6666.8937   0.0     6666.8937 6666.8937
  C2H5N-01               0.0       0.0       0.0       0.0       0.0       0.0     1.4698+04   0.0     1.4698+04   0.0
  C3H8O-01               0.0       0.0       0.0       0.0       0.0       0.0     3968.9378   0.0     3968.9378   0.0
  CO2                    0.0       0.0       0.0       0.0     9.2000+05 9.2000+05   0.0     9.2000+05 9.2000+05   0.0
  H2O                  5066.8188 5066.8188 5.0669-02 5.0669-02   0.0     5.0669-02   0.0       0.0     5.0669-02   0.0
COMPONENTS: MASS FRAC
  C6H12-01               0.0       0.0       0.0       0.0       0.0       0.0       0.2632    0.0     7.0524-03   1.0000
  C2H5N-01               0.0       0.0       0.0       0.0       0.0       0.0       0.5802    0.0     1.5548-02   0.0
  C3H8O-01               0.0       0.0       0.0       0.0       0.0       0.0       0.1567    0.0     4.1985-03   0.0
  CO2                    0.0       0.0       0.0       0.0       1.0000    1.0000    0.0       1.0000    0.9732    0.0
  H2O                    1.0000    1.0000    1.0000    1.0000    0.0     5.5075-08   0.0       0.0     5.3599-08   0.0
TOTAL FLOW:
  LBMOL/HR             281.2512  281.2512  2.8125-03 2.8125-03 2.0904+04 2.0904+04 275.9012  2.0904+04 2.1180+04  37.0059
  LB/HR                5066.8188 5066.8188 5.0669-02 5.0669-02 9.2000+05 9.2000+05 2.5334+04 9.2000+05 9.4533+05 6666.8937
  CUFT/HR               81.6488   81.6505  8.1651-04 8.1651-04 1.3925+05 1.4995+05 295.3073  9.7381+04 2.5759+04  92.7351
STATE VARIABLES:
  TEMP   F              76.8334   76.8723   76.8723   76.8723   80.5100  122.0000  121.9100  169.9179  116.3300  130.7300
  PRES   PSIA           45.0000   65.0000   45.0000   65.0000  870.2300  870.2300  870.2300 1450.3700 5801.5095 5076.3208
  VFRAC                  0.0       0.0       0.0       0.0       1.0000    1.0000    0.0       1.0000    0.0       0.0
  LFRAC                  1.0000    1.0000    1.0000    1.0000    0.0       0.0       1.0000    0.0       1.0000    1.0000
  SFRAC                  0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0
```

(*Figure C.2.1: Continue*)

```
ENTHALPY:
  BTU/LBMOL           -1.2282+05 -1.2282+05 -1.2282+05 -1.2282+05 -1.6915+05 -1.6877+05 -2.6903+05 -1.6832+05 -1.7013+05 -5.3592+05
  BTU/LB              -6817.7842 -6817.7484 -6817.7484 -6817.7484 -3843.4072 -3834.8686 -2929.9168 -3824.7015 -3811.8442 -2974.7235
  BTU/HR              -3.4544+07 -3.4544+07 -345.4464 -345.4464 -3.5359+09 -3.5281+09 -7.4226+07 -3.5187+09 -3.6035+09 -1.9832+07
ENTROPY:
  BTU/LBMOL-R          -38.8619  -38.8607  -38.8607  -38.8607   -7.3576   -6.6875 -136.7072   -6.9628   -9.3873 -252.7076
  BTU/LB-R              -2.1572   -2.1571   -2.1571   -2.1571   -0.1672   -0.1520   -1.4888   -0.1582   -0.2103   -1.4027
DENSITY:
  LBMOL/CUFT             3.4446    3.4446    3.4446    3.4446    0.1501    0.1394    0.9343    0.2147    0.8223    0.3990
  LB/CUFT               62.0563   62.0550   62.0550   62.0550    6.6068    6.1355   85.7883    9.4475   36.6996   71.8918
AVG MW                  18.0153   18.0153   18.0153   18.0153   44.0098   44.0098   91.8225   44.0098   44.6326  180.1577

ASPEN PLUS   PLAT: WIN32     VER: 22.0                  06/01/2012   PAGE 27
                               EXTRACTION
                              STREAM SECTION

E-109 E-109P E-110 E-110P E-111

E-111CO2 E-111OIL E-111SCF E-111SEP E-11 (CONTINUED)

STREAM ID               E-109     E-109P    E-110     E-110P    E-111     E-111CO2  E-111OIL  E-111SCF  E-111SEP  E-112

SUBSTREAM: NCPSD        STRUCTURE: NON CONVENTIONAL
COMPONENTS: LB/HR
  ALGAE                  0.0       0.0     5.0669+04 5.0669+04   0.0     2.5334+04   0.0       0.0     2.5334+04   0.0
COMPONENTS: MASS FRAC
  ALGAE                  0.0       0.0       1.0000    1.0000    0.0       1.0000    0.0       0.0       1.0000    0.0
TOTAL FLOW:
  LB/HR                  0.0       0.0     5.0669+04 5.0669+04   0.0     2.5334+04   0.0       0.0     2.5334+04   0.0
STATE VARIABLES:
  TEMP   F              MISSING   MISSING   76.8723   76.8723   MISSING  122.0000   MISSING   MISSING  116.3300   MISSING
  PRES   PSIA           45.0000   65.0000   45.0000   65.0000  870.2300  870.2300  870.2300 1450.3700 5801.5095 5076.3208
  VFRAC                 MISSING   MISSING    0.0       0.0      MISSING    0.0      MISSING   MISSING    0.0      MISSING
  LFRAC                 MISSING   MISSING    0.0       0.0      MISSING    0.0      MISSING   MISSING    0.0      MISSING
  SFRAC                 MISSING   MISSING    1.0000    1.0000   MISSING    1.0000   MISSING   MISSING    1.0000   MISSING
ENTHALPY:
  BTU/LB                MISSING   MISSING -6480.9518 -6480.9518  MISSING -6798.5139  MISSING   MISSING -6801.4464  MISSING
  BTU/HR                MISSING   MISSING -3.2838+08 -3.2838+08  MISSING -1.7224+08  MISSING   MISSING -1.7231+08  MISSING
DENSITY:
  LB/CUFT               MISSING   MISSING  141.9785  141.9785   MISSING  141.9785   MISSING   MISSING  141.9785   MISSING
AVG MW                   1.0000    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000
```

(*Figure C.2.1: Continue*)

```
COMPONENT ATTRIBUTES:
ALGAE     PROXANAL
            MOISTURE     MISSING    MISSING    81.7000    81.7000    MISSING   100.0000    MISSING    MISSING   100.0000    MISSING
            FC           MISSING    MISSING     0.0        0.0       MISSING     0.0       MISSING    MISSING     0.0       MISSING
            VM           MISSING    MISSING     0.0        0.0       MISSING     0.0       MISSING    MISSING     0.0       MISSING
            ASH          MISSING    MISSING    18.4000    18.4000    MISSING    18.4000    MISSING    MISSING    18.4000    MISSING
          ULTANAL
            ASH          MISSING    MISSING     0.0        0.0       MISSING     0.0       MISSING    MISSING     0.0       MISSING
            CARBON       MISSING    MISSING     0.0        0.0       MISSING     0.0       MISSING    MISSING     0.0       MISSING
            HYDROGEN     MISSING    MISSING     0.0        0.0       MISSING     0.0       MISSING    MISSING     0.0       MISSING
            NITROGEN     MISSING    MISSING     0.0        0.0       MISSING     0.0       MISSING    MISSING     0.0       MISSING
            CHLORINE     MISSING    MISSING     0.0        0.0       MISSING     0.0       MISSING    MISSING     0.0       MISSING
            SULFUR       MISSING    MISSING     0.0        0.0       MISSING     0.0       MISSING    MISSING     0.0       MISSING
            OXYGEN       MISSING    MISSING     0.0        0.0       MISSING     0.0       MISSING    MISSING     0.0       MISSING
          SULFANAL
            PYRITIC      MISSING    MISSING     0.0        0.0       MISSING     0.0       MISSING    MISSING     0.0       MISSING
            SULFATE      MISSING    MISSING     0.0        0.0       MISSING     0.0       MISSING    MISSING     0.0       MISSING
            ORGANIC      MISSING    MISSING     0.0        0.0       MISSING     0.0       MISSING    MISSING     0.0       MISSING
SUBSTREAM ATTRIBUTES:
PSD
  FRAC1                   0.0        0.0        0.0        0.0       MISSING     0.0        0.0       MISSING     0.0        0.0
  FRAC2                   0.0        0.0        0.0        0.0       MISSING     0.0        0.0       MISSING     0.0        0.0
  FRAC3                   0.0        0.0        0.0        0.0       MISSING     0.0        0.0       MISSING     0.0        0.0
  FRAC4                   0.0        0.0        0.0        0.0       MISSING     0.0        0.0       MISSING     0.0        0.0
  FRAC5                   0.0        0.0        0.0        0.0       MISSING     0.0        0.0       MISSING     0.0        0.0
  FRAC6                   0.0        0.0        0.0        0.0       MISSING     0.0        0.0       MISSING     0.0        0.0
  FRAC7                   0.0        0.0        0.0        0.0       MISSING     0.0        0.0       MISSING     0.0        0.0
  FRAC8                   0.0        0.0        0.0        0.0       MISSING     0.0        0.0       MISSING     0.0        0.0
  FRAC9                   0.0        0.0        0.0        0.0       MISSING     0.0        0.0       MISSING     0.0        0.0
  FRAC10                  0.0        0.0        0.0        0.0       MISSING     0.0        0.0       MISSING     0.0        0.0
♀ ASPEN PLUS   PLAT: WIN32     VER: 22.0                  06/01/2012  PAGE 28
                                 EXTRACTION
                                STREAM SECTION
```

(*Figure C.2.1: Continue*)

```
E-113 E-114 E-115 E-116 PRODUCT
-------------------------------

STREAM ID                E-113      E-114      E-115      E-116      PRODUCT
FROM :                   FOR-USE    FOR-USE    Z-108      Z-108      P-110
TO   :                   ----       ----       ----       ----       FOR-USE
CLASS:                   MIXNCPSD   MIXNCPSD   MIXNCPSD   MIXNCPSD   MIXNCPSD
TOTAL STREAM:
  LB/HR                 1.4698+04  3968.9378  2.5334+04  9.2000+05  2.5334+04
  BTU/HR               -4.2015+07 -1.2261+07 -1.7224+08 -3.5282+09 -7.4226+07
SUBSTREAM: MIXED
PHASE:                   LIQUID     LIQUID     MISSING    VAPOR      LIQUID
COMPONENTS: LBMOL/HR
  C6H12-01                 0.0        0.0        0.0        0.0       37.0059
  C2H5N-01               195.7990     0.0        0.0        0.0      195.7990
  C3H8O-01                 0.0       43.0963     0.0        0.0       43.0963
  CO2                      0.0        0.0        0.0      2.0904+04    0.0
  H2O                      0.0        0.0        0.0      2.8125-03    0.0
COMPONENTS: LB/HR
  C6H12-01                 0.0        0.0        0.0        0.0      6666.8937
  C2H5N-01              1.4698+04     0.0        0.0        0.0      1.4698+04
  C3H8O-01                 0.0     3968.9378     0.0        0.0      3968.9378
  CO2                      0.0        0.0        0.0      9.2000+05    0.0
  H2O                      0.0        0.0        0.0      5.0669-02    0.0
COMPONENTS: MASS FRAC
  C6H12-01                 0.0        0.0      MISSING      0.0        0.2632
  C2H5N-01                 1.0000     0.0      MISSING      0.0        0.5802
  C3H8O-01                 0.0        1.0000   MISSING      0.0        0.1567
  CO2                      0.0        0.0      MISSING      1.0000     0.0
  H2O                      0.0        0.0      MISSING    5.5075-08    0.0
TOTAL FLOW:
  LBMOL/HR               195.7990    43.0963     0.0      2.0904+04  275.9012
  LB/HR                 1.4698+04  3968.9378     0.0      9.2000+05  2.5334+04
  CUFT/HR                163.0189    50.9022     0.0      1.4984+05  295.3072
STATE VARIABLES:
  TEMP    F              130.9100   130.9100   MISSING    121.6000   121.9094
  PRES    PSIA          5076.3208  5076.3208   870.2300   870.2300   870.0000
  VFRAC                    0.0        0.0      MISSING      1.0000     0.0
  LFRAC                    1.0000     1.0000   MISSING      0.0        1.0000
  SFRAC                    0.0        0.0      MISSING      0.0        0.0
```

(*Figure C.2.1: Continue*)

```
  SFRAC                   0.0         0.0         MISSING     0.0         0.0
 ENTHALPY:
   BTU/LBMOL           -2.1458+05  -2.8451+05    MISSING -1.6878+05 -2.6903+05
   BTU/LB              -2858.5557  -3089.3440    MISSING -3834.9522 -2929.9171
   BTU/HR              -4.2015+07  -1.2261+07    MISSING -3.5282+09 -7.4226+07
 ENTROPY:
   BTU/LBMOL-R           -114.7810   -141.7530    MISSING    -6.6938  -136.7073
   BTU/LB-R                -1.5290     -1.5392    MISSING    -0.1521    -1.4888
 DENSITY:
   LBMOL/CUFT               1.2011      0.8466    MISSING     0.1395     0.9343
   LB/CUFT                 90.1619     77.9719    MISSING     6.1397    85.7884
 AVG MW                    75.0672     92.0947    MISSING    44.0098    91.8225

 SUBSTREAM: NCPSD         STRUCTURE: NON CONVENTIONAL
 COMPONENTS: LB/HR
   ALGAE                    0.0         0.0       2.5334+04    0.0         0.0
 ASPEN PLUS    PLAT: WIN32       VER: 22.0                     06/01/2012  PAGE 29
                                    EXTRACTION
                                  STREAM SECTION

 E-113 E-114 E-115 E-116 PRODUCT (CONTINUED)

 STREAM ID                 E-113       E-114       E-115       E-116       PRODUCT

 COMPONENTS: MASS FRAC
   ALGAE                    0.0         0.0         1.0000      0.0         0.0
 TOTAL FLOW:
   LB/HR                    0.0         0.0       2.5334+04     0.0         0.0
 STATE VARIABLES:
   TEMP    F               MISSING     MISSING    121.6000     MISSING     MISSING
   PRES    PSIA          5076.3208   5076.3208    870.2300    870.2300    870.0000
   VFRAC                   MISSING     MISSING      0.0        MISSING     MISSING
   LFRAC                   MISSING     MISSING      0.0        MISSING     MISSING
   SFRAC                   MISSING     MISSING      1.0000     MISSING     MISSING
 ENTHALPY:
   BTU/LB                  MISSING     MISSING -6798.7208     MISSING     MISSING
   BTU/HR                  MISSING     MISSING -1.7224+08     MISSING     MISSING
 DENSITY:
   LB/CUFT                 MISSING     MISSING    141.9785     MISSING     MISSING
 AVG MW                     1.0000      1.0000      1.0000      1.0000      1.0000
```

(*Figure C.2.1: Continue*)

```
 AVG MW                     1.0000      1.0000      1.0000      1.0000      1.0000
 COMPONENT ATTRIBUTES:
 ALGAE      PROXANAL
              MOISTURE     MISSING     MISSING    100.0000     MISSING     MISSING
              FC           MISSING     MISSING      0.0        MISSING     MISSING
              VM           MISSING     MISSING      0.0        MISSING     MISSING
              ASH          MISSING     MISSING     18.4000     MISSING     MISSING
            ULTANAL
              ASH          MISSING     MISSING      0.0        MISSING     MISSING
              CARBON       MISSING     MISSING      0.0        MISSING     MISSING
              HYDROGEN     MISSING     MISSING      0.0        MISSING     MISSING
              NITROGEN     MISSING     MISSING      0.0        MISSING     MISSING
              CHLORINE     MISSING     MISSING      0.0        MISSING     MISSING
              SULFUR       MISSING     MISSING      0.0        MISSING     MISSING
              OXYGEN       MISSING     MISSING      0.0        MISSING     MISSING
            SULFANAL
              PYRITIC      MISSING     MISSING      0.0        MISSING     MISSING
              SULFATE      MISSING     MISSING      0.0        MISSING     MISSING
              ORGANIC      MISSING     MISSING      0.0        MISSING     MISSING
 SUBSTREAM ATTRIBUTES:
 PSD
   FRAC1                    0.0         0.0         0.0        MISSING      0.0
   FRAC2                    0.0         0.0         0.0        MISSING      0.0
   FRAC3                    0.0         0.0         0.0        MISSING      0.0
   FRAC4                    0.0         0.0         0.0        MISSING      0.0
   FRAC5                    0.0         0.0         0.0        MISSING      0.0
   FRAC6                    0.0         0.0         0.0        MISSING      0.0
   FRAC7                    0.0         0.0         0.0        MISSING      0.0
   FRAC8                    0.0         0.0         0.0        MISSING      0.0
   FRAC9                    0.0         0.0         0.0        MISSING      0.0
   FRAC10                   0.0         0.0         0.0        MISSING      0.0
 ASPEN PLUS    PLAT: WIN32       VER: 22.0                     06/01/2012  PAGE 30
                                    EXTRACTION
                              PROBLEM STATUS SECTION

 BLOCK STATUS
 ------------

 ****************************************************************************
 *                                                                          *
 * Calculations were completed normally                                     *
 *                                                                          *
 * All Unit Operation blocks were completed normally                        *
 *                                                                          *
 * All streams were flashed normally                                        *
 *                                                                          *
 ****************************************************************************
```

(*Figure C.2.1: Continue*)

Section C.2.2 - APEN Plus simulator output for Case Scenario 2

```
ASPEN PLUS   PLAT: WIN32      VER: 22.0                    05/07/2012  PAGE 1
                                EXTRACTION
                            RUN CONTROL SECTION

 RUN CONTROL INFORMATION
 -----------------------

 THIS COPY OF ASPEN PLUS LICENSED TO UNIV OF PUERTO RICO

 TYPE OF RUN: NEW

 INPUT FILE NAME: _1453tlf.inm

 OUTPUT PROBLEM DATA FILE NAME: _0313iii
 LOCATED IN:


 PDF SIZE USED FOR INPUT TRANSLATION:
   NUMBER OF FILE RECORDS (PSIZE) =      0
   NUMBER OF IN-CORE RECORDS      =    256
 PSIZE NEEDED FOR SIMULATION      =      1

 CALLING PROGRAM NAME:          apmain
 LOCATED IN:                    C:\PROGRA~1\ASPENT~1\ASPENP~2.0\Engine\xeq

 SIMULATION REQUESTED FOR ENTIRE FLOWSHEET

 DESCRIPTION
 -----------

        THIS VERSION CONSIDERS SIMULATION OF REAL CASE SCENARIO IN TERMS
        OF MASS RATIO OF 10%OF WATER MEDIA IN THE FEED INLET STREAM
        CULTALGAE. THIS VERSION S THE APPROACH TO CALCULATE THE
        CONVERSION OF 22982 .93KGALGAE/HR JAN222012
```

Figure C.2.2. ASPEN print out for Case Scenario 2.

```
ASPEN PLUS   PLAT: WIN32      VER: 22.0                    05/07/2012  PAGE 2
                                EXTRACTION
                            FLOWSHEET SECTION

 FLOWSHEET CONNECTIVITY BY STREAMS
 ---------------------------------

   STREAM     SOURCE     DEST           STREAM     SOURCE     DEST
   E-109      ----       Z-103          E-104      ----       P-101
   E-111      FOR-USE    ----           E-110      FOR-USE    ----
   E-112      FOR-USE    ----           PRODUCT    P-108      FOR-USE
   E-109D     Z-105      P-108          E-109C     Z-105      Z-107
   E-114      Z-107      ----           E-113      Z-107      ----
   E-109B     Z-104      Z-105          E-109A     Z-103      Z-104
   E-106C     Z-102C     Z-102D         E-108      Z-102C     Z-104
   E-106D     Z-102D     Z-102E         E-106E     Z-102E     P-106
   E-106B     Z-102B     Z-102C         E-106A     Z-102A     Z-102B
   E-106P     Z-101      P-105          E-105P     Z-101      P-104
   E-106      P-105      Z-102A         E-104P     P-101      Z-101
   E-105      P-104      ----           E-107      P-106      ----

 FLOWSHEET CONNECTIVITY BY BLOCKS
 --------------------------------

   BLOCK      INLETS                        OUTLETS
   FOR-USE    PRODUCT                       E-111 E-110 E-112
   P-108      E-109D                        PRODUCT
   Z-105      E-109B                        E-109D E-109C
   Z-107      E-109C                        E-114 E-113
   Z-104      E-109A E-108                  E-109B
   Z-103      E-109                         E-109A
   Z-102C     E-106B                        E-106C E-108
   Z-102D     E-106C                        E-106D
   Z-102E     E-106D                        E-106E
   Z-102B     E-106A                        E-106B
   Z-102A     E-106                         E-106A
   Z-101      E-104P                        E-106P E-105P
   P-105      E-106P                        E-106
   P-101      E-104                         E-104P
   P-104      E-105P                        E-105
   P-106      E-106E                        E-107
```

(*Figure C.2.2: Continue)*

```
COMPUTATIONAL  SEQUENCE
----------------------

SEQUENCE  USED  WAS:
    P-101  Z-101  P-104  P-105  Z-102A  Z-102B  Z-102C  Z-102D  Z-102E  P-106  Z-103
    Z-104  Z-105  Z-107  P-108  FOR-USE

OVERALL  FLOWSHEET  BALANCE
-------------------------
ASPEN  PLUS     PLAT:  WIN32       VER:  22.0                        05/07/2012    PAGE  3
                                        EXTRACTION
                                    FLOWSHEET  SECTION

OVERALL  FLOWSHEET  BALANCE  (CONTINUED)

                      ***   MASS  AND  ENERGY  BALANCE    ***
                                          IN               OUT           RELATIVE  DIFF.
    CONVENTIONAL  COMPONENTS  (LBMOL/HR)
        C6H12-01                    0.00000          37.0059          -1.00000
        C2H5N-01                    0.00000          195.799          -1.00000
        C3H8O-01                    0.00000          43.0963          -1.00000
        CO2                         46086.4          46086.4           0.00000
        H2O                         2812.54          2812.54           0.00000
    SUBTOTAL(LBMOL/HR)              48898.9          49174.8         -0.561062E-02
            (LB/HR     )          0.207892E+07     0.210426E+07      -0.120394E-01
    NON-CONVENTIONAL  COMPONENTS  (LB/HR     )
        ALGAE                       50668.7          25334.3           0.500000
    SUBTOTAL(LB/HR     )            50668.7          25334.3           0.500000
    TOTAL  BALANCE
        MASS(LB/HR     )          0.212959E+07     0.212959E+07       0.198402E-06
        ENTHALPY(BTU/HR   )      -0.846923E+10    -0.836974E+10      -0.117465E-01
ASPEN  PLUS     PLAT:  WIN32       VER:  22.0                        05/07/2012    PAGE  4
                                        EXTRACTION
                                PHYSICAL  PROPERTIES  SECTION
```

(*Figure C.2.2: Continue*)

```
COMPONENTS
----------

 ID          TYPE   FORMULA          NAME  OR  ALIAS                               REPORT  NAME
  C6H12-01  C       C6H12O6          C6H12O6                                        C6H12-01
  C2H5N-01  C       C2H5NO2-D1       C2H5NO2-D1                                     C2H5N-01
  C3H8O-01  C       C3H8O3           C3H8O3                                         C3H8O-01
  CO2       C       CO2              CO2                                            CO2
  ALGAE     NC                       MISSING                                        ALGAE
  H2O       C       H2O              H2O                                            H2O

 ID                 ATTRIBUTE  TYPES
  ALGAE              PROXANAL  ULTANAL  SULFANAL
ASPEN  PLUS     PLAT:  WIN32       VER:  22.0                      05/07/2012    PAGE  5
                                       EXTRACTION
                                   U-O-S  BLOCK  SECTION

BLOCK:   FOR-USE   MODEL:  SEP
---------------------------
  INLET  STREAM:              PRODUCT
  OUTLET  STREAMS:            E-111        E-110         E-112
  PROPERTY  OPTION  SET:      UNIQUAC     UNIQUAC  /  IDEAL  GAS

                      ***   MASS  AND  ENERGY  BALANCE    ***
                                         IN                OUT            RELATIVE  DIFF.
      CONV.  COMP.(LBMOL/HR)          275.901            275.901           0.00000
                  (LB/HR     )        25333.9            25333.9          -0.143601E-15
      NONCONV.  COMP(LB/HR     )      0.00000            0.00000           0.00000
   TOTAL  BALANCE
      MASS(LB/HR     )                25333.9            25333.9          -0.143601E-15
      ENTHALPY(BTU/HR   )          -0.742263E+08      -0.741089E+08      -0.158158E-02
```

(*Figure C.2.2: Continue*)

```
                      ***  INPUT DATA  ***

 INLET PRESSURE   PSIA                                      5,076.32

 FLASH SPECS FOR STREAM E-111
 TWO    PHASE  TP  FLASH
 SPECIFIED TEMPERATURE F                                   130.910
 SPECIFIED PRESSURE    PSIA                               5,076.32
 MAXIMUM NO. ITERATIONS                                     30
 CONVERGENCE TOLERANCE                                      0.000100000

 FLASH SPECS FOR STREAM E-110
 TWO    PHASE  TP  FLASH
 SPECIFIED TEMPERATURE F                                   130.730
 SPECIFIED PRESSURE    PSIA                               5,076.32
 MAXIMUM NO. ITERATIONS                                     30
 CONVERGENCE TOLERANCE                                      0.000100000

 FLASH SPECS FOR STREAM E-112
 TWO    PHASE  TP  FLASH
 SPECIFIED TEMPERATURE F                                   130.910
 SPECIFIED PRESSURE    PSIA                               5,076.32
 MAXIMUM NO. ITERATIONS                                     30
 CONVERGENCE TOLERANCE                                      0.000100000
ASPEN PLUS   PLAT: WIN32     VER: 22.0                     05/07/2012   PAGE 6
                                EXTRACTION
                             U-O-S BLOCK SECTION

BLOCK:  FOR-USE  MODEL: SEP (CONTINUED)

 FRACTION OF FEED
   SUBSTREAM= MIXED
     STREAM= E-110       CPT= C6H12-01   FRACTION=          1.00000
                              C2H5N-01                      0.0
                              C3H8O-01                      0.0
     STREAM= E-112       CPT= C6H12-01   FRACTION=          0.0
                              C2H5N-01                      0.0
                              C3H8O-01                      1.00000
```

(*Figure C.2.2: Continue*)

```
                          ***  RESULTS  ***

 HEAT DUTY              BTU/HR                              0.11739E+06

 COMPONENT = C6H12-01
   STREAM      SUBSTREAM     SPLIT FRACTION
   E-110       MIXED                1.00000

 COMPONENT = C2H5N-01
   STREAM      SUBSTREAM     SPLIT FRACTION
   E-111       MIXED                1.00000

 COMPONENT = C3H8O-01
   STREAM      SUBSTREAM     SPLIT FRACTION
   E-112       MIXED                1.00000

BLOCK:  P-101    MODEL: PUMP
-----------------------------
  INLET STREAM:             E-104
  OUTLET STREAM:            E-104P
  PROPERTY OPTION SET:      UNIQUAC    UNIQUAC / IDEAL GAS

                     ***  MASS AND ENERGY BALANCE  ***
                                  IN              OUT        RELATIVE DIFF.
      CONV. COMP.(LBMOL/HR)     2812.54         2812.54         0.00000
                 (LB/HR   )     50668.7         50668.7         0.00000
      NONCONV. COMP(LB/HR   )   50668.7         50668.7         0.00000
   TOTAL BALANCE
      MASS(LB/HR    )           101337.         101337.         0.00000
      ENTHALPY(BTU/HR  )      -0.673825E+09   -0.673825E+09     0.00000
ASPEN PLUS   PLAT: WIN32     VER: 22.0                     05/07/2012   PAGE 7
                                EXTRACTION
                             U-O-S BLOCK SECTION
```

(*Figure C.2.2: Continue*)

```
BLOCK:  P-101    MODEL: PUMP (CONTINUED)

                        ***  INPUT DATA  ***
   OUTLET PRESSURE  PSIA                                      90.0000
   PUMP EFFICIENCY                                             0.60000
   DRIVER EFFICIENCY                                           1.00000

   FLASH SPECIFICATIONS:
   LIQUID PHASE CALCULATION
   NO FLASH PERFORMED
   MAXIMUM NUMBER OF ITERATIONS                                30
   TOLERANCE                                                   0.000100000

                         ***  RESULTS  ***
   VOLUMETRIC FLOW RATE  CUFT/HR                              816.529
   PRESSURE CHANGE  PSI                                        0.0
   NPSH AVAILABLE   FT-LBF/LB                                 207.787
   FLUID POWER  HP                                             0.0
   BRAKE POWER  HP                                             0.0
   ELECTRICITY  KW                                             0.0
   PUMP EFFICIENCY USED                                        0.60000
   NET WORK REQUIRED  HP                                       0.0
   HEAD DEVELOPED FT-LBF/LB                                    0.0

BLOCK:  P-104    MODEL: PUMP
----------------------------
  INLET STREAM:          E-105P
  OUTLET STREAM:         E-105
  PROPERTY OPTION SET:   UNIQUAC   UNIQUAC / IDEAL GAS

                    ***  MASS AND ENERGY BALANCE  ***
                                    IN              OUT        RELATIVE DIFF.
     CONV. COMP.(LBMOL/HR)       1687.52         1687.52         0.00000
                (LB/HR    )      30401.2         30401.2         0.00000
     NONCONV. COMP(LB/HR    )    0.00000         0.00000         0.00000
   TOTAL BALANCE
     MASS(LB/HR    )             30401.2         30401.2         0.00000
     ENTHALPY(BTU/HR  )       -0.207267E+09   -0.207270E+09   0.157463E-04
± ASPEN PLUS   PLAT: WIN32     VER: 22.0                    05/07/2012  PAGE 8
                                  EXTRACTION
                              U-O-S BLOCK SECTION
```

(*Figure C.2.2: Continue)*

```
BLOCK:  P-104    MODEL: PUMP (CONTINUED)

                        ***  INPUT DATA  ***
   OUTLET PRESSURE  PSIA                                      30.0000
   PUMP EFFICIENCY                                             0.60000
   DRIVER EFFICIENCY                                           1.00000

   FLASH SPECIFICATIONS:
   LIQUID PHASE CALCULATION
   NO FLASH PERFORMED
   MAXIMUM NUMBER OF ITERATIONS                                30
   TOLERANCE                                                   0.000100000

                         ***  RESULTS  ***
   VOLUMETRIC FLOW RATE  CUFT/HR                              489.918
   PRESSURE CHANGE  PSI                                       -60.0000
   NPSH AVAILABLE   FT-LBF/LB                                 207.787
   FLUID POWER  HP                                             -2.13782
   BRAKE POWER  HP                                             -1.28269
   ELECTRICITY  KW                                             -0.95650
   PUMP EFFICIENCY USED                                         0.60000
   NET WORK REQUIRED  HP                                       -1.28269
   HEAD DEVELOPED FT-LBF/LB                                  -139.234

BLOCK:  P-105    MODEL: PUMP
----------------------------
  INLET STREAM:          E-106P
  OUTLET STREAM:         E-106
  PROPERTY OPTION SET:   UNIQUAC   UNIQUAC / IDEAL GAS

                    ***  MASS AND ENERGY BALANCE  ***
                                    IN              OUT        RELATIVE DIFF.
     CONV. COMP.(LBMOL/HR)       1125.02         1125.02         0.00000
                (LB/HR    )      20267.5         20267.5         0.00000
     NONCONV. COMP(LB/HR    )    50668.7         50668.7         0.00000
   TOTAL BALANCE
     MASS(LB/HR    )             70936.2         70936.2         0.00000
     ENTHALPY(BTU/HR  )       -0.466558E+09   -0.466559E+09   0.233151E-05
± ASPEN PLUS   PLAT: WIN32     VER: 22.0                    05/07/2012  PAGE 9
                                  EXTRACTION
                              U-O-S BLOCK SECTION
```

(*Figure C.2.2: Continue)*

```
BLOCK:  P-105    MODEL: PUMP (CONTINUED)

                          ***  INPUT DATA  ***
    OUTLET PRESSURE  PSIA                                           60.0000
    PUMP EFFICIENCY                                                  0.60000
    DRIVER EFFICIENCY                                                0.60000

    FLASH SPECIFICATIONS:
    LIQUID PHASE CALCULATION
    NO FLASH PERFORMED
    MAXIMUM NUMBER OF ITERATIONS                                     30
    TOLERANCE                                                        0.000100000

                           ***  RESULTS  ***
    VOLUMETRIC FLOW RATE  CUFT/HR                                  326.612
    PRESSURE CHANGE  PSI                                           -30.0000
    NPSH AVAILABLE    FT-LBF/LB                                    207.787
    FLUID POWER  HP                                                 -0.71261
    BRAKE POWER  HP                                                 -0.42756
    ELECTRICITY  KW                                                 -0.19130
    PUMP EFFICIENCY USED                                             0.60000
    NET WORK REQUIRED  HP                                           -0.25654
    HEAD DEVELOPED FT-LBF/LB                                       -69.6171

BLOCK:  P-106    MODEL: PUMP
----------------------------
  INLET STREAM:           E-106E
  OUTLET STREAM:          E-107
  PROPERTY OPTION SET:    UNIQUAC   UNIQUAC / IDEAL GAS

                     ***  MASS AND ENERGY BALANCE  ***
                                     IN             OUT           RELATIVE DIFF.
      CONV. COMP.(LBMOL/HR)        1125.02         1125.02          0.00000
                  (LB/HR    )      20267.5         20267.5          0.00000
      NONCONV. COMP(LB/HR    )     0.00000         0.00000          0.00000
    TOTAL BALANCE
      MASS(LB/HR    )              20267.5         20267.5          0.00000
      ENTHALPY(BTU/HR   )      -0.138009E+09   -0.138006E+09   -0.223679E-04
‡ ASPEN PLUS    PLAT: WIN32      VER: 22.0                     05/07/2012  PAGE 10
                                      EXTRACTION
                                   U-O-S BLOCK SECTION
```

(*Figure C.2.2: Continue)*

```
BLOCK:  P-106    MODEL: PUMP (CONTINUED)

                          ***  INPUT DATA  ***
    OUTLET PRESSURE  PSIA                                           45.0000
    PUMP EFFICIENCY                                                  0.60000
    DRIVER EFFICIENCY                                                1.00000

    FLASH SPECIFICATIONS:
    LIQUID PHASE CALCULATION
    NO FLASH PERFORMED
    MAXIMUM NUMBER OF ITERATIONS                                     30
    TOLERANCE                                                        0.000100000

                           ***  RESULTS  ***
    VOLUMETRIC FLOW RATE  CUFT/HR                                  328.209
    PRESSURE CHANGE  PSI                                            30.4962
    NPSH AVAILABLE    FT-LBF/LB                                     32.3889
    FLUID POWER  HP                                                  0.72794
    BRAKE POWER  HP                                                  1.21323
    ELECTRICITY  KW                                                  0.90470
    PUMP EFFICIENCY USED                                             0.60000
    NET WORK REQUIRED  HP                                            1.21323
    HEAD DEVELOPED FT-LBF/LB                                        71.1146

BLOCK:  P-108    MODEL: PUMP
----------------------------
  INLET STREAM:           E-109D
  OUTLET STREAM:          PRODUCT
  PROPERTY OPTION SET:    UNIQUAC   UNIQUAC / IDEAL GAS

                     ***  MASS AND ENERGY BALANCE  ***
                                     IN             OUT           RELATIVE DIFF.
      CONV. COMP.(LBMOL/HR)        275.901         275.901          0.00000
                  (LB/HR    )      25333.9         25333.9          0.00000
      NONCONV. COMP(LB/HR    )     0.00000         0.00000          0.00000
    TOTAL BALANCE
      MASS(LB/HR    )              25333.9         25333.9          0.00000
      ENTHALPY(BTU/HR   )      -0.742263E+08   -0.742263E+08   -0.401506E-15
‡ ASPEN PLUS    PLAT: WIN32      VER: 22.0                     05/07/2012  PAGE 11
                                      EXTRACTION
                                   U-O-S BLOCK SECTION
```

(*Figure C.2.2: Continue)*

```
BLOCK:  P-108    MODEL: PUMP (CONTINUED)

                          ***  INPUT DATA  ***
   EQUIPMENT TYPE: PUMP
   OUTLET PRESSURE  PSIA                                        870.230
   PUMP EFFICIENCY                                                0.60000
   DRIVER EFFICIENCY                                              1.00000

   FLASH SPECIFICATIONS:
   LIQUID PHASE CALCULATION
   NO FLASH PERFORMED
   MAXIMUM NUMBER OF ITERATIONS                                    30
   TOLERANCE                                                       0.000100000

                           ***  RESULTS  ***
   VOLUMETRIC FLOW RATE  CUFT/HR                                295.307
   PRESSURE CHANGE  PSI                                           0.0
   NPSH AVAILABLE   FT-LBF/LB                                 1,460.72
   FLUID POWER  HP                                                0.0
   BRAKE POWER  HP                                                0.0
   ELECTRICITY  KW                                                0.0
   PUMP EFFICIENCY USED                                           0.60000
   NET WORK REQUIRED  HP                                          0.0
   HEAD DEVELOPED FT-LBF/LB                                       0.0

BLOCK:  Z-101    MODEL: SEP
---------------------------
  INLET STREAM:          E-104P
  OUTLET STREAMS:        E-106P     E-105P
  PROPERTY OPTION SET:   UNIQUAC   UNIQUAC / IDEAL GAS

                    ***  MASS AND ENERGY BALANCE  ***
                                IN              OUT          RELATIVE DIFF.
     CONV. COMP.(LBMOL/HR)    2812.54         2812.54          0.00000
                (LB/HR   )    50668.7         50668.7          0.00000
     NONCONV. COMP(LB/HR   )  50668.7         50668.7          0.00000
   TOTAL BALANCE
     MASS(LB/HR    )          101337.         101337.          0.00000
     ENTHALPY(BTU/HR  )     -0.673825E+09   -0.673825E+09    -0.424771E-12
```

(*Figure C.2.2: Continue*)

```
                          ***  INPUT DATA  ***

   INLET PRESSURE   PSIA                                         90.0000
 ‡ ASPEN PLUS   PLAT: WIN32     VER: 22.0                     05/07/2012  PAGE 12
                                    EXTRACTION
                                 U-O-S BLOCK SECTION

 BLOCK:  Z-101    MODEL: SEP (CONTINUED)

   FLASH SPECS FOR STREAM E-106P
   TWO    PHASE  TP  FLASH
   PRESSURE DROP          PSI                                    0.0
   MAXIMUM NO. ITERATIONS                                       30
   CONVERGENCE TOLERANCE                                         0.000100000

   FLASH SPECS FOR STREAM E-105P
   TWO    PHASE  TP  FLASH
   PRESSURE DROP          PSI                                    0.0
   MAXIMUM NO. ITERATIONS                                       30
   CONVERGENCE TOLERANCE                                         0.000100000

   FRACTION OF FEED
     SUBSTREAM= MIXED
       STREAM= E-105P    CPT= H2O       FRACTION=          0.60000
     SUBSTREAM= NCPSD
       STREAM= E-105P    CPT= ALGAE     FRACTION=          0.0

                           ***  RESULTS  ***

   HEAT DUTY              BTU/HR                                 0.28615E-03

  COMPONENT = H2O
    STREAM     SUBSTREAM    SPLIT FRACTION
    E-106P     MIXED                0.40000
    E-105P     MIXED                0.60000

  COMPONENT = ALGAE
    STREAM     SUBSTREAM    SPLIT FRACTION
    E-106P     NCPSD                1.00000
```

(*Figure C.2.2: Continue*)

```
BLOCK:  Z-102A   MODEL: HEATER
------------------------------
  INLET STREAM:           E-106
  OUTLET STREAM:          E-106A
  PROPERTY OPTION SET:    UNIQUAC   UNIQUAC / IDEAL GAS
‡ ASPEN PLUS   PLAT: WIN32      VER: 22.0                   05/07/2012  PAGE 13
                                   EXTRACTION
                               U-O-S BLOCK SECTION

BLOCK:  Z-102A   MODEL: HEATER (CONTINUED)

                     ***  MASS AND ENERGY BALANCE  ***
                                  IN              OUT          RELATIVE DIFF.
      CONV. COMP.(LBMOL/HR)     1125.02         1125.02          0.00000
                 (LB/HR    )    20267.5         20267.5          0.00000
      NONCONV. COMP(LB/HR    )  50668.7         50668.7          0.00000
   TOTAL BALANCE
      MASS(LB/HR    )           70936.2         70936.2          0.00000
      ENTHALPY(BTU/HR  )      -0.466559E+09   -0.471445E+09    0.103637E-01

                         ***  INPUT DATA  ***
  TWO    PHASE  TP  FLASH
  SPECIFIED TEMPERATURE                 F                         -40.0900
  SPECIFIED PRESSURE                    PSIA                       14.5038
  MAXIMUM NO. ITERATIONS                                           30
  CONVERGENCE TOLERANCE                                             0.000100000


                          ***  RESULTS  ***
  OUTLET TEMPERATURE    F                                     -40.090
  OUTLET PRESSURE       PSIA                                   14.504
  HEAT DUTY             BTU/HR                               -0.48859E+07
  OUTLET VAPOR FRACTION                                         0.0000
  PRESSURE-DROP CORRELATION PARAMETER                           0.49231E+08


  V-L PHASE EQUILIBRIUM :

     COMP             F(I)          X(I)          Y(I)          K(I)
     H2O              1.0000        1.0000        1.0000        0.20011E-03
```

(*Figure C.2.2: Continue)*

```
BLOCK:  Z-102B   MODEL: HEATER
------------------------------
  INLET STREAM:           E-106A
  OUTLET STREAM:          E-106B
  PROPERTY OPTION SET:    UNIQUAC   UNIQUAC / IDEAL GAS
‡ ASPEN PLUS   PLAT: WIN32      VER: 22.0                   05/07/2012  PAGE 14
                                   EXTRACTION
                               U-O-S BLOCK SECTION

BLOCK:  Z-102B   MODEL: HEATER (CONTINUED)

                     ***  MASS AND ENERGY BALANCE  ***
                                  IN              OUT          RELATIVE DIFF.
      CONV. COMP.(LBMOL/HR)     1125.02         1125.02          0.00000
                 (LB/HR    )    20267.5         20267.5          0.00000
      NONCONV. COMP(LB/HR    )  50668.7         50668.7          0.00000
   TOTAL BALANCE
      MASS(LB/HR    )           70936.2         70936.2          0.00000
      ENTHALPY(BTU/HR  )      -0.471445E+09   -0.440210E+09   -0.662552E-01

                         ***  INPUT DATA  ***
  TWO    PHASE  TP  FLASH
  SPECIFIED TEMPERATURE                 F                          233.100
  SPECIFIED PRESSURE                    PSIA                         1.45038
  MAXIMUM NO. ITERATIONS                                           30
  CONVERGENCE TOLERANCE                                             0.000100000


                          ***  RESULTS  ***
  OUTLET TEMPERATURE    F                                     233.10
  OUTLET PRESSURE       PSIA                                  1.4504
  HEAT DUTY             BTU/HR                               0.31236E+08
  OUTLET VAPOR FRACTION                                       1.0000
  PRESSURE-DROP CORRELATION PARAMETER                         1553.9


  V-L PHASE EQUILIBRIUM :

     COMP             F(I)          X(I)          Y(I)          K(I)
     H2O              1.0000        1.0000        1.0000        15.160
```

(*Figure C.2.2: Continue)*

```
BLOCK:  Z-102C   MODEL: FLASH2
------------------------------
  INLET STREAM:            E-106B
  OUTLET VAPOR STREAM:     E-106C
  OUTLET LIQUID STREAM:    E-108
  PROPERTY OPTION SET:     UNIQUAC   UNIQUAC / IDEAL GAS
‡ ASPEN PLUS   PLAT: WIN32      VER: 22.0                          05/07/2012   PAGE 15
                                    EXTRACTION
                                U-O-S BLOCK SECTION

BLOCK:  Z-102C   MODEL: FLASH2 (CONTINUED)

                     ***  MASS AND ENERGY BALANCE  ***
                                    IN              OUT           RELATIVE DIFF.
      CONV. COMP.(LBMOL/HR)       1125.02         1125.02           0.00000
                 (LB/HR    )      20267.5         20267.5           0.00000
      NONCONV. COMP(LB/HR    )    50668.7         50668.7           0.00000
   TOTAL BALANCE
      MASS(LB/HR    )             70936.2         70936.2           0.00000
      ENTHALPY(BTU/HR   )      -0.440210E+09   -0.444042E+09     0.863023E-02

                         ***  INPUT DATA  ***
  TWO    PHASE  TP  FLASH
  SPECIFIED TEMPERATURE F                                 116.510
  SPECIFIED PRESSURE     PSIA                               1.45038
  MAXIMUM NO. ITERATIONS                                  30
  CONVERGENCE TOLERANCE                                     0.000100000

                          ***  RESULTS  ***
  OUTLET TEMPERATURE     F                                    116.51
  OUTLET PRESSURE        PSIA                                 1.4504
  HEAT DUTY              BTU/HR                             -0.38322E+07
  VAPOR FRACTION                                              1.0000


  V-L PHASE EQUILIBRIUM :

     COMP               F(I)           X(I)           Y(I)           K(I)
     H2O                1.0000         1.0000         1.0000         1.0600
```

(*Figure C.2.2: Continue)*

```
BLOCK:  Z-102D   MODEL: COMPR
------------------------------
  INLET STREAM:            E-106C
  OUTLET STREAM:           E-106D
  PROPERTY OPTION SET:     UNIQUAC   UNIQUAC / IDEAL GAS

                     ***  MASS AND ENERGY BALANCE  ***
                                    IN              OUT           RELATIVE DIFF.
      CONV. COMP.(LBMOL/HR)       1125.02         1125.02           0.00000
                 (LB/HR    )      20267.5         20267.5           0.00000
      NONCONV. COMP(LB/HR    )    0.00000         0.00000           0.00000
‡ ASPEN PLUS   PLAT: WIN32      VER: 22.0                       05/07/2012   PAGE 16
                                    EXTRACTION
                                U-O-S BLOCK SECTION

BLOCK:  Z-102D   MODEL: COMPR (CONTINUED)
   TOTAL BALANCE
      MASS(LB/HR    )             20267.5         20267.5           0.00000
      ENTHALPY(BTU/HR   )      -0.116601E+09   -0.109483E+09    -0.610507E-01

                         ***  INPUT DATA  ***

  POLYTROPIC COMPRESSOR USING ASME METHOD
   OUTLET PRESSURE  PSIA                                  15.0000
   POLYTROPIC EFFICIENCY                                   0.66000
   MECHANICAL EFFICIENCY                                   0.60000
```

(*Figure C.2.2: Continue)*

```
                    ***  RESULTS  ***

   INDICATED  HORSEPOWER REQUIREMENT  HP                 2,797.71
   BRAKE      HORSEPOWER REQUIREMENT  HP                 4,662.84
   NET WORK REQUIRED                  HP                 4,662.84
   POWER LOSSES                       HP                 1,865.14
   ISENTROPIC HORSEPOWER REQUIREMENT  HP                 1,590.71
   CALCULATED OUTLET TEMP  F                               860.709
   EFFICIENCY (POLYTR/ISENTR) USED                           0.66000
   OUTLET VAPOR FRACTION                                     1.00000
   HEAD DEVELOPED,       FT-LBF/LB                     180,390.
   MECHANICAL EFFICIENCY USED                                0.60000
   INLET HEAT CAPACITY RATIO                                 1.32818
   INLET VOLUMETRIC FLOW RATE , CUFT/HR                4,796,150.
   OUTLET VOLUMETRIC FLOW RATE, CUFT/HR                1,062,730.
   INLET  COMPRESSIBILITY FACTOR                             1.00000
   OUTLET COMPRESSIBILITY FACTOR                             1.00000
   AV. ISENT. VOL. EXPONENT                                  1.31664
   AV. ISENT. TEMP EXPONENT                                  1.31664
   AV. ACTUAL VOL. EXPONENT                                  1.55028
   AV. ACTUAL TEMP EXPONENT                                  1.55028

 BLOCK:  Z-102E   MODEL: HEATER
 ------------------------------
   INLET STREAM:           E-106D
   OUTLET STREAM:          E-106E
   PROPERTY OPTION SET:    UNIQUAC   UNIQUAC / IDEAL GAS
‡ ASPEN PLUS   PLAT: WIN32     VER: 22.0                    05/07/2012  PAGE 17
                                  EXTRACTION
                              U-O-S BLOCK SECTION
```

(*Figure C.2.2: Continue*)


```
 BLOCK:  Z-102E   MODEL: HEATER
 ------------------------------
   INLET STREAM:           E-106D
   OUTLET STREAM:          E-106E
   PROPERTY OPTION SET:    UNIQUAC   UNIQUAC / IDEAL GAS
‡ ASPEN PLUS   PLAT: WIN32     VER: 22.0                    05/07/2012  PAGE 17
                                  EXTRACTION
                              U-O-S BLOCK SECTION
```


```
 BLOCK:  Z-102E   MODEL: HEATER (CONTINUED)

                   ***  MASS AND ENERGY BALANCE  ***
                                     IN            OUT        RELATIVE DIFF.
      CONV. COMP.(LBMOL/HR)      1125.02        1125.02          0.00000
                 (LB/HR    )     20267.5        20267.5          0.00000
      NONCONV. COMP(LB/HR    )   0.00000        0.00000          0.00000
   TOTAL BALANCE
      MASS(LB/HR    )            20267.5        20267.5          0.00000
      ENTHALPY(BTU/HR  )       -0.109483E+09  -0.138009E+09      0.206701

                       ***  INPUT DATA  ***
   TWO    PHASE  TP  FLASH
   SPECIFIED TEMPERATURE              F                       85.9100
   SPECIFIED PRESSURE                 PSIA                    14.5038
   MAXIMUM NO. ITERATIONS                                     30
   CONVERGENCE TOLERANCE                                       0.000100000


                        ***  RESULTS  ***
   OUTLET TEMPERATURE     F                               85.910
   OUTLET PRESSURE        PSIA                            14.504
   HEAT DUTY              BTU/HR                        -0.28527E+08
   OUTLET VAPOR FRACTION                                   0.0000
   PRESSURE-DROP CORRELATION PARAMETER                    320.45


   V-L PHASE EQUILIBRIUM :

      COMP             F(I)          X(I)          Y(I)          K(I)
      H2O              1.0000        1.0000        1.0000        0.42357E-01
```

(*Figure C.2.2: Continue*)

```
BLOCK:  Z-103    MODEL: COMPR
-----------------------------
  INLET STREAM:           E-109
  OUTLET STREAM:          E-109A
  PROPERTY OPTION SET:    UNIQUAC   UNIQUAC / IDEAL GAS
ASPEN PLUS   PLAT: WIN32      VER: 22.0                    05/07/2012  PAGE 18
                               EXTRACTION
                           U-O-S BLOCK SECTION

BLOCK:  Z-103    MODEL: COMPR (CONTINUED)

                       ***  MASS AND ENERGY BALANCE  ***
                                  IN                OUT          RELATIVE DIFF.
      CONV. COMP.(LBMOL/HR)     46086.4           46086.4           0.00000
                 (LB/HR    )    0.202825E+07      0.202825E+07      0.00000
      NONCONV. COMP(LB/HR   )    0.00000           0.00000          0.00000
   TOTAL BALANCE
      MASS(LB/HR    )           0.202825E+07      0.202825E+07      0.00000
      ENTHALPY(BTU/HR  )       -0.779540E+10     -0.775746E+10     -0.486696E-02

                            ***  INPUT DATA  ***

  POLYTROPIC POSITIVE DISPLACEMENT COMPRESSOR          USING PIECEWISE INTEGRATION
   OUTLET PRESSURE  PSIA                                 1,450.37
   POLYTROPIC EFFICIENCY                                      0.72000
   MECHANICAL EFFICIENCY                                      0.60000
   CLEARANCE FRACTION                                         0.50000
```

(*Figure C.2.2: Continue*)

```
                          ***  RESULTS  ***

    INDICATED  HORSEPOWER REQUIREMENT  HP              14,910.9
    BRAKE      HORSEPOWER REQUIREMENT  HP              24,851.6
    NET WORK REQUIRED                  HP              24,851.6
    POWER LOSSES                       HP               9,940.62
    ISENTROPIC HORSEPOWER REQUIREMENT  HP              10,502.1
    CALCULATED OUTLET TEMP  F                              169.918
    ISENTROPIC TEMPERATURE  F                              144.034
    EFFICIENCY (POLYTR/ISENTR) USED                          0.72000
    VOLUMETRIC EFFICIENCY                                    0.76835
    DISPLACEMENT              CUFT/HR                 399,554.
    OUTLET VAPOR FRACTION                                    1.00000
    HEAD DEVELOPED,         FT-LBF/LB                  10,480.5
    MECHANICAL EFFICIENCY USED                               0.60000
    INLET HEAT CAPACITY RATIO                                1.28678
    INLET VOLUMETRIC FLOW RATE , CUFT/HR              306,997.
    OUTLET VOLUMETRIC FLOW RATE, CUFT/HR              214,688.
    INLET  COMPRESSIBILITY FACTOR                            1.00000
    OUTLET COMPRESSIBILITY FACTOR                            1.00000
    AV. ISENT. VOL. EXPONENT                                 1.27821
    AV. ISENT. TEMP EXPONENT                                 1.27821
    AV. ACTUAL VOL. EXPONENT                                 1.42824
    AV. ACTUAL TEMP EXPONENT                                 1.42824
ASPEN PLUS   PLAT: WIN32      VER: 22.0                    05/07/2012  PAGE 19
                               EXTRACTION
                           U-O-S BLOCK SECTION

BLOCK:  Z-104    MODEL: RSTOIC
------------------------------
  INLET STREAMS:          E-109A      E-108
  OUTLET STREAM:          E-109B
  PROPERTY OPTION SET:    UNIQUAC   UNIQUAC / IDEAL GAS

                   ***  MASS AND ENERGY BALANCE  ***
                             IN            OUT        GENERATION    RELATIVE DIFF.
CONV. COMP.(LBMOL/HR)     46086.4        46362.3       275.901      -0.134868E-16
           (LB/HR    )   0.202825E+07  0.205359E+07                 -0.123364E-01
NONCONV COMP(LB/HR   )    50668.7        25334.3                      0.500000
  TOTAL BALANCE
     MASS(LB/HR    )     0.207892E+07  0.207892E+07                   0.203238E-06
     ENTHALPY(BTU/HR  )-0.808490E+10 -0.802467E+10                  -0.745055E-02
```

(*Figure C.2.2: Continue*)

```
                          ***  INPUT DATA  ***
STOICHIOMETRY MATRIX:

 REACTION #   1:
  SUBSTREAM MIXED    :
  C6H12-01  0.146E-02C2H5N-01  0.773E-02C3H8O-01  0.170E-02
  SUBSTREAM NCPSD    :
  ALGAE     -1.00


REACTION CONVERSION SPECS: NUMBER=    1
  REACTION #   1:
  SUBSTREAM:NCPSD    KEY COMP:ALGAE    CONV FRAC: 0.5000



TWO    PHASE  TP  FLASH
SPECIFIED TEMPERATURE F                                    121.730
SPECIFIED PRESSURE    PSIA                               5,801.51
MAXIMUM NO. ITERATIONS                                      30
CONVERGENCE TOLERANCE                                       0.000100000
SIMULTANEOUS REACTIONS
GENERATE COMBUSTION REACTIONS FOR FEED SPECIES            NO
ASPEN PLUS   PLAT: WIN32     VER: 22.0                   05/07/2012   PAGE 20
                                 EXTRACTION
                             U-O-S BLOCK SECTION

BLOCK:  Z-104    MODEL: RSTOIC (CONTINUED)

                          ***  RESULTS  ***
OUTLET TEMPERATURE    F                                    121.73
OUTLET PRESSURE       PSIA                                 5801.5
HEAT DUTY             BTU/HR                              0.60235E+08
VAPOR FRACTION                                             0.0000


REACTION EXTENTS:

   REACTION          REACTION
   NUMBER            EXTENT
                     LBMOL/HR
   1                  25334.
```

(*Figure C.2.2: Continue)*

```
REACTION EXTENTS:

   REACTION          REACTION
   NUMBER            EXTENT
                     LBMOL/HR
   1                  25334.

V-L PHASE EQUILIBRIUM :

   COMP             F(I)          X(I)          Y(I)          K(I)
   C6H12-01         0.79819E-03   0.79819E-03   0.16078E-16   0.54754E-14
   C2H5N-01         0.42232E-02   0.42232E-02   0.15513E-12   0.99850E-11
   C3H8O-01         0.92955E-03   0.92955E-03   0.17049E-10   0.49855E-08
   CO2              0.99405       0.99405        1.0000       0.27345
BLOCK:  Z-105    MODEL: SEP
---------------------------
  INLET STREAM:           E-109B
  OUTLET STREAMS:         E-109D     E-109C
  PROPERTY OPTION SET:    UNIQUAC    UNIQUAC / IDEAL GAS

                   ***  MASS AND ENERGY BALANCE  ***
                                  IN             OUT          RELATIVE DIFF.
     CONV. COMP.(LBMOL/HR)      46362.3        46362.3         0.00000
                (LB/HR   )    0.205359E+07   0.205359E+07      0.00000
     NONCONV. COMP(LB/HR   )    25334.3        25334.3         0.00000
   TOTAL BALANCE
     MASS(LB/HR   )           0.207892E+07   0.207892E+07      0.00000
     ENTHALPY(BTU/HR  )      -0.802467E+10  -0.802458E+10   -0.100878E-04

                          ***  INPUT DATA  ***

  INLET PRESSURE    PSIA                                  5,801.51
ASPEN PLUS    PLAT: WIN32     VER: 22.0                   05/07/2012   PAGE 21
                                 EXTRACTION
                             U-O-S BLOCK SECTION
```

(*Figure C.2.2: Continue)*

```
BLOCK:  Z-105    MODEL: SEP (CONTINUED)

  FLASH SPECS FOR STREAM E-109D
  TWO    PHASE  TP  FLASH
  SPECIFIED TEMPERATURE F                                   121.910
  SPECIFIED PRESSURE    PSIA                                870.230
  MAXIMUM NO. ITERATIONS                                     30
  CONVERGENCE TOLERANCE                                       0.000100000

  FLASH SPECS FOR STREAM E-109C
  TWO    PHASE  TP  FLASH
  SPECIFIED TEMPERATURE F                                   121.910
  SPECIFIED PRESSURE    PSIA                                870.230
  MAXIMUM NO. ITERATIONS                                     30
  CONVERGENCE TOLERANCE                                       0.000100000

  FRACTION OF FEED
    SUBSTREAM= MIXED
      STREAM= E-109C     CPT= C6H12-01  FRACTION=           0.0
                              C2H5N-01                      0.0
                              C3H8O-01                      0.0
                              CO2                           1.00000
```

(*Figure C.2.2: Continue)*

```
                              ***  RESULTS  ***

  HEAT DUTY              BTU/HR                                  80951.

 COMPONENT = C6H12-01
   STREAM     SUBSTREAM     SPLIT FRACTION
   E-109D     MIXED                1.00000

 COMPONENT = C2H5N-01
   STREAM     SUBSTREAM     SPLIT FRACTION
   E-109D     MIXED                1.00000

 COMPONENT = C3H8O-01
   STREAM     SUBSTREAM     SPLIT FRACTION
   E-109D     MIXED                1.00000

 COMPONENT = CO2
   STREAM     SUBSTREAM     SPLIT FRACTION
   E-109C     MIXED                1.00000

 COMPONENT = ALGAE
   STREAM     SUBSTREAM     SPLIT FRACTION
   E-109C     NCPSD                1.00000
 ASPEN PLUS   PLAT: WIN32     VER: 22.0                      05/07/2012  PAGE 22
                                 EXTRACTION
                              U-O-S BLOCK SECTION
```

(*Figure C.2.2: Continue)*

```
                                 EXTRACTION
                             U-O-S BLOCK SECTION

BLOCK:  Z-107    MODEL: FLASH2
------------------------------
   INLET STREAM:          E-109C
   OUTLET VAPOR STREAM:   E-114
   OUTLET LIQUID STREAM:  E-113
   PROPERTY OPTION SET:   UNIQUAC   UNIQUAC / IDEAL GAS

                    ***  MASS AND ENERGY BALANCE  ***
                                 IN              OUT          RELATIVE DIFF.
       CONV. COMP.(LBMOL/HR)     46086.4         46086.4          0.00000
                  (LB/HR   )    0.202825E+07    0.202825E+07      0.00000
       NONCONV. COMP(LB/HR   )   25334.3         25334.3          0.00000
    TOTAL BALANCE
       MASS(LB/HR    )          0.205359E+07    0.205359E+07      0.00000
       ENTHALPY(BTU/HR  )      -0.795036E+10   -0.795036E+10      0.00000

                          ***  INPUT DATA  ***
   TWO    PHASE  TP  FLASH
   SPECIFIED TEMPERATURE F                                    121.910
   SPECIFIED PRESSURE    PSIA                                 870.230
   MAXIMUM NO. ITERATIONS                                      30
   CONVERGENCE TOLERANCE                                        0.000100000

                          ***  RESULTS  ***
   OUTLET TEMPERATURE    F                                       121.91
   OUTLET PRESSURE       PSIA                                    870.23
   HEAT DUTY             BTU/HR                                -0.11810E-05
   VAPOR FRACTION                                                  1.0000
```

(*Figure C.2.2: Continue)*

```
  V-L PHASE EQUILIBRIUM :

     COMP                F(I)           X(I)           Y(I)          K(I)
     CO2                 1.0000         1.0000         1.0000        1.8266
♀ ASPEN PLUS    PLAT: WIN32      VER: 22.0                      05/07/2012   PAGE 23
                                   EXTRACTION
                                  STREAM SECTION

 SUBSTREAM ATTR PSD TYPE: PSD
 ----------------------------

 INTERVAL      LOWER LIMIT           UPPER LIMIT
     1           0.0      FT         6.5617-05   FT
     2         6.5617-05  FT         1.3123-04   FT
     3         1.3123-04  FT         1.9685-04   FT
     4         1.9685-04  FT         2.6247-04   FT
     5         2.6247-04  FT         3.2808-04   FT
     6         3.2808-04  FT         3.9370-04   FT
     7         3.9370-04  FT         4.5932-04   FT
     8         4.5932-04  FT         5.2493-04   FT
     9         5.2493-04  FT         5.9055-04   FT
    10         5.9055-04  FT         6.5617-04   FT
♀ ASPEN PLUS    PLAT: WIN32      VER: 22.0                      05/07/2012   PAGE 24
                                   EXTRACTION
                                  STREAM SECTION

 E-104 E-104P E-105 E-105P E-106
 -------------------------------
```

(*Figure C.2.2: Continue)*

E-106A E-106B E-106C E-106D E-106E

STREAM ID	E-104	E-104P	E-105	E-105P	E-106	E-106A	E-106B	E-106C	E-106D	E-106E
FROM :	----	P-101	P-104	Z-101	P-105	Z-102A	Z-102B	Z-102C	Z-102D	Z-102E
TO :	P-101	Z-101	----	P-104	Z-102A	Z-102B	Z-102C	Z-102D	Z-102E	P-106
CLASS:	MIXNCPSD	MIXNCPSD	MIXNCPSD	MIXNCPSD	MIXNCPSD	MIXNCPSD	MIXNCPSD	MIXNCPSD	MIXNCPSD	MIXNCPSD
TOTAL STREAM:										
LB/HR	1.0134+05	1.0134+05	3.0401+04	3.0401+04	7.0936+04	7.0936+04	7.0936+04	2.0267+04	2.0267+04	2.0267+04
BTU/HR	-6.7383+08	-6.7383+08	-2.0727+08	-2.0727+08	-4.6656+08	-4.7145+08	-4.4021+08	-1.1660+08	-1.0948+08	-1.3801+08
SUBSTREAM: MIXED										
PHASE:	LIQUID	LIQUID	LIQUID	LIQUID	LIQUID	LIQUID	VAPOR	VAPOR	VAPOR	LIQUID
COMPONENTS: LBMOL/HR										
C6H12-01	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C2H5N-01	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C3H8O-01	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CO2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
H2O	2812.5396	2812.5396	1687.5237	1687.5237	1125.0158	1125.0158	1125.0158	1125.0158	1125.0158	1125.0158
COMPONENTS: LB/HR										
C6H12-01	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C2H5N-01	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C3H8O-01	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CO2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
H2O	5.0669+04	5.0669+04	3.0401+04	3.0401+04	2.0267+04	2.0267+04	2.0267+04	2.0267+04	2.0267+04	2.0267+04
COMPONENTS: MASS FRAC										
C6H12-01	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C2H5N-01	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C3H8O-01	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CO2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
H2O	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
TOTAL FLOW:										
LBMOL/HR	2812.5396	2812.5396	1687.5237	1687.5237	1125.0158	1125.0158	1125.0158	1125.0158	1125.0158	1125.0158
LB/HR	5.0669+04	5.0669+04	3.0401+04	3.0401+04	2.0267+04	2.0267+04	2.0267+04	2.0267+04	2.0267+04	2.0267+04
CUFT/HR	816.5294	816.5294	489.8869	489.9177	326.6073	307.8141	5.7666+06	4.7961+06	1.0627+06	328.2085
STATE VARIABLES:										
TEMP F	76.9100	76.9100	76.7934	76.9100	76.8843	-40.0900	233.1000	116.5100	860.7086	85.9100
PRES PSIA	90.0000	90.0000	30.0000	90.0000	60.0000	14.5038	1.4504	1.4504	15.0000	14.5038
VFRAC	0.0	0.0	0.0	0.0	0.0	0.0	1.0000	1.0000	1.0000	0.0
LFRAC	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.0	0.0	0.0	1.0000
SFRAC	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

(*Figure C.2.2: Continue)*

```
 ENTHALPY:
   BTU/LBMOL          -1.2282+05 -1.2282+05 -1.2282+05 -1.2282+05 -1.2282+05 -1.2470+05 -1.0270+05 -1.0364+05 -9.7316+04 -1.2267+05
   BTU/LB             -6817.7136 -6817.7136 -6817.8210 -6817.7136 -6817.7373 -6922.0178 -5700.7341 -5753.1142 -5401.8826 -6809.3888
   BTU/HR             -3.4544+08 -3.4544+08 -2.0727+08 -2.0727+08 -1.3818+08 -1.4029+08 -1.1554+08 -1.1660+08 -1.0948+08 -1.3801+08
 ENTROPY:
   BTU/LBMOL-R          -38.8595   -38.8595   -38.8631   -38.8595   -38.8603   -42.8235    -3.9332    -5.4244    -3.0710   -38.5849
   BTU/LB-R              -2.1570    -2.1570    -2.1572    -2.1570    -2.1571    -2.3771    -0.2183    -0.3011    -0.1705    -2.1418
 DENSITY:
   LBMOL/CUFT             3.4445     3.4445     3.4447     3.4445     3.4446     3.6549 1.9509-04  2.3457-04  1.0586-03     3.4277
   LB/CUFT               62.0537    62.0537    62.0576    62.0537    62.0546    65.8432 3.5146-03  4.2258-03  1.9071-02    61.7518
 AVG MW                  18.0153    18.0153    18.0153    18.0153    18.0153    18.0153   18.0153    18.0153    18.0153    18.0153

 ASPEN PLUS   PLAT: WIN32     VER: 22.0                05/07/2012  PAGE 25
                                EXTRACTION
                               STREAM SECTION

 E-104 E-104P E-105 E-105P E-106

 E-106A E-106B E-106C E-106D E-106E (CONTINUED)

 STREAM ID             E-104      E-104P     E-105      E-105P     E-106      E-106A     E-106B     E-106C     E-106D     E-106E

 SUBSTREAM: NCPSD      STRUCTURE: NON CONVENTIONAL
 COMPONENTS: LB/HR
   ALGAE              5.0669+04  5.0669+04   0.0        0.0       5.0669+04  5.0669+04  5.0669+04   0.0        0.0        0.0
 COMPONENTS: MASS FRAC
   ALGAE                 1.0000     1.0000   0.0        0.0          1.0000     1.0000     1.0000   0.0        0.0        0.0
 TOTAL FLOW:
   LB/HR              5.0669+04  5.0669+04   0.0        0.0       5.0669+04  5.0669+04  5.0669+04   0.0        0.0        0.0
 STATE VARIABLES:
   TEMP   F             76.9100    76.9100   MISSING    MISSING     76.8843   -40.0900   233.1000   MISSING    MISSING    MISSING
   PRES   PSIA          90.0000    90.0000   30.0000    90.0000     60.0000    14.5038     1.4504     1.4504    15.0000    14.5038
   VFRAC                 0.0        0.0      MISSING    MISSING      0.0        0.0        0.0      MISSING    MISSING    MISSING
   LFRAC                 0.0        0.0      MISSING    MISSING      0.0        0.0        0.0      MISSING    MISSING    MISSING
   SFRAC                 1.0000     1.0000   MISSING    MISSING      1.0000     1.0000     1.0000   MISSING    MISSING    MISSING
 ENTHALPY:
   BTU/LB             -6480.9341 -6480.9341  MISSING    MISSING -6480.9461 -6535.6624 -6407.7062   MISSING    MISSING    MISSING
   BTU/HR             -3.2838+08 -3.2838+08  MISSING    MISSING -3.2838+08 -3.3115+08 -3.2467+08   MISSING    MISSING    MISSING
 DENSITY:
   LB/CUFT              141.9785   141.9785  MISSING    MISSING    141.9785   141.9785   141.9785   MISSING    MISSING    MISSING
 AVG MW                   1.0000     1.0000    1.0000     1.0000     1.0000     1.0000     1.0000     1.0000     1.0000     1.0000
```

(*Figure C.2.2: Continue)*

```
 COMPONENT ATTRIBUTES:
 ALGAE     PROXANAL
             MOISTURE    81.7000    81.7000    MISSING    MISSING    81.7000    81.7000    81.7000    MISSING    MISSING    MISSING
             FC           0.0        0.0       MISSING    MISSING     0.0        0.0        0.0       MISSING    MISSING    MISSING
             VM           0.0        0.0       MISSING    MISSING     0.0        0.0        0.0       MISSING    MISSING    MISSING
             ASH         18.4000    18.4000    MISSING    MISSING    18.4000    18.4000    18.4000    MISSING    MISSING    MISSING
           ULTANAL
             ASH          0.0        0.0       MISSING    MISSING     0.0        0.0        0.0       MISSING    MISSING    MISSING
             CARBON       0.0        0.0       MISSING    MISSING     0.0        0.0        0.0       MISSING    MISSING    MISSING
             HYDROGEN     0.0        0.0       MISSING    MISSING     0.0        0.0        0.0       MISSING    MISSING    MISSING
             NITROGEN     0.0        0.0       MISSING    MISSING     0.0        0.0        0.0       MISSING    MISSING    MISSING
             CHLORINE     0.0        0.0       MISSING    MISSING     0.0        0.0        0.0       MISSING    MISSING    MISSING
             SULFUR       0.0        0.0       MISSING    MISSING     0.0        0.0        0.0       MISSING    MISSING    MISSING
             OXYGEN       0.0        0.0       MISSING    MISSING     0.0        0.0        0.0       MISSING    MISSING    MISSING
           SULFANAL
             PYRITIC      0.0        0.0       MISSING    MISSING     0.0        0.0        0.0       MISSING    MISSING    MISSING
             SULFATE      0.0        0.0       MISSING    MISSING     0.0        0.0        0.0       MISSING    MISSING    MISSING
             ORGANIC      0.0        0.0       MISSING    MISSING     0.0        0.0        0.0       MISSING    MISSING    MISSING
 SUBSTREAM ATTRIBUTES:
 PSD
   FRAC1                  0.0        0.0        0.0        0.0        0.0        0.0        0.0       MISSING    MISSING    MISSING
   FRAC2                  0.0        0.0        0.0        0.0        0.0        0.0        0.0       MISSING    MISSING    MISSING
   FRAC3                  0.0        0.0        0.0        0.0        0.0        0.0        0.0       MISSING    MISSING    MISSING
   FRAC4                  0.0        0.0        0.0        0.0        0.0        0.0        0.0       MISSING    MISSING    MISSING
   FRAC5                  0.0        0.0        0.0        0.0        0.0        0.0        0.0       MISSING    MISSING    MISSING
   FRAC6                  0.0        0.0        0.0        0.0        0.0        0.0        0.0       MISSING    MISSING    MISSING
   FRAC7                  0.0        0.0        0.0        0.0        0.0        0.0        0.0       MISSING    MISSING    MISSING
   FRAC8                  0.0        0.0        0.0        0.0        0.0        0.0        0.0       MISSING    MISSING    MISSING
   FRAC9                  0.0        0.0        0.0        0.0        0.0        0.0        0.0       MISSING    MISSING    MISSING
   FRAC10                 0.0        0.0        0.0        0.0        0.0        0.0        0.0       MISSING    MISSING    MISSING
 ASPEN PLUS   PLAT: WIN32     VER: 22.0                05/07/2012  PAGE 26
                                EXTRACTION
                               STREAM SECTION

 E-106P E-107 E-108 E-109 E-109A
 ------------------------------
```

(*Figure C.2.2: Continue)*

E-109B E-109C E-109D E-110 E-111

STREAM ID	E-106P	E-107	E-108	E-109	E-109A	E-109B	E-109C	E-109D	E-110	E-111
FROM :	Z-101	P-106	Z-102C	----	Z-103	Z-104	Z-105	Z-105	FOR-USE	FOR-USE
TO :	P-105	----	Z-104	Z-103	Z-104	Z-105	Z-107	P-108	----	----
CLASS:	MIXNCPSD	MIXNCPSD	MIXNCPSD	MIXNCPSD	MIXNCPSD	MIXNCPSD	MIXNCPSD	MIXNCPSD	MIXNCPSD	MIXNCPSD
TOTAL STREAM:										
LB/HR	7.0936+04	2.0267+04	5.0669+04	2.0283+06	2.0283+06	2.0789+06	2.0536+06	2.5334+04	6666.8928	1.4698+04
BTU/HR	-4.6656+08	-1.3801+08	-3.2744+08	-7.7954+09	-7.7575+09	-8.0247+09	-7.9504+09	-7.4226+07	-1.9832+07	-4.2015+07
SUBSTREAM: MIXED										
PHASE:	LIQUID	LIQUID	MISSING	VAPOR	VAPOR	LIQUID	VAPOR	LIQUID	LIQUID	LIQUID
COMPONENTS: LBMOL/HR										
C6H12-01	0.0	0.0	0.0	0.0	0.0	37.0059	0.0	37.0059	37.0059	0.0
C2H5N-01	0.0	0.0	0.0	0.0	0.0	195.7990	0.0	195.7990	0.0	195.7990
C3H8O-01	0.0	0.0	0.0	0.0	0.0	43.0963	0.0	43.0963	0.0	0.0
CO2	0.0	0.0	0.0	4.6086+04	4.6086+04	4.6086+04	4.6086+04	0.0	0.0	0.0
H2O	1125.0158	1125.0158	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
COMPONENTS: LB/HR										
C6H12-01	0.0	0.0	0.0	0.0	0.0	6666.8928	0.0	6666.8928	6666.8928	0.0
C2H5N-01	0.0	0.0	0.0	0.0	0.0	1.4698+04	0.0	1.4698+04	0.0	1.4698+04
C3H8O-01	0.0	0.0	0.0	0.0	0.0	3968.9373	0.0	3968.9373	0.0	0.0
CO2	0.0	0.0	0.0	2.0283+06	2.0283+06	2.0283+06	2.0283+06	0.0	0.0	0.0
H2O	2.0267+04	2.0267+04	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
COMPONENTS: MASS FRAC										
C6H12-01	0.0	0.0	MISSING	0.0	0.0	3.2465-03	0.0	0.2632	1.0000	0.0
C2H5N-01	0.0	0.0	MISSING	0.0	0.0	7.1573-03	0.0	0.5802	0.0	1.0000
C3H8O-01	0.0	0.0	MISSING	0.0	0.0	1.9327-03	0.0	0.1567	0.0	0.0
CO2	0.0	0.0	MISSING	1.0000	1.0000	0.9877	1.0000	0.0	0.0	0.0
H2O	1.0000	1.0000	MISSING	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL FLOW:										
LBMOL/HR	1125.0158	1125.0158	0.0	4.6086+04	4.6086+04	4.6362+04	4.6086+04	275.9011	37.0059	195.7990
LB/HR	2.0267+04	2.0267+04	0.0	2.0283+06	2.0283+06	2.0536+06	2.0283+06	2.5334+04	6666.8928	1.4698+04
CUFT/HR	326.6118	328.2378	0.0	3.0700+05	2.1469+05	6.6645+04	3.3053+05	295.3073	92.7350	163.0189
STATE VARIABLES:										
TEMP F	76.9100	86.0739	MISSING	80.5100	169.9179	121.7300	121.9100	121.9100	130.7300	130.9100
PRES PSIA	90.0000	45.0000	1.4504	870.2300	1450.3700	5801.5095	870.2300	870.2300	5076.3208	5076.3208
VFRAC	0.0	0.0	MISSING	1.0000	1.0000	0.0	1.0000	0.0	0.0	0.0
LFRAC	1.0000	1.0000	MISSING	0.0	0.0	1.0000	0.0	1.0000	1.0000	1.0000
SFRAC	0.0	0.0	MISSING	0.0	0.0	0.0	0.0	0.0	0.0	0.0

(*Figure C.2.2: Continue*)

ENTHALPY:										
BTU/LBMOL	-1.2282+05	-1.2267+05	MISSING	-1.6915+05	-1.6832+05	-1.6937+05	-1.6877+05	-2.6903+05	-5.3592+05	-2.1458+05
BTU/LB	-6817.7136	-6809.2365	MISSING	-3843.4072	-3824.7015	-3823.7615	-3834.8873	-2929.9168	-2974.7235	-2858.5557
BTU/HR	-1.3818+08	-1.3801+08	MISSING	-7.7954+09	-7.7575+09	-7.8524+09	-7.7781+09	-7.4226+07	-1.9832+07	-4.2015+07
ENTROPY:										
BTU/LBMOL-R	-38.8595	-38.5799	MISSING	-7.3576	-6.9628	-8.5732	-6.6889	-136.7072	-252.7076	-114.7810
BTU/LB-R	-2.1570	-2.1415	MISSING	-0.1672	-0.1582	-0.1936	-0.1520	-1.4888	-1.4027	-1.5290
DENSITY:										
LBMOL/CUFT	3.4445	3.4274	MISSING	0.1501	0.2147	0.6957	0.1394	0.9343	0.3990	1.2011
LB/CUFT	62.0537	61.7463	MISSING	6.6068	9.4475	30.8138	6.1365	85.7883	71.8918	90.1619
AVG MW	18.0153	18.0153	MISSING	44.0098	44.0098	44.2943	44.0098	91.8225	180.1577	75.0672

ASPEN PLUS PLAT: WIN32 VER: 22.0 05/07/2012 PAGE 27
EXTRACTION
STREAM SECTION

E-106P E-107 E-108 E-109 E-109A

E-109B E-109C E-109D E-110 E-111 (CONTINUED)

STREAM ID	E-106P	E-107	E-108	E-109	E-109A	E-109B	E-109C	E-109D	E-110	E-111
SUBSTREAM: NCPSD	STRUCTURE: NON CONVENTIONAL									
COMPONENTS: LB/HR										
ALGAE	5.0669+04	0.0	5.0669+04	0.0	0.0	2.5334+04	2.5334+04	0.0	0.0	0.0
COMPONENTS: MASS FRAC										
ALGAE	1.0000	0.0	1.0000	0.0	0.0	1.0000	1.0000	0.0	0.0	0.0
TOTAL FLOW:										
LB/HR	5.0669+04	0.0	5.0669+04	0.0	0.0	2.5334+04	2.5334+04	0.0	0.0	0.0
STATE VARIABLES:										
TEMP F	76.9100	MISSING	116.5100	MISSING	MISSING	121.7300	121.9100	MISSING	MISSING	MISSING
PRES PSIA	90.0000	45.0000	1.4504	870.2300	1450.3700	5801.5095	870.2300	870.2300	5076.3208	5076.3208
VFRAC	0.0	MISSING	0.0	MISSING	MISSING	0.0	0.0	MISSING	MISSING	MISSING
LFRAC	0.0	MISSING	0.0	MISSING	MISSING	0.0	0.0	MISSING	MISSING	MISSING
SFRAC	1.0000	MISSING	1.0000	MISSING	MISSING	1.0000	1.0000	MISSING	MISSING	MISSING
ENTHALPY:										
BTU/LB	-6480.9341	MISSING	-6462.3863	MISSING	MISSING	-6798.6536	-6798.5605	MISSING	MISSING	MISSING
BTU/HR	-3.2838+08	MISSING	-3.2744+08	MISSING	MISSING	-1.7224+08	-1.7224+08	MISSING	MISSING	MISSING
DENSITY:										
LB/CUFT	141.9785	MISSING	141.9785	MISSING	MISSING	141.9785	141.9785	MISSING	MISSING	MISSING
AVG MW	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

(*Figure C.2.2: Continue*)

```
COMPONENT ATTRIBUTES:
ALGAE     PROXANAL
            MOISTURE     81.7000    MISSING    81.7000    MISSING    MISSING    100.0000   100.0000   MISSING    MISSING    MISSING
            FC            0.0       MISSING     0.0       MISSING    MISSING      0.0        0.0      MISSING    MISSING    MISSING
            VM            0.0       MISSING     0.0       MISSING    MISSING      0.0        0.0      MISSING    MISSING    MISSING
            ASH          18.4000    MISSING    18.4000    MISSING    MISSING     18.4000    18.4000   MISSING    MISSING    MISSING
          ULTANAL
            ASH           0.0       MISSING     0.0       MISSING    MISSING      0.0        0.0      MISSING    MISSING    MISSING
            CARBON        0.0       MISSING     0.0       MISSING    MISSING      0.0        0.0      MISSING    MISSING    MISSING
            HYDROGEN      0.0       MISSING     0.0       MISSING    MISSING      0.0        0.0      MISSING    MISSING    MISSING
            NITROGEN      0.0       MISSING     0.0       MISSING    MISSING      0.0        0.0      MISSING    MISSING    MISSING
            CHLORINE      0.0       MISSING     0.0       MISSING    MISSING      0.0        0.0      MISSING    MISSING    MISSING
            SULFUR        0.0       MISSING     0.0       MISSING    MISSING      0.0        0.0      MISSING    MISSING    MISSING
            OXYGEN        0.0       MISSING     0.0       MISSING    MISSING      0.0        0.0      MISSING    MISSING    MISSING
          SULFANAL
            PYRITIC       0.0       MISSING     0.0       MISSING    MISSING      0.0        0.0      MISSING    MISSING    MISSING
            SULFATE       0.0       MISSING     0.0       MISSING    MISSING      0.0        0.0      MISSING    MISSING    MISSING
            ORGANIC       0.0       MISSING     0.0       MISSING    MISSING      0.0        0.0      MISSING    MISSING    MISSING
SUBSTREAM ATTRIBUTES:
PSD
  FRAC1                   0.0       MISSING     0.0       MISSING    MISSING      0.0        0.0        0.0        0.0        0.0
  FRAC2                   0.0       MISSING     0.0       MISSING    MISSING      0.0        0.0        0.0        0.0        0.0
  FRAC3                   0.0       MISSING     0.0       MISSING    MISSING      0.0        0.0        0.0        0.0        0.0
  FRAC4                   0.0       MISSING     0.0       MISSING    MISSING      0.0        0.0        0.0        0.0        0.0
  FRAC5                   0.0       MISSING     0.0       MISSING    MISSING      0.0        0.0        0.0        0.0        0.0
  FRAC6                   0.0       MISSING     0.0       MISSING    MISSING      0.0        0.0        0.0        0.0        0.0
  FRAC7                   0.0       MISSING     0.0       MISSING    MISSING      0.0        0.0        0.0        0.0        0.0
  FRAC8                   0.0       MISSING     0.0       MISSING    MISSING      0.0        0.0        0.0        0.0        0.0
  FRAC9                   0.0       MISSING     0.0       MISSING    MISSING      0.0        0.0        0.0        0.0        0.0
  FRAC10                  0.0       MISSING     0.0       MISSING    MISSING      0.0        0.0        0.0        0.0        0.0
‡ ASPEN PLUS   PLAT: WIN32     VER: 22.0                05/07/2012  PAGE 28
                                 EXTRACTION
                                STREAM SECTION
```

(*Figure C.2.2: Continue*)

```
E-112 E-113 E-114 PRODUCT
-------------------------

STREAM ID                   E-112       E-113       E-114       PRODUCT
FROM :                      FOR-USE     Z-107       Z-107       P-108
TO   :                      ----        ----        ----        FOR-USE
CLASS:                      MIXNCPSD    MIXNCPSD    MIXNCPSD    MIXNCPSD
TOTAL STREAM:
  LB/HR                     3968.9373   2.5334+04   2.0283+06   2.5334+04
  BTU/HR                   -1.2261+07  -1.7224+08  -7.7781+09  -7.4226+07
SUBSTREAM: MIXED
PHASE:                      LIQUID      MISSING     VAPOR       LIQUID
COMPONENTS: LBMOL/HR
  C6H12-01                    0.0         0.0         0.0        37.0059
  C2H5N-01                    0.0         0.0         0.0       195.7990
  C3H8O-01                   43.0963      0.0         0.0        43.0963
  CO2                         0.0         0.0       4.6086+04     0.0
  H2O                         0.0         0.0         0.0         0.0
COMPONENTS: LB/HR
  C6H12-01                    0.0         0.0         0.0      6666.8928
  C2H5N-01                    0.0         0.0         0.0      1.4698+04
  C3H8O-01                 3968.9373      0.0         0.0      3968.9373
  CO2                         0.0         0.0       2.0283+06     0.0
  H2O                         0.0         0.0         0.0         0.0
COMPONENTS: MASS FRAC
  C6H12-01                    0.0       MISSING       0.0         0.2632
  C2H5N-01                    0.0       MISSING       0.0         0.5802
  C3H8O-01                    1.0000    MISSING       0.0         0.1567
  CO2                         0.0       MISSING       1.0000      0.0
  H2O                         0.0       MISSING       0.0         0.0
TOTAL FLOW:
  LBMOL/HR                   43.0963      0.0       4.6086+04   275.9011
  LB/HR                    3968.9373      0.0       2.0283+06   2.5334+04
  CUFT/HR                    50.9022      0.0       3.3053+05   295.3073
STATE VARIABLES:
  TEMP    F                 130.9100    MISSING     121.9100    121.9100
  PRES    PSIA             5076.3208    870.2300    870.2300    870.2300
  VFRAC                       0.0       MISSING       1.0000      0.0
  LFRAC                       1.0000    MISSING       0.0         1.0000
  SFRAC                       0.0       MISSING       0.0         0.0
```

(*Figure C.2.2: Continue*)

```
ENTHALPY:
  BTU/LBMOL          -2.8451+05    MISSING -1.6877+05 -2.6903+05
  BTU/LB             -3089.3440    MISSING -3834.8873 -2929.9168
  BTU/HR             -1.2261+07    MISSING -7.7781+09 -7.4226+07
ENTROPY:
  BTU/LBMOL-R         -141.7530    MISSING    -6.6889  -136.7072
  BTU/LB-R              -1.5392    MISSING    -0.1520    -1.4888
DENSITY:
  LBMOL/CUFT             0.8466    MISSING     0.1394     0.9343
  LB/CUFT               77.9719    MISSING     6.1365    85.7883
AVG MW                  92.0947    MISSING    44.0098    91.8225

SUBSTREAM: NCPSD        STRUCTURE: NON CONVENTIONAL
COMPONENTS: LB/HR
  ALGAE                  0.0      2.5334+04    0.0        0.0
 ASPEN PLUS    PLAT: WIN32      VER: 22.0                  05/07/2012  PAGE 29
                                 EXTRACTION
                               STREAM SECTION

E-112 E-113 E-114 PRODUCT (CONTINUED)

STREAM ID               E-112      E-113      E-114      PRODUCT

COMPONENTS: MASS FRAC
  ALGAE                  0.0         1.0000     0.0        0.0
TOTAL FLOW:
  LB/HR                  0.0      2.5334+04    0.0        0.0
STATE VARIABLES:
  TEMP    F             MISSING   121.9100   MISSING    MISSING
  PRES    PSIA        5076.3208   870.2300   870.2300   870.2300
  VFRAC                 MISSING     0.0      MISSING    MISSING
  LFRAC                 MISSING     0.0      MISSING    MISSING
  SFRAC                 MISSING     1.0000   MISSING    MISSING
ENTHALPY:
  BTU/LB                MISSING -6798.5605   MISSING    MISSING
  BTU/HR                MISSING -1.7224+08   MISSING    MISSING
DENSITY:
  LB/CUFT               MISSING   141.9785   MISSING    MISSING
AVG MW                   1.0000     1.0000     1.0000     1.0000
```

(*Figure C.2.2: Continue)*

```
COMPONENT ATTRIBUTES:
ALGAE     PROXANAL
           MOISTURE   MISSING   100.0000    MISSING    MISSING
           FC         MISSING     0.0       MISSING    MISSING
           VM         MISSING     0.0       MISSING    MISSING
           ASH        MISSING    18.4000    MISSING    MISSING
          ULTANAL
           ASH        MISSING     0.0       MISSING    MISSING
           CARBON     MISSING     0.0       MISSING    MISSING
           HYDROGEN   MISSING     0.0       MISSING    MISSING
           NITROGEN   MISSING     0.0       MISSING    MISSING
           CHLORINE   MISSING     0.0       MISSING    MISSING
           SULFUR     MISSING     0.0       MISSING    MISSING
           OXYGEN     MISSING     0.0       MISSING    MISSING
          SULFANAL
           PYRITIC    MISSING     0.0       MISSING    MISSING
           SULFATE    MISSING     0.0       MISSING    MISSING
           ORGANIC    MISSING     0.0       MISSING    MISSING
SUBSTREAM ATTRIBUTES:
PSD
  FRAC1                 0.0        0.0      MISSING     0.0
  FRAC2                 0.0        0.0      MISSING     0.0
  FRAC3                 0.0        0.0      MISSING     0.0
  FRAC4                 0.0        0.0      MISSING     0.0
  FRAC5                 0.0        0.0      MISSING     0.0
  FRAC6                 0.0        0.0      MISSING     0.0
  FRAC7                 0.0        0.0      MISSING     0.0
  FRAC8                 0.0        0.0      MISSING     0.0
  FRAC9                 0.0        0.0      MISSING     0.0
  FRAC10                0.0        0.0      MISSING     0.0
 ASPEN PLUS   PLAT: WIN32     VER: 22.0                05/07/2012  PAGE 30
                               EXTRACTION
                         PROBLEM STATUS SECTION

BLOCK STATUS
------------

****************************************************************************
*                                                                          *
* Calculations were completed normally                                     *
*                                                                          *
* All Unit Operation blocks were completed normally                        *
*                                                                          *
* All streams were flashed normally                                        *
*                                                                          *
****************************************************************************
```

(*Figure C.2.2: Continue)*

Section C.2.3 - APEN Plus simulator output for Case 3

```
ASPEN PLUS    PLAT: WIN32      VER: 22.0                    05/07/2012   PAGE 1
                                    EXTRACTION
                               RUN CONTROL SECTION

 RUN CONTROL INFORMATION
 -----------------------

 THIS COPY OF ASPEN PLUS LICENSED TO UNIV OF PUERTO RICO

 TYPE OF RUN: NEW

 INPUT FILE NAME: _0806lbp.inm

 OUTPUT PROBLEM DATA FILE NAME: _0806lbp
 LOCATED IN:


 PDF SIZE USED FOR INPUT TRANSLATION:
   NUMBER OF FILE RECORDS (PSIZE) =      0
   NUMBER OF IN-CORE RECORDS      =    256
 PSIZE NEEDED FOR SIMULATION      =    256

 CALLING PROGRAM NAME:           apmain
 LOCATED IN:                     C:\PROGRA~1\ASPENT~1\ASPENP~2.0\Engine\xeq

 SIMULATION REQUESTED FOR ENTIRE FLOWSHEET
```

Figure C.2.3. ASPEN print out for Case Scenario 3.

```
ASPEN PLUS    PLAT: WIN32      VER: 22.0                    05/07/2012   PAGE 2
                                    EXTRACTION
                                FLOWSHEET SECTION

 FLOWSHEET CONNECTIVITY BY STREAMS
 ---------------------------------

   STREAM     SOURCE     DEST           STREAM     SOURCE     DEST
   E-104      ----       Z-102          E-101      ----       Z-107
   E-106      FOR-USE    ----           E-105      FOR-USE    ----
   E-107      FOR-USE    ----           PRODUCT    Z-110      FOR-USE
   E-104C     Z-104      Z-110          E-104D     Z-104      Z-105
   E-109      Z-105      ----           E-108      Z-105      ----
   E-104B     Z-103      Z-104          E-104A     Z-102      Z-103
   E-101C     Z-101B     Z-101C         E-103      Z-101B     Z-103
   E-101D     Z-101C     Z-101D         E-101E     Z-101D     Z-108
   E-101B     Z-101A     Z-101B         E-101A     Z-101      Z-101A
   E-101P     Z-107      Z-101          E-102      Z-108      ----

 FLOWSHEET CONNECTIVITY BY BLOCKS
 --------------------------------

   BLOCK        INLETS                            OUTLETS
   FOR-USE      PRODUCT                           E-106 E-105 E-107
   Z-110        E-104C                            PRODUCT
   Z-104        E-104B                            E-104C E-104D
   Z-105        E-104D                            E-109 E-108
   Z-103        E-104A E-103                      E-104B
   Z-102        E-104                             E-104A
   Z-101B       E-101B                            E-101C E-103
   Z-101C       E-101C                            E-101D
   Z-101D       E-101D                            E-101E
   Z-101A       E-101A                            E-101B
   Z-101        E-101P                            E-101A
   Z-107        E-101                             E-101P
   Z-108        E-101E                            E-102
```

(*Figure C.2.3: Continue)*

```
COMPUTATIONAL SEQUENCE
----------------------

SEQUENCE USED WAS:
   Z-107 Z-101 Z-101A Z-101B Z-101C Z-101D Z-108 Z-102 Z-103 Z-104 Z-105
   Z-110 FOR-USE

OVERALL FLOWSHEET BALANCE
-------------------------

                      ***  MASS AND ENERGY BALANCE  ***
                                   IN               OUT          RELATIVE DIFF.
   CONVENTIONAL COMPONENTS (LBMOL/HR)
      C6H12-01                   0.00000          37.0059          -1.00000
      C2H5N-01                   0.00000          195.799          -1.00000
      C3H8O-01                   0.00000          43.0963          -1.00000
      CO2                        90.8888          90.8888           0.00000
      H2O                        28125.4          28125.4           0.00000
   SUBTOTAL(LBMOL/HR)            28216.3          28492.2         -0.968340E-02
            (LB/HR    )          510687.          536021.         -0.472629E-01
 ASPEN PLUS    PLAT: WIN32      VER: 22.0                     05/07/2012  PAGE 3
                                   EXTRACTION
                                FLOWSHEET SECTION

OVERALL FLOWSHEET BALANCE (CONTINUED)
   NON-CONVENTIONAL COMPONENTS (LB/HR    )
      ALGAE                      50668.7          25334.3          0.500000
   SUBTOTAL(LB/HR    )           50668.7          25334.3          0.500000
   TOTAL BALANCE
      MASS(LB/HR    )            561356.          561355.          0.752670E-06
      ENTHALPY(BTU/HR  )       -0.379820E+10   -0.371184E+10   -0.227381E-01
 ASPEN PLUS    PLAT: WIN32      VER: 22.0                     05/07/2012  PAGE 4
                                   EXTRACTION
                           PHYSICAL PROPERTIES SECTION
```

(*Figure C.2.3: Continue*)

```
COMPONENTS
----------

 ID        TYPE  FORMULA          NAME OR ALIAS                        REPORT NAME
  C6H12-01 C      C6H12O6          C6H12O6                              C6H12-01
  C2H5N-01 C      C2H5NO2-D1       C2H5NO2-D1                           C2H5N-01
  C3H8O-01 C      C3H8O3           C3H8O3                               C3H8O-01
  CO2      C      CO2              CO2                                  CO2
  ALGAE    NC                      MISSING                              ALGAE
  H2O      C      H2O              H2O                                  H2O

 ID              ATTRIBUTE TYPES
  ALGAE           PROXANAL ULTANAL SULFANAL
 ASPEN PLUS    PLAT: WIN32      VER: 22.0                     05/07/2012   PAGE 5
                                  EXTRACTION
                              U-O-S BLOCK SECTION

BLOCK:  FOR-USE  MODEL: SEP
---------------------------
  INLET STREAM:              PRODUCT
  OUTLET STREAMS:            E-106       E-105       E-107
  PROPERTY OPTION SET:       UNIQUAC    UNIQUAC / IDEAL GAS

                      ***  MASS AND ENERGY BALANCE  ***
                                   IN               OUT          RELATIVE DIFF.
      CONV. COMP.(LBMOL/HR)        275.901          275.901          0.00000
                 (LB/HR    )       25333.9          25333.9         -0.287202E-15
      NONCONV. COMP(LB/HR    )    0.00000          0.00000           0.00000
   TOTAL BALANCE
      MASS(LB/HR    )              25333.9          25333.9         -0.287202E-15
      ENTHALPY(BTU/HR  )         -0.742263E+08   -0.741089E+08   -0.158158E-02
```

(*Figure C.2.3: Continue*)

```
                     ***  INPUT DATA  ***

 INLET PRESSURE   PSIA                                   5,076.32

 FLASH SPECS FOR STREAM E-106
 TWO    PHASE  TP  FLASH
 SPECIFIED TEMPERATURE F                                130.910
 SPECIFIED PRESSURE    PSIA                           5,076.32
 MAXIMUM NO. ITERATIONS                                   30
 CONVERGENCE TOLERANCE                                    0.000100000

 FLASH SPECS FOR STREAM E-105
 TWO    PHASE  TP  FLASH
 SPECIFIED TEMPERATURE F                                130.730
 SPECIFIED PRESSURE    PSIA                           5,076.32
 MAXIMUM NO. ITERATIONS                                   30
 CONVERGENCE TOLERANCE                                    0.000100000

 FLASH SPECS FOR STREAM E-107
 TWO    PHASE  TP  FLASH
 SPECIFIED TEMPERATURE F                                130.910
 SPECIFIED PRESSURE    PSIA                           5,076.32
 MAXIMUM NO. ITERATIONS                                   30
 CONVERGENCE TOLERANCE                                    0.000100000
 ASPEN PLUS   PLAT: WIN32     VER: 22.0                05/07/2012  PAGE 6
                                 EXTRACTION
                              U-O-S BLOCK SECTION

BLOCK:  FOR-USE  MODEL: SEP (CONTINUED)

 FRACTION OF FEED
   SUBSTREAM= MIXED
     STREAM= E-105     CPT= C6H12-01  FRACTION=         1.00000
                            C2H5N-01                    0.0
                            C3H8O-01                    0.0
     STREAM= E-107     CPT= C6H12-01  FRACTION=         0.0
                            C2H5N-01                    0.0
                            C3H8O-01                    1.00000
```

(*Figure C.2.3: Continue)*

```
                     ***  RESULTS  ***

 HEAT DUTY               BTU/HR                             0.11739E+06

 COMPONENT = C6H12-01
   STREAM     SUBSTREAM    SPLIT FRACTION
   E-105      MIXED                 1.00000

 COMPONENT = C2H5N-01
   STREAM     SUBSTREAM    SPLIT FRACTION
   E-106      MIXED                 1.00000

 COMPONENT = C3H8O-01
   STREAM     SUBSTREAM    SPLIT FRACTION
   E-107      MIXED                 1.00000

BLOCK:  Z-101    MODEL: HEATER
------------------------------
 INLET STREAM:            E-101P
 OUTLET STREAM:           E-101A
 PROPERTY OPTION SET:     UNIQUAC    UNIQUAC / IDEAL GAS

                  ***  MASS AND ENERGY BALANCE  ***
                                IN             OUT          RELATIVE DIFF.
     CONV. COMP.(LBMOL/HR)     28125.4        28125.4         0.00000
                (LB/HR   )     506687.        506687.         0.00000
     NONCONV. COMP(LB/HR   )   50668.7        50668.7         0.00000
   TOTAL BALANCE
     MASS(LB/HR   )            557356.        557356.         0.00000
     ENTHALPY(BTU/HR  )      -0.378283E+10  -0.383845E+10    0.144909E-01
 ASPEN PLUS   PLAT: WIN32     VER: 22.0                05/07/2012  PAGE 7
                                 EXTRACTION
                              U-O-S BLOCK SECTION
```

(*Figure C.2.3: Continue)*

```
BLOCK:  Z-101     MODEL: HEATER (CONTINUED)

                         ***  INPUT DATA  ***
  TWO    PHASE  TP  FLASH
  SPECIFIED TEMPERATURE              F                          -40.0900
  SPECIFIED PRESSURE                 PSIA                        14.5038
  MAXIMUM NO. ITERATIONS                                         30
  CONVERGENCE TOLERANCE                                           0.000100000



                          ***  RESULTS  ***
  OUTLET TEMPERATURE    F                                    -40.090
  OUTLET PRESSURE       PSIA                                  14.504
  HEAT DUTY             BTU/HR                             -0.55623E+08
  OUTLET VAPOR FRACTION                                       0.0000
  PRESSURE-DROP CORRELATION PARAMETER                         52799.



  V-L PHASE EQUILIBRIUM :

     COMP              F(I)          X(I)          Y(I)          K(I)
     H2O               1.0000        1.0000        1.0000        0.20011E-03

BLOCK:  Z-101A    MODEL: HEATER
------------------------------
  INLET STREAM:            E-101A
  OUTLET STREAM:           E-101B
  PROPERTY OPTION SET:     UNIQUAC    UNIQUAC / IDEAL GAS

                    ***  MASS AND ENERGY BALANCE  ***
                                  IN              OUT         RELATIVE DIFF.
      CONV. COMP.(LBMOL/HR)      28125.4         28125.4        0.00000
                 (LB/HR   )      506687.         506687.        0.00000
      NONCONV. COMP(LB/HR    )   50668.7         50668.7        0.00000
    TOTAL BALANCE
      MASS(LB/HR    )            557356.         557356.        0.00000
      ENTHALPY(BTU/HR  )      -0.383845E+10   -0.321316E+10   -0.162902
 ASPEN PLUS    PLAT: WIN32     VER: 22.0                    05/07/2012   PAGE 8
                                 EXTRACTION
                             U-O-S BLOCK SECTION
```

(*Figure C.2.3: Continue*)

```
BLOCK:  Z-101A    MODEL: HEATER (CONTINUED)

                         ***  INPUT DATA  ***
  TWO    PHASE  TP  FLASH
  SPECIFIED TEMPERATURE              F                          233.100
  SPECIFIED PRESSURE                 PSIA                         1.45038
  MAXIMUM NO. ITERATIONS                                         30
  CONVERGENCE TOLERANCE                                           0.000100000



                          ***  RESULTS  ***
  OUTLET TEMPERATURE    F                                     233.10
  OUTLET PRESSURE       PSIA                                  1.4504
  HEAT DUTY             BTU/HR                              0.62529E+09
  OUTLET VAPOR FRACTION                                       1.0000
  PRESSURE-DROP CORRELATION PARAMETER                         2.4862



  V-L PHASE EQUILIBRIUM :

     COMP              F(I)          X(I)          Y(I)          K(I)
     H2O               1.0000        1.0000        1.0000        15.160

BLOCK:  Z-101B    MODEL: FLASH2
------------------------------
  INLET STREAM:            E-101B
  OUTLET VAPOR STREAM:     E-101C
  OUTLET LIQUID STREAM:    E-103
  PROPERTY OPTION SET:     UNIQUAC    UNIQUAC / IDEAL GAS

                    ***  MASS AND ENERGY BALANCE  ***
                                  IN              OUT         RELATIVE DIFF.
      CONV. COMP.(LBMOL/HR)      28125.4         28125.4        0.00000
                 (LB/HR   )      506687.         506687.        0.00000
      NONCONV. COMP(LB/HR    )   50668.7         50668.7        0.00000
    TOTAL BALANCE
      MASS(LB/HR    )            557356.         557356.        0.00000
      ENTHALPY(BTU/HR  )      -0.321316E+10   -0.324247E+10   0.903968E-02
 ASPEN PLUS    PLAT: WIN32     VER: 22.0                    05/07/2012   PAGE 9
                                 EXTRACTION
                             U-O-S BLOCK SECTION
```

(*Figure C.2.3: Continue*)

```
BLOCK:  Z-101B   MODEL: FLASH2 (CONTINUED)

                         ***  INPUT DATA  ***
  TWO    PHASE  TP  FLASH
  SPECIFIED TEMPERATURE F                                    116.510
  SPECIFIED PRESSURE    PSIA                                   1.45038
  MAXIMUM NO. ITERATIONS                                     30
  CONVERGENCE TOLERANCE                                        0.000100000

                          ***  RESULTS  ***
  OUTLET TEMPERATURE    F                                      116.51
  OUTLET PRESSURE       PSIA                                   1.4504
  HEAT DUTY             BTU/HR                               -0.29311E+08
  VAPOR FRACTION                                               1.0000


  V-L PHASE EQUILIBRIUM :

     COMP              F(I)          X(I)          Y(I)          K(I)
     H2O               1.0000        1.0000        1.0000        1.0600

BLOCK:  Z-101C   MODEL: COMPR
-----------------------------
  INLET STREAM:           E-101C
  OUTLET STREAM:          E-101D
  PROPERTY OPTION SET:    UNIQUAC   UNIQUAC / IDEAL GAS

                     ***  MASS AND ENERGY BALANCE  ***
                                  IN              OUT          RELATIVE DIFF.
      CONV. COMP.(LBMOL/HR)     28125.4         28125.4          0.00000
                 (LB/HR   )     506687.         506687.          0.00000
      NONCONV. COMP(LB/HR   )   0.00000         0.00000          0.00000
   TOTAL BALANCE
      MASS(LB/HR   )            506687.         506687.          0.00000
      ENTHALPY(BTU/HR  )      -0.291503E+10   -0.274074E+10   -0.597904E-01
```

(*Figure C.2.3: Continue*)

```
                         ***  INPUT DATA  ***

   POLYTROPIC COMPRESSOR USING ASME METHOD
    OUTLET PRESSURE   PSIA                                 14.5038
    POLYTROPIC EFFICIENCY                                   0.66000
    MECHANICAL EFFICIENCY                                   1.00000
ASPEN PLUS    PLAT: WIN32      VER: 22.0                  05/07/2012  PAGE 10
                                    EXTRACTION
                                U-O-S BLOCK SECTION

 BLOCK:  Z-101C   MODEL: COMPR (CONTINUED)

                         ***  RESULTS  ***

    INDICATED  HORSEPOWER REQUIREMENT  HP              68,498.8
    BRAKE      HORSEPOWER REQUIREMENT  HP              68,498.8
    NET WORK REQUIRED                  HP              68,498.8
    POWER LOSSES                       HP                   0.0
    ISENTROPIC HORSEPOWER REQUIREMENT  HP              39,024.5
    CALCULATED OUTLET TEMP  F                             846.263
    EFFICIENCY (POLYTR/ISENTR) USED                         0.66000
    OUTLET VAPOR FRACTION                                   1.00000
    HEAD DEVELOPED,        FT-LBF/LB                  176,666.
    MECHANICAL EFFICIENCY USED                              1.00000
    INLET HEAT CAPACITY RATIO                               1.32818
    INLET VOLUMETRIC FLOW RATE , CUFT/HR                    0.119904+09
    OUTLET VOLUMETRIC FLOW RATE, CUFT/HR                    0.271766+08
    INLET  COMPRESSIBILITY FACTOR                           1.00000
    OUTLET COMPRESSIBILITY FACTOR                           1.00000
    AV. ISENT. VOL. EXPONENT                                1.31686
    AV. ISENT. TEMP EXPONENT                                1.31686
    AV. ACTUAL VOL. EXPONENT                                1.55126
    AV. ACTUAL TEMP EXPONENT                                1.55126
```

(*Figure C.2.3: Continue*)

```
BLOCK:  Z-101D   MODEL: HEATER
------------------------------
  INLET STREAM:           E-101D
  OUTLET STREAM:          E-101E
  PROPERTY OPTION SET:    UNIQUAC   UNIQUAC / IDEAL GAS

                   ***  MASS AND ENERGY BALANCE  ***
                                  IN               OUT         RELATIVE DIFF.
      CONV. COMP.(LBMOL/HR)     28125.4          28125.4          0.00000
                 (LB/HR    )    506687.          506687.          0.00000
      NONCONV. COMP(LB/HR    )  0.00000          0.00000          0.00000
    TOTAL BALANCE
      MASS(LB/HR    )           506687.          506687.          0.00000
      ENTHALPY(BTU/HR   )     -0.274074E+10   -0.345023E+10    0.205636
ASPEN PLUS   PLAT: WIN32     VER: 22.0                       05/07/2012   PAGE 11
                                  EXTRACTION
                              U-O-S BLOCK SECTION

BLOCK:  Z-101D   MODEL: HEATER (CONTINUED)

                         ***  INPUT DATA  ***
  TWO    PHASE  TP  FLASH
  SPECIFIED TEMPERATURE                F                          85.9100
  SPECIFIED PRESSURE                   PSIA                       14.5038
  MAXIMUM NO. ITERATIONS                                          30
  CONVERGENCE TOLERANCE                                            0.000100000


                          ***  RESULTS  ***
  OUTLET TEMPERATURE      F                                     85.910
  OUTLET PRESSURE         PSIA                                  14.504
  HEAT DUTY               BTU/HR                              -0.70949E+09
  OUTLET VAPOR FRACTION                                         0.0000
  PRESSURE-DROP CORRELATION PARAMETER                           0.0000


  V-L PHASE EQUILIBRIUM :

     COMP             F(I)           X(I)           Y(I)           K(I)
     H2O              1.0000         1.0000         1.0000         0.42357E-01
```

(*Figure C.2.3: Continue)*

```
BLOCK:  Z-102    MODEL: COMPR
----------------------------
  INLET STREAM:           E-104
  OUTLET STREAM:          E-104A
  PROPERTY OPTION SET:    UNIQUAC   UNIQUAC / IDEAL GAS

                   ***  MASS AND ENERGY BALANCE  ***
                                  IN               OUT         RELATIVE DIFF.
      CONV. COMP.(LBMOL/HR)     90.8888          90.8888          0.00000
                 (LB/HR    )    4000.00          4000.00          0.00000
      NONCONV. COMP(LB/HR    )  0.00000          0.00000          0.00000
    TOTAL BALANCE
      MASS(LB/HR    )           4000.00          4000.00          0.00000
      ENTHALPY(BTU/HR   )     -0.153736E+08   -0.153736E+08   -0.117001E-06
ASPEN PLUS   PLAT: WIN32     VER: 22.0                       05/07/2012   PAGE 12
                                  EXTRACTION
                              U-O-S BLOCK SECTION

BLOCK:  Z-102    MODEL: COMPR (CONTINUED)

                         ***  INPUT DATA  ***

  POLYTROPIC POSITIVE DISPLACEMENT COMPRESSOR          USING PIECEWISE INTEGRATION
   OUTLET PRESSURE  PSIA                                 870.230
   POLYTROPIC EFFICIENCY                                   0.72000
   MECHANICAL EFFICIENCY                                   0.60000
   CLEARANCE FRACTION                                      0.50000
```

(*Figure C.2.3: Continue)*

```
                              ***  RESULTS  ***

   INDICATED  HORSEPOWER REQUIREMENT  HP                          0.00070693
   BRAKE      HORSEPOWER REQUIREMENT  HP                          0.0011782
   NET WORK REQUIRED                  HP                          0.0011782
   POWER LOSSES                       HP                          0.00047128
   ISENTROPIC HORSEPOWER REQUIREMENT  HP                          0.00015755
   CALCULATED OUTLET TEMP  F                                     80.5122
   ISENTROPIC TEMPERATURE  F                                     80.5105
   EFFICIENCY (POLYTR/ISENTR) USED                                0.72000
   VOLUMETRIC EFFICIENCY                                          0.99000
   DISPLACEMENT            CUFT/HR                              611.559
   OUTLET VAPOR FRACTION                                          1.00000
   HEAD DEVELOPED,       FT-LBF/LB                                0.25195
   MECHANICAL EFFICIENCY USED                                     0.60000
   INLET HEAT CAPACITY RATIO                                      1.28678
   INLET VOLUMETRIC FLOW RATE , CUFT/HR                         605.443
   OUTLET VOLUMETRIC FLOW RATE, CUFT/HR                         605.443
   INLET  COMPRESSIBILITY FACTOR                                  1.00000
   OUTLET COMPRESSIBILITY FACTOR                                  1.00000
   AV. ISENT. VOL. EXPONENT                                       1.28678
   AV. ISENT. TEMP EXPONENT                                       1.28678
   AV. ACTUAL VOL. EXPONENT                                       0.924932+10
   AV. ACTUAL TEMP EXPONENT                                       0.184988+11

 BLOCK:  Z-103    MODEL: RSTOIC
 ------------------------------
  INLET STREAMS:         E-104A      E-103
  OUTLET STREAM:         E-104B
  PROPERTY OPTION SET:   UNIQUAC   UNIQUAC / IDEAL GAS
ASPEN PLUS   PLAT: WIN32     VER: 22.0                      05/07/2012  PAGE 13
                                  EXTRACTION
                              U-O-S BLOCK SECTION
```

(*Figure C.2.3: Continue*)

```
                              U-O-S BLOCK SECTION

BLOCK:  Z-103    MODEL: RSTOIC (CONTINUED)

                     ***  MASS AND ENERGY BALANCE  ***
                                IN          OUT       GENERATION    RELATIVE DIFF.
CONV. COMP.(LBMOL/HR)        90.8888      366.790      275.901      -0.232463E-15
           (LB/HR    )       4000.00      29333.9                   -0.863639
NONCONV COMP(LB/HR    )      50668.7      25334.3                    0.500000
  TOTAL BALANCE
    MASS(LB/HR    )          54668.7      54668.3                    0.772865E-05
    ENTHALPY(BTU/HR   )-0.342814E+09 -0.262046E+09                  -0.235605

                          ***  INPUT DATA  ***
  STOICHIOMETRY MATRIX:

   REACTION #    1:
    SUBSTREAM MIXED    :
    C6H12-01  0.146E-02C2H5N-01  0.773E-02C3H8O-01  0.170E-02
    SUBSTREAM NCPSD    :
    ALGAE      -1.00


  REACTION CONVERSION SPECS: NUMBER=     1
    REACTION #    1:
    SUBSTREAM:NCPSD     KEY COMP:ALGAE     CONV FRAC: 0.5000



  TWO    PHASE  TP  FLASH
  SPECIFIED TEMPERATURE F                                112.910
  SPECIFIED PRESSURE      PSIA                         5,801.51
  MAXIMUM NO. ITERATIONS                                  30
  CONVERGENCE TOLERANCE                                    0.000100000
  SIMULTANEOUS REACTIONS
  GENERATE COMBUSTION REACTIONS FOR FEED SPECIES           NO
```

(*Figure C.2.3: Continue*)

```
                              ***   RESULTS   ***
  OUTLET TEMPERATURE     F                                          112.91
  OUTLET PRESSURE        PSIA                                       5801.5
  HEAT DUTY              BTU/HR                                    0.80766E+08
  VAPOR FRACTION                                                    0.0000


  REACTION EXTENTS:

     REACTION            REACTION
     NUMBER              EXTENT
                         LBMOL/HR
     1                    25334.
 ASPEN PLUS    PLAT: WIN32      VER: 22.0                        05/07/2012   PAGE 14
                                   EXTRACTION
                                U-O-S BLOCK SECTION

 BLOCK:  Z-103     MODEL: RSTOIC (CONTINUED)

  V-L PHASE EQUILIBRIUM :

     COMP               F(I)           X(I)           Y(I)           K(I)
     C6H12-01          0.10089        0.10089        0.14141E-13    0.71378E-14
     C2H5N-01          0.53382        0.53382        0.80282E-10    0.76591E-11
     C3H8O-01          0.11750        0.11750        0.11908E-07    0.51615E-08
     CO2               0.24780        0.24780         1.0000        0.20552

 BLOCK:  Z-104     MODEL: SEP
 ---------------------------
  INLET STREAM:            E-104B
  OUTLET STREAMS:          E-104C       E-104D
  PROPERTY OPTION SET:     UNIQUAC    UNIQUAC / IDEAL GAS

                        ***  MASS AND ENERGY BALANCE  ***
                                       IN              OUT         RELATIVE DIFF.
      CONV. COMP.(LBMOL/HR)        366.790          366.790          0.00000
                 (LB/HR    )       29333.9          29333.9          0.124020E-15
      NONCONV. COMP(LB/HR    )     25334.3          25334.3          0.00000
   TOTAL BALANCE
      MASS(LB/HR    )              54668.3          54668.3          0.665464E-16
      ENTHALPY(BTU/HR   )       -0.262046E+09    -0.261803E+09    -0.926038E-03
```

(*Figure C.2.3: Continue)*

```
                         ***  INPUT DATA  ***

   INLET PRESSURE    PSIA                                        5,801.51

   FLASH SPECS FOR STREAM E-104C
   TWO     PHASE   TP  FLASH
   SPECIFIED TEMPERATURE F                                      121.910
   SPECIFIED PRESSURE     PSIA                                  870.230
   MAXIMUM NO. ITERATIONS                                        30
   CONVERGENCE TOLERANCE                                          0.000100000

   FLASH SPECS FOR STREAM E-104D
   TWO     PHASE   TP  FLASH
   SPECIFIED TEMPERATURE F                                      121.910
   SPECIFIED PRESSURE     PSIA                                  870.230
   MAXIMUM NO. ITERATIONS                                        30
   CONVERGENCE TOLERANCE                                          0.000100000
 ASPEN PLUS    PLAT: WIN32       VER: 22.0                      05/07/2012   PAGE 15
                                   EXTRACTION
                                U-O-S BLOCK SECTION

  BLOCK:  Z-104     MODEL: SEP (CONTINUED)

   FRACTION OF FEED
     SUBSTREAM= MIXED
       STREAM= E-104D      CPT= C6H12-01   FRACTION=           0.0
                                C2H5N-01                        0.0
                                C3H8O-01                        0.0
                                CO2                             1.00000
```

(*Figure C.2.3: Continue)*

```
                         ***  RESULTS  ***

  HEAT DUTY             BTU/HR                             0.24266E+06

 COMPONENT = C6H12-01
   STREAM     SUBSTREAM    SPLIT FRACTION
   E-104C     MIXED                1.00000

 COMPONENT = C2H5N-01
   STREAM     SUBSTREAM    SPLIT FRACTION
   E-104C     MIXED                1.00000

 COMPONENT = C3H8O-01
   STREAM     SUBSTREAM    SPLIT FRACTION
   E-104C     MIXED                1.00000

 COMPONENT = CO2
   STREAM     SUBSTREAM    SPLIT FRACTION
   E-104D     MIXED                1.00000

 COMPONENT = ALGAE
   STREAM     SUBSTREAM    SPLIT FRACTION
   E-104D     NCPSD                1.00000

BLOCK:  Z-105    MODEL: FLASH2
------------------------------
  INLET STREAM:           E-104D
  OUTLET VAPOR STREAM:    E-109
  OUTLET LIQUID STREAM:   E-108
  PROPERTY OPTION SET:    UNIQUAC   UNIQUAC / IDEAL GAS

                    ***  MASS AND ENERGY BALANCE  ***
                                 IN             OUT        RELATIVE DIFF.
     CONV. COMP.(LBMOL/HR)     90.8888        90.8888        0.00000
                (LB/HR   )     4000.00        4000.00        0.00000
     NONCONV. COMP(LB/HR   )   25334.3        25334.3        0.00000
   TOTAL BALANCE
     MASS(LB/HR    )           29334.3        29334.3        0.00000
     ENTHALPY(BTU/HR  )      -0.187577E+09  -0.187577E+09    0.00000
‡ ASPEN PLUS   PLAT: WIN32     VER: 22.0                 05/07/2012  PAGE 16
                                 EXTRACTION
                              U-O-S BLOCK SECTION
```

(*Figure C.2.3: Continue)*

```
BLOCK:  Z-105    MODEL: FLASH2 (CONTINUED)

                         ***  INPUT DATA  ***
  TWO    PHASE  TP  FLASH
  SPECIFIED TEMPERATURE F                               121.910
  SPECIFIED PRESSURE    PSIA                            870.230
  MAXIMUM NO. ITERATIONS                                 30
  CONVERGENCE TOLERANCE                                   0.000100000

                          ***  RESULTS  ***
  OUTLET TEMPERATURE     F                                 121.91
  OUTLET PRESSURE        PSIA                              870.23
  HEAT DUTY              BTU/HR                          -0.37265E-07
  VAPOR FRACTION                                           1.0000


  V-L PHASE EQUILIBRIUM :

     COMP             F(I)          X(I)          Y(I)          K(I)
     CO2              1.0000        1.0000        1.0000        1.8266
BLOCK:  Z-107    MODEL: PUMP
----------------------------
  INLET STREAM:           E-101
  OUTLET STREAM:          E-101P
  PROPERTY OPTION SET:    UNIQUAC   UNIQUAC / IDEAL GAS

                    ***  MASS AND ENERGY BALANCE  ***
                                 IN             OUT        RELATIVE DIFF.
     CONV. COMP.(LBMOL/HR)     28125.4        28125.4        0.00000
                (LB/HR   )     506687.        506687.        0.00000
     NONCONV. COMP(LB/HR   )   50668.7        50668.7        0.00000
   TOTAL BALANCE
     MASS(LB/HR    )           557356.        557356.        0.00000
     ENTHALPY(BTU/HR  )      -0.378283E+10  -0.378283E+10    0.00000
```

(*Figure C.2.3: Continue)*

```
                         ***  INPUT DATA  ***
    OUTLET PRESSURE  PSIA                                      45.0000
    PUMP EFFICIENCY                                             0.60000
    DRIVER EFFICIENCY                                           1.00000

    FLASH SPECIFICATIONS:
    LIQUID PHASE CALCULATION
    NO FLASH PERFORMED
    MAXIMUM NUMBER OF ITERATIONS                                30
    TOLERANCE                                                   0.000100000
 ASPEN PLUS    PLAT: WIN32     VER: 22.0                     05/07/2012  PAGE 17
                                   EXTRACTION
                               U-O-S BLOCK SECTION

 BLOCK:  Z-107     MODEL: PUMP (CONTINUED)

                          ***  RESULTS  ***
    VOLUMETRIC FLOW RATE  CUFT/HR                            8,165.30
    PRESSURE CHANGE  PSI                                          0.0
    NPSH AVAILABLE    FT-LBF/LB                                 103.362
    FLUID POWER  HP                                               0.0
    BRAKE POWER  HP                                               0.0
    ELECTRICITY  KW                                               0.0
    PUMP EFFICIENCY USED                                          0.60000
    NET WORK REQUIRED  HP                                         0.0
    HEAD DEVELOPED FT-LBF/LB                                      0.0

 BLOCK:  Z-108     MODEL: PUMP
 ----------------------------
   INLET STREAM:            E-101E
   OUTLET STREAM:           E-102
   PROPERTY OPTION SET:     UNIQUAC    UNIQUAC / IDEAL GAS
```

(*Figure C.2.3: Continue)*

```
                     ***  MASS AND ENERGY BALANCE  ***
                                     IN            OUT        RELATIVE DIFF.
    CONV.  COMP.(LBMOL/HR)       28125.4        28125.4         0.00000
                (LB/HR    )      506687.        506687.         0.00000
    NONCONV. COMP(LB/HR    )     0.00000        0.00000         0.00000
 TOTAL BALANCE
    MASS(LB/HR    )              506687.        506687.         0.00000
    ENTHALPY(BTU/HR  )       -0.345023E+10  -0.345015E+10   -0.223679E-04

                         ***  INPUT DATA  ***
    OUTLET PRESSURE  PSIA                                      45.0000
    PUMP EFFICIENCY                                             0.60000
    DRIVER EFFICIENCY                                           1.00000

    FLASH SPECIFICATIONS:
    LIQUID PHASE CALCULATION
    NO FLASH PERFORMED
    MAXIMUM NUMBER OF ITERATIONS                                30
    TOLERANCE                                                   0.000100000
 ASPEN PLUS    PLAT: WIN32     VER: 22.0                     05/07/2012  PAGE 18
                                   EXTRACTION
                               U-O-S BLOCK SECTION

 BLOCK:  Z-108     MODEL: PUMP (CONTINUED)

                          ***  RESULTS  ***
    VOLUMETRIC FLOW RATE  CUFT/HR                            8,205.21
    PRESSURE CHANGE  PSI                                        30.4962
    NPSH AVAILABLE    FT-LBF/LB                                 32.3889
    FLUID POWER  HP                                             18.1984
    BRAKE POWER  HP                                             30.3307
    ELECTRICITY  KW                                             22.6176
    PUMP EFFICIENCY USED                                         0.60000
    NET WORK REQUIRED  HP                                       30.3307
    HEAD DEVELOPED FT-LBF/LB                                    71.1146
```

(*Figure C.2.3: Continue)*

```
BLOCK:  Z-110    MODEL: PUMP
----------------------------
 INLET STREAM:            E-104C
 OUTLET STREAM:           PRODUCT
 PROPERTY OPTION SET:     UNIQUAC   UNIQUAC / IDEAL GAS

                   ***  MASS AND ENERGY BALANCE  ***
                                 IN             OUT          RELATIVE DIFF.
    CONV. COMP.(LBMOL/HR)      275.901         275.901         0.00000
               (LB/HR    )     25333.9         25333.9         0.00000
    NONCONV. COMP(LB/HR    )   0.00000         0.00000         0.00000
  TOTAL BALANCE
    MASS(LB/HR    )            25333.9         25333.9         0.00000
    ENTHALPY(BTU/HR   )      -0.742263E+08   -0.742263E+08   -0.401506E-15

                       ***  INPUT DATA  ***
  EQUIPMENT TYPE: PUMP
  OUTLET PRESSURE  PSIA                                     870.230
  PUMP EFFICIENCY                                             0.60000
  DRIVER EFFICIENCY                                           1.00000

  FLASH SPECIFICATIONS:
  LIQUID PHASE CALCULATION
  NO FLASH PERFORMED
  MAXIMUM NUMBER OF ITERATIONS                                30
  TOLERANCE                                                   0.000100000
ASPEN PLUS    PLAT: WIN32      VER: 22.0                   05/07/2012   PAGE 19
                                  EXTRACTION
                              U-O-S BLOCK SECTION
```

(*Figure C.2.3: Continue*)

```
BLOCK:  Z-110    MODEL: PUMP (CONTINUED)

                          ***  RESULTS  ***
  VOLUMETRIC FLOW RATE  CUFT/HR                          295.307
  PRESSURE CHANGE   PSI                                    0.0
  NPSH AVAILABLE    FT-LBF/LB                          1,460.72
  FLUID POWER  HP                                          0.0
  BRAKE POWER  HP                                          0.0
  ELECTRICITY  KW                                          0.0
  PUMP EFFICIENCY USED                                     0.60000
  NET WORK REQUIRED  HP                                    0.0
  HEAD DEVELOPED FT-LBF/LB                                 0.0
ASPEN PLUS    PLAT: WIN32      VER: 22.0                05/07/2012   PAGE 20
                                 EXTRACTION
                                STREAM SECTION

SUBSTREAM ATTR PSD TYPE: PSD
----------------------------

INTERVAL      LOWER LIMIT           UPPER LIMIT
   1             0.0      FT        6.5617-05  FT
   2          6.5617-05   FT        1.3123-04  FT
   3          1.3123-04   FT        1.9685-04  FT
   4          1.9685-04   FT        2.6247-04  FT
   5          2.6247-04   FT        3.2808-04  FT
   6          3.2808-04   FT        3.9370-04  FT
   7          3.9370-04   FT        4.5932-04  FT
   8          4.5932-04   FT        5.2493-04  FT
   9          5.2493-04   FT        5.9055-04  FT
  10          5.9055-04   FT        6.5617-04  FT

ASPEN PLUS    PLAT: WIN32      VER: 22.0                05/07/2012   PAGE 21
                                 EXTRACTION
                                STREAM SECTION

E-101 E-101A E-101B E-101C E-101D
---------------------------------
```

(*Figure C.2.3: Continue*)

E-101E E-101P E-102 E-103 E-104

STREAM ID	E-101	E-101A	E-101B	E-101C	E-101D	E-101E	E-101P	E-102	E-103	E-104
FROM :	----	Z-101	Z-101A	Z-101B	Z-101C	Z-101D	Z-107	Z-108	Z-101B	----
TO :	Z-107	Z-101A	Z-101B	Z-101C	Z-101D	Z-108	Z-101	----	Z-103	Z-102
CLASS:	MIXNCPSD	MIXNCPSD	MIXNCPSD	MIXNCPSD	MIXNCPSD	MIXNCPSD	MIXNCPSD	MIXNCPSD	MIXNCPSD	MIXNCPSD
TOTAL STREAM:										
LB/HR	5.5736+05	5.5736+05	5.5736+05	5.0669+05	5.0669+05	5.0669+05	5.5736+05	5.0669+05	5.0669+04	4000.0000
BTU/HR	-3.7828+09	-3.8384+09	-3.2132+09	-2.9150+09	-2.7407+09	-3.4502+09	-3.7828+09	-3.4502+09	-3.2744+08	-1.5374+07
SUBSTREAM: MIXED										
PHASE:	LIQUID	LIQUID	VAPOR	VAPOR	VAPOR	LIQUID	LIQUID	LIQUID	MISSING	VAPOR
COMPONENTS: LBMOL/HR										
C6H12-01	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C2H5N-01	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C3H8O-01	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CO2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	90.8888
H2O	2.8125+04	2.8125+04	2.8125+04	2.8125+04	2.8125+04	2.8125+04	2.8125+04	2.8125+04	0.0	0.0
COMPONENTS: LB/HR										
C6H12-01	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C2H5N-01	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C3H8O-01	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CO2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4000.0000
H2O	5.0669+05	5.0669+05	5.0669+05	5.0669+05	5.0669+05	5.0669+05	5.0669+05	5.0669+05	0.0	0.0
COMPONENTS: MASS FRAC										
C6H12-01	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	MISSING	0.0
C2H5N-01	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	MISSING	0.0
C3H8O-01	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	MISSING	0.0
CO2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	MISSING	1.0000
H2O	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	MISSING	0.0
TOTAL FLOW:										
LBMOL/HR	2.8125+04	2.8125+04	2.8125+04	2.8125+04	2.8125+04	2.8125+04	2.8125+04	2.8125+04	0.0	90.8888
LB/HR	5.0669+05	5.0669+05	5.0669+05	5.0669+05	5.0669+05	5.0669+05	5.0669+05	5.0669+05	0.0	4000.0000
CUFT/HR	8165.2955	7695.3536	1.4417+08	1.1990+08	2.7177+07	8205.2144	8165.2955	8205.9472	0.0	605.4433
STATE VARIABLES:										
TEMP F	76.9100	-40.0900	233.1000	116.5100	846.2629	85.9100	76.9100	86.0739	MISSING	80.5100
PRES PSIA	45.0000	14.5038	1.4504	1.4504	14.5038	14.5038	45.0000	45.0000	1.4504	870.2264
VFRAC	0.0	0.0	1.0000	1.0000	1.0000	0.0	0.0	0.0	MISSING	1.0000
LFRAC	1.0000	1.0000	0.0	0.0	0.0	1.0000	1.0000	1.0000	MISSING	0.0
SFRAC	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	MISSING	0.0

(*Figure C.2.3: Continue*)

ENTHALPY:										
BTU/LBMOL	-1.2282+05	-1.2470+05	-1.0270+05	-1.0364+05	-9.7447+04	-1.2267+05	-1.2282+05	-1.2267+05	MISSING	-1.6915+05
BTU/LB	-6817.7136	-6922.0178	-5700.7341	-5753.1142	-5409.1331	-6809.3888	-6817.7136	-6809.2365	MISSING	-3843.4072
BTU/HR	-3.4544+09	-3.5073+09	-2.8885+09	-2.9150+09	-2.7407+09	-3.4502+09	-3.4544+09	-3.4502+09	MISSING	-1.5374+07
ENTROPY:										
BTU/LBMOL-R	-38.8595	-42.8235	-3.9332	-5.4244	-3.1037	-38.5849	-38.8595	-38.5799	MISSING	-7.3576
BTU/LB-R	-2.1570	-2.3771	-0.2183	-0.3011	-0.1723	-2.1418	-2.1570	-2.1415	MISSING	-0.1672
DENSITY:										
LBMOL/CUFT	3.4445	3.6549	1.9509-04	2.3457-04	1.0349-03	3.4277	3.4445	3.4274	MISSING	0.1501
LB/CUFT	62.0537	65.8432	3.5146-03	4.2258-03	1.8644-02	61.7518	62.0537	61.7463	MISSING	6.6067
AVG MW	18.0153	18.0153	18.0153	18.0153	18.0153	18.0153	18.0153	18.0153	MISSING	44.0098

ASPEN PLUS PLAT: WIN32 VER: 22.0 05/07/2012 PAGE 22
EXTRACTION
STREAM SECTION

E-101 E-101A E-101B E-101C E-101D

E-101E E-101P E-102 E-103 E-104 (CONTINUED)

STREAM ID	E-101	E-101A	E-101B	E-101C	E-101D	E-101E	E-101P	E-102	E-103	E-104
SUBSTREAM: NCPSD	STRUCTURE: NON CONVENTIONAL									
COMPONENTS: LB/HR										
ALGAE	5.0669+04	5.0669+04	5.0669+04	0.0	0.0	0.0	5.0669+04	0.0	5.0669+04	0.0
COMPONENTS: MASS FRAC										
ALGAE	1.0000	1.0000	1.0000	0.0	0.0	0.0	1.0000	0.0	1.0000	0.0
TOTAL FLOW:										
LB/HR	5.0669+04	5.0669+04	5.0669+04	0.0	0.0	0.0	5.0669+04	0.0	5.0669+04	0.0
STATE VARIABLES:										
TEMP F	76.9100	-40.0900	233.1000	MISSING	MISSING	MISSING	76.9100	MISSING	116.5100	MISSING
PRES PSIA	45.0000	14.5038	1.4504	1.4504	14.5038	14.5038	45.0000	45.0000	1.4504	870.2264
VFRAC	0.0	0.0	0.0	MISSING	MISSING	MISSING	0.0	MISSING	0.0	MISSING
LFRAC	0.0	0.0	0.0	MISSING	MISSING	MISSING	0.0	MISSING	0.0	MISSING
SFRAC	1.0000	1.0000	1.0000	MISSING	MISSING	MISSING	1.0000	MISSING	1.0000	MISSING
ENTHALPY:										
BTU/LB	-6480.9341	-6535.6624	-6407.7062	MISSING	MISSING	MISSING	-6480.9341	MISSING	-6462.3863	MISSING
BTU/HR	-3.2838+08	-3.3115+08	-3.2467+08	MISSING	MISSING	MISSING	-3.2838+08	MISSING	-3.2744+08	MISSING
DENSITY:										
LB/CUFT	141.9785	141.9785	141.9785	MISSING	MISSING	MISSING	141.9785	MISSING	141.9785	MISSING
AVG MW	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

(*Figure C.2.3: Continue*)

COMPONENT ATTRIBUTES:										
ALGAE PROXANAL										
MOISTURE	81.7000	81.7000	81.7000	MISSING	MISSING	MISSING	81.7000	MISSING	81.7000	MISSING
FC	0.0	0.0	0.0	MISSING	MISSING	MISSING	0.0	MISSING	0.0	MISSING
VM	0.0	0.0	0.0	MISSING	MISSING	MISSING	0.0	MISSING	0.0	MISSING
ASH	18.4000	18.4000	18.4000	MISSING	MISSING	MISSING	18.4000	MISSING	18.4000	MISSING
ULTANAL										
ASH	0.0	0.0	0.0	MISSING	MISSING	MISSING	0.0	MISSING	0.0	MISSING
CARBON	0.0	0.0	0.0	MISSING	MISSING	MISSING	0.0	MISSING	0.0	MISSING
HYDROGEN	0.0	0.0	0.0	MISSING	MISSING	MISSING	0.0	MISSING	0.0	MISSING
NITROGEN	0.0	0.0	0.0	MISSING	MISSING	MISSING	0.0	MISSING	0.0	MISSING
CHLORINE	0.0	0.0	0.0	MISSING	MISSING	MISSING	0.0	MISSING	0.0	MISSING
SULFUR	0.0	0.0	0.0	MISSING	MISSING	MISSING	0.0	MISSING	0.0	MISSING
OXYGEN	0.0	0.0	0.0	MISSING	MISSING	MISSING	0.0	MISSING	0.0	MISSING
SULFANAL										
PYRITIC	0.0	0.0	0.0	MISSING	MISSING	MISSING	0.0	MISSING	0.0	MISSING
SULFATE	0.0	0.0	0.0	MISSING	MISSING	MISSING	0.0	MISSING	0.0	MISSING
ORGANIC	0.0	0.0	0.0	MISSING	MISSING	MISSING	0.0	MISSING	0.0	MISSING
SUBSTREAM ATTRIBUTES:										
PSD										
FRAC1	0.0	0.0	0.0	MISSING	MISSING	MISSING	0.0	MISSING	0.0	MISSING
FRAC2	0.0	0.0	0.0	MISSING	MISSING	MISSING	0.0	MISSING	0.0	MISSING
FRAC3	0.0	0.0	0.0	MISSING	MISSING	MISSING	0.0	MISSING	0.0	MISSING
FRAC4	0.0	0.0	0.0	MISSING	MISSING	MISSING	0.0	MISSING	0.0	MISSING
FRAC5	0.0	0.0	0.0	MISSING	MISSING	MISSING	0.0	MISSING	0.0	MISSING
FRAC6	0.0	0.0	0.0	MISSING	MISSING	MISSING	0.0	MISSING	0.0	MISSING
FRAC7	0.0	0.0	0.0	MISSING	MISSING	MISSING	0.0	MISSING	0.0	MISSING
FRAC8	0.0	0.0	0.0	MISSING	MISSING	MISSING	0.0	MISSING	0.0	MISSING
FRAC9	0.0	0.0	0.0	MISSING	MISSING	MISSING	0.0	MISSING	0.0	MISSING
FRAC10	0.0	0.0	0.0	MISSING	MISSING	MISSING	0.0	MISSING	0.0	MISSING

E-104A E-104B E-104C E-104D E-105

(*Figure C.2.3: Continue)*

E-106 E-107 E-108 E-109 PRODUCT

STREAM ID	E-104A	E-104B	E-104C	E-104D	E-105	E-106	E-107	E-108	E-109	PRODUCT
FROM :	Z-102	Z-103	Z-104	Z-104	FOR-USE	FOR-USE	FOR-USE	Z-105	Z-105	Z-110
TO :	Z-103	Z-104	Z-110	Z-105	----	----	----	----	----	FOR-USE
CLASS:	MIXNCPSD	MIXNCPSD	MIXNCPSD	MIXNCPSD	MIXNCPSD	MIXNCPSD	MIXNCPSD	MIXNCPSD	MIXNCPSD	MIXNCPSD
TOTAL STREAM:										
LB/HR	4000.0000	5.4668+04	2.5334+04	2.9334+04	6666.8938	1.4698+04	3968.9379	2.5334+04	4000.0000	2.5334+04
BTU/HR	-1.5374+07	-2.6205+08	-7.4226+07	-1.8758+08	-1.9832+07	-4.2015+07	-1.2261+07	-1.7224+08	-1.5340+07	-7.4226+07
SUBSTREAM: MIXED										
PHASE:	VAPOR	LIQUID	LIQUID	VAPOR	LIQUID	LIQUID	LIQUID	MISSING	VAPOR	LIQUID
COMPONENTS: LBMOL/HR										
C6H12-01	0.0	37.0059	37.0059	0.0	37.0059	0.0	0.0	0.0	0.0	37.0059
C2H5N-01	0.0	195.7990	195.7990	0.0	0.0	195.7990	0.0	0.0	0.0	195.7990
C3H8O-01	0.0	43.0963	43.0963	0.0	0.0	0.0	43.0963	0.0	0.0	43.0963
CO2	90.8888	90.8888	0.0	90.8888	0.0	0.0	0.0	0.0	90.8888	0.0
H2O	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
COMPONENTS: LB/HR										
C6H12-01	0.0	6666.8938	6666.8938	0.0	6666.8938	0.0	0.0	0.0	0.0	6666.8938
C2H5N-01	0.0	1.4698+04	1.4698+04	0.0	0.0	1.4698+04	0.0	0.0	0.0	1.4698+04
C3H8O-01	0.0	3968.9379	3968.9379	0.0	0.0	0.0	3968.9379	0.0	0.0	3968.9379
CO2	4000.0000	4000.0000	0.0	4000.0000	0.0	0.0	0.0	0.0	4000.0000	0.0
H2O	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
COMPONENTS: MASS FRAC										
C6H12-01	0.0	0.2273	0.2632	0.0	1.0000	0.0	0.0	MISSING	0.0	0.2632
C2H5N-01	0.0	0.5011	0.5802	0.0	0.0	1.0000	0.0	MISSING	0.0	0.5802
C3H8O-01	0.0	0.1353	0.1567	0.0	0.0	0.0	1.0000	MISSING	0.0	0.1567
CO2	1.0000	0.1364	0.0	1.0000	0.0	0.0	0.0	MISSING	1.0000	0.0
H2O	0.0	0.0	0.0	0.0	0.0	0.0	0.0	MISSING	0.0	0.0
TOTAL FLOW:										
LBMOL/HR	90.8888	366.7900	275.9012	90.8888	37.0059	195.7990	43.0963	0.0	90.8888	275.9012
LB/HR	4000.0000	2.9334+04	2.5334+04	4000.0000	6666.8938	1.4698+04	3968.9379	0.0	4000.0000	2.5334+04
CUFT/HR	605.4433	370.9356	295.3073	651.8424	92.7351	163.0189	50.9022	0.0	651.8424	295.3073
STATE VARIABLES:										
TEMP F	80.5122	112.9100	121.9100	121.9100	130.7300	130.9100	130.9100	MISSING	121.9100	121.9100
PRES PSIA	870.2300	5801.5095	870.2300	870.2300	5076.3208	5076.3208	5076.3208	870.2300	870.2300	870.2300
VFRAC	1.0000	0.0	0.0	1.0000	0.0	0.0	0.0	MISSING	1.0000	0.0
LFRAC	0.0	1.0000	1.0000	0.0	1.0000	1.0000	1.0000	MISSING	0.0	1.0000
SFRAC	0.0	0.0	0.0	0.0	0.0	0.0	0.0	MISSING	0.0	0.0

(*Figure C.2.3: Continue)*

```
 ENTHALPY:
   BTU/LBMOL          -1.6915+05 -2.4453+05 -2.6903+05 -1.6877+05 -5.3592+05 -2.1458+05 -2.8451+05    MISSING -1.6877+05 -2.6903+05
   BTU/LB             -3843.4068 -3057.5720 -2929.9168 -3834.8873 -2974.7235 -2858.5557 -3089.3440    MISSING -3834.8873 -2929.9168
   BTU/HR             -1.5374+07 -8.9691+07 -7.4226+07 -1.5340+07 -1.9832+07 -4.2015+07 -1.2261+07    MISSING -1.5340+07 -7.4226+07
 ENTROPY:
   BTU/LBMOL-R           -7.3576  -104.1978  -136.7072    -6.6889  -252.7076  -114.7810  -141.7530    MISSING    -6.6889  -136.7072
   BTU/LB-R              -0.1672    -1.3029    -1.4888    -0.1520    -1.4027    -1.5290    -1.5392    MISSING    -0.1520    -1.4888
 DENSITY:
   LBMOL/CUFT             0.1501     0.9888     0.9343     0.1394     0.3990     1.2011     0.8466    MISSING     0.1394     0.9343
   LB/CUFT                6.6067    79.0809    85.7883     6.1365    71.8918    90.1619    77.9719    MISSING     6.1365    85.7883
 AVG MW                  44.0098    79.9747    91.8225    44.0098   180.1577    75.0672    92.0947    MISSING    44.0098    91.8225

 ASPEN PLUS   PLAT: WIN32     VER: 22.0                   05/07/2012  PAGE 24
                                  EXTRACTION
                                 STREAM SECTION

 E-104A E-104B E-104C E-104D E-105

 E-106 E-107 E-108 E-109 PRODUCT (CONTINUED)

 STREAM ID               E-104A     E-104B     E-104C     E-104D     E-105      E-106      E-107      E-108      E-109      PRODUCT

 SUBSTREAM: NCPSD        STRUCTURE: NON CONVENTIONAL
 COMPONENTS: LB/HR
   ALGAE                  0.0     2.5334+04    0.0     2.5334+04    0.0        0.0        0.0     2.5334+04    0.0        0.0
 COMPONENTS: MASS FRAC
   ALGAE                  0.0        1.0000    0.0        1.0000    0.0        0.0        0.0        1.0000    0.0        0.0
 TOTAL FLOW:
   LB/HR                  0.0     2.5334+04    0.0     2.5334+04    0.0        0.0        0.0     2.5334+04    0.0        0.0
 STATE VARIABLES:
   TEMP   F              MISSING   112.9100    MISSING   121.9100    MISSING    MISSING    MISSING   121.9100    MISSING    MISSING
   PRES   PSIA          870.2300  5801.5095   870.2300   870.2300  5076.3208  5076.3208  5076.3208   870.2300   870.2300   870.2300
   VFRAC                 MISSING    0.0        MISSING    0.0        MISSING    MISSING    MISSING    0.0        MISSING    MISSING
   LFRAC                 MISSING    0.0        MISSING    0.0        MISSING    MISSING    MISSING    0.0        MISSING    MISSING
   SFRAC                 MISSING     1.0000    MISSING     1.0000    MISSING    MISSING    MISSING     1.0000    MISSING    MISSING
 ENTHALPY:
   BTU/LB                MISSING -6803.2150    MISSING -6798.5605    MISSING    MISSING    MISSING -6798.5605    MISSING    MISSING
   BTU/HR                MISSING -1.7236+08    MISSING -1.7224+08    MISSING    MISSING    MISSING -1.7224+08    MISSING    MISSING
 DENSITY:
   LB/CUFT               MISSING   141.9785    MISSING   141.9785    MISSING    MISSING    MISSING   141.9785    MISSING    MISSING
 AVG MW                   1.0000     1.0000     1.0000     1.0000     1.0000     1.0000     1.0000     1.0000     1.0000     1.0000
```

(*Figure C.2.3: Continue*)

```
 COMPONENT ATTRIBUTES:
 ALGAE    PROXANAL
            MOISTURE     MISSING   100.0000    MISSING   100.0000    MISSING    MISSING    MISSING   100.0000    MISSING    MISSING
            FC           MISSING    0.0        MISSING    0.0        MISSING    MISSING    MISSING    0.0        MISSING    MISSING
            VM           MISSING    0.0        MISSING    0.0        MISSING    MISSING    MISSING    0.0        MISSING    MISSING
            ASH          MISSING    18.4000    MISSING    18.4000    MISSING    MISSING    MISSING    18.4000    MISSING    MISSING
          ULTANAL
            ASH          MISSING    0.0        MISSING    0.0        MISSING    MISSING    MISSING    0.0        MISSING    MISSING
            CARBON       MISSING    0.0        MISSING    0.0        MISSING    MISSING    MISSING    0.0        MISSING    MISSING
            HYDROGEN     MISSING    0.0        MISSING    0.0        MISSING    MISSING    MISSING    0.0        MISSING    MISSING
            NITROGEN     MISSING    0.0        MISSING    0.0        MISSING    MISSING    MISSING    0.0        MISSING    MISSING
            CHLORINE     MISSING    0.0        MISSING    0.0        MISSING    MISSING    MISSING    0.0        MISSING    MISSING
            SULFUR       MISSING    0.0        MISSING    0.0        MISSING    MISSING    MISSING    0.0        MISSING    MISSING
            OXYGEN       MISSING    0.0        MISSING    0.0        MISSING    MISSING    MISSING    0.0        MISSING    MISSING
          SULFANAL
            PYRITIC      MISSING    0.0        MISSING    0.0        MISSING    MISSING    MISSING    0.0        MISSING    MISSING
            SULFATE      MISSING    0.0        MISSING    0.0        MISSING    MISSING    MISSING    0.0        MISSING    MISSING
            ORGANIC      MISSING    0.0        MISSING    0.0        MISSING    MISSING    MISSING    0.0        MISSING    MISSING
 SUBSTREAM ATTRIBUTES:
 PSD
   FRAC1                 MISSING    0.0        0.0        0.0        0.0        0.0        0.0        0.0        MISSING    0.0
   FRAC2                 MISSING    0.0        0.0        0.0        0.0        0.0        0.0        0.0        MISSING    0.0
   FRAC3                 MISSING    0.0        0.0        0.0        0.0        0.0        0.0        0.0        MISSING    0.0
   FRAC4                 MISSING    0.0        0.0        0.0        0.0        0.0        0.0        0.0        MISSING    0.0
   FRAC5                 MISSING    0.0        0.0        0.0        0.0        0.0        0.0        0.0        MISSING    0.0
   FRAC6                 MISSING    0.0        0.0        0.0        0.0        0.0        0.0        0.0        MISSING    0.0
   FRAC7                 MISSING    0.0        0.0        0.0        0.0        0.0        0.0        0.0        MISSING    0.0
   FRAC8                 MISSING    0.0        0.0        0.0        0.0        0.0        0.0        0.0        MISSING    0.0
   FRAC9                 MISSING    0.0        0.0        0.0        0.0        0.0        0.0        0.0        MISSING    0.0
   FRAC10                MISSING    0.0        0.0        0.0        0.0        0.0        0.0        0.0        MISSING    0.0
 ASPEN PLUS   PLAT: WIN32     VER: 22.0                   05/07/2012  PAGE 25
                                  EXTRACTION
                              PROBLEM STATUS SECTION

 BLOCK STATUS
 ------------

 ****************************************************************************
 *                                                                          *
 * Calculations were completed normally                                     *
 *                                                                          *
 * All Unit Operation blocks were completed normally                        *
 *                                                                          *
 * All streams were flashed normally                                        *
 *                                                                          *
 ****************************************************************************
```

(*Figure C.2.3: Continue*)

Section C.2.4 - APEN Plus simulator output for Case Scenario 4

```
ASPEN PLUS   PLAT: WIN32     VER: 22.0                    05/07/2012  PAGE 1
                                 EXTRACTION
                             RUN CONTROL SECTION

 RUN CONTROL INFORMATION
 -----------------------

 THIS COPY OF ASPEN PLUS LICENSED TO UNIV OF PUERTO RICO

 TYPE OF RUN: NEW

 INPUT FILE NAME: _2034ynk.inm

 OUTPUT PROBLEM DATA FILE NAME: _5827uad
 LOCATED IN:


 PDF SIZE USED FOR INPUT TRANSLATION:
   NUMBER OF FILE RECORDS (PSIZE) =     0
   NUMBER OF IN-CORE RECORDS      =   256
 PSIZE NEEDED FOR SIMULATION    =     1

 CALLING PROGRAM NAME:          apmain
 LOCATED IN:                    C:\PROGRA~1\ASPENT~1\ASPENP~2.0\Engine\xeq

 SIMULATION REQUESTED FOR ENTIRE FLOWSHEET

 DESCRIPTION
 -----------

        VESION ANTERIOR 19 WAS SIMULATED WITH THREE LITTLE
        REPREESENTATIVES. TOD AY A MASS OF ALGAE WILL BE ADJUSTED TO RUN
        WITH NORMALIZED THESE COMPOUN S. THIS APPLIES CASE 1-5. (14688.34
        TO 22982.93) JAN212012
```

Figure C.2.4. ASPEN print out for Case Scenario 4.

```
       WITH NORMALIZED THESE COMPOUN S. THIS APPLIES CASE 1-5. (14688.34
       TO 22982.93) JAN212012
‡ ASPEN PLUS    PLAT: WIN32      VER: 22.0                   05/07/2012   PAGE 2
                                    EXTRACTION
                                 FLOWSHEET SECTION

 FLOWSHEET CONNECTIVITY BY STREAMS
 ---------------------------------

   STREAM     SOURCE     DEST           STREAM     SOURCE     DEST
   E-106      ----       Z-103          E-101      ----       Z-108
   E-108      FOR-USE    ----           E-107      FOR-USE    ----
   E-109      FOR-USE    ----           PRODUCT    Z-113      FOR-USE
   E-106C     Z-105      Z-113          E-106D     Z-105      Z-106
   E-111      Z-106      ----           E-110      Z-106      ----
   E-106B     Z-104      Z-105          E-106A     Z-103      Z-104
   E-103C     Z-110C     Z-110D         E-105      Z-110C     Z-104
   E-103D     Z-110D     Z-110E         E-103E     Z-110E     Z-111
   E-103B     Z-110B     Z-110C         E-103A     Z-110A     Z-110B
   E-103P     Z-101      Z-10           E-102P     Z-101      Z-109
   E-103      Z-10       Z-110A         E-101P     Z-108      Z-101
   E-102      Z-109      ----           E-104      Z-111      ----

 FLOWSHEET CONNECTIVITY BY BLOCKS
 --------------------------------

   BLOCK        INLETS                          OUTLETS
   FOR-USE      PRODUCT                         E-108 E-107 E-109
   Z-113        E-106C                          PRODUCT
   Z-105        E-106B                          E-106C E-106D
   Z-106        E-106D                          E-111 E-110
   Z-104        E-106A E-105                    E-106B
   Z-103        E-106                           E-106A
   Z-110C       E-103B                          E-103C E-105
   Z-110D       E-103C                          E-103D
   Z-110E       E-103D                          E-103E
   Z-110B       E-103A                          E-103B
   Z-110A       E-103                           E-103A
   Z-101        E-101P                          E-103P E-102P
   Z-10         E-103P                          E-103
   Z-108        E-101                           E-101P
   Z-109        E-102P                          E-102
   Z-111        E-103E                          E-104
```
)

(*Figure C.2.4: Continue*)

```
 COMPUTATIONAL SEQUENCE
 ----------------------

 SEQUENCE USED WAS:
    Z-108 Z-101 Z-109 Z-10 Z-110A Z-110B Z-110C Z-110D Z-110E Z-111 Z-103
    Z-104 Z-105 Z-106 Z-113 FOR-USE

 OVERALL FLOWSHEET BALANCE
 -------------------------
‡ ASPEN PLUS    PLAT: WIN32      VER: 22.0                  05/07/2012   PAGE 3
                                    EXTRACTION
                                 FLOWSHEET SECTION

 OVERALL FLOWSHEET BALANCE (CONTINUED)

                      ***  MASS AND ENERGY BALANCE  ***
                                  IN              OUT          RELATIVE DIFF.
    CONVENTIONAL COMPONENTS (LBMOL/HR)
       C6H12-01               0.00000         37.0059          -1.00000
       C2H5N-01               0.00000         195.799          -1.00000
       C3H8O-01               0.00000         43.0963          -1.00000
       CO2                    90.8888         90.8888           0.00000
       H2O                    28125.4         28125.4           0.00000
    SUBTOTAL(LBMOL/HR)        28216.3         28492.2          -0.968340E-02
            (LB/HR    )       510687.         536021.          -0.472629E-01
    NON-CONVENTIONAL COMPONENTS (LB/HR    )
       ALGAE                  50668.7         25334.3           0.500000
    SUBTOTAL(LB/HR    )       50668.7         25334.3           0.500000
    TOTAL BALANCE
       MASS(LB/HR    )        561356.         561355.           0.752669E-06
       ENTHALPY(BTU/HR  )   -0.379820E+10   -0.371601E+10    -0.216380E-01
‡ ASPEN PLUS    PLAT: WIN32      VER: 22.0                  05/07/2012   PAGE 4
                                    EXTRACTION
                              PHYSICAL PROPERTIES SECTION
```

(*Figure C.2.4: Continue*)

```
COMPONENTS
----------

 ID        TYPE  FORMULA         NAME OR ALIAS                          REPORT NAME
  C6H12-01 C      C6H12O6         C6H12O6                                C6H12-01
  C2H5N-01 C      C2H5NO2-D1      C2H5NO2-D1                             C2H5N-01
  C3H8O-01 C      C3H8O3          C3H8O3                                 C3H8O-01
  CO2      C      CO2             CO2                                    CO2
  ALGAE    NC                     MISSING                                ALGAE
  H2O      C      H2O             H2O                                    H2O

 ID              ATTRIBUTE TYPES
  ALGAE           PROXANAL ULTANAL SULFANAL
♀ ASPEN PLUS    PLAT: WIN32      VER: 22.0                    05/07/2012   PAGE 5
                                   EXTRACTION
                               U-O-S BLOCK SECTION

BLOCK:  FOR-USE  MODEL: SEP
---------------------------
  INLET STREAM:            PRODUCT
  OUTLET STREAMS:          E-108       E-107       E-109
  PROPERTY OPTION SET:     UNIQUAC   UNIQUAC / IDEAL GAS

                     ***  MASS AND ENERGY BALANCE  ***
                                IN                OUT          RELATIVE DIFF.
      CONV. COMP.(LBMOL/HR)    275.901           275.901          0.00000
                 (LB/HR   )    25333.9           25333.9        -0.143601E-15
      NONCONV. COMP(LB/HR   )  0.00000           0.00000          0.00000
    TOTAL BALANCE
      MASS(LB/HR    )          25333.9           25333.9        -0.143601E-15
      ENTHALPY(BTU/HR  )     -0.742263E+08    -0.741089E+08     -0.158158E-02
```

(*Figure C.2.4: Continue*)

```
                         ***  INPUT DATA  ***

   INLET PRESSURE    PSIA                                       5,076.32

   FLASH SPECS FOR STREAM E-108
   TWO     PHASE   TP  FLASH
   SPECIFIED TEMPERATURE F                                    130.910
   SPECIFIED PRESSURE      PSIA                              5,076.32
   MAXIMUM NO. ITERATIONS                                        30
   CONVERGENCE TOLERANCE                                          0.000100000

   FLASH SPECS FOR STREAM E-107
   TWO     PHASE   TP  FLASH
   SPECIFIED TEMPERATURE F                                    130.730
   SPECIFIED PRESSURE      PSIA                              5,076.32
   MAXIMUM NO. ITERATIONS                                        30
   CONVERGENCE TOLERANCE                                          0.000100000

   FLASH SPECS FOR STREAM E-109
   TWO     PHASE   TP  FLASH
   SPECIFIED TEMPERATURE F                                    130.910
   SPECIFIED PRESSURE      PSIA                              5,076.32
   MAXIMUM NO. ITERATIONS                                        30
   CONVERGENCE TOLERANCE                                          0.000100000
♀ ASPEN PLUS    PLAT: WIN32        VER: 22.0                   05/07/2012   PAGE 6
                                     EXTRACTION
                                 U-O-S BLOCK SECTION

 BLOCK:  FOR-USE   MODEL: SEP (CONTINUED)

   FRACTION OF FEED
     SUBSTREAM= MIXED
       STREAM= E-107       CPT= C6H12-01  FRACTION=           1.00000
                                C2H5N-01                      0.0
                                C3H8O-01                      0.0
       STREAM= E-109       CPT= C6H12-01  FRACTION=           0.0
                                C2H5N-01                      0.0
                                C3H8O-01                      1.00000
```

(*Figure C.2.4: Continue*)

```
                         ***  RESULTS  ***

 HEAT DUTY              BTU/HR                              0.11739E+06

 COMPONENT = C6H12-01
   STREAM     SUBSTREAM    SPLIT FRACTION
   E-107      MIXED                1.00000

 COMPONENT = C2H5N-01
   STREAM     SUBSTREAM    SPLIT FRACTION
   E-108      MIXED                1.00000

 COMPONENT = C3H8O-01
   STREAM     SUBSTREAM    SPLIT FRACTION
   E-109      MIXED                1.00000

BLOCK:  Z-10     MODEL: PUMP
----------------------------
  INLET STREAM:          E-103P
  OUTLET STREAM:         E-103
  PROPERTY OPTION SET:   UNIQUAC   UNIQUAC / IDEAL GAS

                     ***  MASS AND ENERGY BALANCE  ***
                                  IN                OUT         RELATIVE DIFF.
     CONV. COMP.(LBMOL/HR)     1125.02           1125.02         0.00000
                (LB/HR   )     20267.5           20267.5         0.00000
     NONCONV. COMP(LB/HR   )   50668.7           50668.7         0.00000
   TOTAL BALANCE
     MASS(LB/HR    )           70936.2           70936.2         0.00000
     ENTHALPY(BTU/HR  )     -0.466558E+09   -0.466560E+09    0.378870E-05
‡ ASPEN PLUS    PLAT: WIN32     VER: 22.0                    05/07/2012   PAGE 7
                                   EXTRACTION
                               U-O-S BLOCK SECTION
```

(*Figure C.2.4: Continue*)

```
                               U-O-S BLOCK SECTION

BLOCK:  Z-10     MODEL: PUMP (CONTINUED)

                         ***  INPUT DATA  ***
   OUTLET PRESSURE  PSIA                                   45.0000
   PUMP EFFICIENCY                                          0.65000
   DRIVER EFFICIENCY                                        1.00000

   FLASH SPECIFICATIONS:
   LIQUID PHASE CALCULATION
   NO FLASH PERFORMED
   MAXIMUM NUMBER OF ITERATIONS                             30
   TOLERANCE                                                0.000100000

                         ***  RESULTS  ***
   VOLUMETRIC FLOW RATE  CUFT/HR                           326.612
   PRESSURE CHANGE  PSI                                    -45.0000
   NPSH AVAILABLE    FT-LBF/LB                             207.787
   FLUID POWER  HP                                          -1.06891
   BRAKE POWER  HP                                          -0.69479
   ELECTRICITY  KW                                          -0.51811
   PUMP EFFICIENCY USED                                     0.65000
   NET WORK REQUIRED  HP                                    -0.69479
   HEAD DEVELOPED FT-LBF/LB                               -104.426
```

(*Figure C.2.4: Continue*)

```
    HEAD DEVELOPED FT-LBF/LB                                         -104.426

 BLOCK:  Z-101    MODEL: SEP
 ----------------------------
   INLET STREAM:            E-101P
   OUTLET STREAMS:          E-103P      E-102P
   PROPERTY OPTION SET:     UNIQUAC    UNIQUAC / IDEAL GAS

                        ***  MASS AND ENERGY BALANCE  ***
                                     IN               OUT         RELATIVE DIFF.
       CONV. COMP.(LBMOL/HR)      28125.4          28125.4          0.00000
                  (LB/HR    )     506687.          506687.          0.00000
       NONCONV. COMP(LB/HR    )   50668.7          50668.7          0.00000
    TOTAL BALANCE
       MASS(LB/HR    )            557356.          557356.          0.00000
       ENTHALPY(BTU/HR   )      -0.378283E+10    -0.378283E+10    -0.740562E-11

                            ***  INPUT DATA  ***

   INLET PRESSURE    PSIA                                            90.0000
 ASPEN PLUS    PLAT: WIN32     VER: 22.0                          05/07/2012  PAGE 8
                                  EXTRACTION
                              U-O-S BLOCK SECTION

 BLOCK:  Z-101    MODEL: SEP (CONTINUED)

   FLASH SPECS FOR STREAM E-103P
   TWO    PHASE   TP  FLASH
   PRESSURE DROP           PSI                                     0.0
   MAXIMUM NO. ITERATIONS                                         30
   CONVERGENCE TOLERANCE                                           0.000100000

   FLASH SPECS FOR STREAM E-102P
   TWO    PHASE   TP  FLASH
   PRESSURE DROP           PSI                                     0.0
   MAXIMUM NO. ITERATIONS                                         30
   CONVERGENCE TOLERANCE                                           0.000100000

   FRACTION OF FEED
     SUBSTREAM= MIXED
       STREAM= E-102P     CPT= H2O        FRACTION=           0.96000
     SUBSTREAM= NCPSD
       STREAM= E-102P     CPT= ALGAE      FRACTION=           0.0
```

(*Figure C.2.4: Continue*)

```
                            ***  RESULTS  ***

   HEAD DUTY              BTU/HR                               0.28014E-01

  COMPONENT = H2O
    STREAM     SUBSTREAM     SPLIT FRACTION
    E-103P     MIXED                 0.040000
    E-102P     MIXED                 0.96000

  COMPONENT = ALGAE
    STREAM     SUBSTREAM     SPLIT FRACTION
    E-103P     NCPSD                 1.00000

 BLOCK:  Z-103    MODEL: COMPR
 ----------------------------
   INLET STREAM:            E-106
   OUTLET STREAM:           E-106A
   PROPERTY OPTION SET:     UNIQUAC    UNIQUAC / IDEAL GAS
 ASPEN PLUS    PLAT: WIN32      VER: 22.0                  05/07/2012   PAGE 9
                                  EXTRACTION
                              U-O-S BLOCK SECTION

 BLOCK:  Z-103    MODEL: COMPR (CONTINUED)

                        ***  MASS AND ENERGY BALANCE  ***
                                     IN               OUT         RELATIVE DIFF.
       CONV. COMP.(LBMOL/HR)      90.8888          90.8888          0.00000
                  (LB/HR    )     4000.00          4000.00          0.00000
       NONCONV. COMP(LB/HR    )   0.00000          0.00000          0.00000
    TOTAL BALANCE
       MASS(LB/HR    )            4000.00          4000.00          0.00000
       ENTHALPY(BTU/HR   )      -0.153736E+08    -0.152988E+08    -0.486795E-02
```

(*Figure C.2.4: Continue*)

```
                    ***  INPUT DATA  ***

 POLYTROPIC POSITIVE DISPLACEMENT COMPRESSOR          USING PIECEWISE INTEGRATION
  OUTLET PRESSURE  PSIA                                1,450.51
  POLYTROPIC EFFICIENCY                                    0.72000
  MECHANICAL EFFICIENCY                                    0.60000
  CLEARANCE FRACTION                                       0.50000

                    ***  RESULTS  ***

  INDICATED  HORSEPOWER REQUIREMENT  HP                   29.4125
  BRAKE      HORSEPOWER REQUIREMENT  HP                   49.0208
  NET WORK REQUIRED                  HP                   49.0208
  POWER LOSSES                       HP                   19.6083
  ISENTROPIC HORSEPOWER REQUIREMENT  HP                   20.7158
  CALCULATED OUTLET TEMP  F                              169.936
  ISENTROPIC TEMPERATURE  F                              144.046
  EFFICIENCY (POLYTR/ISENTR) USED                          0.72000
  VOLUMETRIC EFFICIENCY                                    0.76830
  DISPLACEMENT             CUFT/HR                       788.028
  OUTLET VAPOR FRACTION                                    1.00000
  HEAD DEVELOPED,        FT-LBF/LB                    10,482.6
  MECHANICAL EFFICIENCY USED                               0.60000
  INLET HEAT CAPACITY RATIO                                1.28678
  INLET VOLUMETRIC FLOW RATE , CUFT/HR                   605.441
  OUTLET VOLUMETRIC FLOW RATE, CUFT/HR                   423.365
  INLET  COMPRESSIBILITY FACTOR                            1.00000
  OUTLET COMPRESSIBILITY FACTOR                            1.00000
  AV. ISENT. VOL. EXPONENT                                 1.27821
  AV. ISENT. TEMP EXPONENT                                 1.27821
  AV. ACTUAL VOL. EXPONENT                                 1.42824
  AV. ACTUAL TEMP EXPONENT                                 1.42824
‡ ASPEN PLUS   PLAT: WIN32     VER: 22.0                 05/07/2012   PAGE 10
                                  EXTRACTION
                               U-O-S BLOCK SECTION
```

(*Figure C.2.4: Continue*)

```
BLOCK:  Z-104    MODEL: RSTOIC
------------------------------
  INLET STREAMS:         E-106A      E-105
  OUTLET STREAM:         E-106B
  PROPERTY OPTION SET:   UNIQUAC   UNIQUAC / IDEAL GAS

                  ***  MASS AND ENERGY BALANCE  ***
                            IN           OUT       GENERATION   RELATIVE DIFF.
CONV. COMP.(LBMOL/HR)    90.8888      366.790       275.901     -0.774877E-16
           (LB/HR   )    4000.00      29333.9                   -0.863639
NONCONV COMP(LB/HR   )   50668.7      25334.3                    0.500000
  TOTAL BALANCE
     MASS(LB/HR   )      54668.7      54668.3                    0.772865E-05
     ENTHALPY(BTU/HR  )-0.342739E+09 -0.262046E+09              -0.235438

                        ***  INPUT DATA  ***
  STOICHIOMETRY MATRIX:

   REACTION #   1:
    SUBSTREAM MIXED    :
    C6H12-01  0.146E-02C2H5N-01  0.773E-02C3H8O-01  0.170E-02
    SUBSTREAM NCPSD    :
    ALGAE      -1.00


  REACTION CONVERSION SPECS: NUMBER=    1
    REACTION #   1:
    SUBSTREAM:NCPSD    KEY COMP:ALGAE    CONV FRAC: 0.5000



  TWO    PHASE  TP  FLASH
  SPECIFIED TEMPERATURE F                              112.910
  SPECIFIED PRESSURE     PSIA                        5,801.51
  MAXIMUM NO. ITERATIONS                                 30
  CONVERGENCE TOLERANCE                                   0.000100000
  SIMULTANEOUS REACTIONS
  GENERATE COMBUSTION REACTIONS FOR FEED SPECIES        NO
‡ ASPEN PLUS   PLAT: WIN32     VER: 22.0                05/07/2012   PAGE 11
                                  EXTRACTION
                               U-O-S BLOCK SECTION
```

(*Figure C.2.4: Continue*)

```
                              U-O-S BLOCK SECTION

BLOCK:  Z-104     MODEL: RSTOIC (CONTINUED)

                            ***  RESULTS  ***

  OUTLET TEMPERATURE    F                                       112.91
  OUTLET PRESSURE       PSIA                                    5801.5
  HEAT DUTY             BTU/HR                                 0.80691E+08
  VAPOR FRACTION                                                0.0000


  REACTION EXTENTS:

     REACTION            REACTION
     NUMBER              EXTENT
                         LBMOL/HR
     1                    25334.

  V-L PHASE EQUILIBRIUM :

     COMP                F(I)           X(I)           Y(I)           K(I)
     C6H12-01           0.10089        0.10089        0.14141E-13    0.71378E-14
     C2H5N-01           0.53382        0.53382        0.80282E-10    0.76591E-11
     C3H8O-01           0.11750        0.11750        0.11908E-07    0.51615E-08
     CO2                0.24780        0.24780         1.0000        0.20552

BLOCK:  Z-105     MODEL: SEP
---------------------------
  INLET STREAM:            E-106B
  OUTLET STREAMS:          E-106C      E-106D
  PROPERTY OPTION SET:     UNIQUAC   UNIQUAC / IDEAL GAS

                       ***  MASS AND ENERGY BALANCE  ***
                                     IN              OUT         RELATIVE DIFF.
      CONV. COMP.(LBMOL/HR)        366.790         366.790          0.00000
                 (LB/HR    )       29333.9         29333.9          0.248039E-15
      NONCONV. COMP(LB/HR    )     25334.3         25334.3          0.00000
   TOTAL BALANCE
      MASS(LB/HR    )              54668.3         54668.3          0.133093E-15
      ENTHALPY(BTU/HR   )        -0.262046E+09   -0.261803E+09    -0.926038E-03
```

(*Figure C.2.4: Continue*)

```
                          ***  INPUT DATA  ***

   INLET PRESSURE    PSIA                                    5,801.51
 ASPEN PLUS    PLAT: WIN32      VER: 22.0                   05/07/2012   PAGE 12
                                    EXTRACTION
                                U-O-S BLOCK SECTION

 BLOCK:  Z-105     MODEL: SEP (CONTINUED)

   FLASH SPECS FOR STREAM E-106C
   TWO     PHASE   TP  FLASH
   SPECIFIED TEMPERATURE F                                  121.910
   SPECIFIED PRESSURE     PSIA                              870.230
   MAXIMUM NO. ITERATIONS                                    30
   CONVERGENCE TOLERANCE                                      0.000100000

   FLASH SPECS FOR STREAM E-106D
   TWO     PHASE   TP  FLASH
   SPECIFIED TEMPERATURE F                                  121.910
   SPECIFIED PRESSURE     PSIA                              870.230
   MAXIMUM NO. ITERATIONS                                    30
   CONVERGENCE TOLERANCE                                      0.000100000

   FRACTION OF FEED
     SUBSTREAM= MIXED
       STREAM= E-106D      CPT= C6H12-01   FRACTION=         0.0
                                C2H5N-01                     0.0
                                C3H8O-01                     0.0
                                CO2                          1.00000
```

(*Figure C.2.4: Continue*)

```
                          ***  RESULTS  ***

 HEAT DUTY              BTU/HR                               0.24266E+06

 COMPONENT = C6H12-01
   STREAM     SUBSTREAM    SPLIT FRACTION
   E-106C     MIXED                1.00000

 COMPONENT = C2H5N-01
   STREAM     SUBSTREAM    SPLIT FRACTION
   E-106C     MIXED                1.00000

 COMPONENT = C3H8O-01
   STREAM     SUBSTREAM    SPLIT FRACTION
   E-106C     MIXED                1.00000

 COMPONENT = CO2
   STREAM     SUBSTREAM    SPLIT FRACTION
   E-106D     MIXED                1.00000

 COMPONENT = ALGAE
   STREAM     SUBSTREAM    SPLIT FRACTION
   E-106D     NCPSD                1.00000
 ASPEN PLUS   PLAT: WIN32     VER: 22.0                    05/07/2012   PAGE 13
                                 EXTRACTION
                              U-O-S BLOCK SECTION

BLOCK:  Z-106    MODEL: FLASH2
------------------------------
  INLET STREAM:           E-106D
  OUTLET VAPOR STREAM:    E-111
  OUTLET LIQUID STREAM:   E-110
  PROPERTY OPTION SET:    UNIQUAC    UNIQUAC / IDEAL GAS
```

(*Figure C.2.4: Continue*)

```
                      ***  MASS AND ENERGY BALANCE  ***
                                   IN              OUT          RELATIVE DIFF.
    CONV. COMP.(LBMOL/HR)        90.8888         90.8888          0.00000
               (LB/HR    )       4000.00         4000.00          0.00000
    NONCONV. COMP(LB/HR    )     25334.3         25334.3          0.00000
 TOTAL BALANCE
    MASS(LB/HR    )              29334.3         29334.3          0.00000
    ENTHALPY(BTU/HR  )       -0.187577E+09   -0.187579E+09     0.133751E-04

                          ***  INPUT DATA  ***
 TWO    PHASE  TP  FLASH
 SPECIFIED TEMPERATURE F                                  121.730
 SPECIFIED PRESSURE    PSIA                               870.230
 MAXIMUM NO. ITERATIONS                                    30
 CONVERGENCE TOLERANCE                                     0.000100000

                          ***  RESULTS  ***
 OUTLET TEMPERATURE    F                                     121.73
 OUTLET PRESSURE       PSIA                                  870.23
 HEAT DUTY             BTU/HR                               -2508.9
 VAPOR FRACTION                                              1.0000


 V-L PHASE EQUILIBRIUM :

    COMP             F(I)          X(I)          Y(I)          K(I)
    CO2              1.0000        1.0000        1.0000        1.8230

BLOCK:  Z-108    MODEL: PUMP
----------------------------
  INLET STREAM:           E-101
  OUTLET STREAM:          E-101P
  PROPERTY OPTION SET:    UNIQUAC    UNIQUAC / IDEAL GAS
 ASPEN PLUS   PLAT: WIN32     VER: 22.0                    05/07/2012   PAGE 14
                                 EXTRACTION
                              U-O-S BLOCK SECTION
```

(*Figure C.2.4: Continue*)

```
                       U-O-S BLOCK SECTION

BLOCK:  Z-108    MODEL: PUMP (CONTINUED)

                    ***  MASS AND ENERGY BALANCE  ***
                                 IN              OUT          RELATIVE DIFF.
      CONV. COMP.(LBMOL/HR)     28125.4         28125.4          0.00000
                 (LB/HR   )     506687.         506687.          0.00000
      NONCONV. COMP(LB/HR   )   50668.7         50668.7          0.00000
   TOTAL BALANCE
      MASS(LB/HR    )            557356.         557356.          0.00000
      ENTHALPY(BTU/HR  )       -0.378283E+10   -0.378283E+10     0.00000

                        ***  INPUT DATA  ***
   OUTLET PRESSURE  PSIA                                     90.0000
   PUMP EFFICIENCY                                            0.60000
   DRIVER EFFICIENCY                                          1.00000

   FLASH SPECIFICATIONS:
   LIQUID PHASE CALCULATION
   NO FLASH PERFORMED
   MAXIMUM NUMBER OF ITERATIONS                               30
   TOLERANCE                                                  0.000100000

                         ***  RESULTS  ***
   VOLUMETRIC FLOW RATE  CUFT/HR                           8,165.30
   PRESSURE CHANGE  PSI                                       0.0
   NPSH AVAILABLE   FT-LBF/LB                               207.787
   FLUID POWER  HP                                            0.0
   BRAKE POWER  HP                                            0.0
   ELECTRICITY  KW                                            0.0
   PUMP EFFICIENCY USED                                       0.60000
   NET WORK REQUIRED  HP                                      0.0
   HEAD DEVELOPED FT-LBF/LB                                   0.0
```

(*Figure C.2.4: Continue*)

```
   HEAD DEVELOPED FT-LBF/LB                                   0.0

 BLOCK:  Z-109    MODEL: PUMP
 ----------------------------
   INLET STREAM:           E-102P
   OUTLET STREAM:          E-102
   PROPERTY OPTION SET:    UNIQUAC   UNIQUAC / IDEAL GAS
± ASPEN PLUS    PLAT: WIN32      VER: 22.0                05/07/2012  PAGE 15
                                   EXTRACTION
                               U-O-S BLOCK SECTION

 BLOCK:  Z-109    MODEL: PUMP (CONTINUED)

                    ***  MASS AND ENERGY BALANCE  ***
                                  IN              OUT          RELATIVE DIFF.
     CONV. COMP.(LBMOL/HR)      27000.4         27000.4          0.00000
                (LB/HR   )      486419.         486419.          0.00000
     NONCONV. COMP(LB/HR   )    0.00000         0.00000          0.00000
   TOTAL BALANCE
     MASS(LB/HR    )            486419.         486419.          0.00000
     ENTHALPY(BTU/HR  )       -0.331627E+10   -0.331632E+10     0.157463E-04

                        ***  INPUT DATA  ***
   OUTLET PRESSURE  PSIA                                     30.0000
   PUMP EFFICIENCY                                            0.60000
   DRIVER EFFICIENCY                                          1.00000

   FLASH SPECIFICATIONS:
   LIQUID PHASE CALCULATION
   NO FLASH PERFORMED
   MAXIMUM NUMBER OF ITERATIONS                               30
   TOLERANCE                                                  0.000100000
```

(*Figure C.2.4: Continue*)

```
                        ***  RESULTS  ***
  VOLUMETRIC FLOW RATE  CUFT/HR                          7,838.68
  PRESSURE CHANGE  PSI                                     -60.0000
  NPSH AVAILABLE    FT-LBF/LB                              207.787
  FLUID POWER  HP                                          -34.2052
  BRAKE POWER  HP                                          -20.5231
  ELECTRICITY  KW                                          -15.3041
  PUMP EFFICIENCY USED                                       0.60000
  NET WORK REQUIRED  HP                                    -20.5231
  HEAD DEVELOPED FT-LBF/LB                                -139.234

BLOCK:  Z-110A   MODEL: HEATER
------------------------------
  INLET STREAM:            E-103
  OUTLET STREAM:           E-103A
  PROPERTY OPTION SET:     UNIQUAC   UNIQUAC / IDEAL GAS
ASPEN PLUS    PLAT: WIN32      VER: 22.0                05/07/2012   PAGE 16
                                  EXTRACTION
                              U-O-S BLOCK SECTION

BLOCK:  Z-110A   MODEL: HEATER (CONTINUED)

                    ***  MASS AND ENERGY BALANCE  ***
                                 IN             OUT        RELATIVE DIFF.
    CONV. COMP.(LBMOL/HR)      1125.02         1125.02         0.00000
               (LB/HR    )     20267.5         20267.5         0.00000
    NONCONV. COMP(LB/HR    )   50668.7         50668.7         0.00000
  TOTAL BALANCE
    MASS(LB/HR    )            70936.2         70936.2         0.00000
    ENTHALPY(BTU/HR  )       -0.466560E+09   -0.471445E+09    0.103622E-01

                        ***  INPUT DATA  ***
  TWO    PHASE  TP  FLASH
  SPECIFIED TEMPERATURE               F                      -40.0900
  SPECIFIED PRESSURE                  PSIA                    14.5038
  MAXIMUM NO. ITERATIONS                                      30
  CONVERGENCE TOLERANCE                                        0.000100000
```

(*Figure C.2.4: Continue*)

```
                        ***  RESULTS  ***
  OUTLET TEMPERATURE     F                                -40.090
  OUTLET PRESSURE        PSIA                              14.504
  HEAT DUTY              BTU/HR                           -0.48852E+07
  OUTLET VAPOR FRACTION                                    0.0000
  PRESSURE-DROP CORRELATION PARAMETER                      0.33000E+08


  V-L PHASE EQUILIBRIUM :

     COMP              F(I)          X(I)          Y(I)          K(I)
     H2O               1.0000        1.0000        1.0000        0.20011E-03

BLOCK:  Z-110B   MODEL: HEATER
------------------------------
  INLET STREAM:            E-103A
  OUTLET STREAM:           E-103B
  PROPERTY OPTION SET:     UNIQUAC   UNIQUAC / IDEAL GAS
ASPEN PLUS    PLAT: WIN32      VER: 22.0                05/07/2012   PAGE 17
                                  EXTRACTION
                              U-O-S BLOCK SECTION

BLOCK:  Z-110B   MODEL: HEATER (CONTINUED)

                    ***  MASS AND ENERGY BALANCE  ***
                                 IN             OUT        RELATIVE DIFF.
    CONV. COMP.(LBMOL/HR)      1125.02         1125.02         0.00000
               (LB/HR    )     20267.5         20267.5         0.00000
    NONCONV. COMP(LB/HR    )   50668.7         50668.7         0.00000
  TOTAL BALANCE
    MASS(LB/HR    )            70936.2         70936.2         0.00000
    ENTHALPY(BTU/HR  )       -0.471445E+09   -0.440210E+09   -0.662552E-01

                        ***  INPUT DATA  ***
  TWO    PHASE  TP  FLASH
  SPECIFIED TEMPERATURE               F                      233.100
  SPECIFIED PRESSURE                  PSIA                     1.45038
  MAXIMUM NO. ITERATIONS                                      30
  CONVERGENCE TOLERANCE                                        0.000100000
```

(*Figure C.2.4: Continue*)

```
                          ***  RESULTS  ***
 OUTLET TEMPERATURE    F                                        233.10
 OUTLET PRESSURE       PSIA                                     1.4504
 HEAT DUTY             BTU/HR                                  0.31236E+08
 OUTLET VAPOR FRACTION                                          1.0000
 PRESSURE-DROP CORRELATION PARAMETER                            1553.9


 V-L PHASE EQUILIBRIUM :

    COMP              F(I)         X(I)         Y(I)         K(I)
    H2O               1.0000       1.0000       1.0000       15.160

BLOCK:  Z-110C   MODEL: FLASH2
------------------------------
 INLET STREAM:            E-103B
 OUTLET VAPOR STREAM:     E-103C
 OUTLET LIQUID STREAM:    E-105
 PROPERTY OPTION SET:     UNIQUAC   UNIQUAC / IDEAL GAS
‡ ASPEN PLUS    PLAT: WIN32      VER: 22.0                    05/07/2012   PAGE 18
                                  EXTRACTION
                              U-O-S BLOCK SECTION

BLOCK:  Z-110C   MODEL: FLASH2 (CONTINUED)

                        ***  MASS AND ENERGY BALANCE  ***
                                   IN              OUT        RELATIVE DIFF.
    CONV. COMP.(LBMOL/HR)      1125.02          1125.02          0.00000
               (LB/HR    )     20267.5          20267.5          0.00000
    NONCONV. COMP(LB/HR    )   50668.7          50668.7          0.00000
  TOTAL BALANCE
    MASS(LB/HR    )            70936.2          70936.2          0.00000
    ENTHALPY(BTU/HR   )      -0.440210E+09   -0.444042E+09    0.863023E-02

                          ***  INPUT DATA  ***
 TWO    PHASE   TP  FLASH
 SPECIFIED TEMPERATURE F                                     116.510
 SPECIFIED PRESSURE    PSIA                                   1.45038
 MAXIMUM NO. ITERATIONS                                      30
 CONVERGENCE TOLERANCE                                        0.000100000
```

(*Figure C.2.4: Continue*)

```
    ENTHALPY(BTU/HR   )      -0.440210E+09   -0.444042E+09    0.863023E-02

                          ***  INPUT DATA  ***
 TWO    PHASE   TP  FLASH
 SPECIFIED TEMPERATURE F                                     116.510
 SPECIFIED PRESSURE    PSIA                                   1.45038
 MAXIMUM NO. ITERATIONS                                      30
 CONVERGENCE TOLERANCE                                        0.000100000

                          ***  RESULTS  ***
 OUTLET TEMPERATURE    F                                        116.51
 OUTLET PRESSURE       PSIA                                     1.4504
 HEAT DUTY             BTU/HR                                 -0.38322E+07
 VAPOR FRACTION                                                 1.0000


 V-L PHASE EQUILIBRIUM :

    COMP              F(I)         X(I)         Y(I)         K(I)
    H2O               1.0000       1.0000       1.0000       1.0600

BLOCK:  Z-110D   MODEL: COMPR
------------------------------
 INLET STREAM:            E-103C
 OUTLET STREAM:           E-103D
 PROPERTY OPTION SET:     UNIQUAC   UNIQUAC / IDEAL GAS

                        ***  MASS AND ENERGY BALANCE  ***
                                   IN              OUT        RELATIVE DIFF.
    CONV. COMP.(LBMOL/HR)      1125.02          1125.02          0.00000
               (LB/HR    )     20267.5          20267.5          0.00000
    NONCONV. COMP(LB/HR    )   0.00000          0.00000          0.00000
‡ ASPEN PLUS    PLAT: WIN32      VER: 22.0                    05/07/2012   PAGE 19
                                  EXTRACTION
                              U-O-S BLOCK SECTION
```

(*Figure C.2.4: Continue*)

```
BLOCK:  Z-110D   MODEL: COMPR (CONTINUED)
   TOTAL BALANCE
      MASS(LB/HR    )            20267.5         20267.5          0.00000
      ENTHALPY(BTU/HR  )      -0.116601E+09   -0.109629E+09   -0.597904E-01

                          ***  INPUT DATA  ***

  POLYTROPIC COMPRESSOR USING ASME METHOD
   OUTLET PRESSURE  PSIA                                     14.5038
   POLYTROPIC EFFICIENCY                                      0.66000
   MECHANICAL EFFICIENCY                                      1.00000

                          ***  RESULTS  ***

   INDICATED  HORSEPOWER REQUIREMENT  HP                2,739.95
   BRAKE      HORSEPOWER REQUIREMENT  HP                2,739.95
   NET WORK REQUIRED                  HP                2,739.95
   POWER LOSSES                       HP                    0.0
   ISENTROPIC HORSEPOWER REQUIREMENT  HP                1,560.98
   CALCULATED OUTLET TEMP  F                              846.263
   EFFICIENCY (POLYTR/ISENTR) USED                          0.66000
   OUTLET VAPOR FRACTION                                    1.00000
   HEAD DEVELOPED,        FT-LBF/LB                   176,666.
   MECHANICAL EFFICIENCY USED                               1.00000
   INLET HEAT CAPACITY RATIO                                1.32818
   INLET VOLUMETRIC FLOW RATE , CUFT/HR             4,796,150.
   OUTLET VOLUMETRIC FLOW RATE, CUFT/HR             1,087,060.
   INLET  COMPRESSIBILITY FACTOR                            1.00000
   OUTLET COMPRESSIBILITY FACTOR                            1.00000
   AV. ISENT. VOL. EXPONENT                                 1.31686
   AV. ISENT. TEMP EXPONENT                                 1.31686
   AV. ACTUAL VOL. EXPONENT                                 1.55126
   AV. ACTUAL TEMP EXPONENT                                 1.55126
```

(*Figure C.2.4: Continue*)

```
BLOCK:  Z-110E   MODEL: HEATER
------------------------------
  INLET STREAM:           E-103D
  OUTLET STREAM:          E-103E
  PROPERTY OPTION SET:    UNIQUAC   UNIQUAC / IDEAL GAS
‡ ASPEN PLUS   PLAT: WIN32     VER: 22.0                   05/07/2012  PAGE 20
                                    EXTRACTION
                                U-O-S BLOCK SECTION

BLOCK:  Z-110E   MODEL: HEATER (CONTINUED)

                    ***  MASS AND ENERGY BALANCE  ***
                                  IN              OUT       RELATIVE DIFF.
     CONV. COMP.(LBMOL/HR)      1125.02         1125.02        0.00000
                (LB/HR    )     20267.5         20267.5        0.00000
     NONCONV. COMP(LB/HR    )   0.00000         0.00000        0.00000
   TOTAL BALANCE
     MASS(LB/HR    )            20267.5         20267.5        0.00000
     ENTHALPY(BTU/HR  )      -0.109629E+09   -0.138009E+09   0.205636

                          ***  INPUT DATA  ***
  TWO    PHASE  TP  FLASH
  SPECIFIED TEMPERATURE              F                        85.9100
  SPECIFIED PRESSURE                 PSIA                     14.5038
  MAXIMUM NO. ITERATIONS                                      30
  CONVERGENCE TOLERANCE                                        0.000100000


                          ***  RESULTS  ***
  OUTLET TEMPERATURE    F                                   85.910
  OUTLET PRESSURE       PSIA                                14.504
  HEAT DUTY             BTU/HR                            -0.28380E+08
  OUTLET VAPOR FRACTION                                     0.0000
  PRESSURE-DROP CORRELATION PARAMETER                       0.0000
```

(*Figure C.2.4: Continue*)

```
  PRESSURE-DROP CORRELATION PARAMETER                           0.0000


  V-L PHASE EQUILIBRIUM :

     COMP              F(I)          X(I)          Y(I)          K(I)
     H2O               1.0000        1.0000        1.0000        0.42357E-01

 BLOCK:  Z-111    MODEL: PUMP
 ----------------------------
   INLET STREAM:          E-103E
   OUTLET STREAM:         E-104
   PROPERTY OPTION SET:   UNIQUAC   UNIQUAC / IDEAL GAS
 ASPEN PLUS   PLAT: WIN32     VER: 22.0                     05/07/2012  PAGE 21
                                  EXTRACTION
                              U-O-S BLOCK SECTION

 BLOCK:  Z-111    MODEL: PUMP (CONTINUED)

                         ***  MASS AND ENERGY BALANCE  ***
                                     IN             OUT        RELATIVE DIFF.
     CONV. COMP.(LBMOL/HR)      1125.02         1125.02          0.00000
                (LB/HR   )      20267.5         20267.5          0.00000
     NONCONV. COMP(LB/HR   )    0.00000         0.00000          0.00000
   TOTAL BALANCE
     MASS(LB/HR    )             20267.5         20267.5          0.00000
     ENTHALPY(BTU/HR  )       -0.138009E+09   -0.138006E+09   -0.223679E-04

                            ***  INPUT DATA  ***
   OUTLET PRESSURE  PSIA                                       45.0000
   PUMP EFFICIENCY                                              0.60000
   DRIVER EFFICIENCY                                            1.00000

   FLASH SPECIFICATIONS:
   LIQUID PHASE CALCULATION
   NO FLASH PERFORMED
   MAXIMUM NUMBER OF ITERATIONS                                 30
   TOLERANCE                                                    0.000100000
```

(*Figure C.2.4: Continue*)

```
                             ***  RESULTS  ***
    VOLUMETRIC FLOW RATE  CUFT/HR                              328.209
    PRESSURE CHANGE  PSI                                        30.4962
    NPSH AVAILABLE   FT-LBF/LB                                  32.3889
    FLUID POWER  HP                                              0.72794
    BRAKE POWER  HP                                              1.21323
    ELECTRICITY  KW                                              0.90470
    PUMP EFFICIENCY USED                                         0.60000
    NET WORK REQUIRED  HP                                        1.21323
    HEAD DEVELOPED FT-LBF/LB                                    71.1146

 BLOCK:  Z-113    MODEL: PUMP
 ----------------------------
   INLET STREAM:          E-106C
   OUTLET STREAM:         PRODUCT
   PROPERTY OPTION SET:   UNIQUAC   UNIQUAC / IDEAL GAS
 ASPEN PLUS   PLAT: WIN32     VER: 22.0                     05/07/2012  PAGE 22
                                  EXTRACTION
                              U-O-S BLOCK SECTION

 BLOCK:  Z-113    MODEL: PUMP (CONTINUED)

                         ***  MASS AND ENERGY BALANCE  ***
                                     IN             OUT        RELATIVE DIFF.
     CONV. COMP.(LBMOL/HR)      275.901         275.901          0.00000
                (LB/HR   )      25333.9         25333.9          0.00000
     NONCONV. COMP(LB/HR   )    0.00000         0.00000          0.00000
   TOTAL BALANCE
     MASS(LB/HR    )             25333.9         25333.9          0.00000
     ENTHALPY(BTU/HR  )       -0.742263E+08   -0.742263E+08   -0.401506E-15

                            ***  INPUT DATA  ***
   EQUIPMENT TYPE: PUMP
   OUTLET PRESSURE  PSIA                                      870.230
   PUMP EFFICIENCY                                              0.60000
   DRIVER EFFICIENCY                                            1.00000

   FLASH SPECIFICATIONS:
   LIQUID PHASE CALCULATION
   NO FLASH PERFORMED
   MAXIMUM NUMBER OF ITERATIONS                                 30
   TOLERANCE                                                    0.000100000
```

(*Figure C.2.4: Continue*)

```
                          ***  RESULTS  ***
    VOLUMETRIC FLOW RATE  CUFT/HR                            295.307
    PRESSURE CHANGE  PSI                                       0.0
    NPSH AVAILABLE    FT-LBF/LB                            1,460.72
    FLUID POWER  HP                                            0.0
    BRAKE POWER  HP                                            0.0
    ELECTRICITY  KW                                            0.0
    PUMP EFFICIENCY USED                                       0.60000
    NET WORK REQUIRED  HP                                      0.0
    HEAD DEVELOPED FT-LBF/LB                                   0.0
± ASPEN PLUS    PLAT: WIN32      VER: 22.0                    05/07/2012   PAGE 23
                                    EXTRACTION
                                   STREAM SECTION

 SUBSTREAM ATTR PSD TYPE: PSD
 ----------------------------

 INTERVAL      LOWER LIMIT          UPPER LIMIT
     1           0.0      FT        6.5617-05  FT
     2         6.5617-05  FT        1.3123-04  FT
     3         1.3123-04  FT        1.9685-04  FT
     4         1.9685-04  FT        2.6247-04  FT
     5         2.6247-04  FT        3.2808-04  FT
     6         3.2808-04  FT        3.9370-04  FT
     7         3.9370-04  FT        4.5932-04  FT
     8         4.5932-04  FT        5.2493-04  FT
     9         5.2493-04  FT        5.9055-04  FT
    10         5.9055-04  FT        6.5617-04  FT

± ASPEN PLUS    PLAT: WIN32      VER: 22.0                    05/07/2012   PAGE 24
                                    EXTRACTION
                                   STREAM SECTION

 E-101 E-101P E-102 E-102P E-103
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(*Figure C.2.4: Continue*)

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E-103A E-103B E-103C E-103D E-103E
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STREAM ID	E-101	E-101P	E-102	E-102P	E-103	E-103A	E-103B	E-103C	E-103D	E-103E
FROM :	----	Z-108	Z-109	Z-101	Z-10	Z-110A	Z-110B	Z-110C	Z-110D	Z-110E
TO :	Z-108	Z-101	----	Z-109	Z-110A	Z-110B	Z-110C	Z-110D	Z-110E	Z-111
CLASS:	MIXNCPSD	MIXNCPSD	MIXNCPSD	MIXNCPSD	MIXNCPSD	MIXNCPSD	MIXNCPSD	MIXNCPSD	MIXNCPSD	MIXNCPSD
TOTAL STREAM:										
LB/HR	5.5736+05	5.5736+05	4.8642+05	4.8642+05	7.0936+04	7.0936+04	7.0936+04	2.0267+04	2.0267+04	2.0267+04
BTU/HR	-3.7828+09	-3.7828+09	-3.3163+09	-3.3163+09	-4.6656+08	-4.7145+08	-4.4021+08	-1.1660+08	-1.0963+08	-1.3801+08
SUBSTREAM: MIXED										
PHASE:	LIQUID	LIQUID	LIQUID	LIQUID	LIQUID	LIQUID	VAPOR	VAPOR	VAPOR	LIQUID
COMPONENTS: LBMOL/HR										
C6H12-01	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C2H5N-01	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C3H8O-01	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CO2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
H2O	2.8125+04	2.8125+04	2.7000+04	2.7000+04	1125.0160	1125.0160	1125.0160	1125.0160	1125.0160	1125.0160
COMPONENTS: LB/HR										
C6H12-01	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C2H5N-01	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C3H8O-01	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CO2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
H2O	5.0669+05	5.0669+05	4.8642+05	4.8642+05	2.0267+04	2.0267+04	2.0267+04	2.0267+04	2.0267+04	2.0267+04
COMPONENTS: MASS FRAC										
C6H12-01	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C2H5N-01	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C3H8O-01	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CO2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
H2O	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
TOTAL FLOW:										
LBMOL/HR	2.8125+04	2.8125+04	2.7000+04	2.7000+04	1125.0160	1125.0160	1125.0160	1125.0160	1125.0160	1125.0160
LB/HR	5.0669+05	5.0669+05	4.8642+05	4.8642+05	2.0267+04	2.0267+04	2.0267+04	2.0267+04	2.0267+04	2.0267+04
CUFT/HR	8165.2955	8165.2955	7838.1911	7838.6837	326.6045	307.8141	5.7666+06	4.7961+06	1.0871+06	328.2086
STATE VARIABLES:										
TEMP F	76.9100	76.9100	76.7934	76.9100	76.8683	-40.0900	233.1000	116.5100	846.2629	85.9100
PRES PSIA	90.0000	90.0000	30.0000	90.0000	45.0000	14.5038	1.4504	1.4504	14.5038	14.5038
VFRAC	0.0	0.0	0.0	0.0	0.0	0.0	1.0000	1.0000	1.0000	0.0
LFRAC	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.0	0.0	0.0	1.0000
SFRAC	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

(*Figure C.2.4: Continue*)

ENTHALPY:										
BTU/LBMOL	-1.2282+05	-1.2282+05	-1.2282+05	-1.2282+05	-1.2282+05	-1.2470+05	-1.0270+05	-1.0364+05	-9.7447+04	-1.2267+05
BTU/LB	-6817.7136	-6817.7136	-6817.8210	-6817.7136	-6817.7520	-6922.0178	-5700.7341	-5753.1142	-5409.1331	-6809.3888
BTU/HR	-3.4544+09	-3.4544+09	-3.3163+09	-3.3163+09	-1.3818+08	-1.4029+08	-1.1554+08	-1.1660+08	-1.0963+08	-1.3801+08
ENTROPY:										
BTU/LBMOL-R	-38.8595	-38.8595	-38.8631	-38.8595	-38.8608	-42.8235	-3.9332	-5.4244	-3.1037	-38.5849
BTU/LB-R	-2.1570	-2.1570	-2.1572	-2.1570	-2.1571	-2.3771	-0.2183	-0.3011	-0.1723	-2.1418
DENSITY:										
LBMOL/CUFT	3.4445	3.4445	3.4447	3.4445	3.4446	3.6549	1.9509-04	2.3457-04	1.0349-03	3.4277
LB/CUFT	62.0537	62.0537	62.0576	62.0537	62.0551	65.8432	3.5146-03	4.2258-03	1.8644-02	61.7518
AVG MW	18.0153	18.0153	18.0153	18.0153	18.0153	18.0153	18.0153	18.0153	18.0153	18.0153

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EXTRACTION

STREAM SECTION

E-101 E-101P E-102 E-102P E-103

E-103A E-103B E-103C E-103D E-103E (CONTINUED)

STREAM ID	E-101	E-101P	E-102	E-102P	E-103	E-103A	E-103B	E-103C	E-103D	E-103E
SUBSTREAM: NCPSD	STRUCTURE: NON CONVENTIONAL									
COMPONENTS: LB/HR										
ALGAE	5.0669+04	5.0669+04	0.0	0.0	5.0669+04	5.0669+04	5.0669+04	0.0	0.0	0.0
COMPONENTS: MASS FRAC										
ALGAE	1.0000	1.0000	0.0	0.0	1.0000	1.0000	1.0000	0.0	0.0	0.0
TOTAL FLOW:										
LB/HR	5.0669+04	5.0669+04	0.0	0.0	5.0669+04	5.0669+04	5.0669+04	0.0	0.0	0.0
STATE VARIABLES:										
TEMP F	76.9100	76.9100	MISSING	MISSING	76.8683	-40.0900	233.1000	MISSING	MISSING	MISSING
PRES PSIA	90.0000	90.0000	30.0000	90.0000	45.0000	14.5038	1.4504	1.4504	14.5038	14.5038
VFRAC	0.0	0.0	MISSING	MISSING	0.0	0.0	0.0	MISSING	MISSING	MISSING
LFRAC	0.0	0.0	MISSING	MISSING	0.0	0.0	0.0	MISSING	MISSING	MISSING
SFRAC	1.0000	1.0000	MISSING	MISSING	1.0000	1.0000	1.0000	MISSING	MISSING	MISSING
ENTHALPY:										
BTU/LB	-6480.9341	-6480.9341	MISSING	MISSING	-6480.9536	-6535.6624	-6407.7062	MISSING	MISSING	MISSING
BTU/HR	-3.2838+08	-3.2838+08	MISSING	MISSING	-3.2838+08	-3.3115+08	-3.2467+08	MISSING	MISSING	MISSING
DENSITY:										
LB/CUFT	141.9785	141.9785	MISSING	MISSING	141.9785	141.9785	141.9785	MISSING	MISSING	MISSING
AVG MW	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

(*Figure C.2.4: Continue*)

COMPONENT ATTRIBUTES:										
ALGAE PROXANAL										
MOISTURE	81.7000	81.7000	MISSING	MISSING	81.7000	81.7000	81.7000	MISSING	MISSING	MISSING
FC	0.0	0.0	MISSING	MISSING	0.0	0.0	0.0	MISSING	MISSING	MISSING
VM	0.0	0.0	MISSING	MISSING	0.0	0.0	0.0	MISSING	MISSING	MISSING
ASH	18.4000	18.4000	MISSING	MISSING	18.4000	18.4000	18.4000	MISSING	MISSING	MISSING
ULTANAL										
ASH	0.0	0.0	MISSING	MISSING	0.0	0.0	0.0	MISSING	MISSING	MISSING
CARBON	0.0	0.0	MISSING	MISSING	0.0	0.0	0.0	MISSING	MISSING	MISSING
HYDROGEN	0.0	0.0	MISSING	MISSING	0.0	0.0	0.0	MISSING	MISSING	MISSING
NITROGEN	0.0	0.0	MISSING	MISSING	0.0	0.0	0.0	MISSING	MISSING	MISSING
CHLORINE	0.0	0.0	MISSING	MISSING	0.0	0.0	0.0	MISSING	MISSING	MISSING
SULFUR	0.0	0.0	MISSING	MISSING	0.0	0.0	0.0	MISSING	MISSING	MISSING
OXYGEN	0.0	0.0	MISSING	MISSING	0.0	0.0	0.0	MISSING	MISSING	MISSING
SULFANAL										
PYRITIC	0.0	0.0	MISSING	MISSING	0.0	0.0	0.0	MISSING	MISSING	MISSING
SULFATE	0.0	0.0	MISSING	MISSING	0.0	0.0	0.0	MISSING	MISSING	MISSING
ORGANIC	0.0	0.0	MISSING	MISSING	0.0	0.0	0.0	MISSING	MISSING	MISSING
SUBSTREAM ATTRIBUTES:										
PSD										
FRAC1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	MISSING	MISSING	MISSING
FRAC2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	MISSING	MISSING	MISSING
FRAC3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	MISSING	MISSING	MISSING
FRAC4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	MISSING	MISSING	MISSING
FRAC5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	MISSING	MISSING	MISSING
FRAC6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	MISSING	MISSING	MISSING
FRAC7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	MISSING	MISSING	MISSING
FRAC8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	MISSING	MISSING	MISSING
FRAC9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	MISSING	MISSING	MISSING
FRAC10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	MISSING	MISSING	MISSING

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EXTRACTION

STREAM SECTION

E-103P E-104 E-105 E-106 E-106A

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(*Figure C.2.4: Continue*)

E-106B E-106C E-106D E-107 E-108

STREAM ID	E-103P	E-104	E-105	E-106	E-106A	E-106B	E-106C	E-106D	E-107	E-108
FROM :	Z-101	Z-111	Z-110C	----	Z-103	Z-104	Z-105	Z-105	FOR-USE	FOR-USE
TO :	Z-10	----	Z-104	Z-103	Z-104	Z-105	Z-113	Z-106	----	----
CLASS:	MIXNCPSD	MIXNCPSD	MIXNCPSD	MIXNCPSD	MIXNCPSD	MIXNCPSD	MIXNCPSD	MIXNCPSD	MIXNCPSD	MIXNCPSD
TOTAL STREAM:										
LB/HR	7.0936+04	2.0267+04	5.0669+04	4000.0000	4000.0000	5.4668+04	2.5334+04	2.9334+04	6666.8928	1.4698+04
BTU/HR	-4.6656+08	-1.3801+08	-3.2744+08	-1.5374+07	-1.5299+07	-2.6205+08	-7.4226+07	-1.8758+08	-1.9832+07	-4.2015+07
SUBSTREAM: MIXED										
PHASE:	LIQUID	LIQUID	MISSING	VAPOR	VAPOR	LIQUID	LIQUID	VAPOR	LIQUID	LIQUID
COMPONENTS: LBMOL/HR										
C6H12-01	0.0	0.0	0.0	0.0	0.0	37.0059	37.0059	0.0	37.0059	0.0
C2H5N-01	0.0	0.0	0.0	0.0	0.0	195.7990	195.7990	0.0	0.0	195.7990
C3H8O-01	0.0	0.0	0.0	0.0	0.0	43.0963	43.0963	0.0	0.0	0.0
CO2	0.0	0.0	0.0	90.8888	90.8888	90.8888	0.0	90.8888	0.0	0.0
H2O	1125.0160	1125.0160	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
COMPONENTS: LB/HR										
C6H12-01	0.0	0.0	0.0	0.0	0.0	6666.8928	6666.8928	0.0	6666.8928	0.0
C2H5N-01	0.0	0.0	0.0	0.0	0.0	1.4698+04	1.4698+04	0.0	0.0	1.4698+04
C3H8O-01	0.0	0.0	0.0	0.0	0.0	3968.9373	3968.9373	0.0	0.0	0.0
CO2	0.0	0.0	0.0	4000.0000	4000.0000	4000.0000	0.0	4000.0000	0.0	0.0
H2O	2.0267+04	2.0267+04	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
COMPONENTS: MASS FRAC										
C6H12-01	0.0	0.0	MISSING	0.0	0.0	0.2273	0.2632	0.0	1.0000	0.0
C2H5N-01	0.0	0.0	MISSING	0.0	0.0	0.5011	0.5802	0.0	0.0	1.0000
C3H8O-01	0.0	0.0	MISSING	0.0	0.0	0.1353	0.1567	0.0	0.0	0.0
CO2	0.0	0.0	MISSING	1.0000	1.0000	0.1364	0.0	1.0000	0.0	0.0
H2O	1.0000	1.0000	MISSING	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL FLOW:										
LBMOL/HR	1125.0160	1125.0160	0.0	90.8888	90.8888	366.7900	275.9011	90.8888	37.0059	195.7990
LB/HR	2.0267+04	2.0267+04	0.0	4000.0000	4000.0000	2.9334+04	2.5334+04	4000.0000	6666.8928	1.4698+04
CUFT/HR	326.6118	328.2379	0.0	605.4408	423.3652	370.9355	295.3073	651.8424	92.7350	163.0189
STATE VARIABLES:										
TEMP F	76.9100	86.0739	MISSING	80.5100	169.9357	112.9100	121.9100	121.9100	130.7300	130.9100
PRES PSIA	90.0000	45.0000	1.4504	870.2300	1450.5100	5801.5095	870.2300	870.2300	5076.3208	5076.3208
VFRAC	0.0	0.0	MISSING	1.0000	1.0000	0.0	0.0	1.0000	0.0	0.0
LFRAC	1.0000	1.0000	MISSING	0.0	0.0	1.0000	1.0000	0.0	1.0000	1.0000
SFRAC	0.0	0.0	MISSING	0.0	0.0	0.0	0.0	0.0	0.0	0.0

(*Figure C.2.4: Continue*)

ENTHALPY:										
BTU/LBMOL	-1.2282+05	-1.2267+05	MISSING	-1.6915+05	-1.6832+05	-2.4453+05	-2.6903+05	-1.6877+05	-5.3592+05	-2.1458+05
BTU/LB	-6817.7136	-6809.2365	MISSING	-3843.4072	-3824.6977	-3057.5720	-2929.9168	-3834.8873	-2974.7235	-2858.5557
BTU/HR	-1.3818+08	-1.3801+08	MISSING	-1.5374+07	-1.5299+07	-8.9691+07	-7.4226+07	-1.5340+07	-1.9832+07	-4.2015+07
ENTROPY:										
BTU/LBMOL-R	-38.8595	-38.5799	MISSING	-7.3576	-6.9627	-104.1978	-136.7072	-6.6889	-252.7076	-114.7810
BTU/LB-R	-2.1570	-2.1415	MISSING	-0.1672	-0.1582	-1.3029	-1.4888	-0.1520	-1.4027	-1.5290
DENSITY:										
LBMOL/CUFT	3.4445	3.4274	MISSING	0.1501	0.2147	0.9888	0.9343	0.1394	0.3990	1.2011
LB/CUFT	62.0537	61.7463	MISSING	6.6068	9.4481	79.0809	85.7883	6.1365	71.8918	90.1619
AVG MW	18.0153	18.0153	MISSING	44.0098	44.0098	79.9747	91.8225	44.0098	180.1577	75.0672

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EXTRACTION

STREAM SECTION

E-103P E-104 E-105 E-106 E-106A

E-106B E-106C E-106D E-107 E-108 (CONTINUED)

STREAM ID	E-103P	E-104	E-105	E-106	E-106A	E-106B	E-106C	E-106D	E-107	E-108
SUBSTREAM: NCPSD	STRUCTURE: NON CONVENTIONAL									
COMPONENTS: LB/HR										
ALGAE	5.0669+04	0.0	5.0669+04	0.0	0.0	2.5334+04	0.0	2.5334+04	0.0	0.0
COMPONENTS: MASS FRAC										
ALGAE	1.0000	0.0	1.0000	0.0	0.0	1.0000	0.0	1.0000	0.0	0.0
TOTAL FLOW:										
LB/HR	5.0669+04	0.0	5.0669+04	0.0	0.0	2.5334+04	0.0	2.5334+04	0.0	0.0
STATE VARIABLES:										
TEMP F	76.9100	MISSING	116.5100	MISSING	MISSING	112.9100	MISSING	121.9100	MISSING	MISSING
PRES PSIA	90.0000	45.0000	1.4504	870.2300	1450.5100	5801.5095	870.2300	870.2300	5076.3208	5076.3208
VFRAC	0.0	MISSING	0.0	MISSING	MISSING	0.0	MISSING	0.0	MISSING	MISSING
LFRAC	0.0	MISSING	0.0	MISSING	MISSING	0.0	MISSING	0.0	MISSING	MISSING
SFRAC	1.0000	MISSING	1.0000	MISSING	MISSING	1.0000	MISSING	1.0000	MISSING	MISSING
ENTHALPY:										
BTU/LB	-6480.9341	MISSING	-6462.3863	MISSING	MISSING	-6803.2150	MISSING	-6798.5605	MISSING	MISSING
BTU/HR	-3.2838+08	MISSING	-3.2744+08	MISSING	MISSING	-1.7235+08	MISSING	-1.7224+08	MISSING	MISSING
DENSITY:										
LB/CUFT	141.9785	MISSING	141.9785	MISSING	MISSING	141.9785	MISSING	141.9785	MISSING	MISSING
AVG MW	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

(*Figure C.2.4: Continue*)

COMPONENT ATTRIBUTES:										
ALGAE PROXANAL										
MOISTURE	81.7000	MISSING	81.7000	MISSING	MISSING	100.0000	MISSING	100.0000	MISSING	MISSING
FC	0.0	MISSING	0.0	MISSING	MISSING	0.0	MISSING	0.0	MISSING	MISSING
VM	0.0	MISSING	0.0	MISSING	MISSING	0.0	MISSING	0.0	MISSING	MISSING
ASH	18.4000	MISSING	18.4000	MISSING	MISSING	18.4000	MISSING	18.4000	MISSING	MISSING
ULTANAL										
ASH	0.0	MISSING	0.0	MISSING	MISSING	0.0	MISSING	0.0	MISSING	MISSING
CARBON	0.0	MISSING	0.0	MISSING	MISSING	0.0	MISSING	0.0	MISSING	MISSING
HYDROGEN	0.0	MISSING	0.0	MISSING	MISSING	0.0	MISSING	0.0	MISSING	MISSING
NITROGEN	0.0	MISSING	0.0	MISSING	MISSING	0.0	MISSING	0.0	MISSING	MISSING
CHLORINE	0.0	MISSING	0.0	MISSING	MISSING	0.0	MISSING	0.0	MISSING	MISSING
SULFUR	0.0	MISSING	0.0	MISSING	MISSING	0.0	MISSING	0.0	MISSING	MISSING
OXYGEN	0.0	MISSING	0.0	MISSING	MISSING	0.0	MISSING	0.0	MISSING	MISSING
SULFANAL										
PYRITIC	0.0	MISSING	0.0	MISSING	MISSING	0.0	MISSING	0.0	MISSING	MISSING
SULFATE	0.0	MISSING	0.0	MISSING	MISSING	0.0	MISSING	0.0	MISSING	MISSING
ORGANIC	0.0	MISSING	0.0	MISSING	MISSING	0.0	MISSING	0.0	MISSING	MISSING
SUBSTREAM ATTRIBUTES:										
PSD										
FRAC1	0.0	MISSING	0.0	MISSING	MISSING	0.0	0.0	0.0	0.0	0.0
FRAC2	0.0	MISSING	0.0	MISSING	MISSING	0.0	0.0	0.0	0.0	0.0
FRAC3	0.0	MISSING	0.0	MISSING	MISSING	0.0	0.0	0.0	0.0	0.0
FRAC4	0.0	MISSING	0.0	MISSING	MISSING	0.0	0.0	0.0	0.0	0.0
FRAC5	0.0	MISSING	0.0	MISSING	MISSING	0.0	0.0	0.0	0.0	0.0
FRAC6	0.0	MISSING	0.0	MISSING	MISSING	0.0	0.0	0.0	0.0	0.0
FRAC7	0.0	MISSING	0.0	MISSING	MISSING	0.0	0.0	0.0	0.0	0.0
FRAC8	0.0	MISSING	0.0	MISSING	MISSING	0.0	0.0	0.0	0.0	0.0
FRAC9	0.0	MISSING	0.0	MISSING	MISSING	0.0	0.0	0.0	0.0	0.0
FRAC10	0.0	MISSING	0.0	MISSING	MISSING	0.0	0.0	0.0	0.0	0.0

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EXTRACTION

STREAM SECTION

(*Figure C.2.4: Continue*)

STREAM SECTION

E-109 E-110 E-111 PRODUCT

STREAM ID	E-109	E-110	E-111	PRODUCT
FROM :	FOR-USE	Z-106	Z-106	Z-113
TO :	----	----	----	FOR-USE
CLASS:	MIXNCPSD	MIXNCPSD	MIXNCPSD	MIXNCPSD
TOTAL STREAM:				
LB/HR	3968.9373	2.5334+04	4000.0000	2.5334+04
BTU/HR	-1.2261+07	-1.7224+08	-1.5340+07	-7.4226+07
SUBSTREAM: MIXED				
PHASE:	LIQUID	MISSING	VAPOR	LIQUID
COMPONENTS: LBMOL/HR				
C6H12-01	0.0	0.0	0.0	37.0059
C2H5N-01	0.0	0.0	0.0	195.7990
C3H8O-01	43.0963	0.0	0.0	43.0963
CO2	0.0	0.0	90.8888	0.0
H2O	0.0	0.0	0.0	0.0
COMPONENTS: LB/HR				
C6H12-01	0.0	0.0	0.0	6666.8928
C2H5N-01	0.0	0.0	0.0	1.4698+04
C3H8O-01	3968.9373	0.0	0.0	3968.9373
CO2	0.0	0.0	4000.0000	0.0
H2O	0.0	0.0	0.0	0.0
COMPONENTS: MASS FRAC				
C6H12-01	0.0	MISSING	0.0	0.2632
C2H5N-01	0.0	MISSING	0.0	0.5802
C3H8O-01	1.0000	MISSING	0.0	0.1567
CO2	0.0	MISSING	1.0000	0.0
H2O	0.0	MISSING	0.0	0.0
TOTAL FLOW:				
LBMOL/HR	43.0963	0.0	90.8888	275.9011
LB/HR	3968.9373	0.0	4000.0000	2.5334+04
CUFT/HR	50.9022	0.0	651.6407	295.3073
STATE VARIABLES:				
TEMP F	130.9100	MISSING	121.7300	121.9100
PRES PSIA	5076.3208	870.2300	870.2300	870.2300
VFRAC	0.0	MISSING	1.0000	0.0
LFRAC	1.0000	MISSING	0.0	1.0000
SFRAC	0.0	MISSING	0.0	0.0

(*Figure C.2.4: Continue*)

```
ENTHALPY:
  BTU/LBMOL          -2.8451+05    MISSING -1.6877+05 -2.6903+05
  BTU/LB             -3089.3440    MISSING -3834.9249 -2929.9168
  BTU/HR             -1.2261+07    MISSING -1.5340+07 -7.4226+07
ENTROPY:
  BTU/LBMOL-R         -141.7530    MISSING    -6.6917  -136.7072
  BTU/LB-R              -1.5392    MISSING    -0.1521    -1.4888
DENSITY:
  LBMOL/CUFT             0.8466    MISSING     0.1395     0.9343
  LB/CUFT               77.9719    MISSING     6.1384    85.7883
AVG MW                  92.0947    MISSING    44.0098    91.8225

SUBSTREAM: NCPSD        STRUCTURE: NON CONVENTIONAL
COMPONENTS: LB/HR
  ALGAE                   0.0      2.5334+04    0.0        0.0
 ASPEN PLUS    PLAT: WIN32      VER: 22.0                  05/07/2012   PAGE 29
                                 EXTRACTION
                                STREAM SECTION

E-109 E-110 E-111 PRODUCT (CONTINUED)

STREAM ID               E-109      E-110      E-111      PRODUCT

COMPONENTS: MASS FRAC
  ALGAE                   0.0        1.0000     0.0        0.0
TOTAL FLOW:
  LB/HR                   0.0      2.5334+04    0.0        0.0
STATE VARIABLES:
  TEMP    F             MISSING    121.7300   MISSING    MISSING
  PRES    PSIA         5076.3208   870.2300   870.2300   870.2300
  VFRAC                 MISSING      0.0      MISSING    MISSING
  LFRAC                 MISSING      0.0      MISSING    MISSING
  SFRAC                 MISSING      1.0000   MISSING    MISSING
ENTHALPY:
  BTU/LB                MISSING -6798.6536    MISSING    MISSING
  BTU/HR                MISSING -1.7224+08    MISSING    MISSING
DENSITY:
  LB/CUFT               MISSING    141.9785   MISSING    MISSING
AVG MW                   1.0000     1.0000     1.0000     1.0000
```

(*Figure C.2.4: Continue*)

```
COMPONENT ATTRIBUTES:
ALGAE     PROXANAL
            MOISTURE     MISSING   100.0000    MISSING    MISSING
            FC           MISSING     0.0       MISSING    MISSING
            VM           MISSING     0.0       MISSING    MISSING
            ASH          MISSING    18.4000    MISSING    MISSING
          ULTANAL
            ASH          MISSING     0.0       MISSING    MISSING
            CARBON       MISSING     0.0       MISSING    MISSING
            HYDROGEN     MISSING     0.0       MISSING    MISSING
            NITROGEN     MISSING     0.0       MISSING    MISSING
            CHLORINE     MISSING     0.0       MISSING    MISSING
            SULFUR       MISSING     0.0       MISSING    MISSING
            OXYGEN       MISSING     0.0       MISSING    MISSING
          SULFANAL
            PYRITIC      MISSING     0.0       MISSING    MISSING
            SULFATE      MISSING     0.0       MISSING    MISSING
            ORGANIC      MISSING     0.0       MISSING    MISSING
SUBSTREAM ATTRIBUTES:
PSD
  FRAC1                    0.0       0.0       MISSING     0.0
  FRAC2                    0.0       0.0       MISSING     0.0
  FRAC3                    0.0       0.0       MISSING     0.0
  FRAC4                    0.0       0.0       MISSING     0.0
  FRAC5                    0.0       0.0       MISSING     0.0
  FRAC6                    0.0       0.0       MISSING     0.0
  FRAC7                    0.0       0.0       MISSING     0.0
  FRAC8                    0.0       0.0       MISSING     0.0
  FRAC9                    0.0       0.0       MISSING     0.0
  FRAC10                   0.0       0.0       MISSING     0.0
 ASPEN PLUS    PLAT: WIN32      VER: 22.0                  05/07/2012   PAGE 30
                                 EXTRACTION
                            PROBLEM STATUS SECTION

BLOCK STATUS
------------

****************************************************************************
*                                                                          *
* Calculations were completed normally                                     *
*                                                                          *
* All Unit Operation blocks were completed normally                        *
*                                                                          *
* All streams were flashed normally                                        *
*                                                                          *
****************************************************************************
```

(*Figure C.2.4: Continue*)

Section C.2.5 - APEN Plus simulator output for Case 5

```
ASPEN PLUS    PLAT: WIN32      VER: 22.0                       05/07/2012   PAGE 1
                                    EXTRACTION
                               RUN CONTROL SECTION

 RUN CONTROL INFORMATION
 -----------------------

 THIS COPY OF ASPEN PLUS LICENSED TO UNIV OF PUERTO RICO

 TYPE OF RUN: NEW

 INPUT FILE NAME: _0806lbp.inm

 OUTPUT PROBLEM DATA FILE NAME: _0806lbp
 LOCATED IN:


 PDF SIZE USED FOR INPUT TRANSLATION:
   NUMBER OF FILE RECORDS (PSIZE) =      0
   NUMBER OF IN-CORE RECORDS      =    256
 PSIZE NEEDED FOR SIMULATION    =    256

 CALLING PROGRAM NAME:           apmain
 LOCATED IN:                     C:\PROGRA~1\ASPENT~1\ASPENP~2.0\Engine\xeq

 SIMULATION REQUESTED FOR ENTIRE FLOWSHEET
```

Figure C.2.5. ASPEN print out for Case Scenario 5.

```
 FLOWSHEET CONNECTIVITY BY BLOCKS
 --------------------------------

   BLOCK        INLETS                         OUTLETS
   FOR-USE      PRODUCT                        E-111 E-110 E-112
   P-108        E-109C                         PRODUCT
   Z-105        E-109B                         E-109C E-109D
   Z-106        E-109D                         E-114 E-113
   Z-104        E-109A E-108                   E-109B
   Z-103        E-109                          E-109A
   Z-101        E-104P                         E-105P E-106P
   Z-102        E-106                          E-107 E-108
   P-101        E-104                          E-104P
   P-104        E-105P                         E-105
   P-105        E-106P                         E-106
   P-106        E-107                          E-107P

 COMPUTATIONAL SEQUENCE
 ----------------------

 SEQUENCE USED WAS:
    P-101 Z-101 P-104 P-105 Z-102 P-106 Z-103 Z-104 Z-105 Z-106 P-108
    FOR-USE

 OVERALL FLOWSHEET BALANCE
 -------------------------

                      ***  MASS AND ENERGY BALANCE  ***
                                     IN            OUT          RELATIVE DIFF.
    CONVENTIONAL COMPONENTS (LBMOL/HR)
       C6H12-01                  0.00000       37.0059        -1.00000
       C2H5N-01                  0.00000       195.799        -1.00000
       C3H8O-01                  0.00000       43.0963        -1.00000
       CO2                       90.8888       90.8888         0.00000
       H2O                       2812.54       2812.54         0.00000
    SUBTOTAL(LBMOL/HR)           2903.43       3179.33        -0.867797E-01
            (LB/HR    )          54668.7       80002.6        -0.316664
 ASPEN PLUS    PLAT: WIN32     VER: 22.0                  05/07/2012   PAGE 3
                                   EXTRACTION
                                FLOWSHEET SECTION
```

(*Figure C.2.5: Continue*)

```
OVERALL FLOWSHEET BALANCE (CONTINUED)
   NON-CONVENTIONAL COMPONENTS (LB/HR    )
      ALGAE                          50668.7         25334.3        0.500000
   SUBTOTAL(LB/HR    )               50668.7         25334.3        0.500000
   TOTAL BALANCE
      MASS(LB/HR    )                105337.         105337.        0.401107E-05
      ENTHALPY(BTU/HR  )           -0.689199E+09   -0.607125E+09   -0.119086
‡ ASPEN PLUS    PLAT: WIN32      VER: 22.0                       05/07/2012   PAGE 4
                                     EXTRACTION
                             PHYSICAL PROPERTIES SECTION

COMPONENTS
----------

 ID        TYPE  FORMULA         NAME OR ALIAS                      REPORT NAME
  C6H12-01 C      C6H12O6         C6H12O6                             C6H12-01
  C2H5N-01 C      C2H5NO2-D1      C2H5NO2-D1                          C2H5N-01
  C3H8O-01 C      C3H8O3          C3H8O3                              C3H8O-01
  CO2      C      CO2             CO2                                 CO2
  ALGAE    NC                     MISSING                             ALGAE
  H2O      C      H2O             H2O                                 H2O

 ID               ATTRIBUTE TYPES
  ALGAE            PROXANAL ULTANAL SULFANAL
‡ ASPEN PLUS    PLAT: WIN32      VER: 22.0                       05/07/2012   PAGE 5
                                     EXTRACTION
                                 U-O-S BLOCK SECTION

BLOCK:  FOR-USE  MODEL: SEP
---------------------------
  INLET STREAM:             PRODUCT
  OUTLET STREAMS:           E-111        E-110        E-112
  PROPERTY OPTION SET:      UNIQUAC   UNIQUAC / IDEAL GAS

                       ***  MASS AND ENERGY BALANCE  ***
                                      IN              OUT           RELATIVE DIFF.
      CONV. COMP.(LBMOL/HR)        275.901         275.901          0.00000
                  (LB/HR    )      25333.9         25333.9         -0.287202E-15
      NONCONV. COMP(LB/HR    )     0.00000         0.00000          0.00000
   TOTAL BALANCE
      MASS(LB/HR    )              25333.9         25333.9         -0.287202E-15
      ENTHALPY(BTU/HR  )         -0.742263E+08   -0.741089E+08    -0.158164E-02
```

(*Figure C.2.5: Continue*)

```
                           ***  INPUT DATA  ***

   INLET PRESSURE    PSIA                                          5,076.32

   FLASH SPECS FOR STREAM E-111
   TWO    PHASE  TP  FLASH
   SPECIFIED TEMPERATURE F                                        130.910
   SPECIFIED PRESSURE     PSIA                                  5,076.32
   MAXIMUM NO. ITERATIONS                                           30
   CONVERGENCE TOLERANCE                                             0.000100000

   FLASH SPECS FOR STREAM E-110
   TWO    PHASE  TP  FLASH
   SPECIFIED TEMPERATURE F                                        130.730
   SPECIFIED PRESSURE     PSIA                                  5,076.32
   MAXIMUM NO. ITERATIONS                                           30
   CONVERGENCE TOLERANCE                                             0.000100000

   FLASH SPECS FOR STREAM E-112
   TWO    PHASE  TP  FLASH
   SPECIFIED TEMPERATURE F                                        130.910
   SPECIFIED PRESSURE     PSIA                                  5,076.32
   MAXIMUM NO. ITERATIONS                                           30
   CONVERGENCE TOLERANCE                                             0.000100000
‡ ASPEN PLUS    PLAT: WIN32       VER: 22.0                     05/07/2012   PAGE 6
                                     EXTRACTION
                                 U-O-S BLOCK SECTION

 BLOCK:  FOR-USE  MODEL: SEP (CONTINUED)

   FRACTION OF FEED
     SUBSTREAM= MIXED
       STREAM= E-110      CPT= C6H12-01  FRACTION=           1.00000
                               C2H5N-01                       0.0
                               C3H8O-01                       0.0
       STREAM= E-112      CPT= C6H12-01  FRACTION=           0.0
                               C2H5N-01                       0.0
                               C3H8O-01                       1.00000
```

(*Figure C.2.5: Continue*)

```
                    ***  RESULTS  ***

 HEAT DUTY              BTU/HR                              0.11740E+06

 COMPONENT = C6H12-01
   STREAM     SUBSTREAM    SPLIT FRACTION
   E-110      MIXED                1.00000

 COMPONENT = C2H5N-01
   STREAM     SUBSTREAM    SPLIT FRACTION
   E-111      MIXED                1.00000

 COMPONENT = C3H8O-01
   STREAM     SUBSTREAM    SPLIT FRACTION
   E-112      MIXED                1.00000

 BLOCK:  P-101    MODEL: PUMP
 ----------------------------
   INLET STREAM:           E-104
   OUTLET STREAM:          E-104P
   PROPERTY OPTION SET:    UNIQUAC   UNIQUAC / IDEAL GAS

                  ***  MASS AND ENERGY BALANCE  ***
                                     IN            OUT        RELATIVE DIFF.
      CONV. COMP.(LBMOL/HR)      2812.54        2812.54         0.00000
                 (LB/HR   )      50668.7        50668.7         0.00000
      NONCONV. COMP(LB/HR   )    50668.7        50668.7         0.00000
    TOTAL BALANCE
      MASS(LB/HR   )             101337.        101337.         0.00000
      ENTHALPY(BTU/HR  )      -0.673825E+09  -0.673825E+09      0.00000
 ASPEN PLUS    PLAT: WIN32     VER: 22.0                    05/07/2012   PAGE 7
                                 EXTRACTION
                             U-O-S BLOCK SECTION

 BLOCK:  P-101    MODEL: PUMP (CONTINUED)

                      ***  INPUT DATA  ***
   OUTLET PRESSURE  PSIA                                  90.0000
   PUMP EFFICIENCY                                         0.60000
   DRIVER EFFICIENCY                                       1.00000

   FLASH SPECIFICATIONS:
   LIQUID PHASE CALCULATION
   NO FLASH PERFORMED
   MAXIMUM NUMBER OF ITERATIONS                            30
   TOLERANCE                                               0.000100000
```

(*Figure C.2.5: Continue*)

```
                    ***  RESULTS  ***
   VOLUMETRIC FLOW RATE  CUFT/HR                          816.529
   PRESSURE CHANGE  PSI                                     0.0
   NPSH AVAILABLE    FT-LBF/LB                            207.787
   FLUID POWER  HP                                          0.0
   BRAKE POWER  HP                                          0.0
   ELECTRICITY  KW                                          0.0
   PUMP EFFICIENCY USED                                     0.60000
   NET WORK REQUIRED  HP                                    0.0
   HEAD DEVELOPED FT-LBF/LB                                 0.0

 BLOCK:  P-104    MODEL: PUMP
 ----------------------------
   INLET STREAM:           E-105P
   OUTLET STREAM:          E-105
   PROPERTY OPTION SET:    UNIQUAC   UNIQUAC / IDEAL GAS

                  ***  MASS AND ENERGY BALANCE  ***
                                     IN            OUT        RELATIVE DIFF.
      CONV. COMP.(LBMOL/HR)      2534.38        2534.38         0.00000
                 (LB/HR   )      45657.5        45657.5         0.00000
      NONCONV. COMP(LB/HR   )    0.00000        0.00000         0.00000
    TOTAL BALANCE
      MASS(LB/HR   )             45657.5        45657.5         0.00000
      ENTHALPY(BTU/HR  )      -0.311280E+09  -0.311275E+09   -0.145801E-04
 ASPEN PLUS    PLAT: WIN32     VER: 22.0                    05/07/2012   PAGE 8
                                 EXTRACTION
                             U-O-S BLOCK SECTION

 BLOCK:  P-104    MODEL: PUMP (CONTINUED)

                      ***  INPUT DATA  ***
   OUTLET PRESSURE  PSIA                                  100.000
   PUMP EFFICIENCY                                          0.60000
   DRIVER EFFICIENCY                                        1.00000

   FLASH SPECIFICATIONS:
   LIQUID PHASE CALCULATION
   NO FLASH PERFORMED
   MAXIMUM NUMBER OF ITERATIONS                             30
   TOLERANCE                                                0.000100000
```

(*Figure C.2.5: Continue*)

```
                          ***  RESULTS  ***
   VOLUMETRIC FLOW RATE  CUFT/HR                              735.774
   PRESSURE CHANGE  PSI                                        20.0000
   NPSH AVAILABLE   FT-LBF/LB                                 184.582
   FLUID POWER  HP                                              1.07022
   BRAKE POWER  HP                                              1.78369
   ELECTRICITY  KW                                              1.33010
   PUMP EFFICIENCY USED                                         0.60000
   NET WORK REQUIRED  HP                                        1.78369
   HEAD DEVELOPED FT-LBF/LB                                    46.4114

 BLOCK:  P-105    MODEL: PUMP
 ----------------------------
  INLET STREAM:          E-106P
  OUTLET STREAM:         E-106
  PROPERTY OPTION SET:   UNIQUAC   UNIQUAC / IDEAL GAS

                      ***  MASS AND ENERGY BALANCE  ***
                                    IN              OUT        RELATIVE DIFF.
      CONV. COMP.(LBMOL/HR)      278.163         278.163         0.00000
                 (LB/HR    )     5011.19         5011.19         0.00000
      NONCONV. COMP(LB/HR    )   50668.7         50668.7         0.00000
   TOTAL BALANCE
      MASS(LB/HR    )            55679.9         55679.9         0.00000
      ENTHALPY(BTU/HR  )       -0.362545E+09   -0.362546E+09   0.865586E-06
 ASPEN PLUS    PLAT: WIN32      VER: 22.0                      05/07/2012   PAGE 9
                                    EXTRACTION
                                U-O-S BLOCK SECTION

 BLOCK:  P-105    MODEL: PUMP (CONTINUED)

                          ***  INPUT DATA  ***
   OUTLET PRESSURE  PSIA                                       45.0000
   PUMP EFFICIENCY                                              0.60000
   DRIVER EFFICIENCY                                            1.00000

   FLASH SPECIFICATIONS:
   LIQUID PHASE CALCULATION
   NO FLASH PERFORMED
   MAXIMUM NUMBER OF ITERATIONS                                 30
   TOLERANCE                                                    0.000100000
```

(*Figure C.2.5: Continue*)

```
                          ***  RESULTS  ***
   VOLUMETRIC FLOW RATE  CUFT/HR                               80.7557
   PRESSURE CHANGE  PSI                                       -35.0000
   NPSH AVAILABLE   FT-LBF/LB                                 184.582
   FLUID POWER  HP                                             -0.20556
   BRAKE POWER  HP                                             -0.12334
   ELECTRICITY  KW                                             -0.091972
   PUMP EFFICIENCY USED                                         0.60000
   NET WORK REQUIRED  HP                                       -0.12334
   HEAD DEVELOPED FT-LBF/LB                                   -81.2199

 BLOCK:  P-106    MODEL: PUMP
 ----------------------------
  INLET STREAM:          E-107
  OUTLET STREAM:         E-107P
  PROPERTY OPTION SET:   UNIQUAC   UNIQUAC / IDEAL GAS

                      ***  MASS AND ENERGY BALANCE  ***
                                    IN              OUT        RELATIVE DIFF.
      CONV. COMP.(LBMOL/HR)      278.163         278.163         0.00000
                 (LB/HR    )     5011.19         5011.19         0.00000
      NONCONV. COMP(LB/HR    )   0.00000         0.00000         0.00000
   TOTAL BALANCE
      MASS(LB/HR    )            5011.19         5011.19         0.00000
      ENTHALPY(BTU/HR  )       -0.341649E+08   -0.341638E+08  -0.328050E-04
 ASPEN PLUS    PLAT: WIN32      VER: 22.0                      05/07/2012   PAGE 10
                                    EXTRACTION
                                U-O-S BLOCK SECTION

 BLOCK:  P-106    MODEL: PUMP (CONTINUED)

                          ***  INPUT DATA  ***
   OUTLET PRESSURE  PSIA                                       90.0000
   PUMP EFFICIENCY                                              0.60000
   DRIVER EFFICIENCY                                            1.00000

   FLASH SPECIFICATIONS:
   LIQUID PHASE CALCULATION
   NO FLASH PERFORMED
   MAXIMUM NUMBER OF ITERATIONS                                 30
   TOLERANCE                                                    0.000100000
```

(*Figure C.2.5: Continue*)

```
                        ***  RESULTS  ***
 VOLUMETRIC FLOW RATE  CUFT/HR                           80.7552
 PRESSURE CHANGE  PSI                                    45.0000
 NPSH AVAILABLE    FT-LBF/LB                            103.361
 FLUID POWER  HP                                          0.26429
 BRAKE POWER  HP                                          0.44048
 ELECTRICITY  KW                                          0.32847
 PUMP EFFICIENCY USED                                     0.60000
 NET WORK REQUIRED  HP                                    0.44048
 HEAD DEVELOPED FT-LBF/LB                               104.425

BLOCK:  P-108    MODEL: PUMP
----------------------------
  INLET STREAM:           E-109C
  OUTLET STREAM:          PRODUCT
  PROPERTY OPTION SET:    UNIQUAC   UNIQUAC / IDEAL GAS

                    ***  MASS AND ENERGY BALANCE  ***
                                  IN            OUT       RELATIVE DIFF.
    CONV. COMP.(LBMOL/HR)      275.901        275.901        0.00000
               (LB/HR   )      25333.9        25333.9        0.00000
    NONCONV. COMP(LB/HR   )    0.00000        0.00000        0.00000
 TOTAL BALANCE
    MASS(LB/HR   )             25333.9        25333.9        0.00000
    ENTHALPY(BTU/HR  )      -0.742263E+08  -0.742263E+08   0.585573E-07
ASPEN PLUS   PLAT: WIN32     VER: 22.0                    05/07/2012  PAGE 11
                               EXTRACTION
                            U-O-S BLOCK SECTION

BLOCK:  P-108    MODEL: PUMP (CONTINUED)

                          ***  INPUT DATA  ***
 EQUIPMENT TYPE: PUMP
 OUTLET PRESSURE  PSIA                                  870.100
 PUMP EFFICIENCY                                          0.60000
 DRIVER EFFICIENCY                                        1.00000

 FLASH SPECIFICATIONS:
 LIQUID PHASE CALCULATION
 NO FLASH PERFORMED
 MAXIMUM NUMBER OF ITERATIONS                             30
 TOLERANCE                                                0.000100000
```

(*Figure C.2.5: Continue*)

```
                        ***  RESULTS  ***
 VOLUMETRIC FLOW RATE  CUFT/HR                          295.307
 PRESSURE CHANGE  PSI                                    -0.13000
 NPSH AVAILABLE    FT-LBF/LB                          1,460.72
 FLUID POWER  HP                                         -0.0027920
 BRAKE POWER  HP                                         -0.0016752
 ELECTRICITY  KW                                         -0.0012492
 PUMP EFFICIENCY USED                                     0.60000
 NET WORK REQUIRED  HP                                   -0.0016752
 HEAD DEVELOPED FT-LBF/LB                                -0.21821

BLOCK:  Z-101    MODEL: FILTER
------------------------------
  INLET STREAM:           E-104P
  OUTLET STREAMS:         E-105P      E-106P
  PROPERTY OPTION SET:    UNIQUAC   UNIQUAC / IDEAL GAS

                    ***  MASS AND ENERGY BALANCE  ***
                                  IN            OUT       RELATIVE DIFF.
    CONV. COMP.(LBMOL/HR)      2812.54        2812.54        0.00000
               (LB/HR   )      50668.7        50668.7        0.143599E-15
    NONCONV. COMP(LB/HR   )    50668.7        50668.7        0.00000
 TOTAL BALANCE
    MASS(LB/HR   )             101337.        101337.        0.143599E-15
    ENTHALPY(BTU/HR  )      -0.673825E+09  -0.673825E+09   0.569701E-09
ASPEN PLUS   PLAT: WIN32     VER: 22.0                    05/07/2012  PAGE 12
                               EXTRACTION
                            U-O-S BLOCK SECTION

BLOCK:  Z-101    MODEL: FILTER (CONTINUED)

                          ***  INPUT DATA  ***

  MAXIMUM PRESSURE DROP  PSI                             10.0000
  FILTER WIDTH TO DIAMETER RATIO                          2.00000
  ANGULAR VELOCITY  RPM                                  12.0000
  CAKE FORMATION ANGLE  DEG                             120.006
  MASS FRACTION OF SOLIDS IN CAKE                         0.91000
  AVERAGE POROSITY                                        0.0100000
  FILTRATION RESISTANCE  FT/LB                            MISSING
  UNIT PRESSURE CAKE RESISTANCE  FT/LB              2,976,330.
  CAKE COMPRESSIBILITY                                    0.0
  AVERAGE PARTICLE DIAMETER  FT                           0.328084-04
  PARTICLE SPHERICITY                                     0.75000
  FILTER-MEDIUM RESISTANCE  1/FT                              MISSING
```

(*Figure C.2.5: Continue*)

```
 FILTER-MEDIUM RESISTANCE  1/FT                               MISSING

                        ***  RESULTS  ***

 FILTER DIAMETER  FT                                       0.38314
 FILTER WIDTH  FT                                          0.76629
 AVERAGE PARTICLE DIAMETER  FT                             MISSING
 AVERAGE SOLID DENSITY  LB/CUFT                          141.979
 TOTAL SOLIDS MASS FLOW RATE  LB/HR                   50,668.7
 SURFACE TENSION  DYNE/CM                                 72.8236
 VOLUME FLOW RATE OF FILTRATE  CUFT/HR                   735.774
 MASS FRACTION OF SOLIDS IN CAKE                           0.91000
 CAKE THICKNESS  FT                                        0.54281
 FILTRATION RESISTANCE  FT/LB                       2,976,330.
 AVERAGE POROSITY                                          0.0100000
 CAKE COMPRESSIBILITY                                      0.0

BLOCK:  Z-102    MODEL: SEP
---------------------------
 INLET STREAM:          E-106
 OUTLET STREAMS:        E-107       E-108
 PROPERTY OPTION SET:   UNIQUAC   UNIQUAC / IDEAL GAS

                   ***  MASS AND ENERGY BALANCE  ***
                                 IN              OUT         RELATIVE DIFF.
    CONV. COMP.(LBMOL/HR)     278.163         278.163          0.00000
               (LB/HR   )     5011.19         5011.19          0.00000
    NONCONV. COMP(LB/HR   )   50668.7         50668.7          0.00000
  TOTAL BALANCE
    MASS(LB/HR    )           55679.9         55679.9          0.00000
    ENTHALPY(BTU/HR  )     -0.362546E+09   -0.362546E+09   -0.478158E-10

                       ***  INPUT DATA  ***

 INLET PRESSURE   PSIA                                        45.0000
ASPEN PLUS   PLAT: WIN32     VER: 22.0                     05/07/2012   PAGE 13
                                EXTRACTION
                            U-O-S BLOCK SECTION
```

(*Figure C.2.5: Continue***)**

```
BLOCK:  Z-102    MODEL: SEP (CONTINUED)

 FLASH SPECS FOR STREAM E-107
 TWO    PHASE  TP  FLASH
 PRESSURE DROP          PSI                                     0.0
 MAXIMUM NO. ITERATIONS                                        30
 CONVERGENCE TOLERANCE                                          0.000100000

 FLASH SPECS FOR STREAM E-108
 TWO    PHASE  TP  FLASH
 PRESSURE DROP          PSI                                     0.0
 MAXIMUM NO. ITERATIONS                                        30
 CONVERGENCE TOLERANCE                                          0.000100000

 FRACTION OF FEED
   SUBSTREAM= MIXED
     STREAM= E-107       CPT= H2O        FRACTION=          1.00000
   SUBSTREAM= NCPSD
     STREAM= E-107       CPT= ALGAE      FRACTION=          0.0

                       ***  RESULTS  ***

 HEAT DUTY              BTU/HR                                  0.17335E-01

 COMPONENT = H2O
   STREAM     SUBSTREAM     SPLIT FRACTION
   E-107      MIXED                1.00000

 COMPONENT = ALGAE
   STREAM     SUBSTREAM     SPLIT FRACTION
   E-108      NCPSD                1.00000

BLOCK:  Z-103    MODEL: COMPR
-----------------------------
 INLET STREAM:          E-109
 OUTLET STREAM:         E-109A
 PROPERTY OPTION SET:   UNIQUAC   UNIQUAC / IDEAL GAS
ASPEN PLUS   PLAT: WIN32     VER: 22.0                     05/07/2012   PAGE 14
                                EXTRACTION
                            U-O-S BLOCK SECTION
```

(*Figure C.2.5: Continue***)**

```
BLOCK:  Z-103     MODEL: COMPR (CONTINUED)

                     ***  MASS AND ENERGY BALANCE  ***
                                   IN              OUT          RELATIVE DIFF.
      CONV. COMP.(LBMOL/HR)     90.8888         90.8888           0.00000
                 (LB/HR   )     4000.00         4000.00           0.00000
      NONCONV. COMP(LB/HR   )   0.00000         0.00000           0.00000
   TOTAL BALANCE
      MASS(LB/HR   )            4000.00         4000.00           0.00000
      ENTHALPY(BTU/HR  )      -0.153736E+08   -0.152988E+08     -0.486700E-02

                          ***  INPUT DATA  ***

  POLYTROPIC POSITIVE DISPLACEMENT COMPRESSOR          USING PIECEWISE INTEGRATION
   OUTLET PRESSURE  PSIA                                1,450.37
   POLYTROPIC EFFICIENCY                                    0.72000
   MECHANICAL EFFICIENCY                                    0.60000
   CLEARANCE FRACTION                                       0.50000

                          ***  RESULTS  ***

   INDICATED  HORSEPOWER REQUIREMENT  HP                   29.4067
   BRAKE      HORSEPOWER REQUIREMENT  HP                   49.0112
   NET WORK REQUIRED                  HP                   49.0112
   POWER LOSSES                       HP                   19.6045
   ISENTROPIC HORSEPOWER REQUIREMENT  HP                   20.7118
   CALCULATED OUTLET TEMP  F                              169.919
   ISENTROPIC TEMPERATURE  F                              144.035
   EFFICIENCY (POLYTR/ISENTR) USED                          0.72000
   VOLUMETRIC EFFICIENCY                                    0.76835
   DISPLACEMENT             CUFT/HR                       787.982
   OUTLET VAPOR FRACTION                                    1.00000
   HEAD DEVELOPED,        FT-LBF/LB                    10,480.6
   MECHANICAL EFFICIENCY USED                               0.60000
   INLET HEAT CAPACITY RATIO                                1.28678
   INLET VOLUMETRIC FLOW RATE , CUFT/HR                   605.443
   OUTLET VOLUMETRIC FLOW RATE, CUFT/HR                   423.395
   INLET  COMPRESSIBILITY FACTOR                            1.00000
   OUTLET COMPRESSIBILITY FACTOR                            1.00000
   AV. ISENT. VOL. EXPONENT                                 1.27821
   AV. ISENT. TEMP EXPONENT                                 1.27821
   AV. ACTUAL VOL. EXPONENT                                 1.42824
   AV. ACTUAL TEMP EXPONENT                                 1.42824
‡ ASPEN PLUS    PLAT: WIN32     VER: 22.0                  05/07/2012  PAGE 15
                                  EXTRACTION
                              U-O-S BLOCK SECTION
```

(*Figure C.2.5: Continue***)**

```
BLOCK:  Z-104     MODEL: RSTOIC
------------------------------
   INLET STREAMS:          E-109A      E-108
   OUTLET STREAM:          E-109B
   PROPERTY OPTION SET:    UNIQUAC    UNIQUAC / IDEAL GAS

                     ***  MASS AND ENERGY BALANCE  ***
                                IN           OUT        GENERATION    RELATIVE DIFF.
CONV. COMP.(LBMOL/HR)       90.8888       366.790       275.901     -0.154975E-15
            (LB/HR   )      4000.00       29333.9                   -0.863639
NONCONV COMP(LB/HR   )      50668.7       25334.3                    0.500000
   TOTAL BALANCE
      MASS(LB/HR   )        54668.7       54668.3                    0.772865E-05
      ENTHALPY(BTU/HR  )-0.343679E+09 -0.262046E+09                 -0.237529

                          ***  INPUT DATA  ***
   STOICHIOMETRY MATRIX:

    REACTION #   1:
     SUBSTREAM MIXED    :
     C6H12-01  0.146E-02C2H5N-01  0.773E-02C3H8O-01  0.170E-02
     SUBSTREAM NCPSD    :
     ALGAE     -1.00


   REACTION CONVERSION SPECS: NUMBER=     1
     REACTION #   1:
     SUBSTREAM:NCPSD     KEY COMP:ALGAE     CONV FRAC: 0.5000



   TWO    PHASE  TP  FLASH
   SPECIFIED TEMPERATURE F                                112.910
   SPECIFIED PRESSURE     PSIA                             40.0000
   MAXIMUM NO. ITERATIONS                                  30
   CONVERGENCE TOLERANCE                                    0.000100000
   SIMULTANEOUS REACTIONS
   GENERATE COMBUSTION REACTIONS FOR FEED SPECIES         NO
‡ ASPEN PLUS    PLAT: WIN32     VER: 22.0                05/07/2012   PAGE 16
                                  EXTRACTION
                              U-O-S BLOCK SECTION
```

(*Figure C.2.5: Continue***)**

```
BLOCK:  Z-104     MODEL: RSTOIC (CONTINUED)

                           ***  RESULTS  ***
  OUTLET TEMPERATURE     F                                         112.91
  OUTLET PRESSURE        PSIA                                      40.000
  HEAT DUTY              BTU/HR                                   0.81631E+08
  VAPOR FRACTION                                                  0.21976


  REACTION EXTENTS:

     REACTION            REACTION
     NUMBER              EXTENT
                         LBMOL/HR
     1                    25334.

  V-L PHASE EQUILIBRIUM :

     COMP                F(I)          X(I)           Y(I)           K(I)
     C6H12-01           0.10089       0.12931        0.14809E-12    0.11452E-11
     C2H5N-01           0.53382       0.68417        0.75421E-09    0.11024E-08
     C3H8O-01           0.11750       0.15059        0.11542E-06    0.76645E-06
     CO2                0.24780       0.35929E-01     1.0000         27.833

BLOCK:  Z-105     MODEL: SEP
---------------------------
  INLET STREAM:            E-109B
  OUTLET STREAMS:          E-109C      E-109D
  PROPERTY OPTION SET:     UNIQUAC    UNIQUAC / IDEAL GAS

                      ***  MASS AND ENERGY BALANCE  ***
                                      IN              OUT           RELATIVE DIFF.
      CONV. COMP.(LBMOL/HR)        366.790          366.790          0.00000
                 (LB/HR    )       29333.9          29333.9          0.248039E-15
      NONCONV. COMP(LB/HR    )     25334.3          25334.3          0.00000
   TOTAL BALANCE
      MASS(LB/HR    )              54668.3          54668.3          0.266186E-15
      ENTHALPY(BTU/HR   )        -0.262046E+09    -0.261805E+09    -0.916463E-03
```

(*Figure C.2.5: Continue***)**

```
                          ***  INPUT DATA  ***

  INLET PRESSURE    PSIA                                          5,801.51
ASPEN PLUS    PLAT: WIN32      VER: 22.0                          05/07/2012   PAGE 17
                                   EXTRACTION
                               U-O-S BLOCK SECTION

BLOCK:  Z-105     MODEL: SEP (CONTINUED)

  FLASH SPECS FOR STREAM E-109C
  TWO     PHASE   TP  FLASH
  SPECIFIED TEMPERATURE F                                         121.910
  SPECIFIED PRESSURE     PSIA                                     870.230
  MAXIMUM NO. ITERATIONS                                           30
  CONVERGENCE TOLERANCE                                             0.000100000

  FLASH SPECS FOR STREAM E-109D
  TWO     PHASE   TP  FLASH
  SPECIFIED TEMPERATURE F                                         121.730
  SPECIFIED PRESSURE     PSIA                                     870.230
  MAXIMUM NO. ITERATIONS                                           30
  CONVERGENCE TOLERANCE                                             0.000100000

  FRACTION OF FEED
    SUBSTREAM= MIXED
      STREAM= E-109D      CPT= C6H12-01   FRACTION=               0.0
                               C2H5N-01                           0.0
                               C3H8O-01                           0.0
                               CO2                                1.00000
```

(*Figure C.2.5: Continue***)**

```
                         ***   RESULTS   ***

 HEAT DUTY              BTU/HR                             0.24016E+06

 COMPONENT = C6H12-01
   STREAM     SUBSTREAM     SPLIT FRACTION
   E-109C     MIXED                  1.00000

 COMPONENT = C2H5N-01
   STREAM     SUBSTREAM     SPLIT FRACTION
   E-109C     MIXED                  1.00000

 COMPONENT = C3H8O-01
   STREAM     SUBSTREAM     SPLIT FRACTION
   E-109C     MIXED                  1.00000

 COMPONENT = CO2
   STREAM     SUBSTREAM     SPLIT FRACTION
   E-109D     MIXED                  1.00000

 COMPONENT = ALGAE
   STREAM     SUBSTREAM     SPLIT FRACTION
   E-109D     NCPSD                  1.00000
 ASPEN PLUS    PLAT: WIN32      VER: 22.0                  05/07/2012   PAGE 18
                                    EXTRACTION
                                U-O-S BLOCK SECTION

BLOCK:  Z-106     MODEL: FLASH2
------------------------------
  INLET STREAM:           E-109D
  OUTLET VAPOR STREAM:    E-114
  OUTLET LIQUID STREAM:   E-113
  PROPERTY OPTION SET:    UNIQUAC    UNIQUAC / IDEAL GAS

                    ***   MASS AND ENERGY BALANCE   ***
                                  IN             OUT          RELATIVE DIFF.
     CONV. COMP.(LBMOL/HR)     90.8888         90.8888         0.00000
                (LB/HR    )    4000.00         4000.00         0.00000
     NONCONV. COMP(LB/HR    )  25334.3         25334.3         0.00000
   TOTAL BALANCE
     MASS(LB/HR    )           29334.3         29334.3         0.00000
     ENTHALPY(BTU/HR   )      -0.187579E+09   -0.187577E+09   -0.133751E-04
```

(*Figure C.2.5: Continue*)

```
       ENTHALPY(BTU/HR   )      -0.187579E+09   -0.187577E+09   -0.133751E-04

                         ***   INPUT DATA   ***
   TWO    PHASE   TP  FLASH
   SPECIFIED TEMPERATURE F                                     121.910
   SPECIFIED PRESSURE     PSIA                                 870.000
   MAXIMUM NO. ITERATIONS                                       30
   CONVERGENCE TOLERANCE                                        0.000100000

                          ***   RESULTS   ***
   OUTLET TEMPERATURE     F                                       121.91
   OUTLET PRESSURE        PSIA                                    870.00
   HEAT DUTY              BTU/HR                                  2508.9
   VAPOR FRACTION                                                 1.0000


   V-L PHASE EQUILIBRIUM :

     COMP               F(I)           X(I)            Y(I)           K(I)
     CO2                1.0000         1.0000          1.0000         1.8271
 ASPEN PLUS    PLAT: WIN32      VER: 22.0                  05/07/2012   PAGE 19
                                    EXTRACTION
                                  STREAM SECTION

 SUBSTREAM ATTR PSD TYPE: PSD
 ---------------------------

 INTERVAL      LOWER LIMIT           UPPER LIMIT
     1             0.0      FT        6.5617-05   FT
     2         6.5617-05    FT        1.3123-04   FT
     3         1.3123-04    FT        1.9685-04   FT
     4         1.9685-04    FT        2.6247-04   FT
     5         2.6247-04    FT        3.2808-04   FT
     6         3.2808-04    FT        3.9370-04   FT
     7         3.9370-04    FT        4.5932-04   FT
     8         4.5932-04    FT        5.2493-04   FT
     9         5.2493-04    FT        5.9055-04   FT
    10         5.9055-04    FT        6.5617-04   FT

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                                    EXTRACTION
                                  STREAM SECTION

 E-104 E-104P E-105 E-105P E-106
 ------------------------------
```

(*Figure C.2.5: Continue*)

E-106P E-107 E-107P E-108 E-109

STREAM ID	E-104	E-104P	E-105	E-105P	E-106	E-106P	E-107	E-107P	E-108	E-109
FROM :	----	P-101	P-104	Z-101	P-105	Z-101	Z-102	P-106	Z-102	----
TO :	P-101	Z-101	----	P-104	Z-102	P-105	P-106	----	Z-104	Z-103
CLASS:	MIXNCPSD	MIXNCPSD	MIXNCPSD	MIXNCPSD	MIXNCPSD	MIXNCPSD	MIXNCPSD	MIXNCPSD	MIXNCPSD	MIXNCPSD
TOTAL STREAM:										
LB/HR	1.0134+05	1.0134+05	4.5657+04	4.5657+04	5.5680+04	5.5680+04	5011.1889	5011.1889	5.0669+04	4000.0000
BTU/HR	-6.7383+08	-6.7383+08	-3.1128+08	-3.1128+08	-3.6255+08	-3.6255+08	-3.4165+07	-3.4164+07	-3.2838+08	-1.5374+07
SUBSTREAM: MIXED										
PHASE:	LIQUID	LIQUID	LIQUID	LIQUID	LIQUID	LIQUID	LIQUID	LIQUID	MISSING	VAPOR
COMPONENTS: LBMOL/HR										
C6H12-01	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C2H5N-01	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C3H8O-01	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CO2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	90.8888
H2O	2812.5396	2812.5396	2534.3763	2534.3763	278.1633	278.1633	278.1633	278.1633	0.0	0.0
COMPONENTS: LB/HR										
C6H12-01	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C2H5N-01	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C3H8O-01	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CO2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4000.0000
H2O	5.0669+04	5.0669+04	4.5657+04	4.5657+04	5011.1889	5011.1889	5011.1889	5011.1889	0.0	0.0
COMPONENTS: MASS FRAC										
C6H12-01	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	MISSING	0.0
C2H5N-01	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	MISSING	0.0
C3H8O-01	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	MISSING	0.0
CO2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	MISSING	1.0000
H2O	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	MISSING	0.0
TOTAL FLOW:										
LBMOL/HR	2812.5396	2812.5396	2534.3763	2534.3763	278.1633	278.1633	278.1633	278.1633	0.0	90.8888
LB/HR	5.0669+04	5.0669+04	4.5657+04	4.5657+04	5011.1889	5011.1889	5011.1889	5011.1889	0.0	4000.0000
CUFT/HR	816.5294	816.5294	735.8166	735.7738	80.7552	80.7557	80.7552	80.7657	0.0	605.4433
STATE VARIABLES:										
TEMP F	76.9100	76.9100	77.0179	76.9100	76.8989	76.9100	76.8989	77.1417	MISSING	80.5100
PRES PSIA	90.0000	90.0000	100.0000	80.0000	45.0000	80.0000	45.0000	90.0000	45.0000	870.2264
VFRAC	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	MISSING	1.0000
LFRAC	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	MISSING	0.0
SFRAC	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	MISSING	0.0

(*Figure C.2.5: Continue*)

ENTHALPY:										
BTU/LBMOL	-1.2282+05	-1.2282+05	-1.2282+05	-1.2282+05	-1.2282+05	-1.2282+05	-1.2282+05	-1.2282+05	MISSING	-1.6915+05
BTU/LB	-6817.7136	-6817.7136	-6817.6142	-6817.7136	-6817.7238	-6817.7136	-6817.7238	-6817.5002	MISSING	-3843.4072
BTU/HR	-3.4544+08	-3.4544+08	-3.1128+08	-3.1128+08	-3.4165+07	-3.4165+07	-3.4165+07	-3.4164+07	MISSING	-1.5374+07
ENTROPY:										
BTU/LBMOL-R	-38.8595	-38.8595	-38.8562	-38.8595	-38.8599	-38.8595	-38.8599	-38.8524	MISSING	-7.3576
BTU/LB-R	-2.1570	-2.1570	-2.1568	-2.1570	-2.1571	-2.1570	-2.1571	-2.1566	MISSING	-0.1672
DENSITY:										
LBMOL/CUFT	3.4445	3.4445	3.4443	3.4445	3.4445	3.4445	3.4445	3.4441	MISSING	0.1501
LB/CUFT	62.0537	62.0537	62.0501	62.0537	62.0541	62.0537	62.0541	62.0460	MISSING	6.6067
AVG MW	18.0153	18.0153	18.0153	18.0153	18.0153	18.0153	18.0153	18.0153	MISSING	44.0098

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EXTRACTION
STREAM SECTION

E-104 E-104P E-105 E-105P E-106

E-106P E-107 E-107P E-108 E-109 (CONTINUED)

STREAM ID	E-104	E-104P	E-105	E-105P	E-106	E-106P	E-107	E-107P	E-108	E-109
SUBSTREAM: NCPSD	STRUCTURE: NON CONVENTIONAL									
COMPONENTS: LB/HR										
ALGAE	5.0669+04	5.0669+04	0.0	0.0	5.0669+04	5.0669+04	0.0	0.0	5.0669+04	0.0
COMPONENTS: MASS FRAC										
ALGAE	1.0000	1.0000	0.0	0.0	1.0000	1.0000	0.0	0.0	1.0000	0.0
TOTAL FLOW:										
LB/HR	5.0669+04	5.0669+04	0.0	0.0	5.0669+04	5.0669+04	0.0	0.0	5.0669+04	0.0
STATE VARIABLES:										
TEMP F	76.9100	76.9100	MISSING	MISSING	76.8989	76.9100	MISSING	MISSING	76.8989	MISSING
PRES PSIA	90.0000	90.0000	100.0000	80.0000	45.0000	80.0000	45.0000	90.0000	45.0000	870.2264
VFRAC	0.0	0.0	MISSING	MISSING	0.0	0.0	MISSING	MISSING	0.0	MISSING
LFRAC	0.0	0.0	MISSING	MISSING	0.0	0.0	MISSING	MISSING	0.0	MISSING
SFRAC	1.0000	1.0000	MISSING	MISSING	1.0000	1.0000	MISSING	MISSING	1.0000	MISSING
ENTHALPY:										
BTU/LB	-6480.9341	-6480.9341	MISSING	MISSING	-6480.9393	-6480.9341	MISSING	MISSING	-6480.9393	MISSING
BTU/HR	-3.2838+08	-3.2838+08	MISSING	MISSING	-3.2838+08	-3.2838+08	MISSING	MISSING	-3.2838+08	MISSING
DENSITY:										
LB/CUFT	141.9785	141.9785	MISSING	MISSING	141.9785	141.9785	MISSING	MISSING	141.9785	MISSING
AVG MW	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

(*Figure C.2.5: Continue*)

```
  LB/CUFT           141.9785  141.9785   MISSING   MISSING  141.9785  141.9785   MISSING   MISSING  141.9785   MISSING
AVG MW                1.0000    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000
COMPONENT ATTRIBUTES:
ALGAE    PROXANAL
           MOISTURE  81.7000   81.7000   MISSING   MISSING   81.7000   81.7000   MISSING   MISSING   81.7000   MISSING
           FC         0.0       0.0      MISSING   MISSING    0.0       0.0      MISSING   MISSING    0.0      MISSING
           VM         0.0       0.0      MISSING   MISSING    0.0       0.0      MISSING   MISSING    0.0      MISSING
           ASH       18.4000   18.4000   MISSING   MISSING   18.4000   18.4000   MISSING   MISSING   18.4000   MISSING
         ULTANAL
           ASH        0.0       0.0      MISSING   MISSING    0.0       0.0      MISSING   MISSING    0.0      MISSING
           CARBON     0.0       0.0      MISSING   MISSING    0.0       0.0      MISSING   MISSING    0.0      MISSING
           HYDROGEN   0.0       0.0      MISSING   MISSING    0.0       0.0      MISSING   MISSING    0.0      MISSING
           NITROGEN   0.0       0.0      MISSING   MISSING    0.0       0.0      MISSING   MISSING    0.0      MISSING
           CHLORINE   0.0       0.0      MISSING   MISSING    0.0       0.0      MISSING   MISSING    0.0      MISSING
           SULFUR     0.0       0.0      MISSING   MISSING    0.0       0.0      MISSING   MISSING    0.0      MISSING
           OXYGEN     0.0       0.0      MISSING   MISSING    0.0       0.0      MISSING   MISSING    0.0      MISSING
         SULFANAL
           PYRITIC    0.0       0.0      MISSING   MISSING    0.0       0.0      MISSING   MISSING    0.0      MISSING
           SULFATE    0.0       0.0      MISSING   MISSING    0.0       0.0      MISSING   MISSING    0.0      MISSING
           ORGANIC    0.0       0.0      MISSING   MISSING    0.0       0.0      MISSING   MISSING    0.0      MISSING
SUBSTREAM ATTRIBUTES:
PSD
  FRAC1               0.0       0.0      MISSING   MISSING    0.0       0.0       0.0       0.0       0.0      MISSING
  FRAC2               0.0       0.0      MISSING   MISSING    0.0       0.0       0.0       0.0       0.0      MISSING
  FRAC3               0.0       0.0      MISSING   MISSING    0.0       0.0       0.0       0.0       0.0      MISSING
  FRAC4               0.0       0.0      MISSING   MISSING    0.0       0.0       0.0       0.0       0.0      MISSING
  FRAC5               0.0       0.0      MISSING   MISSING    0.0       0.0       0.0       0.0       0.0      MISSING
  FRAC6               0.0       0.0      MISSING   MISSING    0.0       0.0       0.0       0.0       0.0      MISSING
  FRAC7               0.0       0.0      MISSING   MISSING    0.0       0.0       0.0       0.0       0.0      MISSING
  FRAC8               0.0       0.0      MISSING   MISSING    0.0       0.0       0.0       0.0       0.0      MISSING
  FRAC9               0.0       0.0      MISSING   MISSING    0.0       0.0       0.0       0.0       0.0      MISSING
  FRAC10              0.0       0.0      MISSING   MISSING    0.0       0.0       0.0       0.0       0.0      MISSING
♀ ASPEN PLUS   PLAT: WIN32     VER: 22.0                 05/07/2012  PAGE 22
                                  EXTRACTION
                                STREAM SECTION

E-109A E-109B E-109C E-109D E-110
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```

(*Figure C.2.5: Continue*)

```
E-111 E-112 E-113 E-114 PRODUCT
-------------------------------

STREAM ID            E-109A     E-109B     E-109C     E-109D     E-110      E-111      E-112      E-113      E-114      PRODUCT
FROM :               Z-103      Z-104      Z-105      Z-105      FOR-USE    FOR-USE    FOR-USE    Z-106      Z-106      P-108
TO   :               Z-104      Z-105      P-108      Z-106      ----       ----       ----       ----       ----       FOR-USE
CLASS:               MIXNCPSD   MIXNCPSD   MIXNCPSD   MIXNCPSD   MIXNCPSD   MIXNCPSD   MIXNCPSD   MIXNCPSD   MIXNCPSD   MIXNCPSD
TOTAL STREAM:
  LB/HR             4000.0000  5.4668+04  2.5334+04  2.9334+04  6666.8928  1.4698+04  3968.9373  2.5334+04  4000.0000  2.5334+04
  BTU/HR           -1.5299+07 -2.6205+08 -7.4226+07 -1.8758+08 -1.9832+07 -4.2015+07 -1.2261+07 -1.7224+08 -1.5340+07 -7.4226+07
SUBSTREAM: MIXED
PHASE:               VAPOR      MIXED      LIQUID     VAPOR      LIQUID     LIQUID     LIQUID     MISSING    VAPOR      LIQUID
COMPONENTS: LBMOL/HR
  C6H12-01            0.0       37.0059    37.0059     0.0       37.0059     0.0        0.0        0.0        0.0       37.0059
  C2H5N-01            0.0      195.7990   195.7990     0.0        0.0      195.7990     0.0        0.0        0.0      195.7990
  C3H8O-01            0.0       43.0963    43.0963     0.0        0.0        0.0       43.0963     0.0        0.0       43.0963
  CO2                90.8888    90.8888     0.0       90.8888     0.0        0.0        0.0        0.0       90.8888     0.0
  H2O                 0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.0
COMPONENTS: LB/HR
  C6H12-01            0.0      6666.8928  6666.8928    0.0      6666.8928    0.0        0.0        0.0        0.0      6666.8928
  C2H5N-01            0.0      1.4698+04  1.4698+04    0.0        0.0      1.4698+04    0.0        0.0        0.0      1.4698+04
  C3H8O-01            0.0      3968.9373  3968.9373    0.0        0.0        0.0      3968.9373    0.0        0.0      3968.9373
  CO2              4000.0000   4000.0000    0.0      4000.0000    0.0        0.0        0.0        0.0      4000.0000    0.0
  H2O                 0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.0
COMPONENTS: MASS FRAC
  C6H12-01            0.0        0.2273     0.2632     0.0        1.0000     0.0        0.0      MISSING      0.0        0.2632
  C2H5N-01            0.0        0.5011     0.5802     0.0        0.0        1.0000     0.0      MISSING      0.0        0.5802
  C3H8O-01            0.0        0.1353     0.1567     0.0        0.0        0.0        1.0000   MISSING      0.0        0.1567
  CO2                 1.0000     0.1364     0.0        1.0000     0.0        0.0        0.0      MISSING      1.0000     0.0
  H2O                 0.0        0.0        0.0        0.0        0.0        0.0        0.0      MISSING      0.0        0.0
TOTAL FLOW:
  LBMOL/HR           90.8888   366.7900   275.9011    90.8888    37.0059   195.7990    43.0963     0.0       90.8888   275.9011
  LB/HR            4000.0000  2.9334+04  2.5334+04  4000.0000  6666.8928  1.4698+04  3968.9373    0.0      4000.0000  2.5334+04
  CUFT/HR           423.3946  1.2686+04   295.3073   651.6407    92.7350   163.0189    50.9022     0.0      652.0148   295.3072
STATE VARIABLES:
  TEMP   F          169.9187   112.9100   121.9100   121.7300   130.7300   130.9100   130.9100   MISSING   121.9100   121.9097
  PRES   PSIA      1450.3700    40.0000   870.2300   870.2300  5076.3208  5076.3208  5076.3208   870.0000  870.0000   870.1000
  VFRAC               1.0000     0.2198     0.0        1.0000     0.0        0.0        0.0      MISSING      1.0000     0.0
  LFRAC               0.0        0.7802     1.0000     0.0        1.0000     1.0000     1.0000   MISSING      0.0        1.0000
  SFRAC               0.0        0.0        0.0        0.0        0.0        0.0        0.0      MISSING      0.0        0.0
```

(*Figure C.2.5: Continue*)

```
ENTHALPY:
  BTU/LBMOL         -1.6832+05 -2.4453+05 -2.6903+05 -1.6877+05 -5.3592+05 -2.1458+05 -2.8451+05    MISSING -1.6877+05 -2.6903+05
  BTU/LB            -3824.7014 -3057.5720 -2929.9168 -3834.9249 -2974.7235 -2858.5557 -3089.3440    MISSING -3834.8873 -2929.9170
  BTU/HR            -1.5299+07 -8.9691+07 -7.4226+07 -1.5340+07 -1.9832+07 -4.2015+07 -1.2261+07    MISSING -1.5340+07 -7.4226+07
ENTROPY:
  BTU/LBMOL-R          -6.9628  -103.6020  -136.7072    -6.6917  -252.7076  -114.7810  -141.7530    MISSING    -6.6884  -136.7073
  BTU/LB-R             -0.1582    -1.2954    -1.4888    -0.1521    -1.4027    -1.5290    -1.5392    MISSING    -0.1520    -1.4888
DENSITY:
  LBMOL/CUFT            0.2147 2.8913-02     0.9343     0.1395     0.3990     1.2011     0.8466    MISSING     0.1394     0.9343
  LB/CUFT               9.4475     2.3123    85.7883     6.1384    71.8918    90.1619    77.9719    MISSING     6.1348    85.7884
AVG MW                 44.0098    79.9747    91.8225    44.0098   180.1577    75.0672    92.0947    MISSING    44.0098    91.8225

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                                EXTRACTION
                               STREAM SECTION

E-109A E-109B E-109C E-109D E-110

E-111 E-112 E-113 E-114 PRODUCT (CONTINUED)

STREAM ID               E-109A     E-109B     E-109C     E-109D     E-110      E-111      E-112      E-113      E-114      PRODUCT

SUBSTREAM: NCPSD        STRUCTURE: NON CONVENTIONAL
COMPONENTS: LB/HR
  ALGAE                  0.0     2.5334+04    0.0     2.5334+04    0.0        0.0        0.0     2.5334+04    0.0        0.0
COMPONENTS: MASS FRAC
  ALGAE                  0.0        1.0000    0.0        1.0000    0.0        0.0        0.0        1.0000    0.0        0.0
TOTAL FLOW:
  LB/HR                  0.0     2.5334+04    0.0     2.5334+04    0.0        0.0        0.0     2.5334+04    0.0        0.0
STATE VARIABLES:
  TEMP   F              MISSING   112.9100    MISSING   121.7300    MISSING    MISSING    MISSING   121.9100    MISSING    MISSING
  PRES   PSIA         1450.3700    40.0000   870.2300   870.2300  5076.3208  5076.3208  5076.3208   870.0000   870.0000   870.1000
  VFRAC                 MISSING    0.0        MISSING    0.0        MISSING    MISSING    MISSING    0.0        MISSING    MISSING
  LFRAC                 MISSING    0.0        MISSING    0.0        MISSING    MISSING    MISSING    0.0        MISSING    MISSING
  SFRAC                 MISSING     1.0000    MISSING     1.0000    MISSING    MISSING    MISSING     1.0000    MISSING    MISSING
ENTHALPY:
  BTU/LB                MISSING -6803.2150    MISSING -6798.6536    MISSING    MISSING    MISSING -6798.5605    MISSING    MISSING
  BTU/HR                MISSING -1.7235+08    MISSING -1.7224+08    MISSING    MISSING    MISSING -1.7224+08    MISSING    MISSING
DENSITY:
  LB/CUFT               MISSING   141.9785    MISSING   141.9785    MISSING    MISSING    MISSING   141.9785    MISSING    MISSING
AVG MW                   1.0000     1.0000     1.0000     1.0000     1.0000     1.0000     1.0000     1.0000     1.0000     1.0000
```

(*Figure C.2.5: Continue*)

```
COMPONENT ATTRIBUTES:
ALGAE    PROXANAL
           MOISTURE     MISSING   100.0000    MISSING   100.0000    MISSING    MISSING    MISSING   100.0000    MISSING    MISSING
           FC           MISSING    0.0        MISSING    0.0        MISSING    MISSING    MISSING    0.0        MISSING    MISSING
           VM           MISSING    0.0        MISSING    0.0        MISSING    MISSING    MISSING    0.0        MISSING    MISSING
           ASH          MISSING    18.4000    MISSING    18.4000    MISSING    MISSING    MISSING    18.4000    MISSING    MISSING
         ULTANAL
           ASH          MISSING    0.0        MISSING    0.0        MISSING    MISSING    MISSING    0.0        MISSING    MISSING
           CARBON       MISSING    0.0        MISSING    0.0        MISSING    MISSING    MISSING    0.0        MISSING    MISSING
           HYDROGEN     MISSING    0.0        MISSING    0.0        MISSING    MISSING    MISSING    0.0        MISSING    MISSING
           NITROGEN     MISSING    0.0        MISSING    0.0        MISSING    MISSING    MISSING    0.0        MISSING    MISSING
           CHLORINE     MISSING    0.0        MISSING    0.0        MISSING    MISSING    MISSING    0.0        MISSING    MISSING
           SULFUR       MISSING    0.0        MISSING    0.0        MISSING    MISSING    MISSING    0.0        MISSING    MISSING
           OXYGEN       MISSING    0.0        MISSING    0.0        MISSING    MISSING    MISSING    0.0        MISSING    MISSING
         SULFANAL
           PYRITIC      MISSING    0.0        MISSING    0.0        MISSING    MISSING    MISSING    0.0        MISSING    MISSING
           SULFATE      MISSING    0.0        MISSING    0.0        MISSING    MISSING    MISSING    0.0        MISSING    MISSING
           ORGANIC      MISSING    0.0        MISSING    0.0        MISSING    MISSING    MISSING    0.0        MISSING    MISSING
SUBSTREAM ATTRIBUTES:
PSD
  FRAC1                 MISSING    0.0        0.0        0.0        0.0        0.0        0.0        0.0        MISSING    0.0
  FRAC2                 MISSING    0.0        0.0        0.0        0.0        0.0        0.0        0.0        MISSING    0.0
  FRAC3                 MISSING    0.0        0.0        0.0        0.0        0.0        0.0        0.0        MISSING    0.0
  FRAC4                 MISSING    0.0        0.0        0.0        0.0        0.0        0.0        0.0        MISSING    0.0
  FRAC5                 MISSING    0.0        0.0        0.0        0.0        0.0        0.0        0.0        MISSING    0.0
  FRAC6                 MISSING    0.0        0.0        0.0        0.0        0.0        0.0        0.0        MISSING    0.0
  FRAC7                 MISSING    0.0        0.0        0.0        0.0        0.0        0.0        0.0        MISSING    0.0
  FRAC8                 MISSING    0.0        0.0        0.0        0.0        0.0        0.0        0.0        MISSING    0.0
  FRAC9                 MISSING    0.0        0.0        0.0        0.0        0.0        0.0        0.0        MISSING    0.0
  FRAC10                MISSING    0.0        0.0        0.0        0.0        0.0        0.0        0.0        MISSING    0.0
ASPEN PLUS   PLAT: WIN32     VER: 22.0                   05/07/2012  PAGE 24
                                EXTRACTION
                           PROBLEM STATUS SECTION

BLOCK STATUS
------------

****************************************************************************
*                                                                          *
* Calculations were completed normally                                     *
*                                                                          *
* All Unit Operation blocks were completed normally                        *
*                                                                          *
* All streams were flashed normally                                        *
*                                                                          *
****************************************************************************
```

(*Figure C.2.5: Continue*)

References

AspenTech : Company : University Program : Available Products http://www-.aspentech.com/corporate/university/products.aspx (accessed May 26, 2012).

APPPENDIX D: CAPCOST ANALYSIS

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D.1 - Cost information for Case Scenario 1 in 5-year project

Table D.1.1. Economic Options for Case Scenario 1 in 5-year project.

Cost of Land	$	9,758,808
Taxation Rate		42%
Annual Interest Rate		10%
Salvage Value		0
Working Capital	$	23,584,680.93
FCI_L	$	101,762,637.8
Total Module Factor		1.18
Grass Roots Factor		0.50

Table D.1.2. Economic Information for Case Scenario 1 in 5-year project.

Revenue From Sales	$	198,762,429
C_{RM} (Raw Materials Costs)	$	21,312,162
C_{UT} (Cost of Utilities)	$	57,369,864
C_{WT} (Waste Treatment Costs)	$	5,298,060
C_{OL} (Cost of Operating Labor)	$	14,014,880

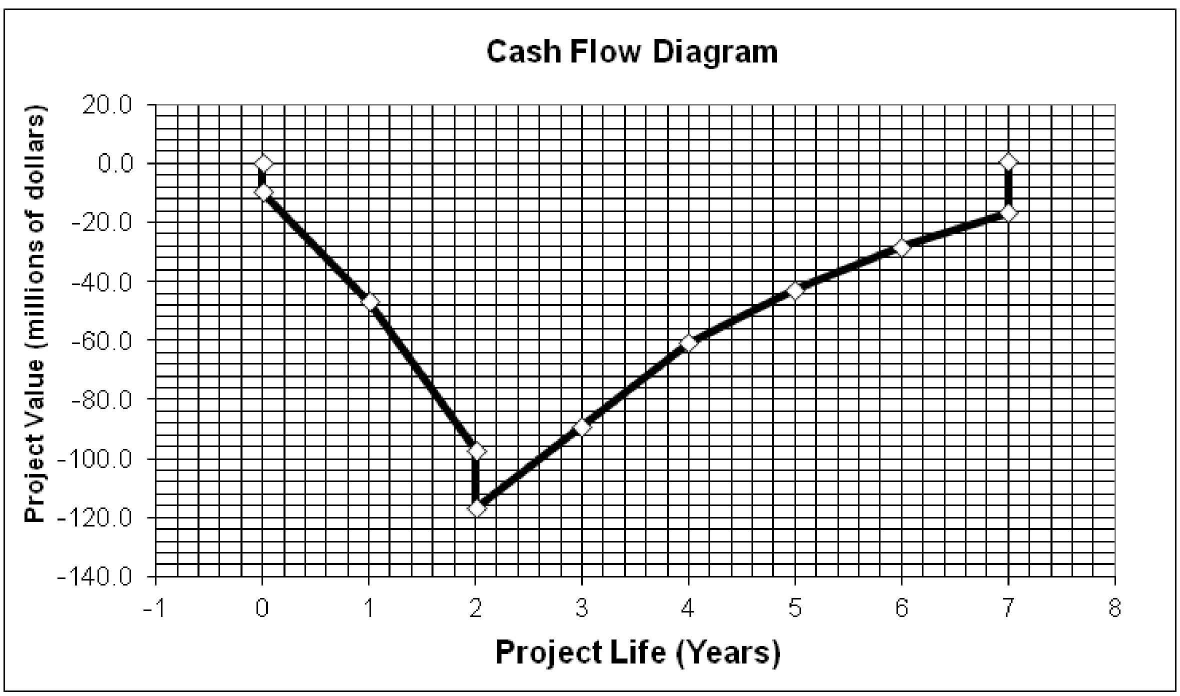

Figure D.1.1. Cash flow diagram for Case Scenario 1 in 5-year project.

Net Present Value (millions)	0.46
Discounted Cash Flow Rate of Return	10.13%
Discounted Payback Period (years)	3.9

Figure D.1.2. Discounted profitability criterion for Case Scenario 1 in 5-year project.

D.2 - Cost information for Case Scenario 1 in 10-year project

Table D.2.1. Economic Options for Case Scenario 1 in 10-year project.

Cost of Land	$	9,758,808
Taxation Rate		42%
Annual Interest Rate		10%
Salvage Value		0
Working Capital	$	23,584,681
FCI_L	$	101,762,638
Total Module Factor		1.18
Grass Roots Factor		0.50

Table D.2.2. Economic Information for Case Scenario 1 in 10-year project.

Revenue From Sales	$	186,548,001
C_{RM} (Raw Materials Costs)	$	21,312,162
C_{UT} (Cost of Utilities)	$	57,369,864
C_{WT} (Waste Treatment Costs)	$	5,298,060
C_{OL} (Cost of Operating Labor)	$	14,014,880

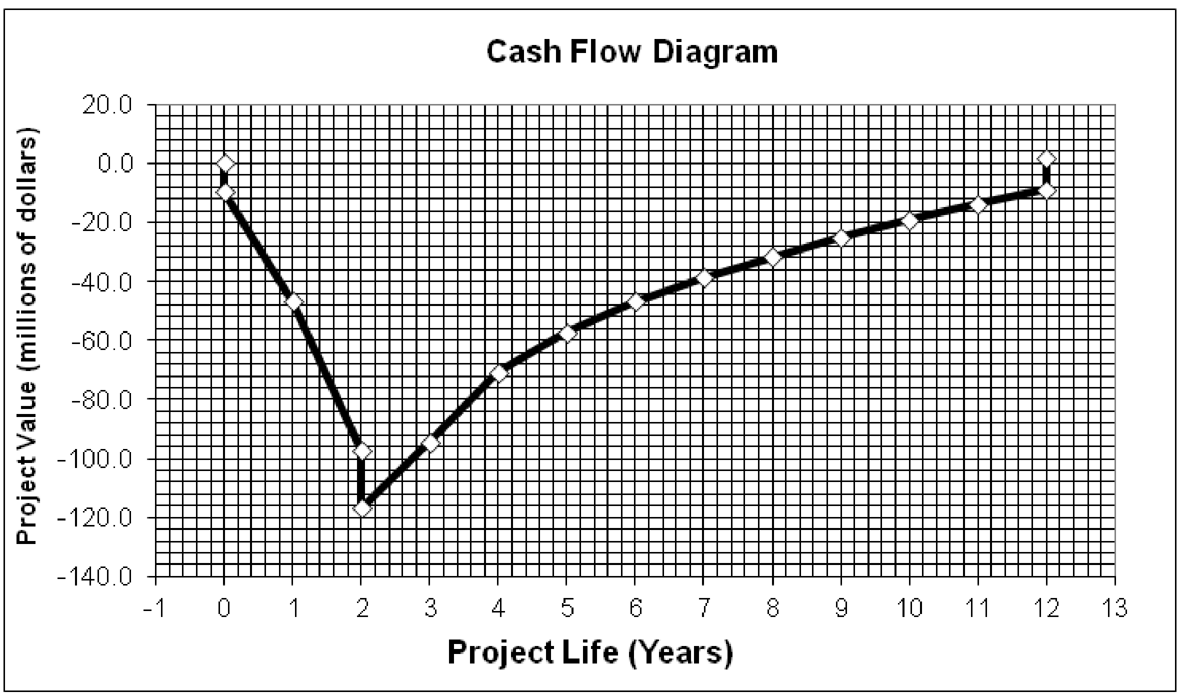

Figure D.2.1. Cash flow diagram for Case Scenario 1 in 10-year project.

Net Present Value (millions)	1.87
Discounted Cash Flow Rate of Return	10.35%
Discounted Payback Period (years)	6.4

Figure D.2.2. Discounted profitability criterion for Case Scenario 1 in 10-year project.

D.3 - Cost information for Case Scenario 1 in 20-year project

Table D.3.1. Economic Options for Case Scenario 1 in 20-year project.

Cost of Land	$	9,758,808
Taxation Rate		42%
Annual Interest Rate		10%
Salvage Value		0
Working Capital	$	23,584,681
FCI_L	$	101,762,638
Total Module Factor		1.18
Grass Roots Factor		0.50

Table D.3.2. Economic Information for Case Scenario 1 in 20-year project.

Revenue From Sales	$	167,671,112
C_{RM} (Raw Materials Costs)	$	21,312,162
C_{UT} (Cost of Utilities)	$	57,369,864
C_{WT} (Waste Treatment Costs)	$	5,298,060
C_{OL} (Cost of Operating Labor)	$	14,014,880

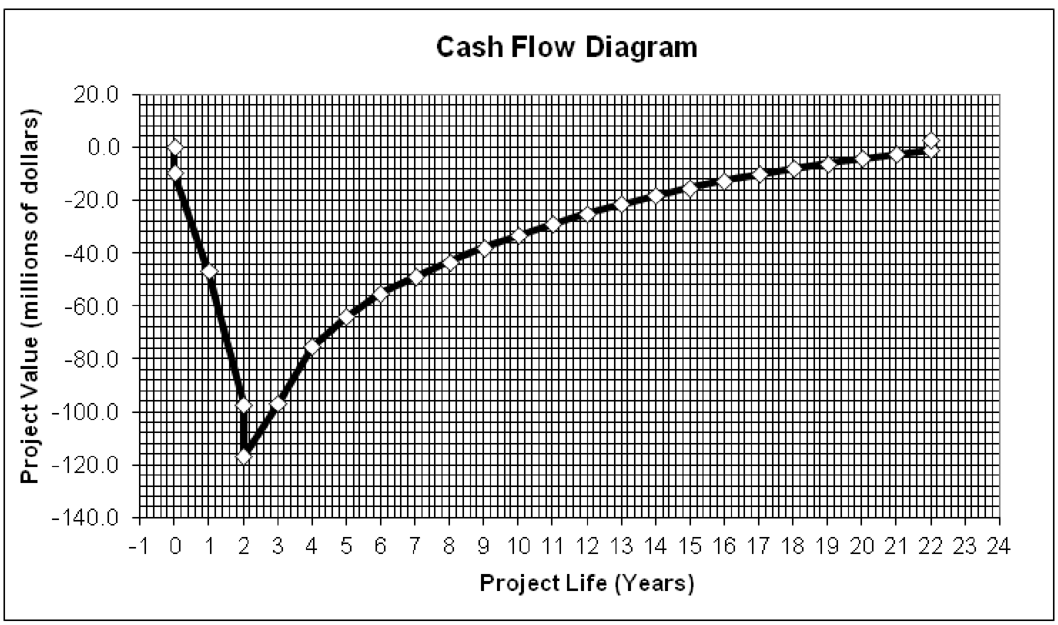

Figure D.3.1. Cash flow diagram for Case Scenario 1 in 20-year project.

Net Present Value (millions)	2.98
Discounted Cash Flow Rate of Return	10.40%
Discounted Payback Period (years)	8.9

Figure D.3.2. Discounted profitability criterion for Case Scenario 1 in 20-year project.

D.4 - Cost information for Case Scenario 2 in 5-year project

Table D.4.1. Economic Options for Case Scenario 2 in 5-year project.

Cost of Land	$	9,758,808
Taxation Rate		42%
Annual Interest Rate		10%
Salvage Value		0
Working Capital	$	23,010,318
FCI_L	$	80,694,001
Total Module Factor		1.18
Grass Roots Factor		0.50

Table D.4.2. Economic Information for Case Scenario 2 in 5-year project.

Revenue From Sales	$	181,218,052
C_{RM} (Raw Materials Costs)	$	21,312,162
C_{UT} (Cost of Utilities)	$	54,159,306
C_{WT} (Waste Treatment Costs)	$	5,298,060
C_{OL} (Cost of Operating Labor)	$	12,936,723

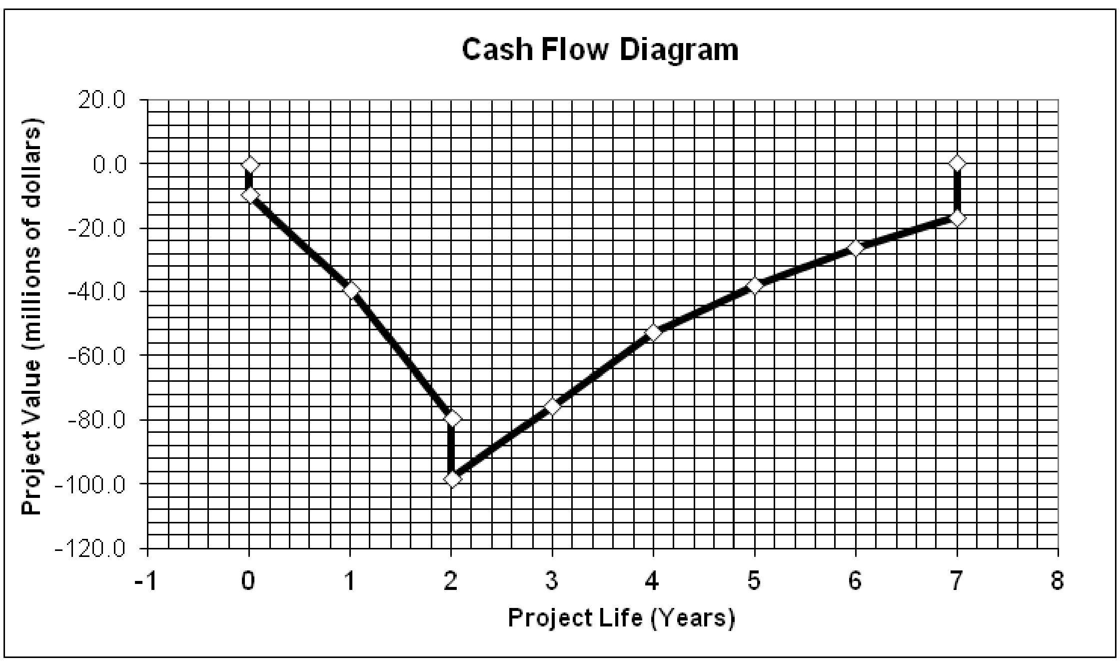

Figure D.4.1. Cash flow diagram for Case Scenario 2 in 5-year project.

Net Present Value (millions)	0.19
Discounted Cash Flow Rate of Return	10.06%
Discounted Payback Period (years)	3.8

Figure D.4.2. Discounted profitability criterion for Case Scenario 2 in 5-year project.

D.5 - Cost information for Case Scenario 2 in 10-year project

Table D.5.1. Economic Options for Case Scenario 2 in 10-year project.

Cost of Land	$	9,758,808
Taxation Rate		42%
Annual Interest Rate		10%
Salvage Value		0
Working Capital	$	23,010,318
FCI_L	$	80,694,001
Total Module Factor		1.18
Grass Roots Factor		0.50

Table D.5.2. Economic Information for Case Scenario 2 in 10-year project.

Revenue From Sales	$	171,668,548
C_{RM} (Raw Materials Costs)	$	21,312,162
C_{UT} (Cost of Utilities)	$	54,159,306
C_{WT} (Waste Treatment Costs)	$	5,298,060
C_{OL} (Cost of Operating Labor)	$	12,936,723

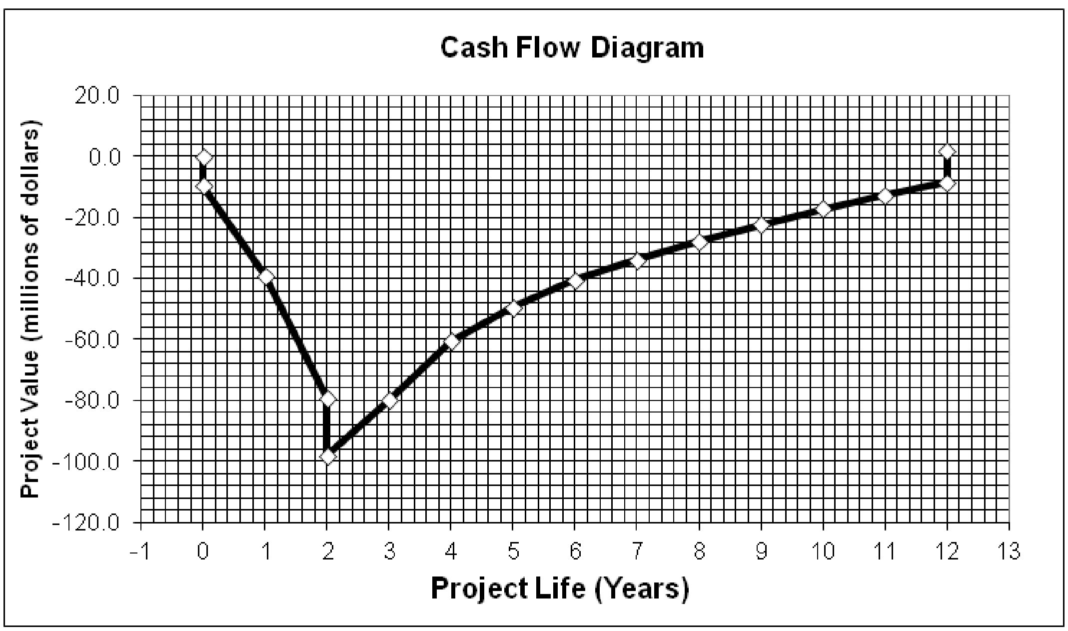

Figure D.5.1. Cash flow diagram for Case Scenario 2 in 10-year project.

Net Present Value (millions)	1.83
Discounted Cash Flow Rate of Return	10.40%
Discounted Payback Period (years)	5.9

Figure D.5.2. Discounted profitability criterion for Case Scenario 2 in 10-year project.

D.6 - Cost information for Case Scenario 2 in 20-year project

Table D.6.1. Economic Options for Case Scenario 2 in 20-year project.

Cost of Land	$	9,758,808
Taxation Rate		42%
Annual Interest Rate		10%
Salvage Value		0
Working Capital	$	23,010,318
FCI_L	$	80,694,001
Total Module Factor		1.18
Grass Roots Factor		0.50

Table D.6.2. Economic Information for Case Scenario 2 in 20-year project.

Revenue From Sales	$	166,560,718
C_{RM} (Raw Materials Costs)	$	21,312,162
C_{UT} (Cost of Utilities)	$	54,159,306
C_{WT} (Waste Treatment Costs)	$	5,298,060
C_{OL} (Cost of Operating Labor)	$	12,936,723

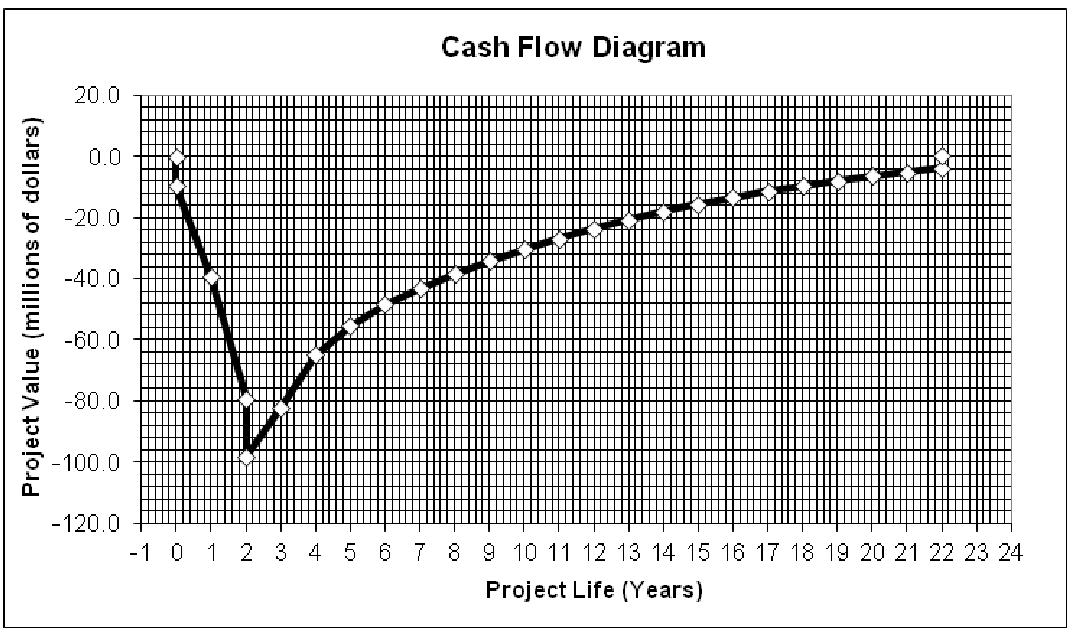

Figure D.6.1. Cash flow diagram for Case Scenario 2 in 20-year project.

Net Present Value (millions)	0.10
Discounted Cash Flow Rate of Return	10.02%
Discounted Payback Period (years)	8.5

Figure D.6.2. Discounted profitability criterion for Case Scenario 2 in 20-year project.

D.7 - Cost information for Case Scenario 3 in 5-year project

Table D.7.1. Economic Options for Case Scenario 3 in 5-year project.

Cost of Land	$	9,758,808
Taxation Rate		42%
Annual Interest Rate		10%
Salvage Value		0
Working Capital	$	28,348,543
FCI_L	$	88,499,339
Total Module Factor		1.18
Grass Roots Factor		0.50

Table D.7.2. Economic Information for Case Scenario 3 in 5-year project.

Revenue From Sales	$	250,285,265
C_{RM} (Raw Materials Costs)	$	19,332,032
C_{UT} (Cost of Utilities)	$	112,562,498
C_{WT} (Waste Treatment Costs)	$	5,298,060
C_{OL} (Cost of Operating Labor)	$	10,980,068

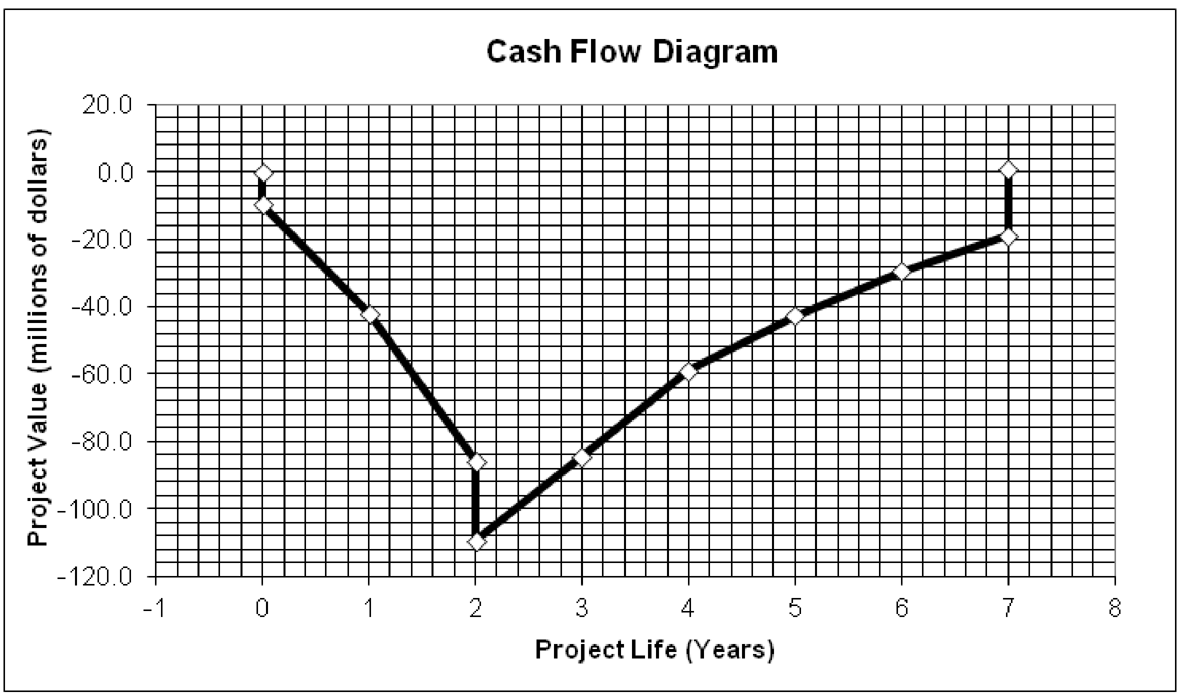

Figure D.7.1. Cash flow diagram for Case Scenario 3 in 5-year project.

Net Present Value (millions)	0.61
Discounted Cash Flow Rate of Return	10.18%
Discounted Payback Period (years)	3.7

Figure D.7.2. Discounted profitability criterion for Case Scenario 3 in 5-year project.

D.8 - Cost information for Case Scenario 3 in 10-year project

Table D.8.1. Economic Options for Case Scenario 3 in 10-year project.

Cost of Land	$	9,758,808
Taxation Rate		42%
Annual Interest Rate		10%
Salvage Value		0
Working Capital	$	28,348,543
FCI_L	$	88,499,339
Total Module Factor		1.18
Grass Roots Factor		0.50

Table D.8.2. Economic Information for Case Scenario 3 in 10-year project.

Revenue From Sales	$	239,847,386
C_{RM} (Raw Materials Costs)	$	19,332,032
C_{UT} (Cost of Utilities)	$	112,562,498
C_{WT} (Waste Treatment Costs)	$	5,298,060
C_{OL} (Cost of Operating Labor)	$	10,980,068

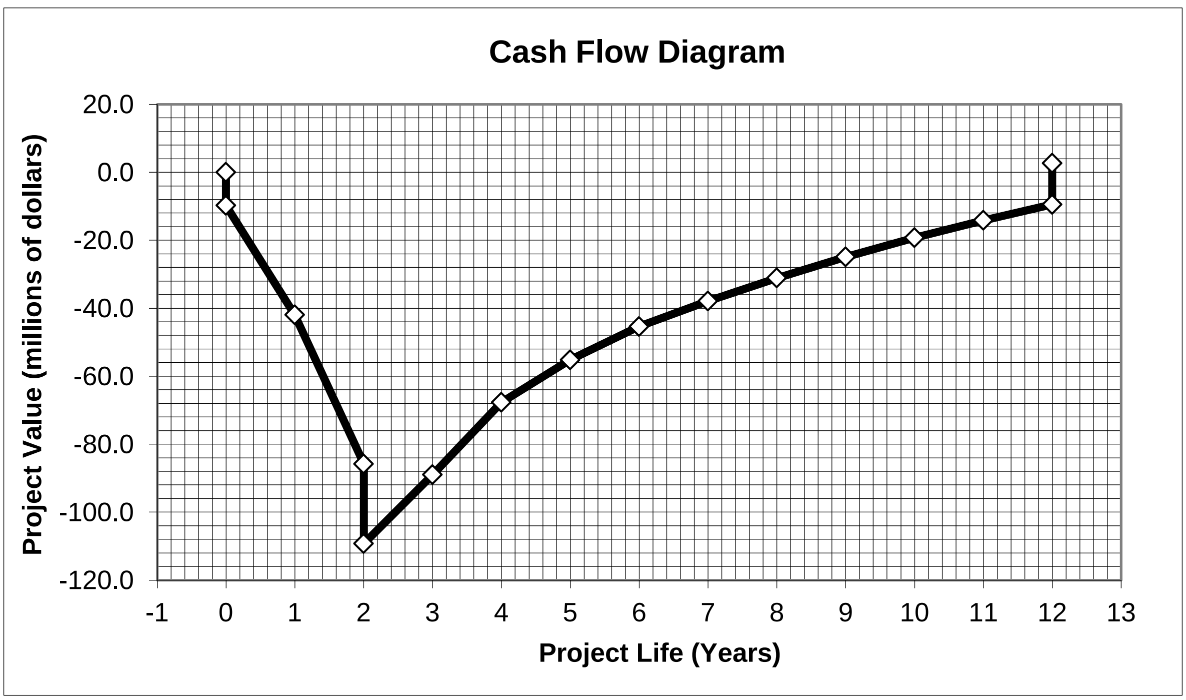

Figure D.8.1. Cash flow diagram for Case Scenario 3 in 10-year project.

Net Present Value (millions)	2.66
Discounted Cash Flow Rate of Return	10.52%
Discounted Payback Period (years)	5.7

Figure D.8.1. Discounted profitability criterion for Case Scenario 3 in 10-year project.

D.9 - Cost information for Case Scenario 3 in 20-year project

Table D.9.1. Economic Options for Case Scenario 3 in 20-year project.

Cost of Land	$	9,758,808
Taxation Rate		42%
Annual Interest Rate		10%
Salvage Value		0
Working Capital	$	28,348,543
FCI_L	$	88,499,339
Total Module Factor		1.18
Grass Roots Factor		0.50

Table D.18: Economic Information for Case Scenario 3 in 20-year project.

Revenue From Sales	$	234,295,419
C_{RM} (Raw Materials Costs)	$	19,332,032
C_{UT} (Cost of Utilities)	$	112,562,498
C_{WT} (Waste Treatment Costs)	$	5,298,060
C_{OL} (Cost of Operating Labor)	$	10,980,068

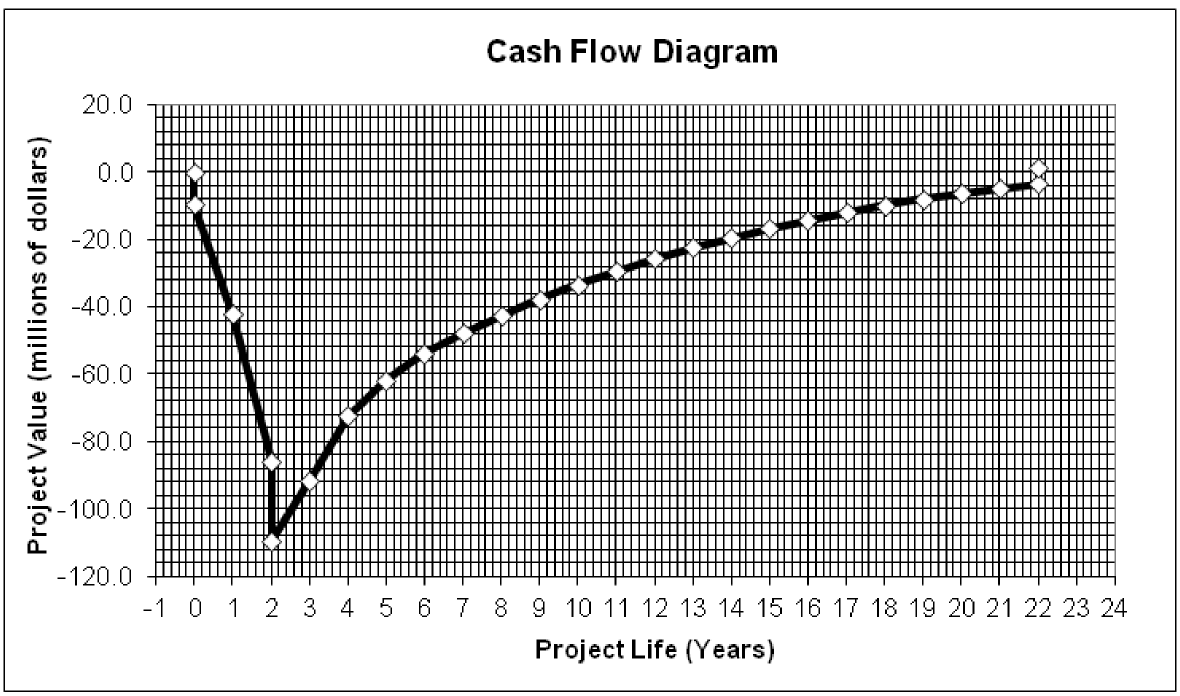

Figure D.9.1. Cash flow diagram for Case Scenario 3 in 20-year project.

Net Present Value (millions)	1.15
Discounted Cash Flow Rate of Return	10.16%
Discounted Payback Period (years)	8.1

Figure D.9.2. Discounted profitability criterion for Case Scenario 3 in 20-year project.

D.10 - Cost information for Case Scenario 4 in 5-year project

Table D.10.1. Economic Options for Case Scenario 4 in 5-year project.

Cost of Land	$	9,758,808
Taxation Rate		42%
Annual Interest Rate		10%
Salvage Value		0
Working Capital	$	22,686,646
FCI_L	$	80,758,497
Total Module Factor		1.18
Grass Roots Factor		0.50

Table D.10.2. Economic Information for Case Scenario 4 in 5-year project.

Revenue From Sales	$	177,664,753
C_{RM} (Raw Materials Costs)	$	19,332,032
C_{UT} (Cost of Utilities)	$	54,931,497
C_{WT} (Waste Treatment Costs)	$	5,298,060
C_{OL} (Cost of Operating Labor)	$	12,058,225

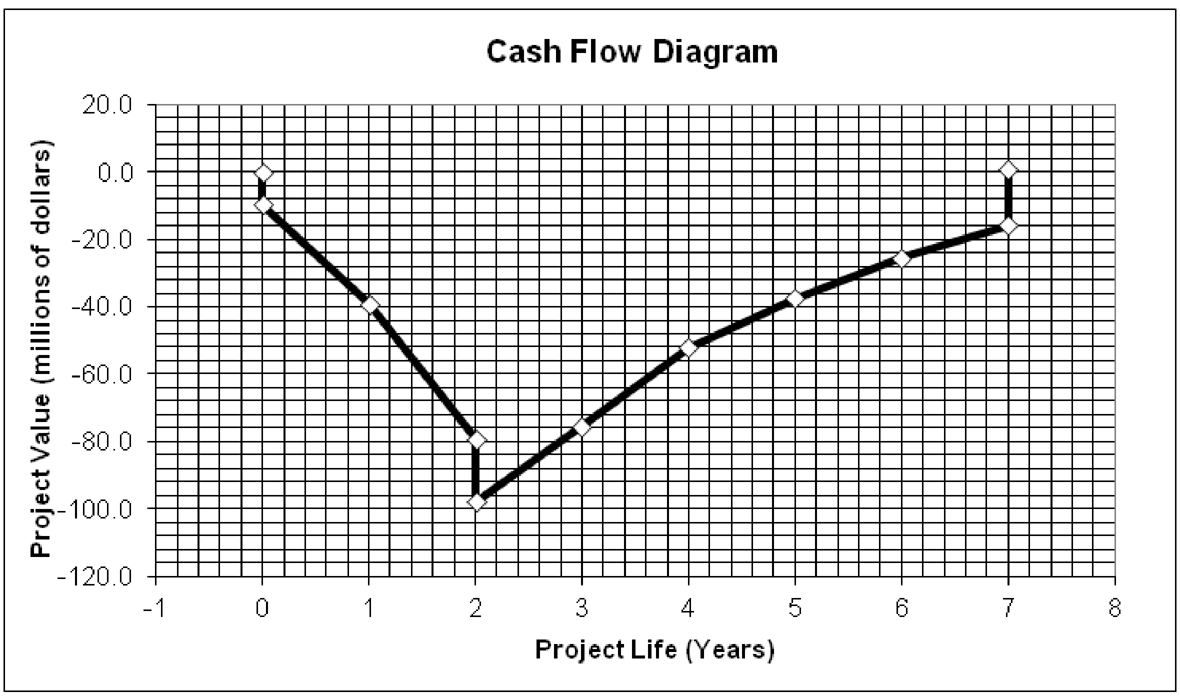

Figure D.10.1. Cash flow diagram for Case Scenario 4 in 5-year project.

Net Present Value (millions)	0.84
Discounted Cash Flow Rate of Return	10.27%
Discounted Payback Period (years)	3.7

Figure D.10.2. Discounted profitability criterion for Case Scenario 4 in 5-year project.

D.11 - Cost information for Case Scenario 4 in 10-year project

Table D.11.1. Economic Options for Case Scenario 4 in 10-year project.

Cost of Land	$	9,758,808
Taxation Rate		42%
Annual Interest Rate		10%
Salvage Value		0
Working Capital	$	22,686,646
FCI_L	$	80,758,497
Total Module Factor		1.18
Grass Roots Factor		0.50

Table D.11.2. Economic Information for Case Scenario 4 in 10-year project.

Revenue From Sales	$	167,448,993
C_{RM} (Raw Materials Costs)	$	19,332,032
C_{UT} (Cost of Utilities)	$	5,4931,497
C_{WT} (Waste Treatment Costs)	$	5,298,060
C_{OL} (Cost of Operating Labor)	$	12,058,225

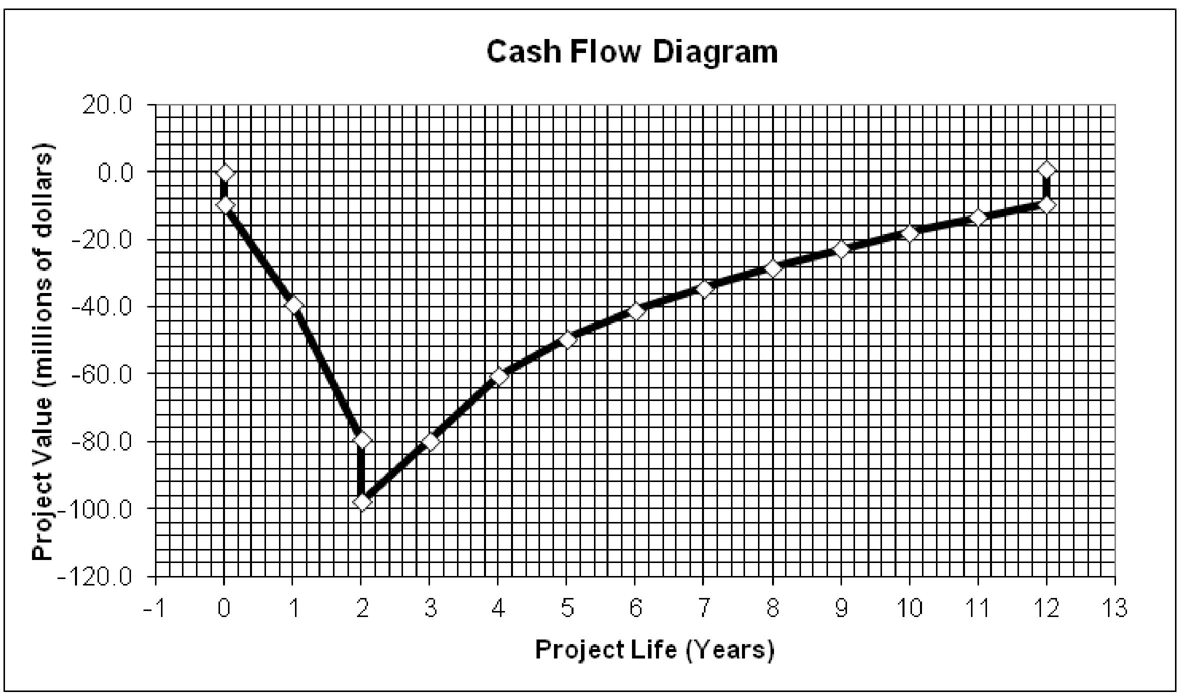

Figure D.11.1. Cash flow diagram for Case Scenario 4 in 10-year project.

Net Present Value (millions)	0.94
Discounted Cash Flow Rate of Return	10.21%
Discounted Payback Period (years)	6.0

Figure D.11.2. Discounted profitability criterion for Case Scenario 4 in 10-year project.

D.12 - Cost information for Case Scenario 4 in 20-year project

Table D.12.1. Economic Options for Case Scenario 4 in 20-year project.

Cost of Land	$	9,758,808
Taxation Rate		42%
Annual Interest Rate		10%
Salvage Value		0
Working Capital	$	22,686,646
FCI_L	$	80,758,497
Total Module Factor		1.18
Grass Roots Factor		0.50

Table D.12.2. Economic Information for Case Scenario 4 in 20-year project.

Revenue From Sales	$	163,007,419
C_{RM} (Raw Materials Costs)	$	19,332,032
C_{UT} (Cost of Utilities)	$	54,931,497
C_{WT} (Waste Treatment Costs)	$	5,298,060
C_{OL} (Cost of Operating Labor)	$	12,058,225

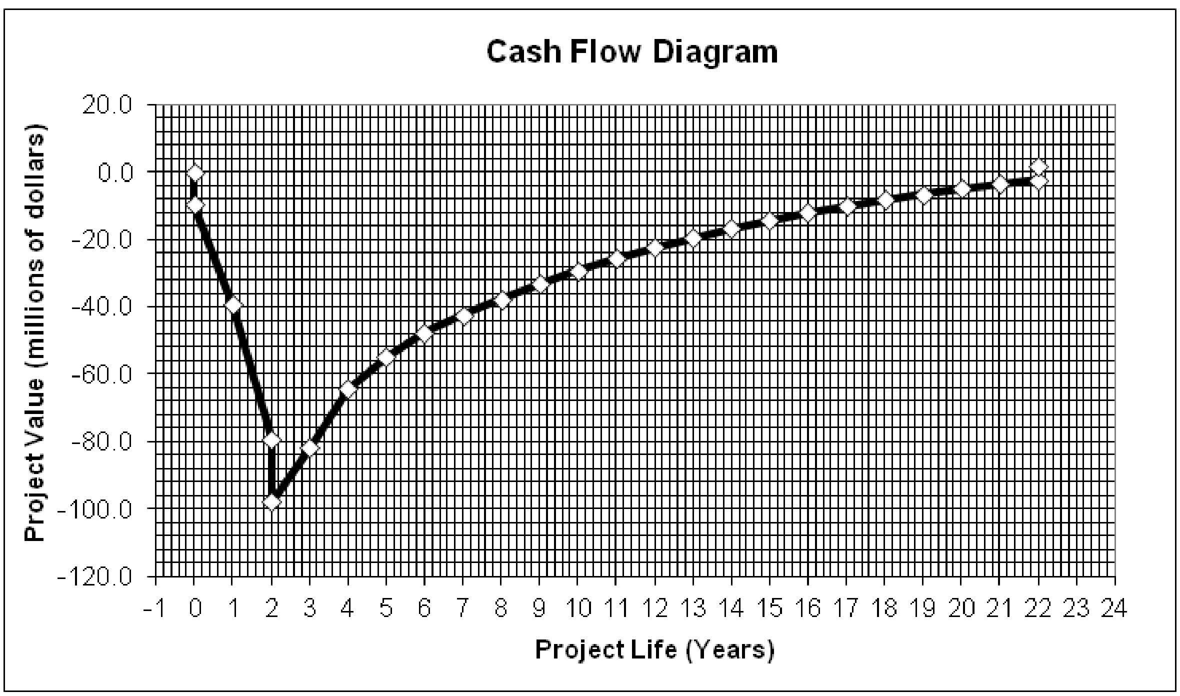

Figure D.12.1. Cash flow diagram for Case Scenario 4 in 20-year project.

Net Present Value (millions)	1.59
Discounted Cash Flow Rate of Return	10.25%
Discounted Payback Period (years)	8.2

Figure D.12.2. Discounted profitability criterion for Case Scenario 4 in 20-year project.

D.13 - Cost information for Case Scenario 5 in 5-year project

Table D.13.1. Economic Options for Case Scenario 5 in 5-year project.

Cost of Land	$	9,758,808
Taxation Rate		42%
Annual Interest Rate		10%
Salvage Value		0
Working Capital	$	22,923,617
FCI_L	$	96,760,710
Total Module Factor		1.18
Grass Roots Factor		0.50

Table D.13.2. Economic Information for Case Scenario 5 in 5-year project.

Revenue From Sales	$	188,768,787
C_{RM} (Raw Materials Costs)	$	21,312,162
C_{UT} (Cost of Utilities)	$	53,313,443
C_{WT} (Waste Treatment Costs)	$	5,298,060
C_{OL} (Cost of Operating Labor)	$	12,936,723

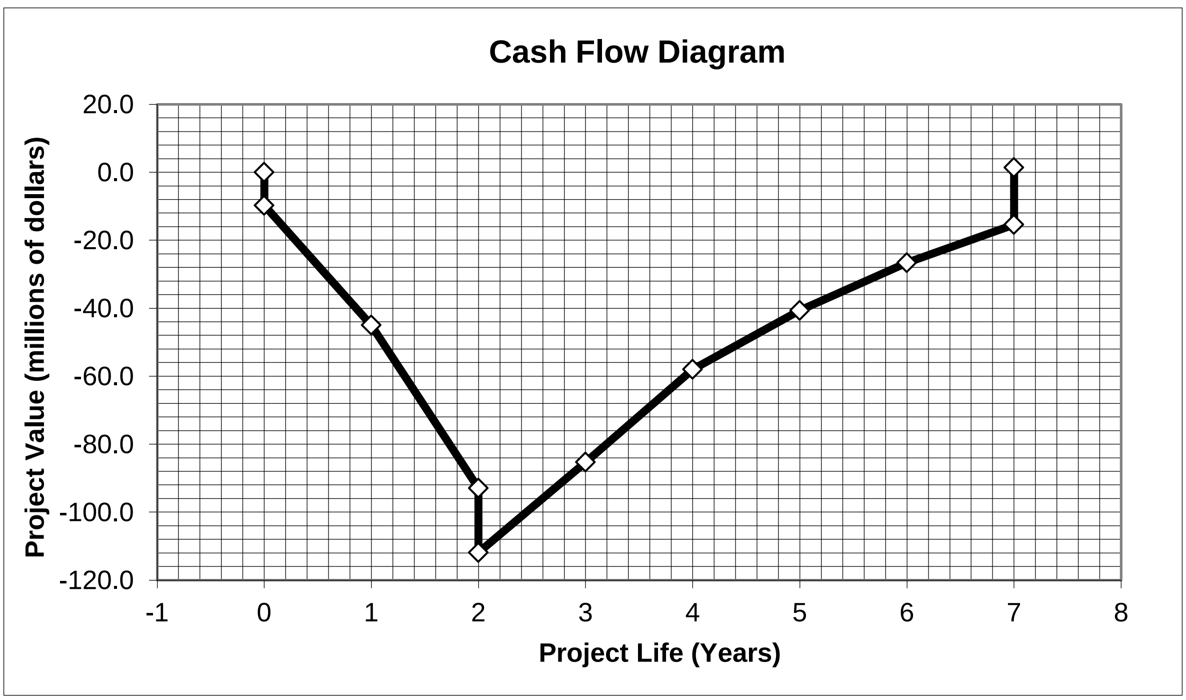

Figure D.13.1. Cash flow diagram for Case Scenario 5 in 5-year project.

Net Present Value (millions)	1.39
Discounted Cash Flow Rate of Return	10.40%
Discounted Payback Period (years)	3.9

Figure D.13.2. Discounted profitability criterion for Case Scenario 5 in 5-year project.

D.14 - Cost information for Case Scenario 5 in 10-year project

Table D.14.1. Economic Options for Case Scenario 5 in 10-year project.

Cost of Land	$	9,758,808
Taxation Rate		42%
Annual Interest Rate		10%
Salvage Value		0
Working Capital	$	22,923,617
FCI_L	$	96,760,710
Total Module Factor		1.18
Grass Roots Factor		0.50

Table D.14.2. Economic Information for Case Scenario 5 in10-year project.

Revenue From Sales	$	176,332,241
C_{RM} (Raw Materials Costs)	$	21,312,162
C_{UT} (Cost of Utilities)	$	53,313,443
C_{WT} (Waste Treatment Costs)	$	5,298,060
C_{OL} (Cost of Operating Labor)	$	12,936,723

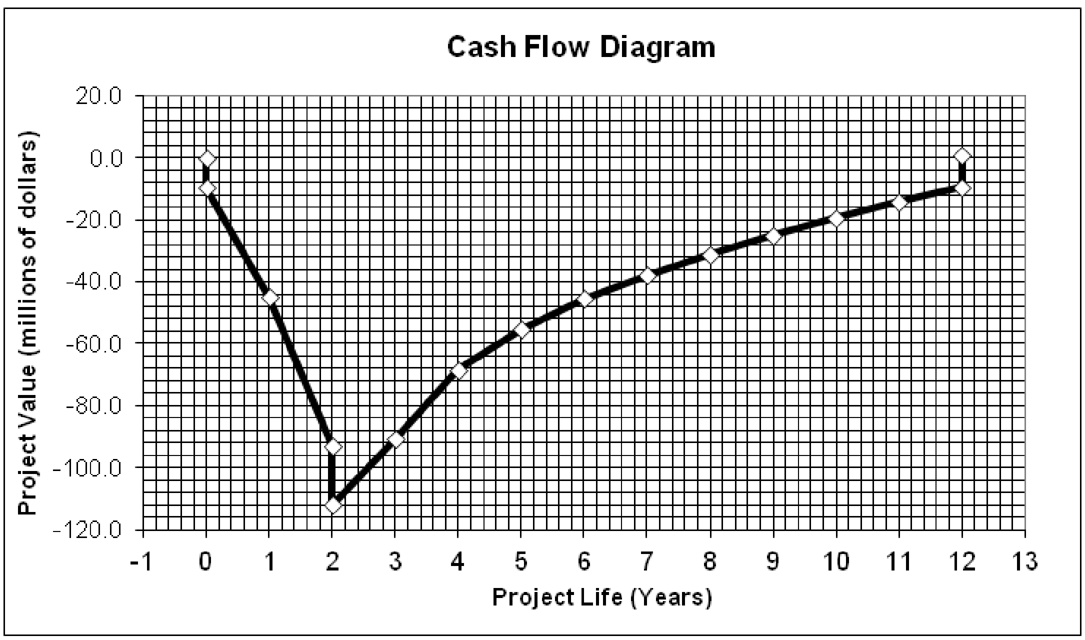

Figure D.14.1. Cash flow diagram for Case Scenario 5 in 10-year project.

Net Present Value (millions)	0.96
Discounted Cash Flow Rate of Return	10.19%
Discounted Payback Period (years)	6.4

Figure D.14.2. Discounted profitability criterion for Case Scenario 5 in 10-year project.

D.15 - Cost information for Case Scenario 5 in 20-year project

Table D.15.1 Economic Options for Case Scenario 5 in 20-year project.

Cost of Land	$	9758,808
Taxation Rate		42%
Annual Interest Rate		10%
Salvage Value		0
Working Capital	$	22,923,617
FCI_L	$	96760,710
Total Module Factor		1.18
Grass Roots Factor		0.50

Table D.15.2. Economic Information for Case Scenario 5 in 20-year project.

Revenue From Sales	$ 171,002,292
C_{RM} (Raw Materials Costs)	$ 21312,162
C_{UT} (Cost of Utilities)	$ 53313,443
C_{WT} (Waste Treatment Costs)	$ 5298,060
C_{OL} (Cost of Operating Labor)	$ 12,936,723

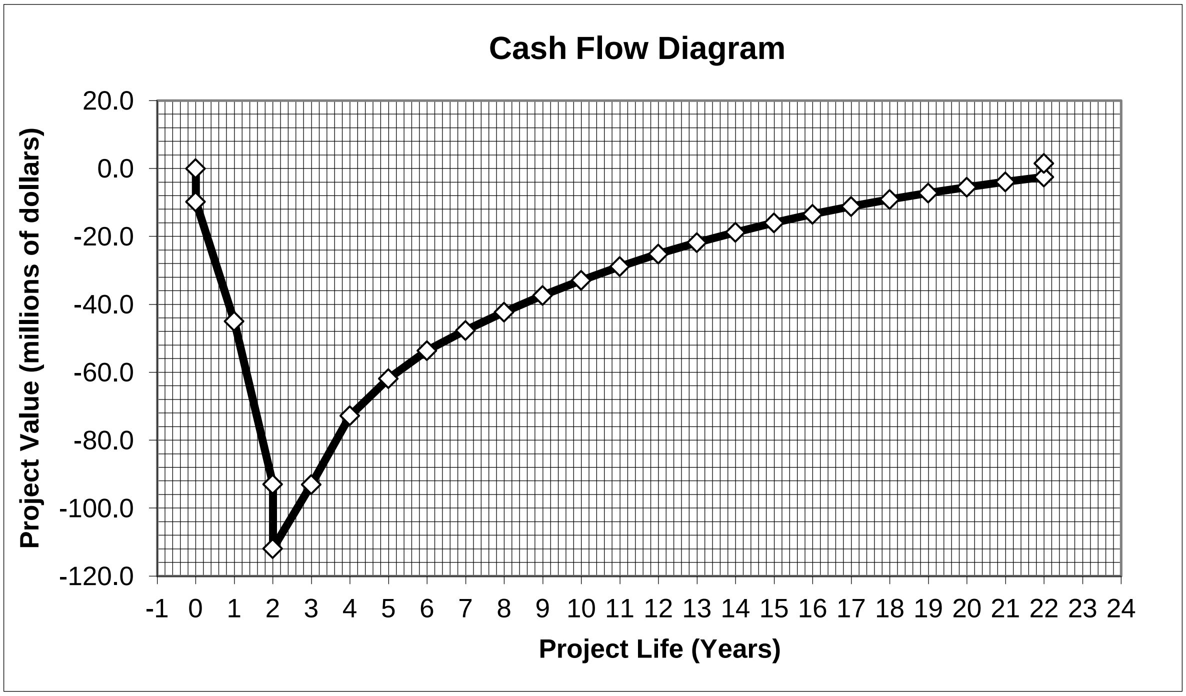

Figure D.15.1 Cash flow diagram for Case Scenario 5 in 20-year project.

Net Present Value (millions)	1.53
Discounted Cash Flow Rate of Return	10.21%
Discounted Payback Period (years)	9.0

Figure D.15.2. Discounted profitability criterion for Case Scenario 5 in 20-year project.