SYNTHESIS AND OPTIMSIATION OF A LIGNOCELLULOSIC BIOMASS PRE-PROCESSING SYSTEM FOR THERMOCHEMICAL BIOREFINERIES

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ABSTRACT

Fossil resources are widely utilised as sources for energy and chemical productions by society. Despite of its vast usage, it is often also identified as non-sustainable resources due to its limited availability and its contribution to greenhouse gas emission. In such regards, biomass, particularly lignocellulosic biomass is identified as a promising renewable source of carbon that has potential to replace fossil resources in energy and chemical productions. Biorefinery or integrated biorefinery is a processing facility that uses biomass as feedstock to produce value-added products, such as energy, fuels and chemicals. Integrated biorefinery can also be regarded as a processing facility that jointly apply various types of biomass processing technologies that produces useful products from biomass. In such regards, one of the important research and development areas for biorefinery or integrated biorefinery is to synthesise and integrate wide spectrums of biomass processing technologies as a whole.

In the last decade, various Process Systems Engineering (PSE) approaches have been presented to synthesise a sustainable biorefinery and integrated biorefinery. It is noted that these approaches are mainly mathematical optimisation approaches. On the other hand, as a sustainable biorefinery should depolymerise biomass to intermediates which match with the specifications of further processing steps. Thus, biomass pre-processing system is essential in a biorefinery. The biomass pre-processing system

helps to prepare and standardise the biomass into a more appropriate form prior to biomass conversion process. In this work, the more appropriate form of biomass is termed as bio-precursor. However, to date there is no systematic approach for synthesising biomass pre-processing system. In such regards, systematic synthesis of biomass pre-processing system is required. This thesis first presents background of the work, objectives, research methodology and scopes of this study. It is then followed by literature review on the topics related to this work. Next, in order to fill the identified research gaps, in this thesis, a superstructure based mathematical optimisation model is proposed to address the synthesis and optimisation of lignocellulosic biomass pre-processing system in a thermochemical biorefinery. A novel and new modelling technique is used to address the need of tracking particle size of the lignocellulosic biomass. On the other hand, two scenarios are considered which are maximising productivity and minimising energy requirement. Furthermore, a sensitivity analysis is conducted as well in this theses. Finally, possible future opportunities of this research work are highlighted in the last part of this thesis.

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LIST OF SYMBOLS/ ABBREVIATIONS

Abbreviation

ATM	Automated Targeting Model
BPS	Biomass Pre-processing system
C	Cellulose
CAMD	Computer Aided Molecular Design
CO_2	Carbon Dioxide
DOE	Department of Energy
EFBs	Empty Fruit Bunches
FFBs	Fresh Fruit Bunches
FT	Fischer- Tropsch
GHGs	Greenhouse Gases
HC	Hemicellulose
IChemE	Institution of Chemical Engineering
IEA	International Energy Agency
L	Lignin
LCB	Lignocellulosic Biomass

LCBPS	Lignocellulosic Biomass Pre-processing System
LP	Linear Programming
MINLP	Mixed-integer non-linear programming
MRR	Moisture Removal Ratio
NLP	Non-linear programming
NREL	National Renewable Energy Laboratory
PKSs	Palm Kernel Shells
PMFs	Palm Mesocarp Fibres
PSE	Process Systems Engineering
SER	Specific Energy Requirement
SRR	Size Reduction Ratio
W	Moisture

Sets

b	Index for lignocellulosic biomass
c	Index for comminution technology
d	Index for drying technology
i	Index for lignocellulosic biomass pre-processing technology set
i'	Index for second lignocellulosic biomass pre-processing technology set

i''	Index for third lignocellulosic biomass pre-processing technology set
k	Index for biomass intermediate
k'	Index for secondary biomass intermediate
p	Index for bio-precursor
Z	Index for compositions in lignocellulosic biomass

Parameters

$F_b^{AVAILABLE}$	Available flow rate of lignocellulosic biomass b
$K_{i'}$	Kick's constant of the material to technology i'
K_i	Kick's constant of the material to technology i
MRR_i	Moisture removal ratio of technology i
$MRR_{i'}$	Moisture removal ratio of technology i'
$MRR_{i,max}^{UL}$	Highest operating parameter possible of listed drying technologies in technology set i
Q_i	Thermal requirement of drying technology i
$Q_{i'}$	Kick's constant of the material to technology i'
S^{BM}	Highest particle size of the feed biomass b
S_i^{LL}	Lower limit of allowable inlet feed's nominal particle size to technology i

S_i^{UL}	Upper limit of allowable inlet feed's nominal particle size to technology *i*
SRR_i	Size removal ratio of technology *i*
$S_{i'}^{LL}$	Lower limit of allowable inlet feed's nominal particle size to technology *i′*
$S_{i'}^{UL}$	Upper limit of allowable inlet feed's nominal particle size to technology *i′*
$SRR_{i'}$	Size removal ratio of technology *i′*
$SRR_{i,\max}^{UL}$	Highest operating parameter possible of listed comminution technologies in technology set *i*
S_p^{UL}	Lower limit of nominal particle size's requirement for bio-precursor *p*
S_p^{LL}	Upper limit of nominal particle size's requirement for bio-precursor *p*
$X_i^{W,LL}$	Lower limit of allowable inlet feed's moisture content to technology *i*
$X_i^{W,UL}$	Upper limit of allowable inlet feed's moisture content to technology *i*
$X_{i'}^{W,LL}$	Lower limit of allowable inlet feed's moisture content to technology *i′*
$X_{i'}^{W,UL}$	Upper limit of allowable inlet feed's moisture content to technology *i′*
η_i	Thermal efficiency of drying technology *i*
$\eta_{i'}$	Thermal efficiency of drying technology *i′*

$X_p^{W,LL}$	Lower limit of moisture content's requirement for bio-precursor *p*
$X_p^{W,UL}$	Upper limit of moisture content's requirement for bio-precursor *p*
$X_{b,max}^{W}$	Highest moisture content of lignocellulosic biomass *b*

Variables

A_{HM}	$\log(SRR_i)$ of hammer mill
A_{KM}	$\log(SRR_i)$ of knife mill
A_{KS}	$\log(SRR_i)$ of knife shredder
B_{KM}	Moisture content of inlet to knife mill
B_{HM}	Moisture content of inlet to hammer mill
E_i	Energy requirement for technology *i*
$E_{i'}$	Energy requirement of technology *i'*
E_{TOTAL}	Total energy requirement
F_b	Flow rate of lignocellulosic biomass *b*
F_{bi}	Flow rate of lignocellulosic biomass *b* to technology *i*
F_i^{IN}	Flow rate of inlet to technology *i*
$F_i^{OUT,Z}$	Compositional flow rate of outlet from technology *i*

F_i^{MR}	Moisture removed from technology *i*
F_k	Flow rate of biomass intermediate *k*
$F_{ki'}$	Flow rate of biomass intermediate k to *technology i*'
$F_{i'}^{IN}$	Flow rate of inlet to technology *i'*
$F_{i'}^{OUT,Z}$	Compositional flow rate of outlet from technology *i'*
$F_{i'}^{MR}$	Moisture removed from technology *i'*
F_p	Flow rate of bio-precursor *p*
$F_{k'}$	Flow rate of biomass intermediate *k'*
$F_{k'i''}$	Flow rate of biomass intermediate *k'* to technology *i''*
I_i	Binary integer for technology *i*
K_{KM}	Kick's constant of inlet to knife mill
K_{HM}	Kick's constant of inlet to hammer mill
K_{KS}	Kick's constant of inlet to knife shredder
N	Targeted number of pre-processing technology set
N_i	Targeted number of pre-processing technology set based on estimation using technology *i*
N_d	Targeted number of pre-processing technology set based on estimation using drying technology *d*

N_c	Targeted number of pre-processing technology set based on estimation using comminution technology *c*
S_i	Particle size of inlet to technology *i*
S_i^{OUT}	Particle size of outlet from technology *i*
S_k	Particle size of biomass intermediate *k*
$S_{i'}$	Particle size of inlet to technology *i*
$S_{N=2}$	Largest nominal particle size (stage 2)
$S_{i'}^{\mathrm{OUT}}$	Particle size of outlet from technology *i'*
$S_{N=1}$	Largest nominal particle size (stage 1)
X_i^{Z}	Composition of inlet to technology *i*
X_k^{Z}	Composition of intermediate *k*
X_p^{Z}	Composition of bioprecursor *p*

CHAPTER 1

INTRODUCTION

1.1 Background

In current living style, society is highly dependent on fossil resources (e.g. petroleum, natural gas, coal, etc.) to fulfil its major energy needs. On the other hand, chemical industries are also highly relied on these fossil resources as important feedstocks for productions of various chemical intermediates and products. According to Maity (2015a), more than 80% of energy and around 90% of organic chemicals in the world are currently derived from the fossil resources.

Rapid increase of world's population with improved standard of living has caused the global energy and chemical consumptions to increase incessantly (Maity, 2015a). As a result, global consumption of fossil resources has increased substantially. As shown in Figure 1.1, the global consumptions of the fossil resources such as oil (i.e. petroleum), natural gas and coal are increasing since year 1965 (BP, 2016). However, these fossil resources are non-renewable and thus their availabilities will be depleted ultimately.

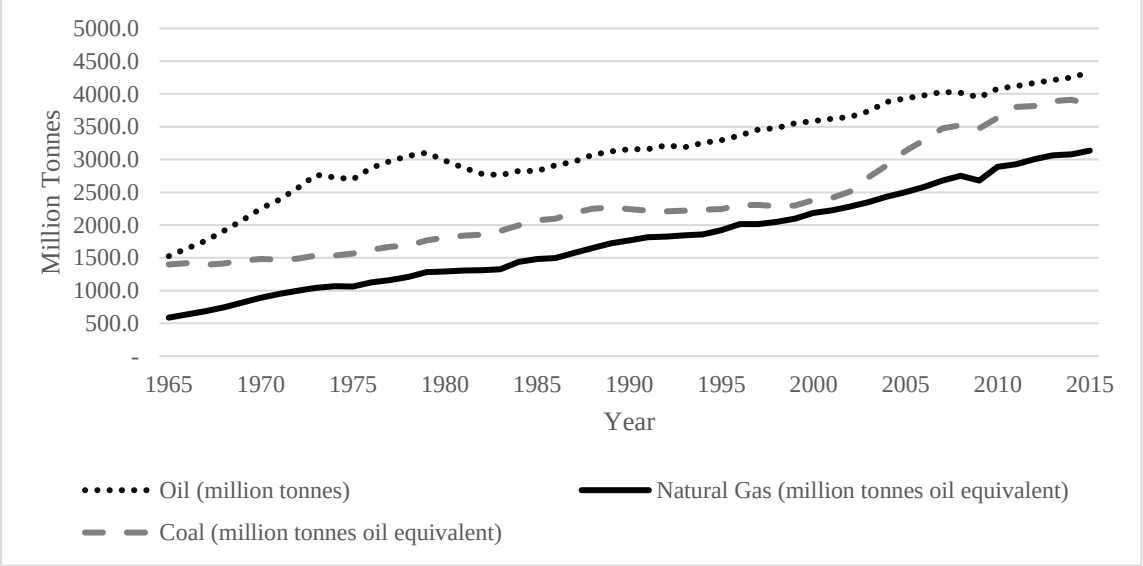


Figure 1.1: Global consumptions of fossil resources from 1965 to 2015 (adapted from BP, 2016)

On the other hand, large scale utilisations of these fossil resources generate one of the most significant greenhouse gases (GHGs), i.e. carbon dioxide (CO_2). The GHGs emission is believed to be one of the reasons that causes global warming (Maity, 2015a). As shown in Figure 1.1, the CO_2 emission has seen increased since year 1965.

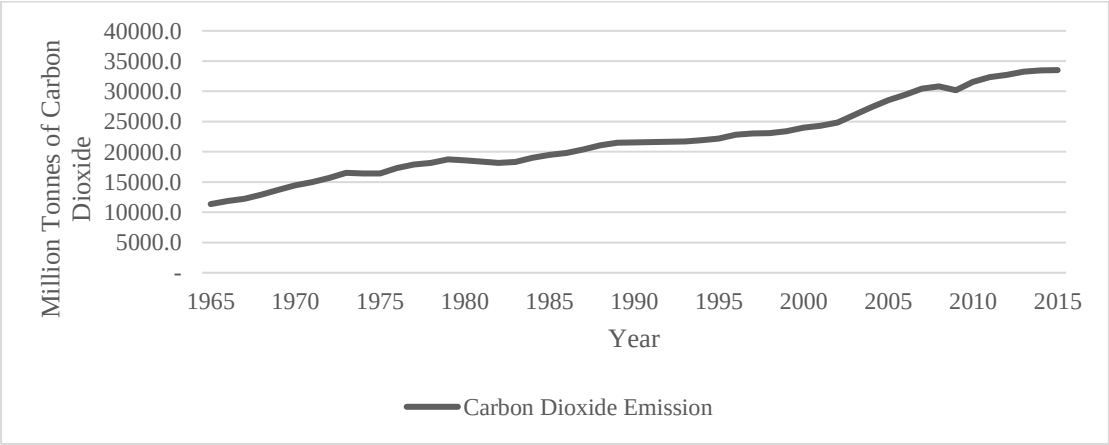


Figure 1.2: Global carbon dioxide emission from 1965 to 2015 (adapted from BP, 2016))

All of the abovementioned concerns have motivated the advancement of sustainable and renewable resources to replace the fossil resources for energy and chemicals productions. Among all the renewable resources (such as solar, wind, etc.), *biomass*, particularly *lignocellulosic biomass*, is often regarded as one of the most promising renewable sources of carbon that has the potential to fulfil the requirement of chemicals feedstock as well as energy production (Ghatak, 2011). Thus, new concepts have been continuously evolving to seek for possibilities of using biomass to produce an array of fuels and multitude of chemical products.

1.2 Biomass: Lignocellulosic Biomass

A comprehensive definition of biomass, including all the potential bio-renewable resources, is "*any organic matter that is available on a renewable or recurring basis, including dedicated energy crops and trees, agricultural residues, algae and aquatic plants, wood and wood residues, animal wastes, and other waste materials usable for the production of energy, fuels, chemicals and materials* (Kamm et al., 2006). Based on this definition, it is thus important to point out that biomass can be available in different forms and characteristics.

Lignocellulosic biomass (LCB) is one type of biomass which is often getting a lot of attention due to its highly renewable and ubiquitous nature, as well as its non-competiveness with food crops (i.e. sugar and starchy biomass such as corn). In general, LCB is a type of biomass that is primarily composed of *cellulose*, *hemicellulose*, and *lignin* (Silveira et al., 2015). Example of LCB include grasses, corn stover, straws, etc.

It is important to note that cellulose, hemicellulose and lignin are organic components with prominent carbon contents (i.e. the carbohydrates).

Meanwhile, LCB generally originates from plants which naturally capture CO_2 from atmosphere during photosynthesis. By contrast, fossil resources originate from CO_2 stored by nature through the photosynthesis of ancient organisms during millions years ago. Thus, large scale utilisation of the fossil resources for energy and chemical productions releases the ancient CO_2 into earth's atmosphere (Ghatak, 2011). Therefore, the LCB (and even other types of biomass) is more preferred than the fossil resources due to its comparatively lower net carbon release to the atmosphere. However, in order to convert the LCB (or other biomass) into different value-added products such as energy, fuels, and chemicals, a unique processing facility named *biorefinery* is required.

1.3 Concept of biorefinery

Biorefinery is a concept of using biomass as major feedstocks to produce value-added products. Kamm et al. (1998) firstly defined biorefinery as a complex system of sustainable, environment, and resources-friendly technologies for the comprehensive utilisation and exploitation of biological raw materials. The biorefinery concept has been developed as analogous to crude oil refineries (i.e. conventional refineries). Similar with conventional refineries, biorefineries should follow a strategy of feedstock separation into more useful and treatable fractions. Then, each of these fractions must create a production line to diversify their product slates. Thus, in general, a biorefinery

usually involves a series of "biomass refining processes" such as biomass feedstocks selection, pre-processing, intermediate conversion process, and final product conversion process (Dusselier et al., 2014), as depicted by Figure 1.3. In other words, the biorefinery typically embraces a wide range of biomass processing technologies which are able to "refine" the biomass into different types of value-added products.

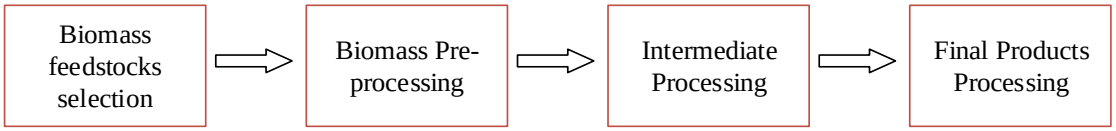


Figure 1.3: Biomass refining processes in biorefinery application (adapted from Dusselier et al., 2014)

Figure 1.4 illustrates the general processing structure of a biorefinery and its corresponding "biomass refining processes" as depicted previously in Figure 1.3. As shown in Figure 1.4, a biorefinery typically has a biomass pre-processing system (BPS) in which the raw biomass is normally standardised into *bio-precursor* before it can be further processed via a subsequent biomass conversion process. In such contexts, bio-precursor is defined as a compound or substance (i.e. pre-treated biomass) that can be directly utilised in the first biomass conversion unit of a biomass conversion process to produce intermediates and/or products for subsequent processing steps. Meanwhile, the biomass conversion process can be regarded as a biomass processing technology or a collective of biomass processing technologies which *chemically* transforms the biomass or pre-processed biomass into products of interest. Examples of biomass conversion processes are gasification, pyrolysis, fermentation, etc.

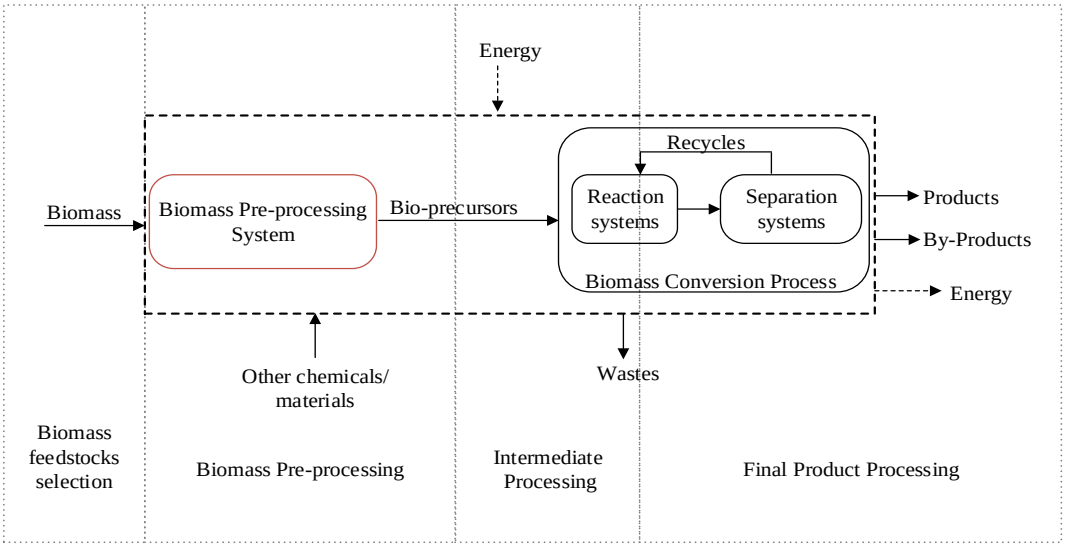


Figure 1.4: General processing structure of a biorefinery with its corresponding biomass refining processes

Meanwhile, a concept of *integrated biorefinery* is also proposed by Fernando et al. (2006). It can be regarded as an advanced biorefinery which integrates several biomass processing technologies as a whole in order to minimise the overall cost while increasing the flexibility in its products generation. Note that these technologies include physical, chemical, thermochemical, and biochemical technologies.

On the other hand, current established biomass processing technologies of biorefinery can be categorised into several notable platforms such as sugar platform, thermochemical platform, biogas platform, carbon-rich chains platform and plant product platform. In such regards, a biorefinery classification system has often been made between the biomass conversion processes such as thermochemical biorefinery

and biochemical biorefinery (De Jong and Jungmeier, 2015). In next section 1.4, much focus is given to discuss thermochemical biorefinery.

1.4 Thermochemical biorefinery

Thermochemical biorefinery is a type of biorefinery which employs thermochemical biomass processing technologies as the main biomass conversion process (i.e. thermochemical conversion process) to convert biomass (e.g. LCB) into various useful intermediates and/or products. The thermochemical conversion process usually involves reactions such as thermal decomposition, thermal oxidation, etc. In these reactions, the feedstock is usually treated under medium-to-high temperature and/or medium-to-high pressure with or without catalysts. Notable examples of thermal conversion processes include combustion, gasification and pyrolysis.

Meanwhile, as the thermochemical biorefinery is essentially a type of biorefinery, the overall processing structure of a thermochemical biorefinery should much resemble the general processing structure of a biorefinery (as shown previously in Figure 1.4).

1.5 Lignocellulosic Biomass Pre-processing

As mentioned previously in Section 1.2, biomass including LCB, can be available in different forms and characteristics. On the other hand, as shown in Figure 1.4 previously, a biorefinery, regardless of which types of biorefinery, typically has a

BPS in which the raw biomass is normally standardised into bio-precursor before it can be further processed via the biomass conversion process. In such regards, biomass pre-processing is an important biomass refining process in biorefinery application. BPS normally consists of different biomass pre-processing technologies. There are a number of lignocellulosic biomass pre-processing technologies, which can be generally categorised into the following four different groups: 1) Comminution/size reduction, 2) drying, 3) pre-treatment, and 4) hydrolysis.

On the other hand, over the past few years, there are various systematic approaches which have been proposed to address different issues arising during synthesis and design of biorefinery, particularly on screening of potential processing pathways (e.g., Halasz et al., 2005, Ng et al., 2009c, Bao et al., 2011, etc.). Although significant works have been focused in the area of synthesis and design of biorefinery, limited research works have been carried out in the area of synthesis of a BPS.

1.6 Problem Statement

Many established approaches have been developed by the research community in the realm of synthesising the conceptual design of biorefinery. However, BPS is regarded as an important system in a biorefinery. On the other hand, there are a number of biomass pre-processing technologies nowadays. Moreover, the critical operating parameters of biomass pre-processing technologies are crucial to determine the overall performance of a BPS. In such regards, it is realised that the synthesis and optimisation of biomass pre-processing system is yet to be examined thoroughly. This serves as the

main motivation of this thesis. Meanwhile, as mentioned previously, LCB is a notable biomass which receives more attention recently. Therefore, in this work, LCB is taken as the main type of biomass to be studied. As mentioned previously, there are different type of biorefinery based the different processing systems. However, in this work, thermochemical biorefinery is selected for further study.

1.7 Research Objective

The main aim of this research is to develop a systematic tool for synthesis and optimisation of lignocellulosic biomass pre-processing system (LCBPS) in a thermochemical biorefinery.

1.8 Outline of Thesis

In this thesis, introductions to the background of this research work, biorefinery concept, LCB and thermochemical biorefinery are presented in Chapter 1. In addition, Chapter 1 also covers brief introduction to biomass pre-processing and highlights the main research gap and objectives of this research work. Meanwhile, Chapter 2 provides detailed descriptions on the concepts related to this work, such as biorefinery and biomass. Chapter 2 also presents a literature review on process synthesis in process design, as well as process synthesis of biorefinery. Additional focus is also given to cover different lignocellulosic biomass pre-processing technologies related to this research work in Chapter 2. This is followed by the discussion of research scopes and research methodologies, which are presented in Chapter 3. Chapter 4 discusses the main work that has been done in this research which is a presentation of a systematic

approach for synthesis and optimisation of lignocellulosic biomass pre-processing system for thermochemical biorefinery. Chapter 5 concludes the research work and points out potential future works that can be done.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Chapter 2 aims to provide literature reviews on the topics related to this research work. Firstly, a general review on biomass and biorefinery is provided in Section 2.2. In particular, the need of biomass pre-processing system in a biorefinery is highlighted. Next, introduction of lignocellulosic biomass pre-processing technologies and overview of process synthesis and PSE approaches are presented in Sections 2.3 and 2.4 respectively. A review on PSE approaches for synthesis and optimisation of biorefinery is also included in Section 2.4. Finally, based on the literature review, the research gaps are identified and discussed in Section 2.5.

2.2 Biorefinery and Biomass

2.2.1 Biomass

Biomass is defined as any organic matter that is available on a renewable or recurring basis, including dedicated energy crops and trees, agricultural residues, algae and aquatic plants, wood and wood residues, animal wastes, and other waste materials usable for the production of energy, fuels, chemicals and materials (Kamm et al., 2006).

According to this definition, biomass can be available in different forms and characteristics. In general, based on the chemical nature, biomass can be classified into three broad categories, as followed: (1) sugar and starchy biomass, (2) triglycerides biomass, and (3) LCB (Maity, 2015a).

Sugar and starchy biomass is usually a type of biomass that consists of sucrose or starch, for examples, sugar beet, sugar cane, corn, etc. This type of biomass is often regarded as important food crops. Meanwhile, triglycerides biomass is a type of biomass that consists of lipids which are esters formed between glycerol and fatty acids, for examples, vegetable oils, micro-algal oils, etc. On the other hand, the LCB is often getting a lot of attention due to several reasons, such as its highly renewable and ubiquitous nature, as well as its non-competitiveness with food crops (i.e. sugar and starchy biomass). Note that LCB is widely available at relatively low cost in different forms, such as agriculture residues, forestry residues, industrial wastes, etc. In such regards, in this research work, LCB is considered as the main biomass of interest. Example of LCB include grasses, corn stover, straws, etc. Generally, LCB primarily composed of *cellulose*, *hemicellulose*, and *lignin* (Silveira et al. 2015).

Cellulose is a linear unbranched homo-polysaccharide composed of D-glucose monomers linked by β-(1→4) glyosidic bonds. Meanwhile, hemicellulose is composed of different monosaccharides, such as D-mannose, D-galactose, D-xylose, D-glucose, etc. On the other hand, lignin is an amorphous non-polysaccharidic polymer matrix of phenyl-propane units. Hemicelluloses serve as a connection between the lignin and the cellulose fibers and give cohesion to the whole cellulose-hemicellulose-lignin network

(Barakat et al., 2013). Furthermore, it is important to point out that cellulose, hemicellulose and lignin are naturally organic components with prominent carbon contents. As a thermochemical biorefinery usually requires carbon feedstock, LCB is often regarded as good feedstock for a thermochemical biorefinery.

2.2.2 Biorefinery

The initial concept of biorefinery was originated in late 1990s, as a result of scarcity of fossil fuels and increasing trends of use of biomass as a renewable feedstock for production of non-food products, e.g., bioethanol biorefinery via fermentation process in corn industry, ethanol biorefinery via gasification in pulp and paper industry, etc.) (Kamm and Kamm, 2004, Fernando et al., 2006, Kamm et al., 2006). Since then, there are several definitions for biorefineries emphasising the key elements of sustainability, integration, and multiple value-added productions.

Kamm et al. (1998) defined biorefinery as a complex system of sustainable, environment, and resources-friendly technologies for the comprehensive utilisation and exploitation of biological raw materials (i.e. biomass). US Department of Energy (DOE) has proposed a similar definition: biorefinery is an overall concept of a processing plant where biomass feedstocks are converted and extracted into spectrum of valuable products (Kamm et al., 2006). Meanwhile, according to International Energy Agency (IEA) Bioenergy Task 42, biorefineries can be defined as facilities that perform "biorefining activity", which the biorefining is the sustainable processing of biomass into a spectrum of marketable products and energy (IEA, 2008). Based on the different

definitions mentioned previously, it is important to point out that biorefinery concept has been developed as analogous to petroleum refineries (Sadhukhan et al., 2014). Therefore, biorefineries is used to convert feedstock into useful and treatable fractions. Each fraction is then used to create a production line to diversify their product slate and to increase profit and adaptability for low carbon pathways.

On the other hand, Fernando et al. (2006) proposed a concept of integrated biorefinery which integrates several biomass processing technologies as a whole to minimise the overall cost while increasing the flexibility in its products generation. On the other hand, according to Fernando et al. (2006), a sustainable biorefinery has to fulfil four main critical parameters such as: (1) Minimise the consumption of energy and potential impact to the environment; (2) Accommodate variable seasonal and annual patterns of biomass feedstock and quality; (3) Depolymerise target macromolecules (e.g., biomass) to intermediates which match the specifications of further processing steps; (4) Maximise the yield and quality of target products.

As highlighted in the definition of biorefinery by IEA Bioenergy Task 42, the biorefinery concept is essentially based on the concept of "biorefining" or "biomass refining", as shown in Figure 2.1. Generally, biomass refining process allows an efficient use of biomass and generation of value-added products through valorisation. Different biomass processing technologies are normally required during different biomass refining processes. For example, the type of biomass processing technologies needed for "biomass pre-processing" (i.e. one of the "biomass refining processes" as shown in Figure 2.1) is biomass pre-processing technologies.

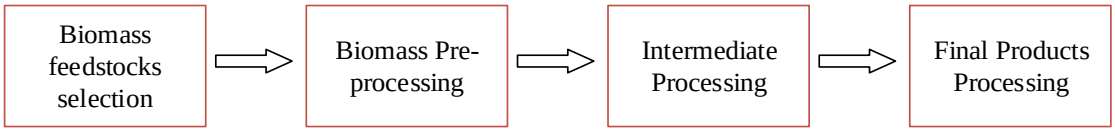


Figure 2.1: Biorefining or Biomass Refining Processes in biorefinery application

Meanwhile, the term "biorefinery process" is often used interchangeably with "biomass processing technology", as shown in various literature (e.g., Dusselier et al., 2014, Sadhukhan et al., 2014, Maity, 2015b). In fact, the former can refer to a standalone biomass processing technology or a collective of biomass processing technology that can process biomass to produce useful and valuable substances or products. For example, a rotary dryer for drying is a standalone biomass processing technology; while a gasification process can consist of multiple processing technologies, such as gasifier, hopper, gas separation unit, etc.

Note also that most of the biomass processing technologies or biorefinery processes can be generally categorised into a biochemical process, thermochemical process, physical/mechanical process and chemical process. Table 2.1 shows the descriptions and examples for the processes. Note that these processes are categorised according to how the biomass is processed, even though some of the listed examples might just be standalone machines and do not involve any biomass conversion.

Table 2.1: Categories of biomass processing technologies/ biorefinery processes

Category	**Description**	**Example**
Biochemical	• Involve degradation of biomass under the presences of microorganisms and/or enzymes • Have potential to convert feedstocks into final products in one or few steps and using mild reaction conditions (e.g. fermentation at 20-32^{o}C) • Less energy intensive • Long reaction or retention time	• Anaerobic digestion • Fermentation • Enzymatic hydrolysis
Thermochemical	• Involve thermal decomposition and/or thermal oxidation of biomass with or without metal-based catalysts • Short reaction or retention time • High energy intensive	• Combustion • Gasification • Pyrolysis
Physical/mechanical	• Does not alter the chemical nature of the feedstock • Does not involve utilisations of other chemicals • Less or high energy intensive	• Drying • Milling • Chipping • Filtration • Sedimentation • Centrifugal separation
Chemical	• Involve using other chemicals to process the biomass • Operating conditions can be mild or heavy	• Transesterification • Hydro-deoxygenation • Decarboxylation • Acid hydrolysis

On the other hand, US DOE and National Renewable Energy Laboratory (NREL) further the established biomass processing technologies based on five platforms: 1) sugar platform; 2) thermochemical platform; 3) biogas platform; 4) carbon-rich chains platform, and 5) plant products platform (Maity, 2015a). Sugar

platform involves fermentation of sugars extracted from biomass to produce fuel. Thermochemical platform involves gasification and pyrolysis of biomass to produce syngas (i.e., a gas mixture of carbon dioxide, carbon monoxide, hydrogen, methane and steam) and bio-oil respectively. Meanwhile, biogas platform focuses on decomposition of biomass by using anaerobic digestion to produce biogas (i.e. a gas mixture of methane and carbon dioxide). Carbon-rich chains platform involves conversion of vegetable oils into biodiesel by transesterification. Plant products platform develops plant strains that produce greater amounts of desirable feedstocks using selective breeding and genetic engineering (Maity, 2015a). Note that in this work, the type of biorefinery to be studied is thermochemical biorefinery which employs thermochemical conversion process as the main biomass conversion process (e.g. gasification, pyrolysis, etc).

However, note that raw LCB (or any raw biomass in fact) is often not readily usable in biomass conversion process. The compositions of LCB often vary in accordance to geographical origin. Additionally, raw LCB is normally available in rather different and large particle size. In other words, raw LCB typically vary in both compositions and properties, such as moisture content, particle size, etc. Furthermore, as mentioned previously, one critical parameter of a sustainable biorefinery is the ability to depolymerise target molecule (i.e., biomass) to intermediates which match the specifications of further processing steps (Fernando et al., 2006). Therefore, a biorefinery often requires a "biomass refining process" which is known as "biomass pre-processing", as shown in Figure 2.1. It is typically achieved by a biomass pre-processing system (BPS).

A BPS consists of biomass pre-processing technologies which help to prepare and standardise the raw biomass into a feedstock that can be utilised in biomass conversion process. In this work, the pre-processed biomass with more appropriate and standardised form is termed as *bio-precursor*, which is defined as a biomass-based compound or substance that can be utilised in the first biomass conversion unit to produce useful intermediates and/or products for subsequent processing steps. It is important to note that, regardless of which biomass conversion process is used, the raw biomass is often required to be pre-processed and standardised into bio-precursors. As mentioned previously, LCB is the main biomass of interest. Therefore, in Section 2.3, different LCB pre-processing technologies are introduced.

2.3 Lignocellulosic Biomass Pre-processing Technologies

LCB pre-processing technologies can be generally categorised into four different groups as followed:

a) Pre-treatment
b) Hydrolysis
c) Comminution or Size Reduction
d) Drying

Pre-treatment is an important biomass pre-processing technology in biorefinery which its main objective is to alter the macroscopic and microscopic structure of LCB in order to increase its digestibility. It is normally accomplished by utilising different additives (such as chemicals) and energy to form a solid component that can be used to

generate more soluble oligo- (e.g., glucan, xylan) and monosaccharides (e.g., glucose, xylose, etc.) than the raw biomass feedstock. There are different pre-treatment technologies which can be potentially be used in industry, such as dilute acid pre-treatment, alkaline pre-treatment, steam pre-treatment, ammonia fibre explosion pre-treatment, etc.

Hydrolysis is normally the subsequent processing step after pre-treatment. The main objective hydrolysis is to convert the holocellulose (i.e., cellulose and hemicellulose) of LCB into fermentable sugars (e.g., glucose, xylose, etc) with addition of water (Sun and Cheng, 2002). Chemical and enzymatic hydrolysis have been proved to be potentially successful in industrial application. However, enzymatic hydrolysis is commonly employed with different enzymes (e.g., cellulases, xylanases, etc.) to effectively enhance the hydrolysis process (Binod et al. 2011).

Comminution or size reduction is a mechanical process that reduces the size of a feedstock via electrical power. It is often considered as a primordial step of lignocellulosic biorefinery (i.e., biorefinery that processes LCB). This technology reduces the degree of cellulose polymerisation of LCB, increase in specific surface area and reduction in particle size (Kratky and Jirout, 2014). In addition, it helps to increases the volume calorific value of LCB and reduces the mass and heat transfer limitations during the biomass conversion processes (Barakat et al., 2013). There are various comminution machines used in the industry, such as disc chipper, hammer mill, knife mill, shredder, ball mill, colloid mills, etc. The performance of a comminution machine can be expressed in term of size reduction ratio (SRR) (i.e., initial size/ final size). One

major disadvantage of the use of size reduction is its high energy requirement that corresponds to up to 33% of the total electrical demand. Energy requirement generally rises with higher moisture content and with a reduction in the final particle size (Kratky and Jirout, 2014). Specific energy requirement (SER) for size reduction of LCB depends on the ratio of particle size distribution of the materials before and after milling, in which it depends strongly on the equipment or machines used.

Meanwhile, drying is a process that reduces the moisture content of a feedstock via drying medium. There are various types of dryer in the industry, including rotary dryer, flash dryer, belt dryer, etc. The uses of different drying mediums (e.g., hot air, flue gas, etc.) and the number of stages (e.g., single pass, three passes, etc.) imply different energy consumption of the dryer. The performance of a dryer can be usually expressed in term of moisture removal ratio (i.e. discharge moisture/ feed moisture).

Based on the above discussions, among these four groups of lignocellulosic pre-processing technologies, *comminution* and *drying* are normally required as the pre-processing system of thermochemical biorefinery. Meanwhile, comminution, pre-treatment and hydrolysis are normally required for biochemical biorefinery. Figure 2.2 shows a set representation of these lignocellulosic biomass pre-processing technologies.

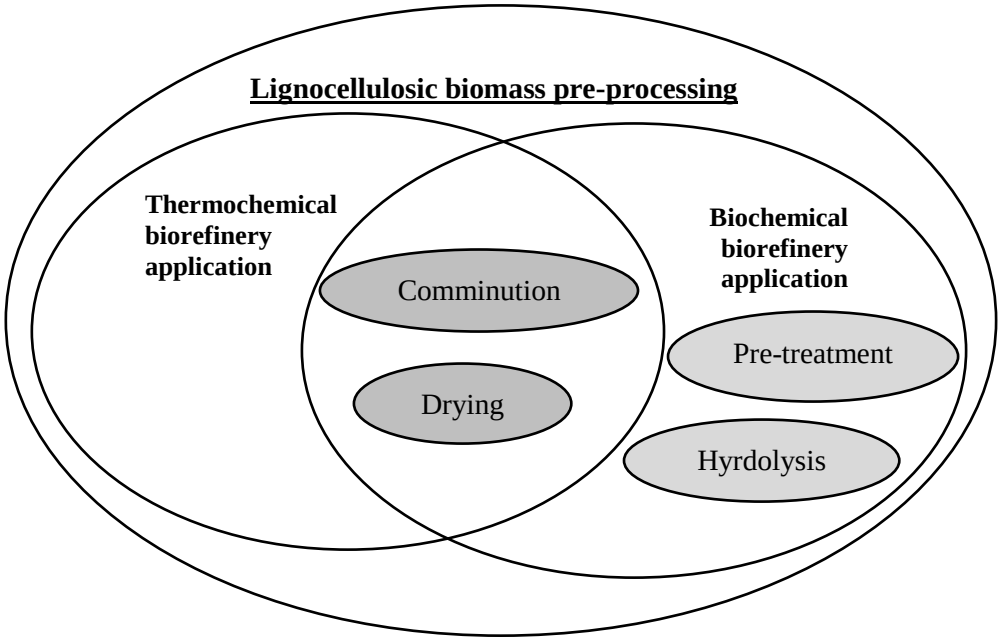


Figure 2. 2: Set representation of lignocellulosic biomass pre-processing

As mentioned previously, biorefinery employs a range of biomass processing technologies to produce multiple products via different type of biomass feedstocks. Since biomass is available in different forms and characteristics, the biomass needs to be pre-processed before it can be converted into value-added products. As such there is a need to systematically screen and determine the optimum pathways. Thus, a systematic process synthesis tool is needed.

2.4 Process synthesis in process design

Generally, process synthesis is defined as "an act of determining the optimal interconnection of processing units as well as the optimal type and design of the units within a process system" (Nishida et al., 1981). In other words, process synthesis is concerned with the activities in which various process elements (e.g., process operation

units) are combined to meet certain processing objectives (El-Halwagi, 1997). Process synthesis problem typically can be represented by Figure 2.3. In such regards, one of the key features of process synthesis is its ability to screen all potential pathways and determine the optimum one that can produce the desired outcome.

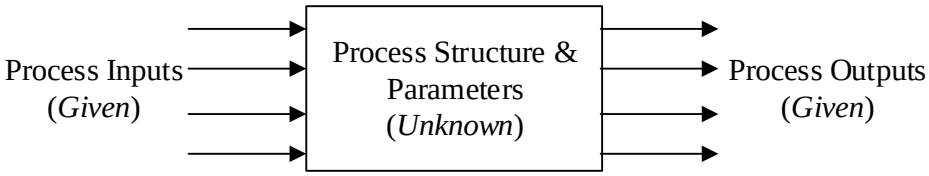


Figure 2. 3 Graphical representation of process synthesis problem (El-Halwagi, 1997)

Over the past few decades, extensive developments have been observed in the area of process synthesis (see works of Hendry et al. (1973), Seider et al. (2004), Kemp (2006), etc.) A relatively new field, namely Process Systems Engineering (PSE) has been established and it is proven to be useful in aiding the process synthesis activities.

Process Systems Engineering (PSE) is a field that comprises the activities involved in the engineering of systems involving physical, chemical, and/or biological processing operations (Stephanopoulos and Reklaitis, 2011). Pioneering work in PSE was initiated by Roger Seargent since early 1960s, in which his works have virtually covered most areas of PSE, such as mathematical process modelling, analysis, and numerical simulation; systematic methods for process synthesis and design; optimisation theories, numerical methods; and process control (Stephanopoulos and

Reklaitis, 2011). PSE is concerned with the development of techniques and tools to address the generic manufacturing problems of design, operation and control for the process industries. Consequently, PSE can provide different systematic approaches to address the synthesis of chemical process in an integrated manner.

Based on various literatures (e.g., Grossmann and Daichendt (1996), Barnicki and Siirola (2004), Li and Kraslawski (2004), Westerberg (2004), etc.), PSE approaches for process synthesis can be generally categorised as followed:

1) Heuristic-based approaches
2) Insight-based approaches
3) Mathematical optimisation/ Mathematical Programming based approaches
4) Hybrid approaches
5) Miscellaneous approaches

Heuristic approaches use rules that are derived from engineering knowledge and experience to generate a good base case design (Stephanopoulos and Han, 1996). Subsequently modification can also be performed to the developed base case to improve its performance. On the other hand, heuristic approach is usually sequential in nature. One of the most well-known heuristic approaches in conventional chemical process synthesis is the *hierarchical decomposition approach*, which is proposed by Douglas (1985; 1988).

In contrast with heuristic approach, insight-based approaches are usually developed by studying or analysing the thermodynamic of the system. As a result, these approaches thus usually provide physical insights to acquire a better understanding of the considered system. Similar with heuristic approach, insight-based approach is also often sequential. One of the most prominent representative of insight-based approaches in chemical process synthesis and design is pinch analysis (e.g., Linnhoff and Flower (1978), Umeda et al. (1978), Papoulias and Grossmann (1983a), Papoulias and Grossmann (1983b), Linnhoff (1993)). Apart from that, other insight-based approaches include graphical approaches, distillation residue curve maps, etc.

Mathematical optimisation approaches (also known as mathematical programming based approaches) formulate synthesis problems as mathematical models. Such model is a mathematical representation of synthesis problem and is generally solved by searching for a solution that minimises (or maximises) an objective function or the optimisation criterion (Grossmann and Daichendt, 1996). By using mathematical optimisation, one can consider and regard multiple aspects of the problem in terms of mathematical model equations. Consequently, it is a much more comprehensive approach as compared with heuristics and insight-based approaches. Based on the formulation due to different cases or scenarios, these mathematical optimisation models can range from relatively straight-forward linear programming (LP) to the increasingly complex mixed-integer linear programming (MILP), non-linear programming (NLP) and mixed-integer non- linear programming (MINLP) which depict real life scenario more accurately (Grossmann, 2002).

It is noted that each of the abovementioned approach has its exclusive pros and cons. For example, heuristic approach is not directly applicable to synthesizing a novel and complex processes such as integrated biorefinery. On the other hand, as heuristic approach is sequential in nature, it cannot guarantee an optimum solution but rather a near optimum solution because of its sequential decomposition strategy (Caballero et al., 2007). This limitation is also applied for insight-based approaches. On the other hand, insight based approaches can only consider limited parameters. Meanwhile, mathematical optimisation approaches require further advances in area like global optimisation (Caballero et al., 2007). Therefore, recent trend of using combination of these approaches has also been observed in PSE. For examples, Automated Targeting Model (ATM) that combines insight-based cascade analysis and mathematical optimisation model is proposed (e.g., El-Halwagi and Manousiouthakis (1990), Ng et al. (2009a, 2009b), a framework that combines hierarchical approach and mathematical programming to synthesise a large chemical process (Daichendt and Grossmann, 1998). Note also that there are also some approaches that are not belong to the abovementioned categories, in which they are grouped under a category named "Miscellaneous approaches". For instance, Graph-theoretic approaches such as P-graph and S-graph (Friedler et al., 1992).

On the other hand, Kokossis and Yang highlighted that PSE approaches can be used to enhance the screening capabilities in the synthesis of biorefinery and/or integrated biorefinery (Kokossis and Yang, 2010). PSE is also useful in supporting the synthesis and design of biorefinery. The following Section 2.5 thus provides a review

on the frameworks and PSE approaches which have been proposed and developed for the synthesis and design of biorefinery (or integrated biorefinery).

2.5 Process synthesis and design of biorefinery

In a biorefinery or integrated biorefinery, several technological processess must be jointly applied to convert biomass into various valuable products. On the other hand, a sustainable biorefinery should achieve different levels of mass and heat integrations. In order to systematically synthesise and design a sustainable integrated biorefinery, significant amounts of research works have been conducted with the aids of PSE and current established knowledges in process synthesis.

On the other hand, there are also some works reported which aim to provide a framework for integrated biorefinery synthesis and design. They are not categorised as any type of PSE approaches which have been mentioned in Section 2.4. For example, Sammons et al. (2007) and Sammons et al. (2008) presented a general and systematic framework for optimising product portfolio and process configuration in integrated biorefinery. This framework enables the inclusion of profitability measures and other techno-economic metrics along with process insights obtained from experimental as well as modelling and simulation studies. Additionally, Sammons et al. (2009) proposed a framework to determine the most optimal route based on measures of economic and environmental performances for an integrated biorefinery. It uses gross profit and net present value as economic metrics in the short term and long term respectively, while environmental impact is evaluated by using the waste reduction

algorithm. Top candidates in economic and environmental performance are then subjected to process integration techniques to further minimise mass and energy usage. On the other hand, Ng et al. (2009c) proposed a hierarchical framework for synthesis and analysis of an integrated biorefinery.

Other that the abovementioned works, the works which are based on PSE approaches for integrated biorefinery are now discussed. However, it should be pointed out that these reported works do not only focus on addressing process synthesis related problems of integrated biorefinery. On the other hand, some of them also focus on providing systematic solutions to address other different challenges that emerge during planning and realisation of sustainable integrated biorefinery. These works have been summarised in Tables 2.2a-2.2h based on the types of PSE approach employed, as well as their scopes of study. On the other hand, brief overview of each work is also included in Tables 2.2a- 2.2h.

Table 2.2a: Summary of PSE approaches for synthesis and design of biorefinery and/or integrated biorefinery

Authors and year	Types of PSE approach	Study Scopes			
		Brief Overview	Aspects of considerations		
			Economic	Environmental	Others
Elms and El-Halwagi (2009)	Mathematical Optimisation	Model for scheduling and operation of flexible biodiesel plant, accommodating a variety of feedstocks.	✓	✓	Process scheduling, multiple feedstocks
Tan et al. (2009)	Mathematical Optimisation	Methodology for optimising multifunctional biofuel systems	✓	✓	Land-use footprint
Gassner and Maréchal (2009)	Mathematical Optimisation	Methodology for optimal conceptual design of thermochemical fuel production processes from biomass	✓		
Zamboni et al. (2009a), Zamboni et al. (2009b)	Mathematical Optimisation	Framework for the optimal conceptual design of biomass thermochemical fuel production	✓	✓	
Elms and El-Halwagi (2010)	Mathematical Optimisation	Systematic approach for design and scheduling of biodiesel production processes	✓	✓	Multiperiod

Table 2.2 b: Summary of PSE approaches for synthesis and design of biorefinery and/or integrated biorefinery (continued)

Authors and years	Types of PSE approach	Study Scopes			
		Brief Overview	Aspects of considerations		
			Economic	Environmental	Others
Pokoo-Aikins et al. (2010a)	Mathematical Optimisation	Systematic procedure with detailed economic analysis and a safety evaluation for sewage sludge-to-biodiesel process	✓		Safety
Pokoo-Aikins et al. (2010b)	Mathematical Optimisation	Design and techno-economic analysis for production of biodiesel from algal oil produced via sequestration of carbon dioxide from the flue gas of a power plant	✓		Techno-economic analysis
Hechinger et al. (2010)	Mathematical Optimisation	Approach to identify optimal molecular structures of biofuel and screen for the production pathway of the biofuel	✓		Reaction network/ Reaction Pathway
Bao et al. (2011)	Mathematical Optimisation	Shortcut approach for synthesis and screening of integrated biorefineries	✓		
Zondervan et al. (2011)	Mathematical Optimisation	Model for finding the optimal processing route for multi-product biorefinery system	✓		

Table 2.2c: Summary of PSE approaches for synthesis and design of biorefinery and/or integrated biorefinery (continued)

Authors and years	Types of PSE approach	Study Scopes			
		Brief Overview	Aspects of considerations		
			Economic	Environmental	Others
Tay et al. (2011c)	Mathematical Optimisation	Approach to synthesise a sustainable integrated biorefinery	✓	✓	
Tay et al. (2011a)	Mathematical Optimisation	Approach to link a stoichiometric equilibrium model of biomass gasification and structural models of synthesis processes for gasification-based integrated biorefinery	✓		
Martín and Grossmann (2011a), Martín and Grossmann (2012)	Mathematical Optimisation	Two different works to address conceptual design of the bioethanol process from switchgrass via gasification and hydrolysis, respectively.	✓		
Martín and Grossmann (2011b)	Mathematical Optimisation	A model to address conceptual design and process optimisation of the FT-diesel process from switchgrass via gasification.	✓		

Table 2.2d: Summary of PSE approaches for synthesis and design of biorefinery and/or integrated biorefinery (continue)

Authors and years	Types of PSE approach	Study Scopes			
		Brief Overview	Aspects of considerations		
			Economic	Environmental	Others
Santibañez-Aguilar et al. (2011)	Mathematical Optimisation	A model for the optimal planning of a biorefinery	✓	✓	Selection of feedstocks
Pham and El-Halwagi (2012)	Mathematical Optimisation	A two-stage approach to the synthesis and optimisation of biorefinery configurations	✓		
Voll and Marquardt (2012)	Mathematical Optimisation	A screening approach to bridge the gap between chemo- or biocatalysis and process design.	✓		Reaction pathway
Ponce-Ortega et al. (2012)	Mathematical Optimisation	An approach for the design of optimal pathways for a biorefinery	✓		
Ng et al. (2012)	Mathematical Optimisation	An approach to address the problem of simultaneous process synthesis, heat and power integration of an integrated biorefinery	✓		

Table 2.2e: Summary of PSE approaches for synthesis and design of biorefinery and/or integrated biorefinery (continue)

Authors and years	Types of PSE approach	Study Scopes			
		Brief Overview	Aspects of considerations		
			Economic	Environmental	Others
Tay et al. (2013)	Mathematical Optimisation	An approach for the synthesis of integrated biorefineries that deal with uncertainties in raw material supply and product demand	✓		Uncertainties in supply and demand
Tang et al. (2013)	Mathematical Optimisation	A model to determine the optimum biomass process network	✓		Uncertainties in supply and demand
Marvin et al. (2013)	Mathematical Optimisation	A strategy that identifies the optimal biomass derived products and corresponding synthesis routes	✓		
Baliban et al. (2013)	Mathematical Optimisation	A framework for thermochemical conversion of biomass to liquid fuels	✓	✓	
Murillo-Alvarado et al. (2013)	Mathematical Optimisation	A systematic approach to identify the optimal pathway configurations of a biorefinery	✓	✓	
Ng et al. (2013)	Mathematical Optimisation	An approach for the synthesis and optimisation of a sustainable integrated biorefinery	✓	✓	Inherent safety, occupational health

Table 2.2f: Summary of PSE approaches for synthesis and design of biorefinery and/or integrated biorefinery (continue)

Authors and years	Types of PSE approach	Study Scopes			
		Brief Overview	Aspects of considerations		
			Economic	Environmental	Others
Martinez-Hernandez et al. (2013)	Mathematical Optimisation	Economic value and environmental impact analysis to conceptually optimises the environmental and economic performances of biorefinery systems	✓	✓	
Baliban et al. (2013)	Mathematical Optimisation	A framework for the production of gasoline, diesel and jet fuel from hardwood biomass, as well as addressing the supply chain problem for the thermochemical biorefinery	✓		Suppy chain
Wang et al. (2013)	Mathematical Optimisation	A model for design of hydrocarbon biorefineries via gasification pathway	✓	✓	
Gebreslassie et al. (2013b)	Mathematical Optimisation	A model for design of algae-based hydrocarbon biorefinery with sequestration of CO_2 from power plant flue gas	✓	✓	

Table 2.2g: Summary of PSE approaches for synthesis and design of biorefinery and/or integrated biorefinery (continue)

Authors and years	Types of PSE approach	Study Scopes			
		Brief Overview	Aspects of considerations		
			Economic	Environmental	Others
Gebreslassie et al. (2013a)	Mathematical Optimisation	A model to address the optimal design and operation of hydrocarbon biorefinery via fast pyrolysis, hydrotreating and hydrocracking of hybrid feedstock	✓	✓	
Kelloway and Daoutidis (2014)	Mathematical Optimisation	A model to design a biorefinery process with the goal of finding products and processing technologies	✓	✓	
Cheali et al. (2014a)	Mathematical Optimisation	An approach for the design of an integrated thermochemical and biochemical biorefinery	✓	✓	
Gong and You (2014a)	Mathematical Optimisation	A model for sustainable design and synthesis of a large-scale algae processing network	✓	✓	
Cheali et al. (2014b)	Mathematical Optimisation	A framework for identifying optimal biorefinery concepts for production of biofuels at an early design stage	✓	✓	Uncertainy in market price

Table 2.2h: Summary of PSE approaches for synthesis and design of biorefinery and/or integrated biorefinery (continue)

Authors and years	Types of PSE approach	Study Scopes			
		Brief Overview	Aspects of considerations		
			Economic	Environmental	Others
Gong and You (2014b)	Mathematical Optimisation	A model of algal biorefinery processes for biological carbon sequestration and utilisation	✓		
Andiappan et al. (2015)	Mathematical Optimisation	Approach to synthesise a sustainable integrated biorefinery	✓	✓	
Tay et al. (2011b)	Insight-based approach	Approach for the evaluation of gas phase equilibrium composition in biomass gasification	✓		
Ng (2010), Tay and Ng (2012)	Combination of mathematical optimisation & insight-based approach	Approach to determine the maximum biofuel production and revenue levels in an integrated biorefinery and the maximum economic performance of a gasification-based integrated biorefinery prior to detail design	✓		
Shabbir et al. (2012)	Combination of mathematical optimisation & insight-based approach	A hybrid approach for synthesis of a sustainable integrated biorefinery	✓	✓	

As shown in Tables 2.2a to 2.2h, most of the works are using mathematical optimisation for design and synthesis of different types of biorefinery and integrated biorefinery One of the main reasons by using mathematical optimisation is the flexibilty to model the process and can consider different aspects such as economic analysis (e.g., Gassner and Marechal (2009), Bao et al. (2011), Zondervan et al. (2011), etc) , safety considerations (e.g., Pokoo-Aikins et al. (2010a), Ng et al. (2013)), environmental impact (Elms and El-Halwagi (2009), Zamboni et al. (2009a), Tay et al. (2011c)). Some of the works also consider these aspectes simultaneously by using various multi-objective optimisation techniques, such as, fuzzy optimisation (Tan et al. 2009), pareto optimisation (Cheali et al. 2014a). Note that most of the mathematical optimisation approaches listed in Tables 2.2a-2.2h normally involves development of superstructures together with mathematical model for the problem, as well as model solving to determine a best solution. Meanwhile, some works focus on developing rigorous mathematical models that consider detailed mass and energy balances (e.g. Martin and Grossmann (2011a), Martin and Grossmann (2012)).

Other than mathematical optimsiation approaches, insight-based approaches for synthesis and design of biorefinery are also presented (Tay et al. (2011b)). In constrast with mathematical optimisation approaches, insight-based approaches can only consider single aspect which is usually economic aspect. However, it is noted that insight-based approach provides useful information (i.e., pinch point) of the design problem. Futhermore, in order to utilise the advantanges of both mathematical optimisation appraoch and insight-based appraoch, Automated Targeting Model has

been presented (Ng (2010), Tay and Ng (2012). On the other hand, it is also noted that most of the works listed in Tables 2.2a-2.2h are developed for thermochemical biorefinery applications (e.g. Zamboni et al. (2009a), Zamboni et al. (2009b), Tay et al. (2011a), Martin and Grossmann (2011b), Baliban et al. (2013), etc).

2.6 Conclusion

Biorefinery is a renewable alternative to conventional refineries and it is envisioned to utilise biomass as a renewable feedstock to produce biofuels and chemicals. Lignocellulosic biomass is one of the most studied biomass. Meanwhile, there are a number of biomass processing technologies for converting biomass feedstocks to value-added products. In such regards, process synthesis is required to systematically screen all and determine the optimum biomass processing technologies to produce particular products from certain biomass. On the other hand, ever since the pioneer works of process synthesis, there are numerous PSE approaches have been developed to assist in the process synthesis activity. Thus, PSE approaches are ideally suited to tackle problems related to synthesis and design of biorefinery. Based on the review, significant amount of research works have been carried out in the area of synthesis and design of integrated biorefinery. As shown in Section 2.5, different mathematical optimisation approaches have been presented to address process synthesis related problems for various types of biorefinery and integrated biorefinery, as well as other concerning issues associated to planning and realisation of biorefinery and/or integrated biorefinery.

On the other hand, as mentioned previously, a sustainable biorefinery or integrated biorefinery must able to depolymerise target macromolecules (e.g. biomass) to intermediates which match with the specifications of further processing steps, as well as to maximise the yield and quality of the target products (Fernando et al., 2006). In order to meet these criteria, biomass must first undergo different pre-processing processes in the biorefinery. In such regards, biomass pre-processing system is particularly one of the most important steps in biorefinery as it will affect the yield and efficiency of subsequent processing. To date, there is no systematic framework and approach based on PSE to optimise the biomass pre-processing systems for the application of biorefinery. Meanwhile, LCB is getting a lot of attention and thermochemical biorefinery is the main biorefinery of interest in this work as mentioned previously. Therefore, this research work aims to propose systematic approach for the synthesis and optimisation of lignocellulosic biomass pre-processing system in a thermochemical biorefinery.

CHAPTER 3

RESEARCH SCOPES AND METHODOLOGIES

3.1 Research Scopes

Based on the identified research gaps, this research work intends to synthesise and optimise a lignocellulosic biomass pre-processing system (LCBPS) in a thermochemical biorefinery. In other words, in this work, a systematic approach is needed for synthesis and optimisation of LCBPS in a thermochemical biorefinery. The systematic approach should help to simultaneously identify which appropriate technologies to be included and determine their important operating parameters (such as size reduction ratio and moisture removal ratio).

It is also important to point out that there might be interactions between these pre-processing technologies. For example, the optimal performance of a size reduction machine can be affected by the inlet moisture content and inlet size of the LCB. Often, the sequences of the pre-processing technologies are important (e.g. in the aforementioned case, it might be better for either drying comes first or size reduction comes first, or vice versa). In such regards, the systematic approach should also assist

to determine the sequence of the selected technologies as well. Therefore, based on the above discussions, three research scopes of this work are summarised as below:

i) To identify appropriate lignocellulosic biomass pre-processing technologies to be included in LCBPS of a thermochemical biorefinery

ii) To identify key operating parameters of lignocellulosic biomass pre-processing technologies in LCBPS of a thermochemical biorefinery

iii) To identify sequence of the lignocellulosic biomass pre-processing technologies in LCBPS of a thermochemical biorefinery.

In the following Section 3.2, a methodology is outlined to discuss how the research work is carried out in order to achieve the objective, in which all of the abovementioned scopes can be fulfilled.

3.2 Research Methodology

The research methodology of this research work is summarised in Figure 3.1. As shown, literature regarding to the previous works related to process synthesis and design, process synthesis and design of biorefinery or integrated biorefinery, and other related key topics are firstly reviewed. The summary of literature review is given in Chapter 2. Next, based on the literature review, the research gaps are identified in Chapter 3. Additionally, research scopes are also highlighted in Chapter 3.

Based on the identified research scopes and literature review in Chapter 2, a systematic approach is proposed in Chapter 4 to synthesise and optimise LCBPS for a thermochemical biorefinery. Note that the approach is mainly developed based on the concept of superstructure-based mathematical optimisation approach.

On the other hand, it is important to note that the process of literature review is continuous even though the research gaps have been identified. In such contexts, focus is given to collect relevant information which are required to conduct model development and model validation. After the model is developed, an example is formulated and solved in Chapter 4 to validate the applicability of the systematic approach.

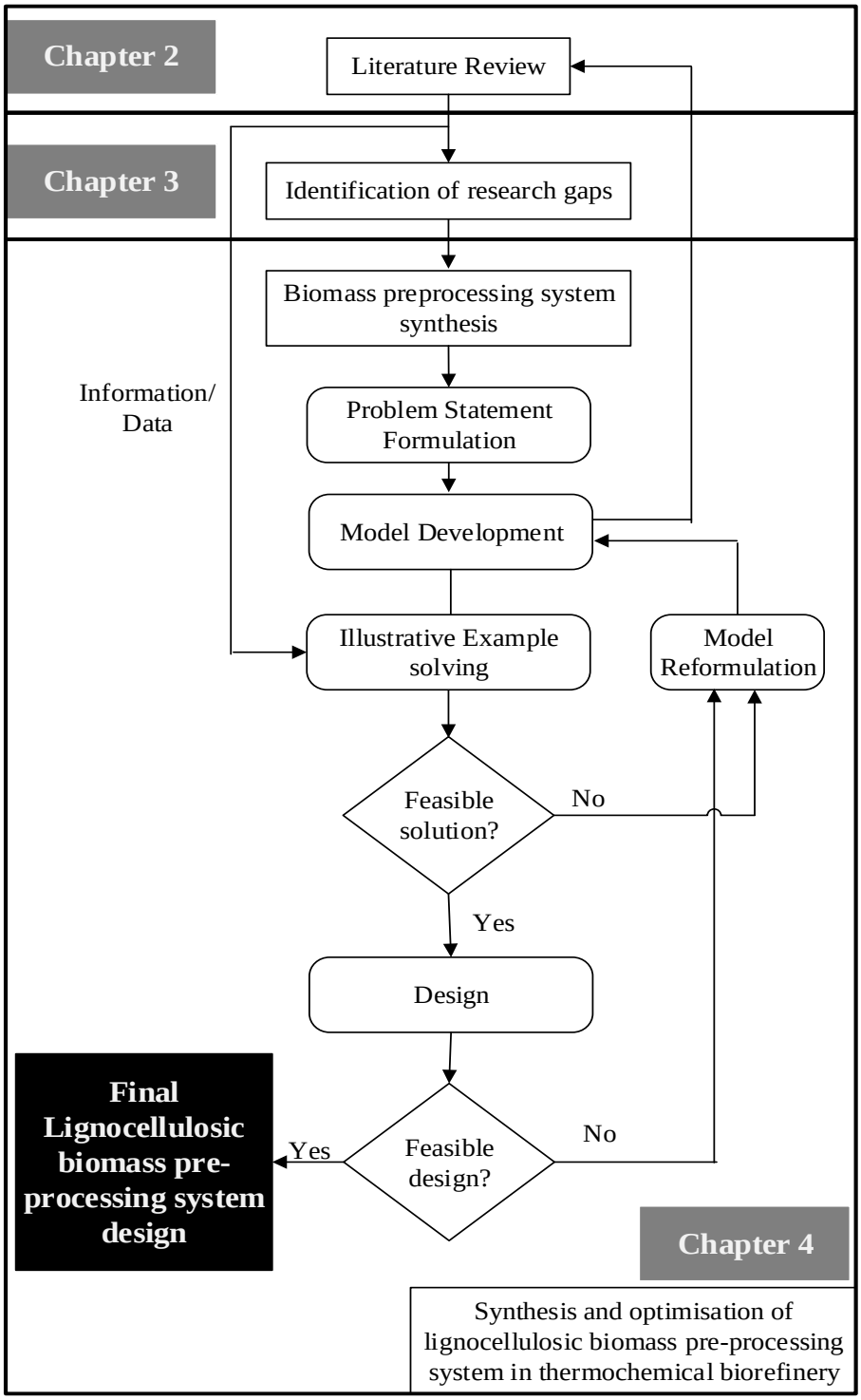


Figure 3.1 Research Methodology

CHAPTER 4

SYNTHESIS AND OPTIMISATION OF A LIGNOCELLULOSIC BIOMASS PRE-PROCESSING SYSTEM IN A THERMOCHEMICAL BIOREFINERY

4.1 Introduction

Based on the identified research gaps in Chapter 2, it is shown that less work has been conducted to synthesis and optimise a biomass pre-processing system. Additionally, as discussed in Chapter 2, mathematical optimisation approach is widely utilised to assist in developing approaches and tools during synthesis and design of biorefinery/ integrated biorefinery. Thus, in this chapter, a superstructural based mathematical optimisation approach is proposed to synthesise and optimise the biomass pre-processing system of a thermochemical biorefinery.

In this chapter, Section 4.2 introduces the generic problem statement of the work in which a superstructure is developed and shown. Next, a mathematical optimisation model is developed in accordance to the developed superstructure. Finally, in order to illustrate the applicability of the approach, an illustrative example based on palm-based biomass is solved in Section 4.3.

4.2 Problem Statement

In this work, generic problem statement for the synthesis of a lignocellulosic biomass pre-processing system (LCBPS) of a thermochemical biorefinery can be stated as follows: Lignocellulosic biomass *b* with available flow rate $F_b^{AVAILABLE}$ has a nominal particle size of S_b. Meanwhile, its compositions of cellulose, hemicellulose, lignin and water are given as X_b^C, X_b^{HC}, X_b^L and X_b^W respectively. The lignocellulosic biomass *b* can be pre-processed through a lignocellulosic pre-processing technology set *i* to produce either biomass intermediate *k* and/ or bio-precursor *p*. Note that as discussed previously in Chapter 2, for thermochemical biorefinery application, only drying and comminution pre-processing technologies are required. Hence, the generic technology set *i* includes lignocellulosic biomass drying technology *d* and lignocellulosic biomass comminution technology *c* i.e. $i \in \{d, c\}$.

The lignocellulosic biomass intermediate *k* is then be further pre-processed through second similar pre-processing technology set *i* or more, in order to produce the bio-precursor *p*. It is important to note that at least one lignocellulosic biomass pre-processing technology set *i* is usually required (i.e. $i_{N=1}$). Figure 4.1 shows the generic super-structural representation of the LCBPS in a thermochemical biorefinery.

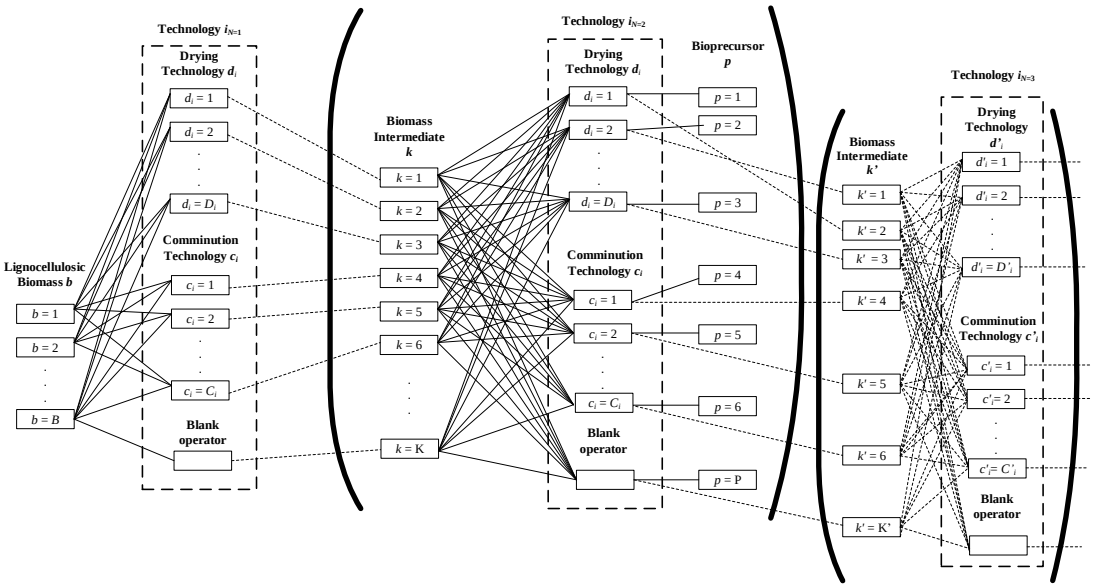


Figure 4.1: Generic super-structural representation of lignocellulosic biomass pre-processing system for thermochemical biorefinery

Meanwhile, in case that the bio-precursor *p* can be directly produced via just the lignocellulosic biomass pre-processing technology in the technology set *i*, no secondary technology set *i* (i.e. $i_{N=2}$) or more (i.e. $i_{N>=2}$) is required to further pre-process biomass intermediate *k* to bio-precursor *p*. In such regards, after the first technology set $i_{N=1}$, the lignocellulosic biomass *b* is allowed to by-pass a "blank" technology in second technology set *i* (i.e. $i_{N=2}$) to produce bio-precursor *p*, as shown in Figure 4.1. On the other hand, there might be a special case that the raw lignocellulosic biomass *b* can directly be used as bio-precursor *p*. In such regards, the lignocellulosic biomass *b* is allowed to by-pass a "blank" technology in the first technology set $i_{N=1}$ and then again by-pass another "blank" technology in second technology set $i_{N=2}$ to produce bio-precursor *p*, as shown in Figure 4.1.

Note that, the repetition of the actions that describe "intermediate *k* to be further pre-processed through another technology set *i*" is represented by using a bracket, as shown in Figure 4.1. In such contexts, the elements that are included in the bracket are biomass intermediate *k*, technology set *i*, and bio-precursor *p*. For instance, in case that two technology set *i* are required, after the first technology set *i* (i.e. $i_{N=1}$), another second technology set *i* (i.e. $i_{N=2}$) is repeatedly included to pre-process the produced biomass intermediate *k*, until the bio-precursor *p* is finally produced.

The generic idea of the problem statement is graphically summarised in Figure 4.2. As shown, lignocellulosic biomass *b* can be pre-processed through drying and comminution pre-processing technologies (i.e. first set of technologies). If the outlets from the technologies do not meet the requirements of the desired bio-precursor *p*, they are then allowed to go through another set of technologies until the desired bio-precursor is produced. Conversely, as shown in Figure 4.2, the outlets from the technologies can also go through a blank technology. For example, if the biomass intermediate is dry enough and tiny enough to not to go through another dryer and comminution machine respectively, the intermediate is then allowed to pass through a blank technology. Note that a LCBPS includes more pre-processing technology sets if it is necessary. In general, the total number of pre-processing set to be considered and included in the superstructure can be firstly and theoritically targeted, in which it will be discussed next in Section 4.3.

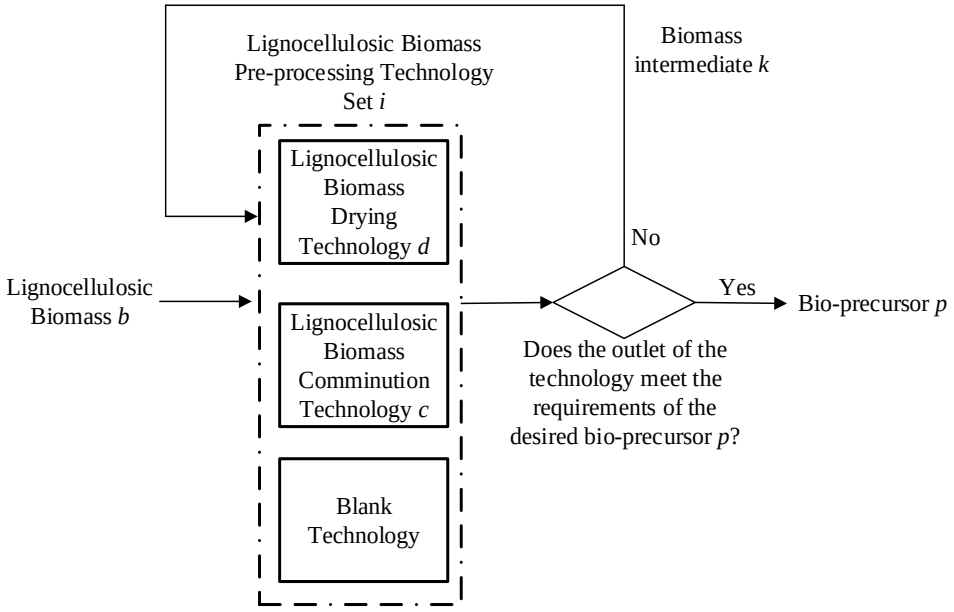


Figure 4.2: Graphical representation of the problem statement

Last but not least, the objective of this work is to develop a systematic optimisation approach to determine the types, important operating parameters (e.g. size reduction ratio and moisture reduction ratio) and sequences of the pre-processing technologies to be considered in a LCBPS for a thermochemical biorefinery. This work employs a super-structural based mathematical optimisation approach, in which development of the mathematical model is discussed in next Section 4.3.

4.3 Model Formulation

In order to gradually demonstrate how the mathematical optimisation model is developed, a two-stages biomass pre-processing system is considered for illustration.

In other words, a scenario in which the lignocellulosic biomass *b* is required to be pre-processed through two consecutive and similar technology sets is considered. Note that, for the ease of explanation, the two consecutive technologies set *i* are termed as first technology set *i* and second technology set *i*'. Figure 4.3 presents a revised super-structural representation for the illustration of this scenario. As shown in Figure 4.3, the lignocellulosic biomass *b* is pre-processed via first technology set *i* to produce biomass intermediate *k*, followed by another second technology set *i*' to produce bio-precursor *p*. Next, the mathematical optimisation model is described for this scenario.

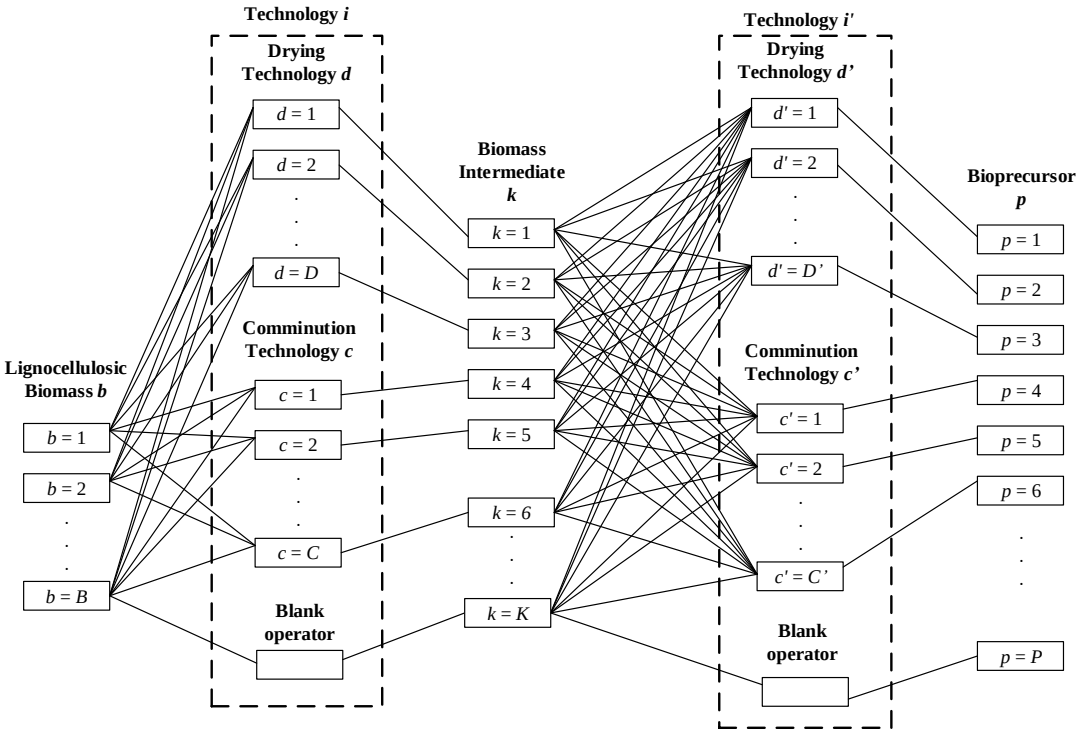


Figure 4.3: Super-structural representation of two-stage lignocellulosic biomass pre-processing system

First, each lignocellulosic biomass *b* with flow rate of F_b can be pre-processed via first technology set *i* with flow rate of F_{bi}, as denoted by Equation 1. Note that the flow rate of the lignocellulosic biomass *b* should not exceed an available flow rate ($F_b^{AVAILABLE}$), as shown in Equation 2.

$$F_b = \sum_i F_{bi} \qquad \forall b \qquad (1)$$

$$F_b \le F_b^{AVAILABLE} \qquad \forall b \qquad (2)$$

Next, the inlet flow rate to each technology in technology set *i*, F_i^{IN} can be determined via Equation 3.

$$F_i^{IN} = \sum_b F_{bi} \qquad \forall i \in d, c \qquad (3)$$

The composition balances (i.e., cellulose, hemicellulose, lignin and water balances) of the lignocellulosic biomass *b* fed to each technology in technology set *i* are shown in Equations 4. Note that C, HC, L and W in the equation denote cellulose, hemicellulose, lignin and moisture respectively.

$$\sum_b F_{bi} X_b^Z = F_i^{IN} X_i^Z \qquad \forall i \in d, c \qquad \forall Z \in C, HC, L, W \qquad (4)$$

where X_i^Z is the composition of the inlet feed to each technology *i* respectively. It is important to point out that the blank technology is also considered as one of the technologies in the technology set *i*. Even though the lignocellulosic biomass *b* does not experience any changes as it passes through the blank technology; however, the

material balances are also considered. Thus, the material balances equations (i.e. Equations 1 and 4) are also applicable to the blank technology.

On the other hand, Equation 5 is included to determine the existence of technology *i* in the LCBPS. Big-M formulation is used in this work, as shown in Equation 5, where I_i are binary integers of the technologies in technology set *i*. The Big-M formulation is a type of simplex algorithm by associating the constraints with large negative constants which would not be part of any optimal solution if it exists (El-Halwagi, 2012). In other words, by using Big-M-formulation, the binary integer will take the form of "1" if the corresponding technology is used and "0" if the corresponding technology is not used.

$$F_i^{\mathrm{IN}} \le (\sum_b \mathrm{F}_b^{\mathrm{AVAILABLE}}) I_i \qquad \forall i \in d,c \qquad (5)$$

Meanwhile, in this work, each technology in technology set *i* has a range of allowable inlet feed's moisture content (governed by a lower limit $\mathrm{X}_i^{\mathrm{W,\,LL}}$ and an upper limit $\mathrm{X}_i^{\mathrm{W,\,UL}}$) and nominal particle size (governed by a lower limit $\mathrm{S}_i^{\mathrm{LL}}$ and an upper limit $\mathrm{S}_i^{\mathrm{UL}}$), as shown in Equations 6 and 7. For the ease of explanation, these aforementioned allowable inlet's properties are termed as moisture content's limitation and nominal particle size's limitation in the later texts.

$$\mathrm{X}_i^{\mathrm{W,\,LL}} I_i \le X_i^{\mathrm{W}} I_i \le \mathrm{X}_i^{\mathrm{W,\,UL}} I_i \qquad \forall i \in d,c \qquad (6)$$

$$\mathrm{S}_i^{\mathrm{UL}} I_i \le S_i I_i \le \mathrm{S}_i^{\mathrm{UL}} I_i \qquad \forall i \in d, c \qquad (7)$$

where S_i is the nominal particle size of the inlet feed to technology *i*.

It is important to point out that a particular technology *i* is only selected if all the properties (i.e. moisture content and nominal particle size) of the inlet is within the allowable limit of the technology *i*. For example, if all the properties of inlet to a particular technology *i* are within the limitation, I_i takes the form of "1", i.e. technology *i* exists). Conversely, if either one of the properties of inlet does not fall within the acceptable limit, I_i then takes the form of "0" (i.e. technology *i* is not chosen and thus does not exist).

Next, the material balances across technology *i* are now discussed. Since technology set *i* only consists of drying technologies and comminution technologies, after the inlet is fed to a technology in technology set *i*, it does not experience changes in its cellulose, hemicellulose and lignin. In such regards, Equation 8 is included.

$$F_i^{\mathrm{OUT,Z}} = F_i^{\mathrm{IN}} X_i^{\mathrm{Z}} \qquad \forall i \in d, c \qquad \forall \mathrm{Z} \in \mathrm{C, HC, L} \qquad (8)$$

Note that Equation 8 is also applicable to the blank technology since there is no compositional changes in the inlet before entering and after exiting the blank technology.

On the other hand, the amount of water in the outlet of the technology *i*, $F_i^{\mathrm{OUT,\,M}}$ can be calculated according to moisture removal ratio MRR_i of the technology in technology set *i*, as shown in Equation 9. Note that in this work, MRR_i is defined as the *ratio of the moisture removed by the technology to the moisture in the inlet feed*. Thus, $F_i^{\mathrm{OUT,\,W}}$ can be calculated by using Equations 10, where F_i^{MR} is the moisture that is removed by the technology in technology set *i*. In case that a technology in technology set *i* does not remove any moisture, the MRR_i is set to zero. Note that, Equations 9 and 10 are also applicable to the blank technology.

$$F_i^{\mathrm{MR}} = F_i X_i^{\mathrm{Z}} \mathrm{MRR}_i \qquad \forall i \in d, c \qquad \mathrm{Z} = \mathrm{W} \tag{9}$$

$$F_i^{\mathrm{OUT,\,Z}} = F_i X_i^{\mathrm{Z}} - F_i^{\mathrm{MR}} \qquad \forall i \in d, c \qquad \mathrm{Z} = \mathrm{W} \tag{10}$$

Meanwhile, for the case of a two-stages pre-processing system, an individual biomass intermediate *k* is produced from technology *i* (i.e. *i* = *k*), as shown in Figure 3. In such regards, the flow rate of biomass intermediate *k* (F_k) can be calculated by Equation 11.

$$F_k = \sum\nolimits_{\mathrm{Z}} F_i^{\mathrm{OUT,\,Z}} \qquad \forall i = k \qquad \forall \mathrm{Z} \in \mathrm{C}, \mathrm{HC}, \mathrm{L}, \mathrm{W} \tag{11}$$

Additionally, the compositions of biomass intermediate *k* can be calculated by Equations 12.

$$X_k^{\mathrm{Z}} = \frac{F_i^{\mathrm{OUT,\,Z}}}{F_k} \qquad \forall i = k \qquad \forall \mathrm{Z} \in \mathrm{C, HC, L, W} \qquad (12)$$

where X_k^{Z} is the compositional content of biomass intermediate *k*. Note that Equation 12 is also applicable for the case of blank technology, in which a biomass intermediate *k* is also generically considered to be produced.

On the other hand, a technology in technology set *i* might able to reduce the size of the inlet feed (i.e. comminution technology) based on the given size reduction ratio SRR_i. In this work, SRR_i is defined as the *ratio of inlet feed's nominal particle size to the outlet's nominal size*. As the nominal particle size is not a conserved term, unlike the conventional material balances, in order to "keep track" on the nominal particle size of the inlet feed, a new modelling technique is presented.

As mentioned previously, most of the lignocellulosic biomass *b* do not have a standardised nominal particle size. For cases of multiple lignocellulosic biomass *b*, the lignocellulosic biomass *b* with the largest nominal particle size is taken as the nominal size ($S_{N=1}$), as shown in Equation 13. The particle size of the inlet feed to technology *i* is then shown by Equation 14.

$$S_{N=1} \geq \mathrm{S}_b \qquad \forall b \qquad (13)$$

$$S_i = S_{N=1} \qquad \forall i \in d, c \qquad (14)$$

As binary integer I_i denotes the existence of technology *i*, I_i can then be used to determine the particle size of the outlet when the feed inlet is pre-processed through a technology in technology set *i*. Therefore, the particle size of the outlet from the technology in technology set *i* S_i^{OUT} can be calculated according to SRR_i, as shown in Equation 15. Furthermore, in order to ease the solving process, Equation 16 is included to reduce the non-linearity by using the concept of Big-M formulation, where S^{BM} is set to be a highest possible value (e.g. the highest particle size of the feed biomass). Based on Equations 15 and 16, when a technology *i* is not selected (i.e. I_i is then 0), then S_i also is 0.

$$\left(\frac{S_i}{\mathrm{SRR}_i}\right) I_i = S_i^{\mathrm{OUT}} \qquad \forall i \in d, c \tag{15}$$

$$S_i \leq \mathrm{S}^{\mathrm{BM}} I_i \qquad \forall i \in d, c \tag{16}$$

In the event that the nominal particle size does not change when the lignocellulosic biomass is pre-processed through a technology in technology set *i* (e.g. drying technology *d*), the SRR_i is set to one (i.e. $\mathrm{SRR}_i = 1$). Meanwhile, note that Equations 15 and 16 are also applicable to the blank technology, whereas SRR_i is also set to one. As mentioned previously, a biomass intermediate *k* is produced after an inlet feed is pre-processed through a technology in technology set *i*. In such regards, the particle size of biomass intermediate *k* (S_k) is then equal to the particle size of the outlet from the technology in technology set *i*, as shown in Equation 17.

$$S_i^{\mathrm{OUT}} = S_k \qquad \forall i = k \qquad (17)$$

On the other hand, energy consumptions of the pre-processing technologies are also considered in this work. The energy consumption of drying technology *i* can be calculated theoretically by using Equation 18.

$$E_i \eta_i = \mathrm{Q}_i F_i^{\mathrm{MR}} \qquad \forall i, i \in d \qquad (18)$$

where E_i , η_i , and Q_i are energy consumption of drying technology *i*, thermal efficiency of the technology *i* and thermal requirement of drying technology *i* respectively. Meanwhile the energy consumption of comminution technology *i* is theoretically given as Equation 19.

$$E_i = I_i \mathrm{K}_i \log(\mathrm{SRR}_i) F_i \qquad \forall i, i \in c \qquad (19)$$

where K_i is the Kick constant of the material to the technology *i*. Note that Equation 26 takes the form of Kick's Law which implies that the specific energy required to comminute a material is directly proportional to the size reduction ratio (Tanaka, 1966).

As for now, the mathematical model for stage 1 (i.e. first pre-processing technology set *i*) has been developed and described. Next, the mathematical model is continued to be developed for stage 2 (i.e. second pre-processing technology set *i'*).

Each biomass intermediate *k* can be further pre-processed by each technology in second technology set *i'* with flow rate of $F_{ki'}$, as given by Equation 20.

$$F_k = \sum_{i'} F_{ki'} \qquad \forall k \qquad (20)$$

The flow rate of inlet feed fed to technology in second technology set *i* $F_{i'}^{\mathrm{IN}}$ is given as Equation 21.

$$F_{i'}^{\mathrm{IN}} = \sum_k F_{ki'} \qquad \forall i' \in d', c' \qquad (21)$$

The composition balances (i.e. cellulose, hemicellulose, lignin and water balances) of the biomass intermediate *k* fed to each technology *i'* are given as Equation 22.

$$\sum_k F_{ki'} X_k^{\mathrm{Z}} = F_{i'}^{\mathrm{IN}} X_{i'}^{\mathrm{Z}} \qquad \forall i' \in d', c' \qquad \forall \mathrm{Z} \in \mathrm{C}, \mathrm{HC}, \mathrm{L}, \mathrm{W} \qquad (22)$$

where $X_{i'}^{\mathrm{Z}}$ is the compositional content of the inlet feed fed to each technology in second technology set *i*'. Similarly, as a blank technology exists in second technology set *i*', Equation 22 is also applicable to the blank technology.

The existence of the technology in second technology set *i*' in the LCBPS is also modelled by using Big-M Formulation, as shown in Equation 23, where $I_{i'}$ is the binary integer of technology *i*'.

$$F_{i'}^{\mathrm{IN}} \le (\sum_b \mathrm{F}_b^{\mathrm{AVAILABLE}}) I_{i'} \qquad \forall i' \in d', c' \qquad (23)$$

On the other hand, each technology in second technology set *i'* has also a range of allowable inlet feed's moisture content (lower limit $\mathrm{X}_{i'}^{\mathrm{W,LL}}$ and upper limit $\mathrm{X}_{i'}^{\mathrm{W,UL}}$) and nominal particle size (lower limit $\mathrm{S}_{i'}^{\mathrm{LL}}$ and upper limit $\mathrm{S}_{i'}^{\mathrm{UL}}$), as shown in Equations 24 and 25.

$$\mathrm{X}_{i'}^{\mathrm{W,LL}} I_{i'} \le X_{i'}^{\mathrm{W}} I_{i'} \le \mathrm{X}_{i'}^{\mathrm{W,UL}} I_{i'} \qquad \forall i' \in d', c' \qquad (24)$$

$$\mathrm{S}_{i'}^{\mathrm{UL}} I_{i'} \le S_{i'} I_{i'} \le \mathrm{S}_{i'}^{\mathrm{UL}} I_{i'} \qquad \forall i' \in d', c' \qquad (25)$$

where $S_{i'}$ is the particle size of the inlet to technology *i'*.

Next, the material balances across the technology in second technology set *i'* are now discussed. Similarly, the cellulose, hemicellulose and lignin of the inlet feed do not change after it is pre-processed through the technology in second technology set *i'* (as they are all drying and comminution technologies). The cellulose, hemicellulose and lignin in the outlet of technology from second technology *i'* can be generally calculated by Equation 26 respectively. Note that Equation 26 is also applicable to the blank technology.

$$F_{i'}^{\mathrm{OUT,Z}} = F_{i'}^{\mathrm{IN}} X_{i'}^{\mathrm{Z}} \qquad \forall i' \in d', c' \qquad \forall \mathrm{Z} \in \mathrm{C, HC, L} \qquad (26)$$

Next, the moisture in the outlet of the second technology set *i*', $F_{i'}^{\mathrm{OUT,\,W}}$ can also be calculated according to moisture removal ratio $\mathrm{MRR}_{i'}$ as shown in Equations 27 and 28, where $F_{i'}^{\mathrm{MR}}$ is the water removed by the technology in second technology set *i*'.

$$F_{i'}^{\mathrm{MR}} = F_{i'}^{\mathrm{IN}} X_{i'}^{\mathrm{Z}} \mathrm{MRR}_{i'} \qquad \forall i' \in d', c' \qquad \mathrm{Z} = \mathrm{W} \tag{27}$$

$$F_{i'}^{\mathrm{OUT,\,Z}} = F_{i'}^{\mathrm{IN}} X_{i'}^{\mathrm{Z}} - F_{i'}^{\mathrm{MR}} \qquad \forall i' \in d', c' \qquad \mathrm{Z} = \mathrm{W} \tag{28}$$

For the case of a two-stage pre-processing system, after the inlet is pre-processed through technology *i'*, a bio-precursor *p* is produced, as shown in Figure 4.3. The flow rate of bio-precursor *p* F_p can then be calculated by Equation 29.

$$F_p = \sum_{\mathrm{Z}} F_{i'}^{\mathrm{OUT,\,Z}} \qquad \forall i' \in p \qquad \forall \mathrm{Z} \in \mathrm{C, HC, L, W} \tag{29}$$

Additionally, the compositions of the outlet from technology *i'* (i.e. bio-precursor *p*) can be calculated by Equation 30, where X_p^{Z} is the compositional content of bio-precursor *p*. Note that Equation 30 are applicable for the case of blank technology, in which a bio-precursor *p* is also generically considered to be produced.

$$X_p^{\mathrm{Z}} = \frac{F_{i'}^{\mathrm{OUT,\,Z}}}{F_p} \qquad \forall i' = p \qquad \forall \mathrm{Z} \in \mathrm{C, HC, L} \tag{30}$$

On the other hand, the nominal particle size of the inlet feed to the technology *i'* ($S_{i'}$) can be mathematically "represented" by Equations 31 and 32 (i.e. in case of multiple biomass intermediate *k* are fed to technology *i'*, $S_{i'}$ takes the nominal particle size of the largest biomass intermediate *k*).

$$S_{N=2} \geq S_k \qquad \forall k \tag{31}$$

$$S_{i'} = S_{N=2} \qquad \forall i' \in d', c' \tag{32}$$

The nominal particle size of the outlet from technology set *i'* $S_{i'}^{OUT}$ can then be calculated by using $SRR_{i'}$, as shown in Equation 33. Similarly, in order to ease the solving process, Equation 34 is also included to reduce the non-linearity by using the concept of Big-M formulation, where S^{BM} is set to have a highest possible value (e.g. the highest particle size of the feed biomass).

Bio-precursor *p* is produced after an inlet feed is pre-processed through technology *i'*. In such regards, the nominal particle size of bio-precursor *p* S_p is then equal to the nominal size of the outlet from the technology in technology set *i'*, as shown in Equation 35. In the event that the nominal particle size does not change when the biomass intermediate *k* is pre-processed through a technology in technology set *i'*, the $SRR_{i'}$ are set to one (i.e. $SRR_{i'} = 1$). Meanwhile, note that Equations 31-34 are also applicable to the blank technology, whereas SRR_i is also set to one.

$$\left(\frac{S_{i'}}{\mathrm{SRR}_{i'}}\right) I_{i'} = S_{i'}^{\mathrm{OUT}} \qquad \forall i' \in d', c' \qquad (33)$$

$$S_{i'} \leq \mathrm{S}^{\mathrm{BM}} I_{i'} \qquad \forall i' \in d', c' \qquad (34)$$

$$S_{i'}^{\mathrm{OUT}} = S_p \qquad \forall i' = p \qquad (35)$$

On the other hand, similarly, the energy consumption of drying technology *i'* can be theoretically calculated by using Equation 36.

$$E_{i'} \eta_{i'} = \mathrm{Q}_{i'} F_{i'}^{\mathrm{MR}} \qquad \forall i', i' \in d' \qquad (36)$$

where $E_{i'}$, $\eta_{i'}$, and $\mathrm{Q}_{i'}$ are energy consumption of drying technology *i'*, thermal efficiency of the technology *i'* and thermal requirement of drying technology *i'* respectively. Meanwhile the energy consumption of comminution technology *i'* is given as Equation 37.

$$E_{i'} = I_{i'} \mathrm{K}_{i'} \log\left(\mathrm{SRR}_{i'}\right) F_{i'} \qquad \forall i', i' \in c' \qquad (37)$$

where $\mathrm{K}_{i'}$ is the Kick's constant of the material to technology *i'*.

As for now, the mathematical model for both stage 1 and stage 2 (i.e. first pre-processing technology set *i* and second pre-processing technology set *i'*) has been developed. It is important to point out that the procedure to develop the mathematical

models for both stage 1 and stage 2 are essentially similar. In such regards, similar modeling steps and concepts are basically repetitive for the case with third pre-processing technology set *i* (e.g. technology set *i''*) or more, with just modifications on the sub-indexes. In other words, the modelling steps presented above is generic and can be applied when more pre-processing technology sets are required. For instance, for the case of which a third technology set *i'''* is required, another biomass intermediate *k'* is produced by second technology set *i'*. By using the sub-indexes (i.e. *k'* and *i''*), Equation 20 is revised to be the following Equation 38. Note that in this case, the index is changed accordingly.

$$F_{k'} = \sum_{i''} F_{k'i''} \qquad \forall k' \qquad (38)$$

Finally, in this work, in order to synthesise a LCBPS, the objective function of the mathematical optimisation model is set to maximise the flow rate of bio-precursor *p* (i.e. maximise the productivity of the LCBPS), as shown by Equation 39. Additionally, the produced bio-precursor *p* should meet the requirements of certain moisture content (i.e. moisture content requirement) and certain nominal particle size (i.e. nominal particle size requirement). These requirements are set as constraints for the mathematical optimisation model, as shown in Equations 40 and 41. Alternatively, the objective function can also be set to minimise the energy requirement as shown by Equation 42, in which E_{TOTAL} can be calculated by using Equation 43.

$$\text{Maximise } \sum_{p} F_{p} \qquad (39)$$

$$X_p^{W,LL} \le X_p^{Z} \le X_p^{W,UL} \qquad Z = W \tag{40}$$

$$S_p^{LL} \le S_p \le S_p^{UL} \tag{41}$$

$$\text{Minimise} \quad E_{TOTAL} \tag{42}$$

$$E_{TOTAL} = \sum_i E_i + \sum_{i'} E_{i'} \tag{43}$$

On the other hand, the number of pre-processing set to be first considered and included in the superstructure can be approximately and presumably targeted by using Equations 44-46. The targeting concept is essentially derived based on the highest operating parameter possible of the listed technologies in a technology set. For instance, if there are two comminution technologies in the technology set which their SRR_i are given as 8 and 9.2, the highest operating parameter $SRR_{i,max}^{UL}$ is then 9.2. It is important to note that the values of N_C and N_D are always taken as the next positive integer. For example, if the calculated value of N_D is 1.4, N_D is taken as 2. Additionally, the number of pre-processing set to be first considered and included in the superstructure, N can then be calculated according to Equation 44. It is important to point out that N is always N_i add 1 because there is always at least 1 pre-processing technology set is required in a LCBPS as mentioned earlier in Section 4.2.

$$N = 1 + N_i \qquad N_i \in N_c, N_d \tag{44}$$

$$N_c = \frac{\mathrm{SRR}_{i,\max}^{\mathrm{UL}}}{\frac{S_{N=1}}{\mathrm{S}_p^{\mathrm{UL}}}} \qquad \forall i \in c \qquad \forall p \qquad (45)$$

$$N_d = \frac{\mathrm{MRR}_{i,\max}^{\mathrm{UL}}}{\frac{\mathrm{X}_p^{\mathrm{W,UL}} - \mathrm{X}_{b,\max}^{\mathrm{W}}}{\mathrm{X}_p^{\mathrm{W,UL}} \mathrm{X}_{b,\max}^{\mathrm{W}} - \mathrm{X}_{b,\max}^{\mathrm{W}}}} \qquad \forall b \quad \forall i \in d \qquad \forall p \qquad (46)$$

where N_c and $\mathrm{SRR}_{i,\max}^{\mathrm{UL}}$ are targeted number of stages according to listed comminution technologies in technology set *i* and the highest operating parameter possible of listed comminution technologies in technology set *i* respectively; while N_{D}, $\mathrm{MRR}_{i,\max}^{\mathrm{UL}}$ and $\mathrm{X}_{b,\max}^{\mathrm{W}}$ are targeted number of stages according to listed drying technologies in technology set *i*, the highest operating parameter possible of listed drying technologies in technology set *i* and the highest moisture content of lignocellulosic biomass *b*. However, it is important to note that the number of pre-processing set to be included can always be customised in accordance to the designer's preference. In such cases, the additional pre-processing sets may not be required and following the concept of the mathematical model, it is then allowed to pass through the blank technology. To illustrate the proposed modelling approach, an illustrative case study is presented in the next section.

4.4 Illustrative Example

Malaysian palm oil industry generates high amounts of palm-based biomass (e.g. empty fruit bunches (EFBs), palm kernel shells (PKSs), and palm mesocarp fibres

(PMFs) as by products or waste (Ng and Ng, 2013). Figure 4.4 illustrates a schematic flow diagram of palm oil mill process.

In a palm oil mill, after palm oil fresh fruit bunches (FFBs) are harvested from oil palm tree, they are sterilised in steam steriliser. Sterilised FFBs are fed to a stripper where fruits are separated from bunches and the EFBs are collected at the end of the stripper. The fruits are mashed by rotating arms in digester, resulting in the release of some palm oil as the mashing process breaks the oil-bearing cells of palm mesocarp. Digested mesh fruits are screw pressed to extract the crude oil. PMF and nut are conveyed to a depericarper for fibre separation. The remaining nut shells are further processed in nut cracker to separate the kernels from the shells (i.e. PKS). Note that palm-based biomass are lignocellulosic biomass which can be used as feedstocks to a thermochemical biorefinery.

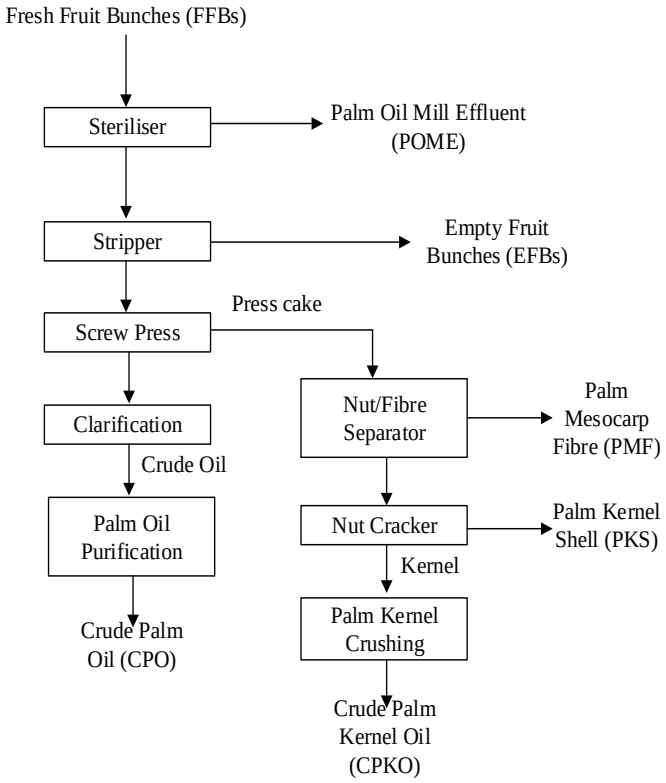


Figure 4.4: Schematic flow diagram of a palm oil mill process (adapted from Ng & Ng, 2013)

In this example, EFB, PKS and PMF are considered as the LCB. Table 4.1 tabulates the available flow rates, compositions and nominal particle size of these three biomass. A thermochemical biorefinery that employs gasification process is considered in which the bio-precursor required for the gasifier is a dry and size-reduced biomass feedstock (i.e. minimum 15 wt% of moisture content and 15 mm nominal particle size). In such regards, in order to prepare and standardise the raw biomass into the required bio-precursor, drying and comminution technologies are considered as the pre-processing technologies.

Table 4.1: Available flow rates, lignocellulosic compositions and nominal size of palm-based biomass

Biomass	Availability (kg/hr)	Compositions and Characteristics				
		Cellulose (wt%)	Hemicellulose (wt%)	Lignin (wt%)	Moisture (wt%)	Nominal Size (mm)
EFB	14040	23	18	14	45	150
PKS	4320	17	26	30	27	20
PMF	7920	27	29	21	23	30

In this example, rotary dryer, flash dryer, sprouted dryer and belt dryer are considered as the drying technologies. Meanwhile, knife mill, hammer mill and knife shredder are considered as the comminution technologies. Table 4.2 shows the information of the drying technologies. Note that in order to ensure the performances of the drying technologies, the inlet's nominal size and moisture content are required to fulfil the technological constraints as shown in Table 4.2. Note also that in this example, the thermal requirements for all types of drying technologies are set to 0.67 kWhr/kg.

Table 4.2: Information of drying technologies

Pre-processing Technology	Allowable inlet feed's moisture content	Allowable inlet feed's nominal size	Moisture Removal Ratio (MRR)	Thermal Efficiency
Rotary Dryer	25 wt% to 65 wt%	25 mm to 125 mm	0.56 to 0.86	0.6
Flash Dryer	25 wt% to 65 wt%	0.5 mm to 50 mm	0.56 to 0.86	0.86
Sprouted Dryer	25 wt% to 72 wt%	$\leq$ 100 mm	0.56 to 0.86	0.87
Belt Dryer	25 wt% to 72 wt%	0 mm to 1000 mm	0.64 to 0.81	0.7

Meanwhile, Table 4.3 shows the information of the comminution technologies. Similarly, in order to ensure the performances of the comminution technologies, the inlet's nominal size and moisture content are also required to fulfil the technological constraints. On the other hand, the Kick's constants of each comminution technologies for fibrous inlet materials (i.e. LCB) are given as polynomial Equations 47-49. Note that these equations are derived from the data collected from the literature (Barakat et al., 2013; Kratky & Jirout, 2010) by using MathLab© curve-fitting functions. It is important to point out that as a result, these equations are only applicable to this particular example.

$$K_{\mathrm{KM}} = 339.9 - 1109A_{\mathrm{KM}} - 7.529B_{\mathrm{KM}} + 947.4A_{\mathrm{KM}}{}^{2} + 170.5A_{\mathrm{KM}}B_{\mathrm{KM}} - 16.53B_{\mathrm{KM}}{}^{2}$$
$$- 362.7A_{\mathrm{KM}}{}^{3} - 76.75A_{\mathrm{KM}}{}^{2}B_{\mathrm{KM}} - 5.958A_{\mathrm{KM}}B_{\mathrm{KM}}{}^{2} + 1.836B_{\mathrm{KM}}{}^{3} + 56.16A_{\mathrm{KM}}{}^{4}$$
$$+ 3.813A_{\mathrm{KM}}{}^{3}B_{\mathrm{KM}} + 4.932A_{\mathrm{KM}}{}^{2}B_{\mathrm{KM}}{}^{2} - 0.7026A_{\mathrm{KM}}B_{\mathrm{KM}}{}^{3} \quad (47)$$

$$K_{\mathrm{HM}} = 49.02 - 10.04A_{\mathrm{HM}} - 72.54B_{\mathrm{HM}} + 11.03A_{\mathrm{HM}}{}^{2} + 2.03A_{\mathrm{HM}}B_{\mathrm{HM}} + 96.17B_{\mathrm{HM}}{}^{2}$$
$$+ 0.7976A_{\mathrm{HM}}{}^{3} + 2.241A_{\mathrm{HM}}{}^{2}B_{\mathrm{HM}} - 4.248A_{\mathrm{HM}}B_{\mathrm{HM}}{}^{2} - 18.67B_{\mathrm{HM}}{}^{3} + 2.451A_{\mathrm{HM}}{}^{4}$$
$$+ 6.563A_{\mathrm{HM}}{}^{3}B_{\mathrm{HM}} - 0.3381A_{\mathrm{HM}}{}^{2}B_{\mathrm{HM}}{}^{2} - 9.35A_{\mathrm{HM}}B_{\mathrm{HM}}{}^{3} - 43.85B_{\mathrm{HM}}{}^{4} \quad (48)$$

$$K_{\mathrm{KS}} = 1.0633A_{\mathrm{KS}} + 0.0203 \quad (49)$$

where A_{KM}, A_{HM} and A_{KS} are $\log(SRR_i)$ of the technologies, while $B_{\mathrm{KM.}}$ and $B_{\mathrm{HM.}}$ are the moisture content of the inlet to the technologies ($X_i^{\mathrm{Z}}, \mathrm{Z} = \mathrm{W}$) respectively. Note also that Equations 47-49 are only applicable within the range of allowable inlet feed's

moisture content of the technologies, this is because the Kick's constant of the comminution technology for each material is typically affected by the moisture content of the material (Barakat et al., 2013). Additionally, Equations 47-49 are also applicable for the technology set *i'* and *i''*.

Table 4.3: Information of comminution technologies

Pre-processing Technology	**Allowable inlet feed's moisture content**	**Allowable inlet feed's nominal size**	**Size Reduction Ratio (SRR)**
Knife mill	4 wt% to 7 wt%	$\geq$25 mm	2 to 14
Hammer mill	4 wt% to 12 wt%	$\geq$25 mm	2.23 to 12.83
Knife Shredder	0 wt% to 100 wt%	0 mm to 1000 mm	2.03 to 4.06

On the other hand, according to Equations 44- 46, N is 3 (with N_i =2) and thus a three-stages LCBPS is considered (i.e. a superstructure of LCBPS which consists of 3 similar sets of pre-processing technologies). Following the modelling procedure as described in Section 4.3, a superstructure is developed as shown in Figure 4.5. According to Figure 4.5, the three palm based biomass can be processed via three stages of pre-processing technology set (i.e. the seven pre-processing technologies) or none (i.e. blank technologies) to produce the required bio-precursor. Therefore, a set of intermediate (*k'*) and third technology set (*i''*) are included.

Following the procedure as described in Section 4.3, a set of equations are added accordingly to consider intermediate *k'* and technology set *i''*. Note that for the drying technologies, the SRR_i are set to one. Meanwhile for the comminution technologies,

the MRR_i are assumed to 0.15 to account for some losses of moisture during the size reduction process.

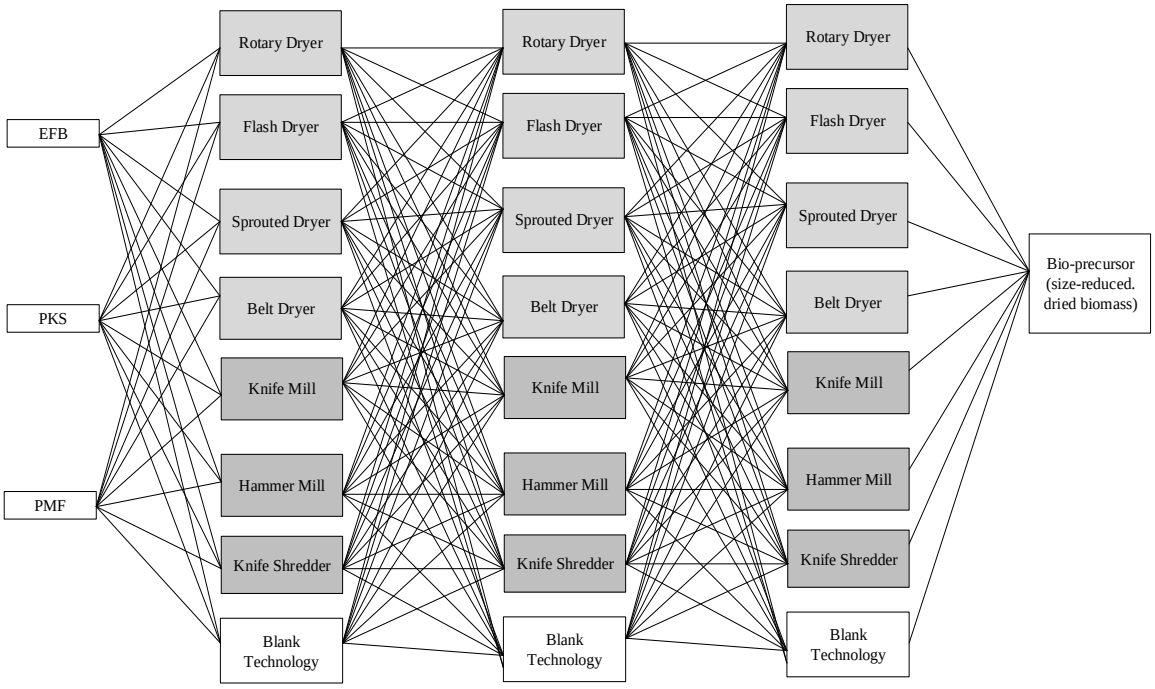


Figure 4.5: Superstructure for the illustrative example

The resulted optimisation model is a mixed integer non-linear programming (MINLP) which is inherently difficult to solve. Additionally, there are a number of bilinear terms in the model (e.g. $F_i^{\mathrm{IN}} X_i^{\mathrm{W}}$) and thus this increases the non-convexity of the problem. In such regards, Equations 50-51 are included in order to slightly improve the solving effort of the model. Note that Equations 50-51 are also applicable to other indices for the cases of multiple stages. (e.g. *i'*, *k'*, etc.)

$$\sum_{\mathrm{Z}} X_i^{\mathrm{Z}} \leq 1 \qquad \forall i \in d, c \qquad \forall \mathrm{Z} \in \mathrm{C}, \mathrm{HC}, \mathrm{L}, \mathrm{W} \qquad (50)$$

$$\sum_Z X_k^Z \le 1 \qquad \forall k \qquad \forall Z \in C, HC, L, W \qquad (51)$$

On the other hand, note that the Equations 40 and 41 are revised to Equations 52 and 53 as the minimum requirements of moisture content and nominal particle size for the bio-precursor are 15 wt% and 0.15 mm respectively as mentioned above. Equations 1-51 together with the added equations due to the addition of third stage are solved by using Lingo 16.0 in which Branch-and Bound solving method is employed.

$$X_p^Z \le 0.15 \qquad \forall p \qquad Z = W \qquad (52)$$

$$S_p \le 15 \qquad \forall p \qquad (53)$$

Additionally, the equipment cost of the technology is also considered in this work. The cost data of each technology is estimated by using Equations 54- 60, as summarised in Table 4.4. These equations are derived by using the cost equations from literatures and sixth-tenth rules (Couper et al (2010); Bruce & Sinclair, (1996)). Note that the F_i in the Equations 54- 60 is in ton/hour and the construction material is assumed to be stainless steel. On the other hand, note also that Equations 54-60 are also applicable to technologies in technology sets *i'*, *i''*, etc. This is because the technology sets are basically identical to each other in this work.

Table 4.4: Cost data for pre-processing technology

Pre-processing technology	**Cost of equipment (k$)**	
Rotary Dryer	$156.6^{0.63} F_i^{0.6}$	(54)
Flash Dryer	$179.52^{0.63} F_i^{0.6}$	(55)
Sprouted Dryer	$45^{0.77} F_i^{0.6}$	(56)
Belt Dryer	$7^{0.77} F_i^{0.6}$	(57)
Knife mill	$27.5^{0.39} F_i^{0.6}$	(58)
Hammer mill	$2.97 F_i^{0.78}$	(59)
Knife Shredder	$7.7^{0.57} F_i^{0.6}$	(60)

4.5 Results and Discussions

4.5.1 Maximise productivity

The resulted optimisation model consists of 554 continuous variables, 72 integer variables and 736 constraints in which the solving time is approximately 4 minutes (solved by using MacBook Pro Intel® Core i5 running at 2.1 GHz). Figure 4.6 shows the optimised result of this example with the maximum productivity of 5.55 kg/s. Two knife shredders and a rotary dryer are selected as the pre-processing technologies in the LCBPS.

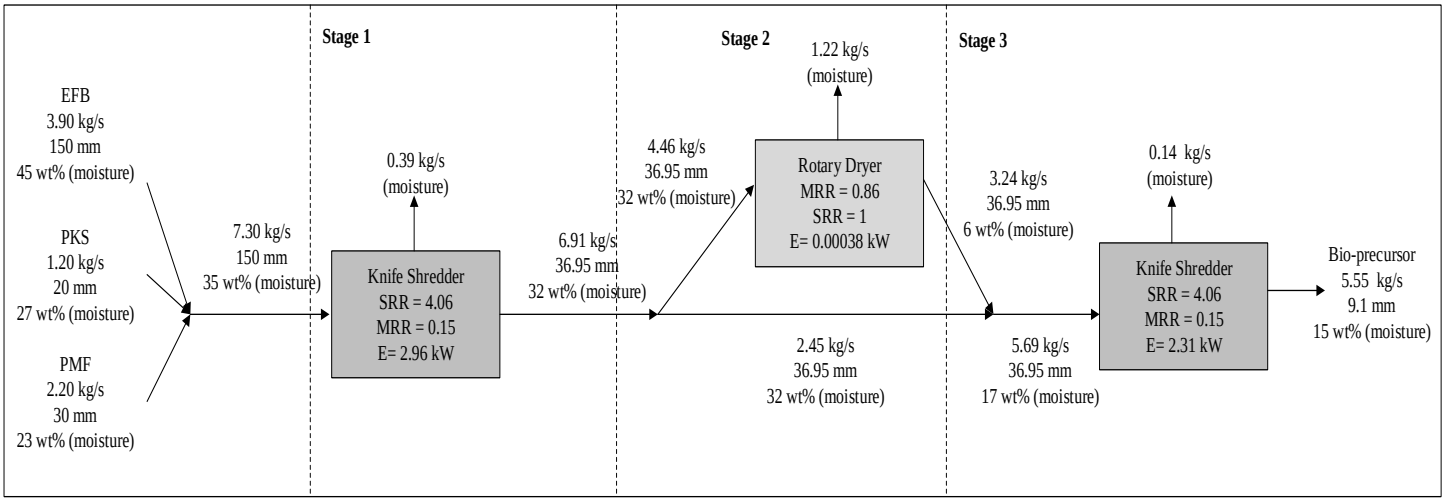


Figure 4.6: Optimised results for the illustrative example with maximum productivity

As shown in Figure 4.6, the three palm based lignocellulosic biomass are first fed to a knife shredder which operates SRR = 4.06 to reduce the nominal particle size of the biomass inlet down to 36.95 mm. Next, the biomass intermediate is spilt to two streams which one of them with the flow rate of 4.46 kg/s is fed into a rotary dryer to

perform drying operation. The rotary dryer operates at MRR= 0.86 to remove 1.22 kg/s of moisture from the inlet. Finally, the outlet from the rotary dryer is mixed with another stream that is spilt from the first knife shredder's outlet and then fed to a second knife shredder which operates at SRR = 4.06. The second and last knife shredder reduces the nominal size of the biomass intermediate to 9.1 mm. During the size reduction process, 0.14 kg/s of moisture is removed and thus results a final bio-precursor which has 15 wt% moisture content. Note that by using the proposed approach, the key operating parameters of the pre-processing technologies (i.e. SRR and MRR) in a LCBPS can be determined. Additionally, the sequence of the technologies in the LCBPS is known as well (i.e. for this case, a knife shredder is required first before a rotary dryer, and lastly followed by another knife shredder). Meanwhile, the total energy consumption of is found to be 5.28 kW.

4.5.2 Minimise energy requirement

In the next scenario, minimisation of energy requirement is considered. Hence, Equations 43 and 44 are used instead of Equation 39. In order to determine a design with the other possible lowest energy requirement, it is necessary to target for the same productivity requirement which is determined previously in Section 4.5.1. Additionally, all of the requirements for the bio-precursor are remained to be the same as well.

The resulted optimisation model consists of 554 continuous variables, 72 integer variables and 736 constraints in which the solving time is approximately 13

minutes (solved by using MacBook Pro Intel® Core i5 running at 2.1 GHz). It is noted that the solving time increases by about 3 folds. This is because the optimisation objective function is now associated with more non-linear functions (i.e. Equation 44 is a large equation which consists of several non-linear equations). Figure 4.7 shows the optimised result of this example with the productivity of 5.55 kg/s and energy requirement of 3.93 kW.

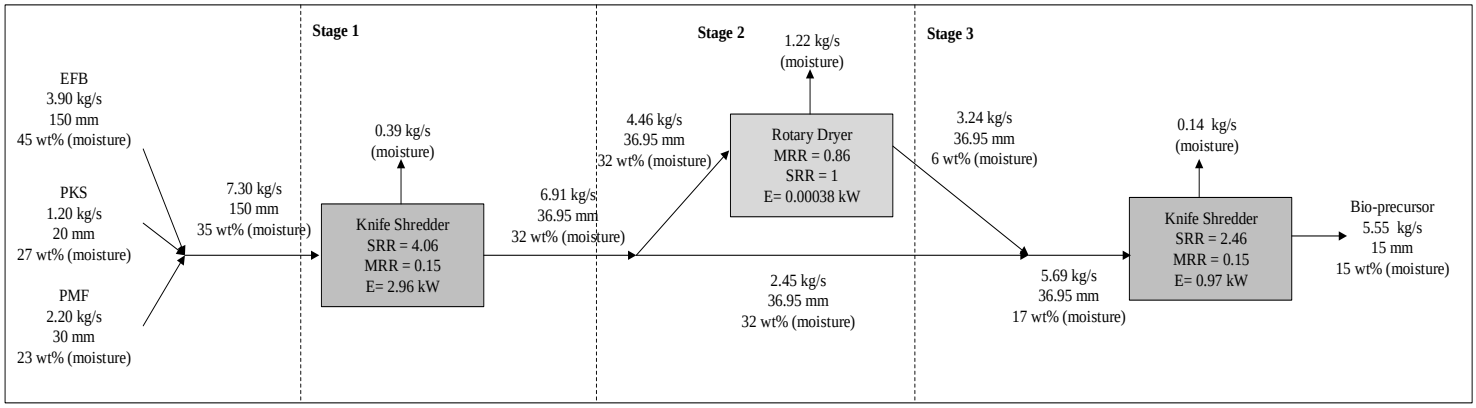


Figure 4.7: Optimised results for the illustrative example with minimum energy requirement

As shown in Figure 4.7, the lignocellulosic biomass are first fed to a knife shredder which operates SRR = 4.06 to reduce the nominal particle size of the biomass inlet down to 36.95 mm. Next, the biomass intermediate is spilt to two streams which one of them with the flow rate of 4.46 kg/s is fed into a rotary dryer to perform drying operation. The rotary dryer operates at MRR= 0.86 to remove 1.22 kg/s of moisture from the inlet. Finally, the outlet from the rotary dryer is mixed with another stream that is spilt from the first knife shredder's outlet and then fed to a second knife shredder which operates at SRR = 2.46. The second and last knife shredder reduces the nominal

size of the biomass intermediate to 15 mm. During the size reduction process, 0.14 kg/s of moisture is removed and thus results a final bio-precursor which has 15 wt% moisture content.

It is interesting to note that the resulted design of minimum energy requirement resembles the design of maximise productivity, with both productivities are targeted to be 5.55 kg/s. The only difference is the SRR of the last knife shredder, which is determined to be 2.46. Due to the reduction in the SRR, the energy requirement of the last knife shredder is thus reduced to 0.97 kW. However, in spite of the reduction of SRR, the final particle size of the bio-precursor can still meet the requirement (i.e. 15 mm).

4.5.3 Sensitivity Analysis

A sensitivity analysis is conducted to have increased understanding of the model. Meanwhile, it can help to identify important connections between observations, model inputs and predictions, leading to the development of better model in the future. The requirements of the bio-precursor are increased by 10% and decreased by 10% for this sensitivity analysis. The impacts of the changing in the bio-precursor's requirements to the productivity are observed.

First, both the moisture and particle size requirements are set to be 16.5 wt% and 16.5 mm respectively. The objective function remains as the same (i.e. maximise productivity). Figure 4.8 shows the resulted design of this sensitivity analysis. As shown in Figure 4.8, the productivity is now increased to 5.65 kg/s. This is an expected outcome due to fact that the moisture requirement is now increased and hence there is more moisture in the bio-precursor. On the other hand, Figure 4.8 shows a different design configuration as well. A belt dryer and two knife shredders are used. As shown in Figure 4.8, EFB is split into two streams. The first stream with flow rate of 1.71 kg/s is mixed with PMF and PKS and fed to a belt dryer that operates at MRR = 0.81. 1.3 kg/s of moisture is firstly removed from the belt dryer. Another EFB stream with a flow rate of 2.19 kg/s is then mixed with the outlet from the belt dryer to be fed into a knife shredder. The knife shredder operates at a SRR of 4.06 that helps to reduce the particle size of its inlet feed to 36.95 mm. After that, the outlet of the knife shredder is fed to another knife shredder that operates at a SRR of 2.8 to reduce the particle size of the biomass to a final 13 mm. Note that the overall energy requirement of this scenario is 3.73 kW.

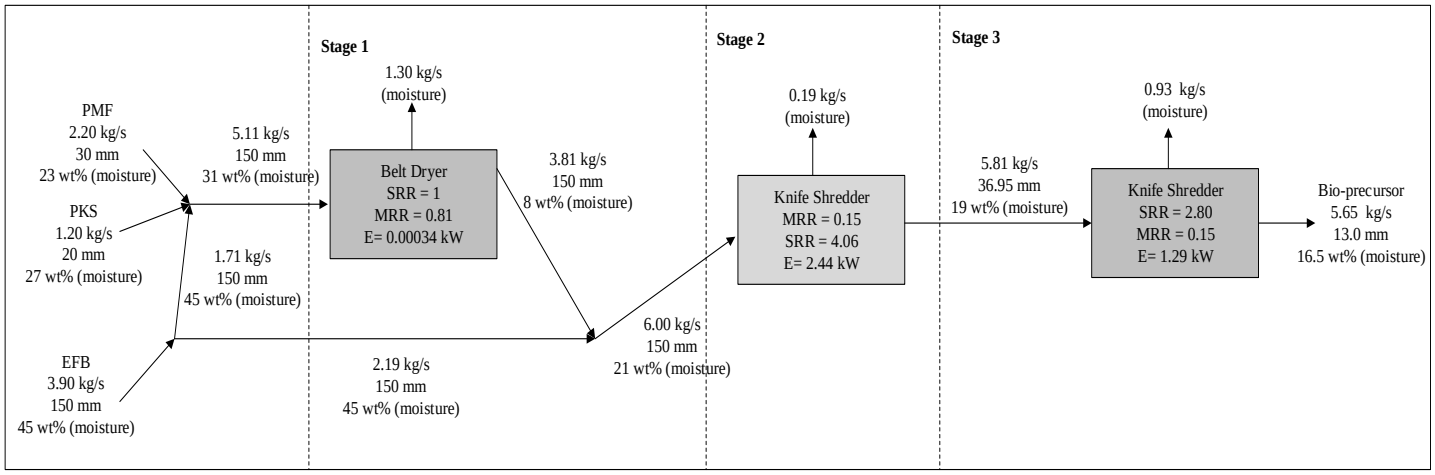


Figure 4.8: Result for the sensitivity analysis (16.5 wt% and 16.5 mm)

On the other hand, for the second sensitivity analysis, both the moisture and particle size requirements are set to be 13.5 wt% and 13.5 mm respectively. Figure 4.9 shows the resulted design of this sensitivity analysis. As shown in Figure 4.9, the productivity is now increased to 5.45 kg/s. This is an expected outcome due to fact that the moisture requirement is now decreased and hence there is less moisture in the bio-precursor. On the other hand, Figure 4.8 shows a different design configuration as well. Similar with the first scenario in Section 4.4.1, a rotary dryer and two knife shredders are used. However, the operating parameters of the technologies are changed to accommodate the changes in the bio-precursor's requirements. As shown in Figure 4.8, the three palm based lignocellulosic biomass are first fed to a knife shredder which operates SRR = 4.06 to reduce the nominal particle size of the biomass inlet down to 36.95 mm. Next, the biomass intermediate is fed into a rotary dryer to perform drying operation. The rotary dryer operates at MRR= 0.60 to remove 1.33 kg/s of moisture from the inlet. Finally, the outlet from the rotary dryer fed to a second knife shredder

which operates at SRR = 2.74. The second and last knife shredder reduces the nominal size of the biomass intermediate to 13.5 mm. During the size reduction process, 0.13 akg/s of moisture is removed and thus results a final bio-precursor which has 13.5 wt% moisture content. Note that the overall energy requirement for this scenario is 4.76 kW.

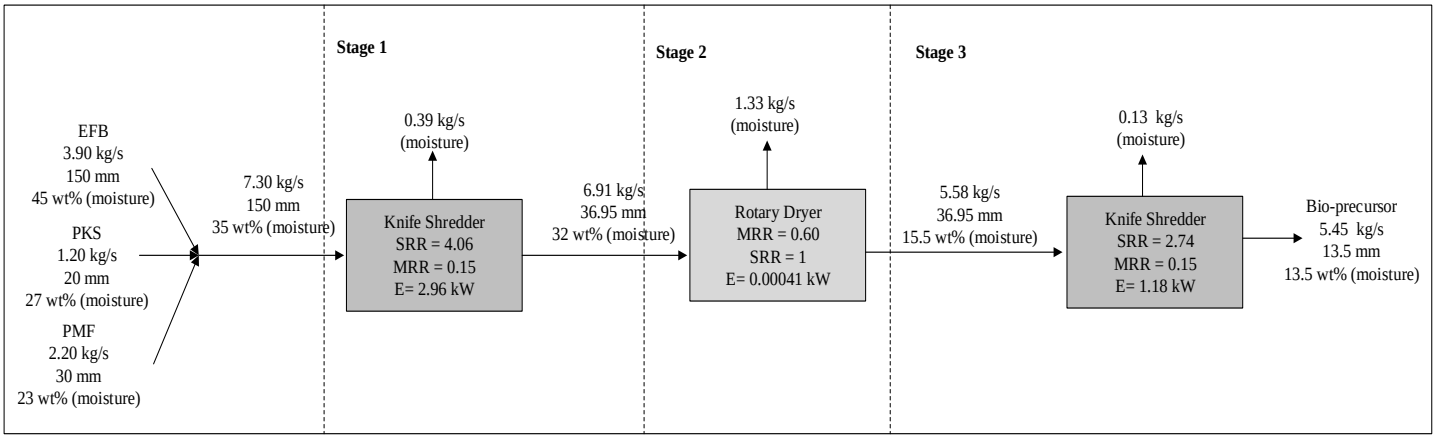


Figure 4.9: Result for the sensitivity analysis (13.5 wt% and 13.5 mm)

Based on the results of the sensitivity analysis, the model is proven to be robust enough to cater the changes in the requirements of bio-precursor. It is also found out that the change in moisture requirement affects the operating parameters of drying technology. Meanwhile, both the requirements have effects on the configuration of the design (i.e. the sequences of technologies and stream splitting).

4.5 Chapter Summary

In this chapter, a systematic approach for the synthesis and optimisation of a LCBPS for a thermochemical biorefinery is presented. The approach is developed

based on a superstructure-based mathematical optimisation approach. First of all, a superstructure is developed which it consists of all considered pre-processing technologies and biomass. Next, a mathematical optimisation model is developed based on the superstructure. Meanwhile, a new modelling concept is utilised to consider the particle size.

By using this approach, the types of pre-processing technologies to be included in the LCBPS can be determined. Meanwhile, the key operating parameters of the pre-processing technologies (i.e. SRR and MRR) can also be found as part of the optimisation result. Additionally, the sequence of the included pre-processing technologies is also determined. An illustrative example with three palm based lignocellulosic biomass is solved to illustrate the proposed approach. On the other hand, 2 different scenarios are considered which are maximising productivity and minimising energy requirements. Sensitivity analysis is also conducted to have better understanding of the mode.

CHAPTER 5

CONCLUSIONS AND FUTURE WORKS

5.1 Conclusions

In this dissertation, Chapter 1 introduces the background of this research work. The provided background serves as foundation for the introductory of the concept of biorefinery, biomass pre-processing, and the other aspects found throughout this research work. Additionally, the main objective and problem statement of this work are also given in Chapter 1.

Chapter 2 provides literature review on the concept of biorefinery and biomass (particularly on lignocellulosic biomass). Additionally, it also introduces different lignocellulosic biomass pre-processing technologies. On the other hand, different types of PSE approaches for chemical process synthesis and design are also briefly reviewed. Most importantly, the previous works on the developments of systematic PSE approaches for synthesis and design of biorefinery and integrated biorefinery are reviewed in Chapter 2. As shown in literature review, a vast majority of the previous

works are mainly based on mathematical optimisation approach. Meanwhile, biomass pre-processing system is found to be very important in biorefinery application in Chapter 2. However, based on the literature review, to date, there is less systematic PSE approach to address the synthesis and optimisation of such system. In Chapter 3, based on the literature review, the scopes of research works are identified. Research methodology is also proposed in Chapter 3 to address these identified research scopes.

In Chapter 4, a superstructure-based mathematical optimisation approach is developed to address the synthesis and optimisation of lignocellulosic biomass pre-processing system for thermochemical biorefinery. First of all, a superstructure is developed which consists of all possible configurations or solutions for the lignocellulosic biomass pre-processing system. Based on the superstructure, a mathematical optimisation model is developed which consists of different continuous and discrete variable, as well as different integers. Additionally, a new modelling technique is proposed and used to develop the optimisation model in which particle size of lignocellulosic biomass can be considered. This modelling technique solves the issue of non-conservative property of particle size and enables the mathematical optimisation model to track and calculate particle size throughout the system. On the other hand, the proposed approach can help to simultaneously determine the types of pre-processing technologies to be included, key operating parameters of these technologies, and the sequence of these technologies. Last but not least, an illustrative example is solved to show the applicability of the proposed approach.

5.2 Future Works

This thesis presents a systematic approach to synthesise and optimise a lignocellulosic biomass pre-processing system for a thermochemical biorefinery. It is noted that in order to enhance the current work, there exists several opportunities which are summarised as potential future works as follows:

1. Extend the model to consider lignocellulosic biomass pre-processing system for biochemical biorefinery.
2. Extend the model to simultaneously consider lignocellulosic biomass pre-processing system for both thermochemical and biochemical biorefinery (i.e. an integrated biorefinery).
3. Consider aspect of lignocellulosic biomass supply in the model as the supply as one of the parameters for a sustainable biorefinery is the ability to accommodate variable seasonal and annual patters of biomass feedstock (Fernando et al. 2006).

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APPENDICES

APPENDIX	TITLE	PAGE
A1	Lingo File for maximising productivity	
A2	Lingo File for mimimising energy requirement	
A3	Lingo File for sensitivity analysis (16.5wt% and 16.5mm)	
A4	Lingo File for sensitivity analysis (13.5wt% and 13.5 mm)	
B1	Lingo Result for maximising productivity	
B2	Lingo Result for minimising energy requirement	
B3	Lingo Result for sensitivity analysis (16.5wt% and 16.5 mm)	
B4	Lingo Result for sensitivity analysis (13.5wt% and 13.5 mm)	

APPENDIX A1

Lingo File

For maximising productivity

```
!INFORMATION;
F_AVAILABLE_EFB = 3.9 ; !kg/s;
X_CHCL_EFB  = 0.55;  X_M_EFB  = 0.45;  S_EFB  = 150 ; !mm;

F_AVAILABLE_PKS = 1.2 ; !kg/s;
X_CHCL_PKS  = 0.73 ; X_M_PKS  = 0.27 ; S_PKS = 20 ; !mm;

F_AVAILABLE_PMF = 2.2 ; !kg/s;
X_CHCL_PMF  = 0.77 ; X_M_PMF  = 0.23 ; S_PMF = 30 ; !mm;

!PROBLEM SIZE DEFINITION FOR EASIER SOLVING;
TOTAL_BIOMASS_AVAILABLE = F_AVAILABLE_EFB + F_AVAILABLE_PKS +
F_AVAILABLE_PMF ;
TOTAL_CHCL_AVAILABLE    = F_AVAILABLE_EFB * X_CHCL_EFB +
F_AVAILABLE_PKS * X_CHCL_PKS + F_AVAILABLE_PMF * X_CHCL_PMF ;
TOTAL_M_AVAILABLE       = F_AVAILABLE_EFB * X_M_EFB    +
F_AVAILABLE_PKS * X_M_PKS    + F_AVAILABLE_PMF * X_M_PMF    ;
F_EFB <= F_AVAILABLE_EFB ;
F_PKS <= F_AVAILABLE_PKS ;
F_PMF <= F_AVAILABLE_PMF ;

!MODEL STARTS;
!STAGE 1;
S_1 >= S_EFB ;
S_1 >= S_PKS ;
S_1 >= S_PMF ;

F_EFB = F_EFB_T1 + F_EFB_T2 + F_EFB_T3 + F_EFB_T4 + F_EFB_T5 +
F_EFB_T6 + F_EFB_T7 + F_EFB_BLANK1 ;  !kg/s = kg/s ;
F_PKS = F_PKS_T1 + F_PKS_T2 + F_PKS_T3 + F_PKS_T4 + F_PKS_T5 +
F_PKS_T6 + F_PKS_T7 + F_PKS_BLANK1 ;  !kg/s = kg/s ;
F_PMF = F_PMF_T1 + F_PMF_T2 + F_PMF_T3 + F_PMF_T4 + F_PMF_T5 +
F_PMF_T6 + F_PMF_T7 + F_PMF_BLANK1 ;  !kg/s = kg/s ;

F_IN_T1 = F_EFB_T1 + F_PKS_T1 + F_PMF_T1 ; !kg/s = kg/s ;
F_IN_T1 * X_CHCL_IN_T1 = F_EFB_T1 * X_CHCL_EFB + F_PKS_T1 *
X_CHCL_PKS + F_PMF_T1 * X_CHCL_PMF ;
```

```
F_IN_T1 * X_M_IN_T1    = F_EFB_T1 * X_M_EFB    + F_PKS_T1 * X_M_PKS
+ F_PMF_T1 * X_M_PMF    ;
X_CHCL_IN_T1 + X_M_IN_T1 <= 1;

F_IN_T2 = F_EFB_T2 + F_PKS_T2 + F_PMF_T2 ; !kg/s = kg/s ;
F_IN_T2 * X_CHCL_IN_T2 = F_EFB_T2 * X_CHCL_EFB + F_PKS_T2 *
X_CHCL_PKS + F_PMF_T2 * X_CHCL_PMF ;
F_IN_T2 * X_M_IN_T2    = F_EFB_T2 * X_M_EFB    + F_PKS_T2 * X_M_PKS
+ F_PMF_T2 * X_M_PMF    ;
X_CHCL_IN_T2 + X_M_IN_T2 <= 1;

F_IN_T3 = F_EFB_T3 + F_PKS_T3 + F_PMF_T3 ; !kg/s = kg/s ;
F_IN_T3 * X_CHCL_IN_T3 = F_EFB_T3 * X_CHCL_EFB + F_PKS_T3 *
X_CHCL_PKS + F_PMF_T3 * X_CHCL_PMF ;
F_IN_T3 * X_M_IN_T3    = F_EFB_T3 * X_M_EFB    + F_PKS_T3 * X_M_PKS
+ F_PMF_T3 * X_M_PMF    ;
X_CHCL_IN_T3 + X_M_IN_T3 <= 1;

F_IN_T4 = F_EFB_T4 + F_PKS_T4 + F_PMF_T4 ;
F_IN_T4 * X_CHCL_IN_T4 = F_EFB_T4 * X_CHCL_EFB + F_PKS_T4 *
X_CHCL_PKS + F_PMF_T4 * X_CHCL_PMF ;
F_IN_T4 * X_M_IN_T4    = F_EFB_T4 * X_M_EFB    + F_PKS_T4 * X_M_PKS
+ F_PMF_T4 * X_M_PMF    ;
X_CHCL_IN_T4 + X_M_IN_T4 <= 1;

F_IN_T5 = F_EFB_T5 + F_PKS_T5 + F_PMF_T5 ; !kg/s = kg/s ;
F_IN_T5 * X_CHCL_IN_T5 = F_EFB_T5 * X_CHCL_EFB + F_PKS_T5 *
X_CHCL_PKS + F_PMF_T5 * X_CHCL_PMF ;
F_IN_T5 * X_M_IN_T5    = F_EFB_T5 * X_M_EFB    + F_PKS_T5 * X_M_PKS
+ F_PMF_T5 * X_M_PMF    ;
X_CHCL_IN_T5 + X_M_IN_T5 <= 1;

F_IN_T6 = F_EFB_T6 + F_PKS_T6 + F_PMF_T6 ; !kg/s = kg/s ;
F_IN_T6 * X_CHCL_IN_T6 = F_EFB_T6 * X_CHCL_EFB + F_PKS_T6 *
X_CHCL_PKS + F_PMF_T6 * X_CHCL_PMF ;
F_IN_T6 * X_M_IN_T6    = F_EFB_T6 * X_M_EFB    + F_PKS_T6 * X_M_PKS
+ F_PMF_T6 * X_M_PMF    ;
X_CHCL_IN_T6 + X_M_IN_T6 <= 1;

F_IN_T7 = F_EFB_T7 + F_PKS_T7 + F_PMF_T7 ; !kg/s = kg/s ;
F_IN_T7 * X_CHCL_IN_T7 = F_EFB_T7 * X_CHCL_EFB + F_PKS_T7 *
X_CHCL_PKS + F_PMF_T7 * X_CHCL_PMF ;
F_IN_T7 * X_M_IN_T7    = F_EFB_T7 * X_M_EFB    + F_PKS_T7 * X_M_PKS
+ F_PMF_T7 * X_M_PMF    ;
X_CHCL_IN_T7 + X_M_IN_T7 <= 1;

F_IN_BLANK1 = F_EFB_BLANK1 + F_PKS_BLANK1 + F_PMF_BLANK1 ;
F_IN_BLANK1 * X_CHCL_IN_BLANK1 = F_EFB_BLANK1 * X_CHCL_EFB +
F_PKS_BLANK1 * X_CHCL_PKS + F_PMF_BLANK1 * X_CHCL_PMF ;
F_IN_BLANK1 * X_M_IN_BLANK1    = F_EFB_BLANK1 * X_M_EFB    +
F_PKS_BLANK1 * X_M_PKS    + F_PMF_BLANK1 * X_M_PMF    ;
X_CHCL_IN_BLANK1 + X_M_IN_BLANK1 <= 1;

F_IN_T1 + F_IN_T2 + F_IN_T3 + F_IN_T4 + F_IN_T5 + F_IN_T6 + F_IN_T7 +
F_IN_BLANK1 = F_IN_T_TOTAL ;
F_IN_T1 <= TOTAL_BIOMASS_AVAILABLE ;
F_IN_T2 <= TOTAL_BIOMASS_AVAILABLE ;
```

```
F_IN_T3 <= TOTAL_BIOMASS_AVAILABLE ;
F_IN_T4 <= TOTAL_BIOMASS_AVAILABLE ;
F_IN_T5 <= TOTAL_BIOMASS_AVAILABLE ;
F_IN_T6 <= TOTAL_BIOMASS_AVAILABLE ;
F_IN_T7 <= TOTAL_BIOMASS_AVAILABLE ;
F_IN_BLANK1 <= TOTAL_BIOMASS_AVAILABLE ;
F_IN_T_TOTAL <= TOTAL_BIOMASS_AVAILABLE ;

(F_IN_T1/TOTAL_BIOMASS_AVAILABLE) <= I_T1 ;
(F_IN_T2/TOTAL_BIOMASS_AVAILABLE) <= I_T2 ;
(F_IN_T3/TOTAL_BIOMASS_AVAILABLE) <= I_T3 ;
(F_IN_T4/TOTAL_BIOMASS_AVAILABLE) <= I_T4 ;
(F_IN_T5/TOTAL_BIOMASS_AVAILABLE) <= I_T5 ;
(F_IN_T6/TOTAL_BIOMASS_AVAILABLE) <= I_T6 ;
(F_IN_T7/TOTAL_BIOMASS_AVAILABLE) <= I_T7 ;
(F_IN_BLANK1/TOTAL_BIOMASS_AVAILABLE) <= I_BLANK1 ;
@BIN(I_T1); @BIN(I_T2);
@BIN(I_T3); @BIN(I_T4);
@BIN(I_T5); @BIN(I_T6);
@BIN(I_T7); @BIN(I_BLANK1);

(0.25 * I_T1)  <= (X_M_IN_T1 * I_T1)          ;
(X_M_IN_T1 * I_T1)          <= (0.65 * I_T1)  ;
(0.25 * I_T2)  <= (X_M_IN_T2 * I_T2)          ;
(X_M_IN_T2 * I_T2)          <= (0.65 * I_T2)  ;
(0.25 * I_T3)  <= (X_M_IN_T3 * I_T3)          ;
(X_M_IN_T3 * I_T3)          <= (0.65 * I_T3)  ;
(0.25 * I_T4)  <= (X_M_IN_T4 * I_T4)          ;
(X_M_IN_T4 * I_T4)          <= (0.72 * I_T4)  ;
(0.04 * I_T5)  <= (X_M_IN_T5 * I_T5)          ;
(X_M_IN_T5 * I_T5)          <= (0.07 * I_T5)  ;
(0.04 * I_T6)  <= (X_M_IN_T6 * I_T6)          ;
(X_M_IN_T6 * I_T6)          <= (0.12 * I_T6)  ;
(0 * I_T7)     <= (X_M_IN_T7 * I_T7)          ;
(X_M_IN_T7 * I_T7)          <= (1 * I_T7)     ;
(0 * I_BLANK1) <= (X_M_IN_BLANK1 * I_BLANK1) ; (X_M_IN_BLANK1 *
I_BLANK1) <= (1 * I_BLANK1) ;

(25  * I_T1)      <= (S_1 * I_T1)      ;
(S_1 * I_T1)      <= (125 * I_T1)      ;
(0.5 * I_T2)      <= (S_1 * I_T2)      ;
(S_1 * I_T2)      <= (50  * I_T2)      ;
(0   * I_T3)      <= (S_1 * I_T3)      ;
(S_1 * I_T3)      <= (100 * I_T3)      ;
(0   * I_T4)      <= (S_1 * I_T4)      ;
(S_1 * I_T4)      <= (150 * I_T4)      ;
(25  * I_T5)      <= (S_1 * I_T5)      ;
(S_1 * I_T5)      <= (150 * I_T5)      ;
(25  * I_T6)      <= (S_1 * I_T6)      ;
(S_1 * I_T6)      <= (150 * I_T6)      ;
(0   * I_T7)      <= (S_1 * I_T7)      ;
(S_1 * I_T7)      <= (150 * I_T7)      ;
(0   * I_BLANK1) <= (S_1 * I_BLANK1) ;
(S_1 * I_BLANK1) <= (150 * I_BLANK1) ;

F_OUTCHCL_T1 = F_IN_T1 * X_CHCL_IN_T1 ;
F_OUTCHCL_T2 = F_IN_T2 * X_CHCL_IN_T2 ;
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```
F_OUTCHCL_T3 = F_IN_T3 * X_CHCL_IN_T3 ;
F_OUTCHCL_T4 = F_IN_T4 * X_CHCL_IN_T4 ;
F_OUTCHCL_T5 = F_IN_T5 * X_CHCL_IN_T5 ;
F_OUTCHCL_T6 = F_IN_T6 * X_CHCL_IN_T6 ;
F_OUTCHCL_T7 = F_IN_T7 * X_CHCL_IN_T7 ;
F_OUTCHCL_BLANK1 = F_IN_BLANK1 * X_CHCL_IN_BLANK1;

F_OUTCHCL_T1 <= TOTAL_CHCL_AVAILABLE ;
F_OUTCHCL_T2 <= TOTAL_CHCL_AVAILABLE ;
F_OUTCHCL_T3 <= TOTAL_CHCL_AVAILABLE ;
F_OUTCHCL_T4 <= TOTAL_CHCL_AVAILABLE ;
F_OUTCHCL_T5 <= TOTAL_CHCL_AVAILABLE ;
F_OUTCHCL_T6 <= TOTAL_CHCL_AVAILABLE ;
F_OUTCHCL_T7 <= TOTAL_CHCL_AVAILABLE ;
F_OUTCHCL_BLANK1 <= TOTAL_CHCL_AVAILABLE ;
F_OUTCHCL_T_TOTAL = F_OUTCHCL_T1 + F_OUTCHCL_T2 + F_OUTCHCL_T3 +
F_OUTCHCL_T4 + F_OUTCHCL_T5 + F_OUTCHCL_T6 + F_OUTCHCL_T7 +
F_OUTCHCL_BLANK1 ;
F_OUTCHCL_T_TOTAL <= TOTAL_CHCL_AVAILABLE ;

F_MR_T1 = F_IN_T1 * X_M_IN_T1 * MRR_T1 ; !kg/s = kg/s;
0.56 <= MRR_T1 ;
MRR_T1 <= 0.86 ;
TR_T1 = 0.67 ;!kWhr/kg ;
EF_T1 = 0.6 ;
P_D_T1 * EF_T1 * 3600 = TR_T1 * F_MR_T1 ; !kWhr/s * 3600 s/hr =
kWhr/kg * kg/s ;

F_MR_T2 = F_IN_T2 * X_M_IN_T2 * MRR_T2 ; !kg/s = kg/s;
0.56 <= MRR_T2 ;
MRR_T2 <= 0.86 ;
TR_T2 = 0.67 ; !kWhr/kg ;
EF_T2 = 0.86 ;
P_D_T2 * EF_T2 * 3600 = TR_T2 * F_MR_T2  ; !kWhr/s * 3600 s/hr =
kWhr/kg * kg/s ;

F_MR_T3 = F_IN_T3 * X_M_IN_T3 * MRR_T3;
0.56 <= MRR_T3 ;
MRR_T3 <= 0.86 ;
TR_T3 = 0.67 ; !kWhr/kg ;
EF_T3 = 0.87 ;
P_D_T3 * EF_T3 * 3600 = TR_T3 * F_MR_T3 ; !kWhr/s * 3600 s/hr =
kWhr/kg * kg/s ;

F_MR_T4 = F_IN_T4 * X_M_IN_T4 * MRR_T4;
0.64 <= MRR_T4 ;
MRR_T4 <= 0.81 ;
TR_T4 = 0.67 ; !kWhr/kg ;
EF_T4 = 0.7 ;
P_D_T4 * EF_T4 * 3600 = TR_T4 * F_MR_T4 ; !kWhr/s * 3600 s/hr =
kWhr/kg * kg/s ;

F_MR_T5 = F_IN_T5 * X_M_IN_T5 * MRR_T5;
MRR_T5 = 0.15 ;
TR_T5 = 0 ; !kWhr/kg ;
EF_T5 = 1 ;
```

```
P_D_T5 * EF_T5 * 3600  = TR_T5 * F_MR_T5 ; !kWhr/s * 3600 s/hr =
kWhr/kg * kg/s ;

F_MR_T6 = F_IN_T6 * X_M_IN_T6 * MRR_T6;
MRR_T6 = 0.15 ;
TR_T6 = 0 ; !kWhr/kg ;
EF_T6 = 1 ;
P_D_T6 * EF_T6 * 3600 = TR_T6 * F_MR_T6 ; !kWhr/s * 3600 s/hr =
kWhr/kg * kg/s ;

F_MR_T7 = F_IN_T7 * X_M_IN_T7 * MRR_T7;
MRR_T7 = 0.15 ;
TR_T7 = 0 ; !kWhr/kg ;
EF_T7 = 1 ;
P_D_T7 * EF_T7 * 3600 = TR_T7 * F_MR_T7 ; !kWhr/s * 3600 s/hr =
kWhr/kg * kg/s ;

F_MR_BLANK1 = F_IN_BLANK1 * X_M_IN_BLANK1 * MRR_BLANK1 ;
MRR_BLANK1 = 0 ;
TR_BLANK1 = 0 ; !kWhr/kg ;
EF_BLANK1 = 1 ;
P_D_BLANK1 * EF_BLANK1 * 3600 = TR_BLANK1 * F_MR_BLANK1 ; !kWhr/s *
3600 s/hr = kWhr/kg * kg/s ;

F_OUTM_T1 = F_IN_T1 * X_M_IN_T1 - F_MR_T1 ; !kg/s = kg/s ;
F_OUTM_T2 = F_IN_T2 * X_M_IN_T2 - F_MR_T2 ; !kg/s = kg/s ;
F_OUTM_T3 = F_IN_T3 * X_M_IN_T3 - F_MR_T3 ; !kg/s = kg/s ;
F_OUTM_T4 = F_IN_T4 * X_M_IN_T4 - F_MR_T4 ; !kg/s = kg/s ;
F_OUTM_T5 = F_IN_T5 * X_M_IN_T5 - F_MR_T5 ; !kg/s = kg/s ;
F_OUTM_T6 = F_IN_T6 * X_M_IN_T6 - F_MR_T6 ; !kg/s = kg/s ;
F_OUTM_T7 = F_IN_T7 * X_M_IN_T7 - F_MR_T7 ; !kg/s = kg/s ;
F_OUTM_BLANK1 = F_IN_BLANK1 * X_M_IN_BLANK1 - F_MR_BLANK1 ; !kg/s =
kg/s
F_OUTM_T_TOTAL = F_OUTM_T1 + F_OUTM_T2 + F_OUTM_T3 + F_OUTM_T4 +
F_OUTM_T5 + F_OUTM_T6 + F_OUTM_T7 + F_OUTM_BLANK1 ;
F_OUTM_T_TOTAL <= TOTAL_M_AVAILABLE ;

P_D_T1 + P_D_T2 + P_D_T3 + P_D_T4 + P_D_T5 + P_D_T6 + P_D_T7 +
P_D_BLANK1 = P_D_T_TOTAL ;

S_IN_T1 = S_1 ; S_IN_T2 = S_1;
S_IN_T3 = S_1 ; S_IN_T4 = S_1 ;
S_IN_T5 = S_1 ; S_IN_T6 = S_1 ;
S_IN_T7 = S_1 ; S_IN_BLANK1 = S_1 ;

(S_IN_T1/SRR_T1) * I_T1 = S_I1 ;
S_I1 <= 10000 * I_T1 ;
SRR_T1 = 1 ;
P_SR_T1 = I_T1 * @LOG10 (SRR_T1) * F_IN_T1 ; !kW = kW/kgs-1 * kgs-1 ;
@FREE (K_T1);
@FREE (P_SR_T1);

(S_IN_T2/SRR_T2) * I_T2 = S_I2 ;
S_I2 <= 10000 * I_T2 ;
SRR_T2 = 1 ;
P_SR_T2 = I_T2 * @LOG10 (SRR_T2) * F_IN_T2 ; !kW = kW/kgs-1 * kgs-1 ;
@FREE (K_T2);
```

```
@FREE (P_SR_T2);

(S_IN_T3/SRR_T3) * I_T3 = S_I3 ;
S_I3 <= 10000 * I_T3 ;
SRR_T3 = 1 ;
P_SR_T3 = I_T3 * @LOG10 (SRR_T3) * F_IN_T3 ; !kW = kW/kgs-1 * kgs-1 ;
@FREE (K_T3);
@FREE (P_SR_T3);

(S_IN_T4/SRR_T4) * I_T4 = S_I4 ;
S_I4 <= 10000 * I_T4 ;
SRR_T4 = 1 ;
P_SR_T4 = I_T4 * @LOG10 (SRR_T4) * F_IN_T4 ; !kW = kW/kgs-1 * kgs-1 ;
@FREE (K_T4);
@FREE (P_SR_T4);

(S_IN_T5/SRR_T5) * I_T5 = S_I5 ;
S_I5 <= 10000 * I_T5 ;
2 <= SRR_T5 ;
SRR_T5 <= 14 ;
A_T5 = @LOG10(SRR_T5);
B_T5 = X_M_IN_T5 ;
K_T5 = 339.9 - 1109*A_T5 - 7.529*B_T5  + 947.4*(A_T5^2) +
170.5*(A_T5)*(B_T5) - 16.53*(B_T5^2) - 362.7*(A_T5^3)
      - 76.75*(A_T5^2)*(B_T5)  - 5.958*(A_T5)*(B_T5^2) + 1.836*(B_T5
^3) + 56.16*(A_T5^4) + 3.813*(A_T5^3)*(B_T5) +
4.932*(A_T5^2)*(B_T5^2) - 0.7026*A_T5*(B_T5^3) ;
P_SR_T5 = I_T5 * K_T5 * @LOG10 (SRR_T5) * F_IN_T5 ; !kW = kW/kgs-1 *
kgs-1 ;
@FREE (K_T5);
@FREE (P_SR_T5);

(S_IN_T6/SRR_T6) * I_T6 = S_I6 ;
S_I6 <= 10000 * I_T6 ;
2.23 <= SRR_T6 ;
SRR_T6 <= 12.825 ;
A_T6 = @LOG10(SRR_T6);
B_T6 = X_M_IN_T6 ;
K_T6 = 49.02 + 10.04 *A_T6 - 72.54*B_T6  + 11.03*(A_T6^2) +
2.03*(A_T6)*(B_T6) + 96.17*(B_T6^2) +0.7976*(A_T6^3)
      +2.241*(A_T6^2)*(B_T6)  - 4.248*(A_T6)*(B_T6^2) -
18.67*(B_T6^3) + 2.451*(A_T6^4) + 6.563*(A_T6^3)*(B_T6) -
0.3381*(A_T6^2)*(B_T6^2) - 9.35*A_T6*(B_T6^3) -43.85*(B_T6^4) ;
P_SR_T6 = I_T6 * K_T6 * @LOG10 (SRR_T6) * F_IN_T6; !kW = kW/kgs-1 *
kgs-1 ;
@FREE (K_T6);
@FREE (P_SR_T6);

(S_IN_T7/SRR_T7) * I_T7 = S_I7 ;
S_I7 <= 10000 * I_T7 ;
2.03 <= SRR_T7 ;
SRR_T7 <= 4.06 ;
A_T7 = @LOG10(SRR_T7);! NEED TO CHANGE;
B_T7 = X_M_IN_T7 ; ! NEED TO CHANGE;
K_T7 = 1.0633 * A_T7 + 0.0203 ;
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P_SR_T7 = I_T7 * K_T7 * @LOG10 (SRR_T7) * F_IN_T7; !kW = kW/kgs-1 *
kgs-1 ;
@FREE (K_T7);
@FREE (P_SR_T7);

(S_IN_BLANK1/SRR_BLANK1) * I_BLANK1 = S_I8 ;
S_I8 <= 10000 * I_BLANK1 ;
SRR_BLANK1 = 1 ;
P_SR_BLANK1 = I_BLANK1 * @LOG10 (SRR_BLANK1) * F_IN_BLANK1 ; !kW =
kW/kgs-1 * kgs-1 ;
@FREE (K_BLANK1);
@FREE (P_SR_BLANK1);

P_SR_T1 + P_SR_T2 + P_SR_T3 + P_SR_T4 + P_SR_T5 + P_SR_T6 + P_SR_T7 +
P_SR_BLANK1 = P_SR_T_TOTAL ;

!TECHNOLOGY COST;
C_T1 = ((2.9*3*18^0.63)*1000)*(((F_IN_T1*3600/1000)/1)^0.6);
C_T2 = ((2.23*1.75*46^0.6)*1000)*(((F_IN_T2*3600/1000)/1)^0.6);
C_T3 = ((45*1^0.7)*1000)*(((F_IN_T3*3600/1000)/1)^0.6);
C_T4 = ((1.4*5^0.77)*1000)*(((F_IN_T4*3600/1000)/1)^0.6);
C_T5 = ((27.5*1*0.39)*1000)*(((F_IN_T5*3600/1000)/1)^0.6);
C_T6 = ((2.97*(F_IN_T6*3600/1000)^0.78)*1000);
C_T7 = ((7.7*1^0.57)*1000)*(((F_IN_T7*3600/1000)/1)^0.6);
C_BLANK1 = F_IN_BLANK1 * 0;

C_T_TOTAL = C_T1 + C_T2 + C_T3 + C_T4 + C_T5 + C_T6 + C_T7 +
C_BLANK1 ;

F_I1 = F_OUTCHCL_T1 + F_OUTM_T1 ; !kg/s = kg/s ;
F_I2 = F_OUTCHCL_T2 + F_OUTM_T2 ; !kg/s = kg/s ;
F_I3 = F_OUTCHCL_T3 + F_OUTM_T3 ; !kg/s = kg/s ;
F_I4 = F_OUTCHCL_T4 + F_OUTM_T4 ; !kg/s = kg/s ;
F_I5 = F_OUTCHCL_T5 + F_OUTM_T5 ; !kg/s = kg/s ;
F_I6 = F_OUTCHCL_T6 + F_OUTM_T6 ; !kg/s = kg/s ;
F_I7 = F_OUTCHCL_T7 + F_OUTM_T7 ; !kg/s = kg/s ;
F_I8 = F_OUTCHCL_BLANK1 + F_OUTM_BLANK1 ; !kg/s = kg/s ;

F_I1 <= TOTAL_BIOMASS_AVAILABLE ;
F_I2 <= TOTAL_BIOMASS_AVAILABLE ;
F_I3 <= TOTAL_BIOMASS_AVAILABLE ;
F_I4 <= TOTAL_BIOMASS_AVAILABLE ;
F_I5 <= TOTAL_BIOMASS_AVAILABLE ;
F_I6 <= TOTAL_BIOMASS_AVAILABLE ;
F_I7 <= TOTAL_BIOMASS_AVAILABLE ;
F_I8 <= TOTAL_BIOMASS_AVAILABLE ;
F_I_TOTAL = F_I1 + F_I2 + F_I3 + F_I4 + F_I5 + F_I6 + F_I7 + F_I8 ;
F_I_TOTAL <= TOTAL_BIOMASS_AVAILABLE ;

F_OUTCHCL_T1  = F_I1 * X_CHCL_I1 ;
F_OUTM_T1     = F_I1 * X_M_I1    ;
X_CHCL_I1 + X_M_I1 <= 1 ; !JUST ADD TO EASE CALCULATION IN LINGO, DO
NOT INCLUDE IN FORMULATION.;

F_OUTCHCL_T2  = F_I2 * X_CHCL_I2 ;
F_OUTM_T2     = F_I2 * X_M_I2    ;
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X_CHCL_I2 + X_M_I2 <= 1 ; !JUST ADD TO EASE CALCULATION IN LINGO, DO
NOT INCLUDE IN FORMULATION.;

F_OUTCHCL_T3  = F_I3 * X_CHCL_I3 ;
F_OUTM_T3     = F_I3 * X_M_I3    ;
X_CHCL_I3 + X_M_I3 <= 1 ; !JUST ADD TO EASE CALCULATION IN LINGO, DO
NOT INCLUDE IN FORMULATION.;

F_OUTCHCL_T4  = F_I4 * X_CHCL_I4 ;
F_OUTM_T4     = F_I4 * X_M_I4    ;
X_CHCL_I4 + X_M_I4 <= 1 ; !JUST ADD TO EASE CALCULATION IN LINGO, DO
NOT INCLUDE IN FORMULATION.;

F_OUTCHCL_T5  = F_I5 * X_CHCL_I5 ;
F_OUTM_T5     = F_I1 * X_M_I5    ;
X_CHCL_I5 + X_M_I5 <= 1 ; !JUST ADD TO EASE CALCULATION IN LINGO, DO
NOT INCLUDE IN FORMULATION.;

F_OUTCHCL_T6  = F_I6 * X_CHCL_I6 ;
F_OUTM_T6     = F_I6 * X_M_I6    ;
X_CHCL_I6 + X_M_I6 <= 1 ; !JUST ADD TO EASE CALCULATION IN LINGO, DO
NOT INCLUDE IN FORMULATION.;

F_OUTCHCL_T7  = F_I7 * X_CHCL_I7 ;
F_OUTM_T7     = F_I7 * X_M_I7    ;
X_CHCL_I7 + X_M_I7 <= 1 ; !JUST ADD TO EASE CALCULATION IN LINGO, DO
NOT INCLUDE IN FORMULATION.;

F_OUTCHCL_BLANK1 = F_I8 * X_CHCL_I8 ;
F_OUTM_BLANK1    = F_I8 * X_M_I8    ;
X_CHCL_I8 + X_M_I8 <= 1 ; !JUST ADD TO EASE CALCULATION IN LINGO, DO
NOT INCLUDE IN FORMULATION.;

I_T1 + I_T2 + I_T3 + I_T4 + I_T5 + I_T6 + I_T7 + I_BLANK1 =
I_T_TOTAL ;

!STAGE 2;
S_2 >= S_I1 ; S_2 >= S_I2 ;
S_2 >= S_I3 ; S_2 >= S_I4 ;
S_2 >= S_I5 ; S_2 >= S_I6 ;
S_2 >= S_I7 ; S_2 >= S_I8 ;

F_I1 = F_I1_TP1 + F_I1_TP2 + F_I1_TP3 + F_I1_TP4 + F_I1_TP5 +
F_I1_TP6 + F_I1_TP7 + F_I1_BLANK2 ; !kg/s = kg/s ;
F_I2 = F_I2_TP1 + F_I2_TP2 + F_I2_TP3 + F_I2_TP4 + F_I2_TP5 +
F_I2_TP6 + F_I2_TP7 + F_I2_BLANK2 ; !kg/s = kg/s ;
F_I3 = F_I3_TP1 + F_I3_TP2 + F_I3_TP3 + F_I3_TP4 + F_I3_TP5 +
F_I3_TP6 + F_I3_TP7 + F_I3_BLANK2 ; !kg/s = kg/s ;
F_I4 = F_I4_TP1 + F_I4_TP2 + F_I4_TP3 + F_I4_TP4 + F_I4_TP5 +
F_I4_TP6 + F_I4_TP7 + F_I4_BLANK2 ; !kg/s = kg/s ;
F_I5 = F_I5_TP1 + F_I5_TP2 + F_I5_TP3 + F_I5_TP4 + F_I5_TP5 +
F_I5_TP6 + F_I5_TP7 + F_I5_BLANK2 ; !kg/s = kg/s ;
F_I6 = F_I6_TP1 + F_I6_TP2 + F_I6_TP3 + F_I6_TP4 + F_I6_TP5 +
F_I6_TP6 + F_I6_TP7 + F_I6_BLANK2 ; !kg/s = kg/s ;
F_I7 = F_I7_TP1 + F_I7_TP2 + F_I7_TP3 + F_I7_TP4 + F_I7_TP5 +
F_I7_TP6 + F_I7_TP7 + F_I7_BLANK2 ; !kg/s = kg/s ;
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F_I8 = F_I8_TP1 + F_I8_TP2 + F_I8_TP3 + F_I8_TP4 + F_I8_TP5 +
F_I8_TP6 + F_I8_TP7 + F_I8_BLANK2 ; !kg/s = kg/s ;

F_IN_TP1 = F_I1_TP1 + F_I2_TP1 + F_I3_TP1 + F_I4_TP1 + F_I5_TP1 +
F_I6_TP1 + F_I7_TP1 + F_I8_TP1 ; !kg/s = kg/s ;
F_IN_TP1 * X_CHCL_IN_TP1  = F_I1_TP1 * X_CHCL_I1  + F_I2_TP1 *
X_CHCL_I2  + F_I3_TP1 * X_CHCL_I3  + F_I4_TP1 * X_CHCL_I4  + F_I5_TP1
* X_CHCL_I5  + F_I6_TP1 * X_CHCL_I6  + F_I7_TP1 * X_CHCL_I7 +
F_I8_TP1 * X_CHCL_I8 ;
F_IN_TP1 * X_M_IN_TP1     = F_I1_TP1 * X_M_I1     + F_I2_TP1 * X_M_I2
+ F_I3_TP1 * X_M_I3     + F_I4_TP1 * X_M_I4     + F_I5_TP1 * X_M_I5
+ F_I6_TP1 * X_M_I6     + F_I7_TP1 * X_M_I7    + F_I8_TP1 *
X_M_I8    ;
X_CHCL_IN_TP1 + X_M_IN_TP1 <=1 ;

F_IN_TP2 = F_I1_TP2 + F_I2_TP2 + F_I3_TP2 + F_I4_TP2 + F_I5_TP2 +
F_I6_TP2 + F_I7_TP2 + F_I8_TP2 ; !kg/s = kg/s ;
F_IN_TP2 * X_CHCL_IN_TP2  = F_I1_TP2 * X_CHCL_I1  + F_I2_TP2 *
X_CHCL_I2  + F_I3_TP2 * X_CHCL_I3  + F_I4_TP2 * X_CHCL_I4  + F_I5_TP2
* X_CHCL_I5  + F_I6_TP2 * X_CHCL_I6  + F_I7_TP2 * X_CHCL_I7 +
F_I8_TP2 * X_CHCL_I8 ;
F_IN_TP2 * X_M_IN_TP2     = F_I1_TP2 * X_M_I1     + F_I2_TP2 * X_M_I2
+ F_I3_TP2 * X_M_I3     + F_I4_TP2 * X_M_I4     + F_I5_TP2 * X_M_I5
+ F_I6_TP2 * X_M_I6     + F_I7_TP2 * X_M_I7    + F_I8_TP2 *
X_M_I8    ;
X_CHCL_IN_Tp2 + X_M_IN_TP2 <=1 ;

F_IN_TP3 = F_I1_TP3 + F_I2_TP3 + F_I3_TP3 + F_I4_TP3 + F_I5_TP3 +
F_I6_TP3 + F_I7_TP3 + F_I8_TP3 ; !kg/s = kg/s ;
F_IN_TP3 * X_CHCL_IN_TP3  = F_I1_TP3 * X_CHCL_I1  + F_I2_TP3 *
X_CHCL_I2  + F_I3_TP3 * X_CHCL_I3  + F_I4_TP3 * X_CHCL_I4  + F_I5_TP3
* X_CHCL_I5  + F_I6_TP3 * X_CHCL_I6  + F_I7_TP3 * X_CHCL_I7 +
F_I8_TP3 * X_CHCL_I8 ;
F_IN_TP3 * X_M_IN_TP3     = F_I1_TP3 * X_M_I1     + F_I2_TP3 * X_M_I2
+ F_I3_TP3 * X_M_I3     + F_I4_TP3 * X_M_I4     + F_I5_TP3 * X_M_I5
+ F_I6_TP3 * X_M_I6     + F_I7_TP3 * X_M_I7    + F_I8_TP3 *
X_M_I8    ;
X_CHCL_IN_TP3 + X_M_IN_TP3 <=1 ;

F_IN_TP4 = F_I1_TP4 + F_I2_TP4 + F_I3_TP4 + F_I4_TP4 + F_I5_TP4 +
F_I6_TP4 + F_I7_TP4 + F_I8_TP4 ; !kg/s = kg/s ;
F_IN_TP4 * X_CHCL_IN_TP4  = F_I1_TP4 * X_CHCL_I1  + F_I2_TP4 *
X_CHCL_I2  + F_I3_TP4 * X_CHCL_I3  + F_I4_TP4 * X_CHCL_I4  + F_I5_TP4
* X_CHCL_I5  + F_I6_TP4 * X_CHCL_I6  + F_I7_TP4 * X_CHCL_I7 +
F_I8_TP4 * X_CHCL_I8 ;
F_IN_TP4 * X_M_IN_TP4     = F_I1_TP4 * X_M_I1     + F_I2_TP4 * X_M_I2
+ F_I3_TP4 * X_M_I3     + F_I4_TP4 * X_M_I4     + F_I5_TP4 * X_M_I5
+ F_I6_TP4 * X_M_I6     + F_I7_TP4 * X_M_I7    + F_I8_TP4 *
X_M_I8    ;
X_CHCL_IN_TP4 + X_M_IN_TP4 <=1 ;

F_IN_TP5 = F_I1_TP5 + F_I2_TP5 + F_I3_TP5 + F_I4_TP5 + F_I5_TP5 +
F_I6_TP5 + F_I7_TP5 + F_I8_TP5 ; !kg/s = kg/s ;
F_IN_TP5 * X_CHCL_IN_TP5  = F_I1_TP5 * X_CHCL_I1  + F_I2_TP5 *
X_CHCL_I2  + F_I3_TP5 * X_CHCL_I3  + F_I4_TP5 * X_CHCL_I4  + F_I5_TP5
* X_CHCL_I5  + F_I6_TP5 * X_CHCL_I6  + F_I7_TP5 * X_CHCL_I7 +
F_I8_TP5 * X_CHCL_I8 ;
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```
F_IN_TP5 * X_M_IN_TP5     = F_I1_TP5 * X_M_I1     + F_I2_TP5 * X_M_I2
+ F_I3_TP5 * X_M_I3     + F_I4_TP5 * X_M_I4     + F_I5_TP5 * X_M_I5
+ F_I6_TP5 * X_M_I6     + F_I7_TP5 * X_M_I7    + F_I8_TP5 *
X_M_I8    ;
X_CHCL_IN_TP5 + X_M_IN_TP5 <=1 ;

F_IN_TP6 = F_I1_TP6 + F_I2_TP6 + F_I3_TP6 + F_I4_TP6 + F_I5_TP6 +
F_I6_TP6 + F_I7_TP6 + F_I8_TP6 ; !kg/s = kg/s ;
F_IN_TP6 * X_CHCL_IN_TP6  = F_I1_TP6 * X_CHCL_I1  + F_I2_TP6 *
X_CHCL_I2  + F_I3_TP6 * X_CHCL_I3  + F_I4_TP6 * X_CHCL_I4  + F_I5_TP6
* X_CHCL_I5  + F_I6_TP6 * X_CHCL_I6  + F_I7_TP6 * X_CHCL_I7 +
F_I8_TP6 * X_CHCL_I8 ;
F_IN_TP6 * X_M_IN_TP6     = F_I1_TP6 * X_M_I1     + F_I2_TP6 * X_M_I2
+ F_I3_TP6 * X_M_I3     + F_I4_TP6 * X_M_I4     + F_I5_TP6 * X_M_I5
+ F_I6_TP6 * X_M_I6     + F_I7_TP6 * X_M_I7    + F_I8_TP6 *
X_M_I8    ;
X_CHCL_IN_TP6 + X_M_IN_TP6 <=1 ;

F_IN_TP7 = F_I1_TP7 + F_I2_TP7 + F_I3_TP7 + F_I4_TP7 + F_I5_TP7 +
F_I6_TP7 + F_I7_TP7 + F_I8_TP7 ; !kg/s = kg/s ;
F_IN_TP7 * X_CHCL_IN_TP7  = F_I1_TP7 * X_CHCL_I1  + F_I2_TP7 *
X_CHCL_I2  + F_I3_TP7 * X_CHCL_I3  + F_I4_TP7 * X_CHCL_I4  + F_I5_TP7
* X_CHCL_I5  + F_I6_TP7 * X_CHCL_I6  + F_I7_TP7 * X_CHCL_I7 +
F_I8_TP7 * X_CHCL_I8 ;
F_IN_TP7 * X_M_IN_TP7     = F_I1_TP7 * X_M_I1     + F_I2_TP7 * X_M_I2
+ F_I3_TP7 * X_M_I3     + F_I4_TP7 * X_M_I4     + F_I5_TP7 * X_M_I5
+ F_I6_TP7 * X_M_I6     + F_I7_TP7 * X_M_I7    + F_I8_TP7 *
X_M_I8    ;
X_CHCL_IN_TP7 + X_M_IN_TP7 <=1 ;

F_IN_BLANK2 = F_I1_BLANK2 + F_I2_BLANK2 + F_I3_BLANK2 + F_I4_BLANK2 +
F_I5_BLANK2 + F_I6_BLANK2 + F_I7_BLANK2 + F_I8_BLANK2 ; !kg/s =
kg/s ;
F_IN_BLANK2 * X_CHCL_IN_BLANK2  = F_I1_BLANK2 * X_CHCL_I1  +
F_I2_BLANK2 * X_CHCL_I2  + F_I3_BLANK2 * X_CHCL_I3  + F_I4_BLANK2 *
X_CHCL_I4  + F_I5_BLANK2 * X_CHCL_I5  + F_I6_BLANK2 * X_CHCL_I6  +
F_I7_BLANK2 * X_CHCL_I7 + F_I8_BLANK2 * X_CHCL_I8 ;
F_IN_BLANK2 * X_M_IN_BLANK2     = F_I1_BLANK2 * X_M_I1     +
F_I2_BLANK2 * X_M_I2     + F_I3_BLANK2 * X_M_I3     + F_I4_BLANK2 *
X_M_I4     + F_I5_BLANK2 * X_M_I5     + F_I6_BLANK2 * X_M_I6     +
F_I7_BLANK2 * X_M_I7    + F_I8_BLANK2 * X_M_I8    ;
X_CHCL_IN_BLANK2 + X_M_IN_BLANK2 <=1 ;

F_IN_TP1 + F_IN_TP2 + F_IN_TP3 + F_IN_TP4 + F_IN_TP5 + F_IN_TP6 +
F_IN_TP7 + F_IN_BLANK2 = F_IN_TP_TOTAL ;
F_IN_TP1 <= TOTAL_BIOMASS_AVAILABLE ;
F_IN_TP2 <= TOTAL_BIOMASS_AVAILABLE ;
F_IN_TP3 <= TOTAL_BIOMASS_AVAILABLE ;
F_IN_TP4 <= TOTAL_BIOMASS_AVAILABLE ;
F_IN_TP5 <= TOTAL_BIOMASS_AVAILABLE ;
F_IN_TP6 <= TOTAL_BIOMASS_AVAILABLE ;
F_IN_TP7 <= TOTAL_BIOMASS_AVAILABLE ;
F_IN_BLANK2 <= TOTAL_BIOMASS_AVAILABLE ;
F_IN_TP_TOTAL <= TOTAL_BIOMASS_AVAILABLE ;

(F_IN_TP1/TOTAL_BIOMASS_AVAILABLE) <= I_TP1 ;
(F_IN_TP2/TOTAL_BIOMASS_AVAILABLE) <= I_TP2 ;
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(F_IN_TP3/TOTAL_BIOMASS_AVAILABLE) <= I_TP3 ;
(F_IN_TP4/TOTAL_BIOMASS_AVAILABLE) <= I_TP4 ;
(F_IN_TP5/TOTAL_BIOMASS_AVAILABLE) <= I_TP5 ;
(F_IN_TP6/TOTAL_BIOMASS_AVAILABLE) <= I_TP6 ;
(F_IN_TP7/TOTAL_BIOMASS_AVAILABLE) <= I_TP7 ;
(F_IN_BLANK2/TOTAL_BIOMASS_AVAILABLE) <= I_BLANK2 ;
@BIN(I_TP1); @BIN(I_TP2);
@BIN(I_TP3); @BIN(I_TP4);
@BIN(I_TP5); @BIN(I_TP6);
@BIN(I_TP7); @BIN(I_BLANK2);

(0.25 * I_TP1) <= (X_M_IN_TP1 * I_TP1)       ;
(X_M_IN_TP1 * I_TP1)       <= (0.65 * I_TP1) ;
(0.25 * I_TP2) <= (X_M_IN_TP2 * I_TP2)       ;
(X_M_IN_TP2 * I_TP2)       <= (0.65 * I_TP2) ;
(0.25 * I_TP3) <= (X_M_IN_TP3 * I_TP3)       ;
(X_M_IN_TP3 * I_TP3)       <= (0.65 * I_TP3) ;
(0.25 * I_TP4) <= (X_M_IN_TP4 * I_TP4)       ;
(X_M_IN_TP4 * I_TP4)       <= (0.72 * I_TP4) ;
(0.04 * I_TP5) <= (X_M_IN_TP5 * I_TP5)       ;
(X_M_IN_TP5 * I_TP5)       <= (0.07 * I_TP5) ;
(0.04 * I_TP6) <= (X_M_IN_TP6 * I_TP6)       ;
(X_M_IN_TP6 * I_TP6)       <= (0.12 * I_TP6) ;
(0 * I_TP7)    <= (X_M_IN_TP7 * I_TP7)       ;
(X_M_IN_TP7 * I_TP7)       <= (1 * I_TP7)    ;
(0 * I_BLANK2) <= (X_M_IN_BLANK2 * I_BLANK2) ;
(X_M_IN_BLANK2 * I_BLANK2) <= (1 * I_BLANK2) ;

(25  * I_TP1)    <= (S_2 * I_TP1)    ;
(S_2 * I_TP1)    <= (125 * I_TP1)    ;
(0.5 * I_TP2)    <= (S_2 * I_TP2)    ;
(S_2 * I_TP2)    <= (50  * I_TP2)    ;
(0   * I_TP3)    <= (S_2 * I_TP3)    ;
(S_2 * I_TP3)    <= (100 * I_TP3)    ;
(0   * I_TP4)    <= (S_2 * I_TP4)    ;
(S_2 * I_TP4)    <= (150 * I_TP4)    ;
(25  * I_TP5)    <= (S_2 * I_TP5)    ;
(S_2 * I_TP5)    <= (150 * I_TP5)    ;
(25  * I_TP6)    <= (S_2 * I_TP6)    ;
(S_2 * I_TP6)    <= (150 * I_TP6)    ;
(0   * I_TP7)    <= (S_2 * I_TP7)    ;
(S_2 * I_TP7)    <= (150 * I_TP7)    ;
(0 * I_BLANK2)   <= (S_2 * I_BLANK2) ;
(S_2 * I_BLANK2) <= (150 * I_BLANK2) ;

F_OUTCHCL_TP1 = (F_IN_TP1 * X_CHCL_IN_TP1)  ;
F_OUTCHCL_TP2 = (F_IN_TP2 * X_CHCL_IN_TP2)  ;
F_OUTCHCL_TP3 = (F_IN_TP3 * X_CHCL_IN_TP3)  ;
F_OUTCHCL_TP4 = (F_IN_TP4 * X_CHCL_IN_TP4)  ;
F_OUTCHCL_TP5 = (F_IN_TP5 * X_CHCL_IN_TP5)  ;
F_OUTCHCL_TP6 = (F_IN_TP6 * X_CHCL_IN_TP6)  ;
F_OUTCHCL_TP7 = (F_IN_TP7 * X_CHCL_IN_TP7)  ;
F_OUTCHCL_BLANK2 = (F_IN_BLANK2 * X_CHCL_IN_BLANK2)  ;

F_OUTCHCL_TP1 <= TOTAL_CHCL_AVAILABLE ;
F_OUTCHCL_TP2 <= TOTAL_CHCL_AVAILABLE ;
F_OUTCHCL_TP3 <= TOTAL_CHCL_AVAILABLE ;
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F_OUTCHCL_TP4 <= TOTAL_CHCL_AVAILABLE ;
F_OUTCHCL_TP5 <= TOTAL_CHCL_AVAILABLE ;
F_OUTCHCL_TP6 <= TOTAL_CHCL_AVAILABLE ;
F_OUTCHCL_TP7 <= TOTAL_CHCL_AVAILABLE ;
F_OUTCHCL_BLANK2 <= TOTAL_CHCL_AVAILABLE ;
F_OUTCHCL_TP_TOTAL = F_OUTCHCL_TP1 + F_OUTCHCL_TP2 + F_OUTCHCL_TP3 +
F_OUTCHCL_TP4 + F_OUTCHCL_TP5 + F_OUTCHCL_TP6 + F_OUTCHCL_TP7 +
F_OUTCHCL_BLANK2 ;
F_OUTCHCL_TP_TOTAL <= TOTAL_CHCL_AVAILABLE ;

F_MR_TP1 = F_IN_TP1 * X_M_IN_TP1 * MRR_TP1 ;
0.56 <= MRR_TP1 ;
MRR_TP1 <= 0.86 ;
TR_TP1 = 0.67 ; !kWhr/kg ;
EF_TP1 = 0.6 ;
P_D_TP1 * EF_TP1 * 3600 = TR_TP1 * F_MR_TP1  ; !kWhr/s * 3600 s/hr =
kWhr/kg * kg/s ;

F_MR_TP2 = F_IN_TP2 * X_M_IN_TP2 * MRR_TP2 ;
0.56 <= MRR_TP2 ;
MRR_TP2 <= 0.86 ;
TR_TP2 = 0.67 ; !kWhr/kg ;
EF_TP2 = 0.86 ;
P_D_TP2 * EF_TP2 * 3600 = TR_TP2 * F_MR_TP2  ; !kWhr/s * 3600 s/hr =
kWhr/kg * kg/s ;

F_MR_TP3 = F_IN_TP3 * X_M_IN_TP3 * MRR_TP3 ;
0.56 <= MRR_TP3 ;
MRR_TP3 <= 0.86 ;
TR_TP3 = 0.67 ; !kWhr/kg ;
EF_TP3 = 0.87 ;
P_D_TP3 * EF_TP3 * 3600 = TR_TP3 * F_MR_TP3 ; !kWhr/s * 3600 s/hr =
kWhr/kg * kg/s ;

F_MR_TP4 = F_IN_TP4 * X_M_IN_TP4 * MRR_TP4 ;
0.64 <= MRR_TP4 ;
MRR_TP4 <= 0.81 ;
TR_TP4 = 0.67 ; !kWhr/kg ;
EF_TP4 = 0.7 ;
P_D_TP4 * EF_TP4 * 3600 = TR_TP4 * F_MR_TP4 ; !kWhr/s * 3600 s/hr =
kWhr/kg * kg/s ;

F_MR_TP5 = F_IN_TP5 * X_M_IN_TP5 * MRR_TP5 ;
MRR_TP5 = 0.15 ;
TR_TP5 = 0 ; !kWhr/kg ;
EF_TP5 = 1 ;
P_D_TP5 * EF_TP5 * 3600  = TR_TP5 * F_MR_TP5 ; !kWhr/s * 3600 s/hr =
kWhr/kg * kg/s ;

F_MR_TP6 = F_IN_TP6 * X_M_IN_TP6 * MRR_TP6 ;
MRR_TP6 = 0.15 ;
TR_TP6 = 0 ; !kWhr/kg ;
EF_TP6 = 1 ;
P_D_TP6 * EF_TP6 * 3600 = TR_TP6 * F_MR_TP6 ; !kWhr/s * 3600 s/hr =
kWhr/kg * kg/s ;

F_MR_TP7 = F_IN_TP7 * X_M_IN_TP7 * MRR_TP7 ;
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MRR_TP7 = 0.15 ;
TR_TP7 = 0 ; !kWhr/kg ;
EF_TP7 = 1 ;
P_D_TP7 * EF_TP7 * 3600 = TR_TP7 * F_MR_TP7 ; !kWhr/s * 3600 s/hr =
kWhr/kg * kg/s ;

F_MR_BLANK2 = F_IN_BLANK2 * X_M_IN_BLANK2 * MRR_BLANK2 ;
MRR_BLANK2 = 0 ;
TR_BLANK2 = 0 ; !kWhr/kg ;
EF_BLANK2 = 1;
P_D_BLANK2 * EF_BLANK2 * 3600 = TR_BLANK2 * F_MR_BLANK2 ; !kWhr/s *
3600 s/hr  = kWhr/kg * kg/s ;

P_D_TP1 + P_D_TP2 + P_D_TP3 + P_D_TP4 + P_D_TP5 + P_D_TP6 + P_D_TP7 +
P_D_BLANK2 = P_D_TP_TOTAL ;

F_OUTM_TP1 = F_IN_TP1 * X_M_IN_TP1 - F_MR_TP1 ;
F_OUTM_TP2 = F_IN_TP2 * X_M_IN_TP2 - F_MR_TP2 ;
F_OUTM_TP3 = F_IN_TP3 * X_M_IN_TP3 - F_MR_TP3 ;
F_OUTM_TP4 = F_IN_TP4 * X_M_IN_TP4 - F_MR_TP4 ;
F_OUTM_TP5 = F_IN_TP5 * X_M_IN_TP5 - F_MR_TP5 ;
F_OUTM_TP6 = F_IN_TP6 * X_M_IN_TP6 - F_MR_TP6 ;
F_OUTM_TP7 = F_IN_TP7 * X_M_IN_TP7 - F_MR_TP7 ;
F_OUTM_BLANK2 = F_IN_BLANK2 * X_M_IN_BLANK2 - F_MR_BLANK2 ;

F_OUTM_TP_TOTAL = F_OUTM_TP1 + F_OUTM_TP2 + F_OUTM_TP3 + F_OUTM_TP4 +
F_OUTM_TP5 + F_OUTM_TP6 + F_OUTM_TP7 + F_OUTM_BLANK2 ;
F_OUTM_TP_TOTAL <= TOTAL_M_AVAILABLE;

S_IN_TP1 = S_2 ; S_IN_TP2 = S_2 ;
S_IN_TP3 = S_2 ; S_IN_TP4 = S_2 ;
S_IN_TP5 = S_2 ; S_IN_TP6 = S_2 ;
S_IN_TP7 = S_2 ; S_IN_BLANK2 = S_2 ;

(S_IN_TP1/SRR_TP1) * I_TP1 = S_IP1 ;
S_IP1 <= 10000 * I_TP1 ;
SRR_TP1 = 1 ;
P_SR_TP1 = I_TP1 * @LOG10 (SRR_TP1) * F_IN_TP1 ; !kW = kW/kgs-1 *
kgs-1 ;
@FREE (K_TP1);
@FREE (P_SR_TP1);

(S_IN_TP2/SRR_TP2) * I_TP2 = S_IP2 ;
S_IP2 <= 10000 * I_TP2 ;
SRR_TP2 = 1 ;
P_SR_TP2 = I_TP2 * @LOG10 (SRR_TP2) * F_IN_TP2 ; !kW = kW/kgs-1 *
kgs-1 ;
@FREE (K_TP2);
@FREE (P_SR_TP2);

(S_IN_TP3/SRR_TP3) * I_TP3 = S_IP3 ;
S_IP3 <= 10000 * I_TP3 ;
SRR_TP3 = 1 ;
P_SR_TP3 = I_TP3 * @LOG10 (SRR_TP3) * F_IN_TP3 ; !kW = kW/kgs-1 *
kgs-1 ;
@FREE (K_TP3);
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@FREE (P_SR_TP3);

(S_IN_TP4/SRR_TP4) * I_TP4 = S_IP4 ;
S_IP4 <= 10000 * I_TP4 ;
SRR_TP4 = 1 ;
P_SR_TP4 = I_TP4 * @LOG10 (SRR_TP4) * F_IN_TP4 ; !kW = kW/kgs-1 *
kgs-1 ;
@FREE (K_TP4);
@FREE (P_SR_TP4);

(S_IN_TP5/SRR_TP5) * I_TP5 = S_IP5 ;
S_IP5 <= 10000 * I_TP5 ;
2 <= SRR_TP5 ;
SRR_TP5 <= 14 ;
A_TP5 = @LOG10(SRR_TP5);
B_TP5 = X_M_IN_TP5 ;
K_TP5 = 339.9 - 1109*A_TP5 - 7.529*B_TP5  + 947.4*(A_TP5^2) +
170.5*(A_TP5)*(B_TP5) - 16.53*(B_TP5^2) - 362.7*(A_TP5^3)
      - 76.75*(A_TP5^2)*(B_TP5)  - 5.958*(A_TP5)*(B_TP5^2) +
1.836*(B_TP5 ^3) + 56.16*(A_TP5^4) + 3.813*(A_TP5^3)*(B_TP5) +
4.932*(A_TP5^2)*(B_TP5^2) - 0.7026*A_TP5*(B_TP5^3) ;
P_SR_TP5 = I_TP5 * K_TP5 * @LOG10 (SRR_TP5) * F_IN_TP5 ; !kW =
kW/kgs-1 * kgs-1 ;
@FREE (K_TP5);
@FREE (P_SR_TP5);

(S_IN_TP6/SRR_TP6) * I_TP6 = S_IP6 ;
S_IP6 <= 10000 * I_TP6 ;
2.23 <= SRR_TP6 ;
SRR_TP6 <= 12.825 ;
A_TP6 = @LOG10(SRR_TP6);
B_TP6 = X_M_IN_TP6 ;
K_TP6 = 49.02 + 10.04 *A_TP6 - 72.54*B_TP6  + 11.03*(A_TP6^2) +
2.03*(A_TP6)*(B_TP6) + 96.17*(B_TP6^2) +0.7976*(A_TP6^3)
      +2.241*(A_T6^2)*(B_TP6)  - 4.248*(A_TP6)*(B_TP6^2) -
18.67*(B_TP6^3) + 2.451*(A_TP6^4) + 6.563*(A_TP6^3)*(B_TP6) -
0.3381*(A_TP6^2)*(B_TP6^2) - 9.35*A_TP6*(B_TP6^3) -43.85*(B_TP6^4) ;
P_SR_TP6 = I_TP6 * K_TP6 * @LOG10 (SRR_TP6) * F_IN_TP6 ; !kW =
kW/kgs-1 * kgs-1 ;
@FREE (K_TP6);
@FREE (P_SR_TP6);

(S_IN_TP7/SRR_TP7) * I_TP7 = S_IP7 ;
S_IP7 <= 10000 * I_TP7 ;
2.03 <= SRR_TP7 ;
SRR_TP7 <= 4.06 ;
A_TP7 = @LOG10(SRR_TP7);
K_TP7 = 1.0633 * A_TP7 + 0.0203 ;
P_SR_TP7 = I_TP7 * K_TP7 * @LOG10 (SRR_TP7) * F_IN_TP7 ; !kW =
kW/kgs-1 * kgs-1 ;

(S_IN_BLANK2/SRR_BLANK2) * I_BLANK2 = S_IP8 ;
S_IP8 <= 10000 * I_BLANK2 ;
SRR_BLANK2 = 1 ;
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P_SR_BLANK2 = I_BLANK2 * @LOG10 (SRR_BLANK2) * F_IN_BLANK2 ; !kW =
kW/kgs-1 * kgs-1 ;
@FREE (K_BLANK2);
@FREE (P_SR_BLANK2);

P_SR_TP1 + P_SR_TP2 + P_SR_TP3 + P_SR_TP4 + P_SR_TP5 + P_SR_TP6 +
P_SR_TP7 + P_SR_BLANK2 = P_SR_TP_TOTAL ;

!TECHNOLOGY COST;
C_TP1 = ((2.9*3*18^0.63)*1000)*(((F_IN_TP1*3600/1000)/1)^0.6);
C_TP2 = ((2.23*1.75*46^0.6)*1000)*(((F_IN_TP2*3600/1000)/1)^0.6);
C_TP3 = ((45*1^0.7)*1000)*(((F_IN_TP3*3600/1000)/1)^0.6);
C_TP4 = ((1.4*5^0.77)*1000)*(((F_IN_TP4*3600/1000)/1)^0.6);
C_TP5 = ((27.5*1*0.39)*1000)*(((F_IN_TP5*3600/1000)/1)^0.6);
C_TP6 = ((2.97*(F_IN_T6*3600/1000)^0.78)*1000);
C_TP7 = ((7.7*1^0.57)*1000)*(((F_IN_TP7*3600/1000)/1)^0.6);
C_BLANK2 = F_IN_BLANK1 * 0;

C_TP_TOTAL = C_TP1 + C_TP2 + C_TP3 + C_TP4 + C_TP5 + C_TP6 + C_TP7 +
C_BLANK2 ;

F_IP1 = F_OUTCHCL_TP1 + F_OUTM_TP1 ; !kg/s = kg/s ;
F_IP2 = F_OUTCHCL_TP2 + F_OUTM_TP2 ; !kg/s = kg/s ;
F_IP3 = F_OUTCHCL_TP3 + F_OUTM_TP3 ; !kg/s = kg/s ;
F_IP4 = F_OUTCHCL_TP4 + F_OUTM_TP4 ; !kg/s = kg/s ;
F_IP5 = F_OUTCHCL_TP5 + F_OUTM_TP5 ; !kg/s = kg/s ;
F_IP6 = F_OUTCHCL_TP6 + F_OUTM_TP6 ; !kg/s = kg/s ;
F_IP7 = F_OUTCHCL_TP7 + F_OUTM_TP7 ; !kg/s = kg/s ;
F_IP8 = F_OUTCHCL_BLANK2 + F_OUTM_BLANK2 ; !kg/s = kg/s ;

F_IP1 <= TOTAL_BIOMASS_AVAILABLE;
F_IP2 <= TOTAL_BIOMASS_AVAILABLE;
F_IP3 <= TOTAL_BIOMASS_AVAILABLE;
F_IP4 <= TOTAL_BIOMASS_AVAILABLE;
F_IP5 <= TOTAL_BIOMASS_AVAILABLE;
F_IP6 <= TOTAL_BIOMASS_AVAILABLE;
F_IP7 <= TOTAL_BIOMASS_AVAILABLE;
F_IP8 <= TOTAL_BIOMASS_AVAILABLE;
F_IP_TOTAL = F_IP1 + F_IP2 + F_IP3 + F_IP4 + F_IP5 + F_IP6 + F_IP7 +
F_IP8 ;
F_IP_TOTAL <= TOTAL_BIOMASS_AVAILABLE;

F_OUTCHCL_TP1  = F_IP1 * X_CHCL_IP1 ;
F_OUTM_TP1     = F_IP1 * X_M_IP1    ;
X_CHCL_IP1 + X_M_IP1 <= 1 ; !JUST ADD TO EASE CALCULATION IN LINGO,
DO NOT INCLUDE IN FORMULATION.;

F_OUTCHCL_TP2  = F_IP2 * X_CHCL_IP2 ;
F_OUTM_TP2     = F_IP2 * X_M_IP2    ; X_CHCL_IP2 + X_M_IP2 <=
1 ; !JUST ADD TO EASE CALCULATION IN LINGO, DO NOT INCLUDE IN
FORMULATION.;


F_OUTCHCL_TP3  = F_IP3 * X_CHCL_IP3 ;
F_OUTM_TP3     = F_IP3 * X_M_IP3    ;
X_CHCL_IP3 + X_M_IP3 <= 1 ; !JUST ADD TO EASE CALCULATION IN LINGO,
DO NOT INCLUDE IN FORMULATION.;
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F_OUTCHCL_TP4  = F_IP4 * X_CHCL_IP4 ;
F_OUTM_TP4     = F_IP4 * X_M_IP4    ;
X_CHCL_IP4 + X_M_IP4 <= 1 ; !JUST ADD TO EASE CALCULATION IN LINGO,
DO NOT INCLUDE IN FORMULATION.;

F_OUTCHCL_TP5  = F_IP5 * X_CHCL_IP5 ;
F_OUTM_TP5     = F_IP5 * X_M_IP5    ;
X_CHCL_IP5 + X_M_IP5 <= 1 ; !JUST ADD TO EASE CALCULATION IN LINGO,
DO NOT INCLUDE IN FORMULATION.;

F_OUTCHCL_TP6  = F_IP6 * X_CHCL_IP6 ;
F_OUTM_TP6     = F_IP6 * X_M_IP6    ;
X_CHCL_IP6 + X_M_IP6 <= 1 ; !JUST ADD TO EASE CALCULATION IN LINGO,
DO NOT INCLUDE IN FORMULATION.;

F_OUTCHCL_TP7  = F_IP7 * X_CHCL_IP7 ;
F_OUTM_TP7     = F_IP7 * X_M_IP7    ;
X_CHCL_IP7 + X_M_IP7 <= 1 ; !JUST ADD TO EASE CALCULATION IN LINGO,
DO NOT INCLUDE IN FORMULATION.;

F_OUTCHCL_BLANK2 = F_IP8 * X_CHCL_IP8 ;
F_OUTM_BLANK2    = F_IP8 * X_M_IP8    ;
X_CHCL_IP8 + X_M_IP8 <= 1 ; !JUST ADD TO EASE CALCULATION IN LINGO,
DO NOT INCLUDE IN FORMULATION.;

I_TP1 + I_TP2 + I_TP3 + I_TP4 + I_TP5 + I_TP6 + I_TP7 + I_BLANK2 =
I_TP_TOTAL ;


!STAGE 3;
S_3 >= S_IP1 ; S_3 >= S_IP2 ;
S_3 >= S_IP3 ; S_3 >= S_IP4 ;
S_3 >= S_IP5 ; S_3 >= S_IP6 ;
S_3 >= S_IP7 ; S_3 >= S_IP8 ;

F_IP1 = F_IP1_TPP1 + F_IP1_TPP2 + F_IP1_TPP3 + F_IP1_TPP4 +
F_IP1_TPP5 + F_IP1_TPP6 + F_IP1_TPP7 + F_IP1_BLANK3 ; !kg/s = kg/s ;
F_IP2 = F_IP2_TPP1 + F_IP2_TPP2 + F_IP2_TPP3 + F_IP2_TPP4 +
F_IP2_TPP5 + F_IP2_TPP6 + F_IP2_TPP7 + F_IP2_BLANK3 ; !kg/s = kg/s ;
F_IP3 = F_IP3_TPP1 + F_IP3_TPP2 + F_IP3_TPP3 + F_IP3_TPP4 +
F_IP3_TPP5 + F_IP3_TPP6 + F_IP3_TPP7 + F_IP3_BLANK3 ; !kg/s = kg/s ;
F_IP4 = F_IP4_TPP1 + F_IP4_TPP2 + F_IP4_TPP3 + F_IP4_TPP4 +
F_IP4_TPP5 + F_IP4_TPP6 + F_IP4_TPP7 + F_IP4_BLANK3 ; !kg/s = kg/s ;
F_IP5 = F_IP5_TPP1 + F_IP5_TPP2 + F_IP5_TPP3 + F_IP5_TPP4 +
F_IP5_TPP5 + F_IP5_TPP6 + F_IP5_TPP7 + F_IP5_BLANK3 ; !kg/s = kg/s ;
F_IP6 = F_IP6_TPP1 + F_IP6_TPP2 + F_IP6_TPP3 + F_IP6_TPP4 +
F_IP6_TPP5 + F_IP6_TPP6 + F_IP6_TPP7 + F_IP6_BLANK3 ; !kg/s = kg/s ;
F_IP7 = F_IP7_TPP1 + F_IP7_TPP2 + F_IP7_TPP3 + F_IP7_TPP4 +
F_IP7_TPP5 + F_IP7_TPP6 + F_IP7_TPP7 + F_IP7_BLANK3 ; !kg/s = kg/s ;
F_IP8 = F_IP8_TPP1 + F_IP8_TPP2 + F_IP8_TPP3 + F_IP8_TPP4 +
F_IP8_TPP5 + F_IP8_TPP6 + F_IP8_TPP7 + F_IP8_BLANK3 ; !kg/s = kg/s ;

!----;
F_IN_TPP1 = F_IP1_TPP1 + F_IP2_TPP1 + F_IP3_TPP1 + F_IP4_TPP1 +
F_IP5_TPP1 + F_IP6_TPP1 + F_IP7_TPP1 + F_IP8_TPP1; !kg/s = kg/s ;
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```
F_IN_TPP1 * X_CHCL_IN_TPP1  = F_IP1_TPP1 * X_CHCL_IP1  + F_IP2_TPP1 *
X_CHCL_IP2  + F_IP3_TPP1 * X_CHCL_IP3  + F_IP4_TPP1 * X_CHCL_IP4  +
F_IP5_TPP1 * X_CHCL_IP5  + F_IP6_TPP1 * X_CHCL_IP6  + F_IP7_TPP1 *
X_CHCL_IP7 + F_IP8_TPP1 * X_CHCL_IP8 ;
F_IN_TPP1 * X_M_IN_TPP1     = F_IP1_TPP1 * X_M_IP1     + F_IP2_TPP1 *
X_M_IP2     + F_IP3_TPP1 * X_M_IP3     + F_IP4_TPP1 * X_M_IP4     +
F_IP5_TPP1 * X_M_IP5     + F_IP6_TPP1 * X_M_IP6     + F_IP7_TPP1 *
X_M_IP7    + F_IP8_TPP1 * X_M_IP8    ;
X_CHCL_IN_TPP1 + X_M_IN_TPP1 <= 1 ; !JUST ADD TO EASE CALCULATION IN
LINGO, DO NOT INCLUDE IN FORMULATION.;

!----;
F_IN_TPP2 = F_IP1_TPP2 + F_IP2_TPP2 + F_IP3_TPP2 + F_IP4_TPP2 +
F_IP5_TPP2 + F_IP6_TPP2 + F_IP7_TPP2 + F_IP8_TPP2 ; !kg/s = kg/s ;
F_IN_TPP2 * X_CHCL_IN_TPP2  = F_IP1_TPP2 * X_CHCL_IP1  + F_IP2_TPP2 *
X_CHCL_IP2  + F_IP3_TPP2 * X_CHCL_IP3  + F_IP4_TPP2 * X_CHCL_IP4  +
F_IP5_TPP2 * X_CHCL_IP5  + F_IP6_TPP2 * X_CHCL_IP6  + F_IP7_TPP2 *
X_CHCL_IP7 + F_IP8_TPP2 * X_CHCL_IP8 ;
F_IN_TPP2 * X_M_IN_TPP2     = F_IP1_TPP2 * X_M_IP1     + F_IP2_TPP2 *
X_M_IP2     + F_IP3_TPP2 * X_M_IP3     + F_IP4_TPP2 * X_M_IP4     +
F_IP5_TPP2 * X_M_IP5     + F_IP6_TPP2 * X_M_IP6     + F_IP7_TPP2 *
X_M_IP7    + F_IP8_TPP2 * X_M_IP8    ;
X_CHCL_IN_TPP2 + X_M_IN_TPP2 <= 1 ; !JUST ADD TO EASE CALCULATION IN
LINGO, DO NOT INCLUDE IN FORMULATION.;

!----;
F_IN_TPP3 = F_IP1_TPP3 + F_IP2_TPP3 + F_IP3_TPP3 + F_IP4_TPP3 +
F_IP5_TPP3 + F_IP6_TPP3 + F_IP7_TPP3 + F_IP8_TPP3 ; !kg/s = kg/s ;
F_IN_TPP3 * X_CHCL_IN_TPP3  = F_IP1_TPP3 * X_CHCL_IP1  + F_IP2_TPP3 *
X_CHCL_IP2  + F_IP3_TPP3 * X_CHCL_IP3  + F_IP4_TPP3 * X_CHCL_IP4  +
F_IP5_TPP3 * X_CHCL_IP5  + F_IP6_TPP3 * X_CHCL_IP6  + F_IP7_TPP3 *
X_CHCL_IP7 + F_IP8_TPP3 * X_CHCL_IP8 ;
F_IN_TPP3 * X_M_IN_TPP3     = F_IP1_TPP3 * X_M_IP1     + F_IP2_TPP3 *
X_M_IP2     + F_IP3_TPP3 * X_M_IP3     + F_IP4_TPP3 * X_M_IP4     +
F_IP5_TPP3 * X_M_IP5     + F_IP6_TPP3 * X_M_IP6     + F_IP7_TPP3 *
X_M_IP7    + F_IP8_TPP3 * X_M_IP8    ;
X_CHCL_IN_TPP3 + X_M_IN_TPP3 <= 1 ; !JUST ADD TO EASE CALCULATION IN
LINGO, DO NOT INCLUDE IN FORMULATION.;

!----;
F_IN_TPP4 = F_IP1_TPP4 + F_IP2_TPP4 + F_IP3_TPP4 + F_IP4_TPP4 +
F_IP5_TPP4 + F_IP6_TPP4 + F_IP7_TPP4 + F_IP8_TPP4 ; !kg/s = kg/s ;
F_IN_TPP4 * X_CHCL_IN_TPP4  = F_IP1_TPP4 * X_CHCL_IP1  + F_IP2_TPP4 *
X_CHCL_IP2  + F_IP3_TPP4 * X_CHCL_IP3  + F_IP4_TPP4 * X_CHCL_IP4  +
F_IP5_TPP4 * X_CHCL_IP5  + F_IP6_TPP4 * X_CHCL_IP6  + F_IP7_TPP4 *
X_CHCL_IP7 + F_IP8_TPP4 * X_CHCL_IP8 ;
F_IN_TPP4 * X_M_IN_TPP4     = F_IP1_TPP4 * X_M_IP1     + F_IP2_TPP4 *
X_M_IP2     + F_IP3_TPP4 * X_M_IP3     + F_IP4_TPP4 * X_M_IP4     +
F_IP5_TPP4 * X_M_IP5     + F_IP6_TPP4 * X_M_IP6     + F_IP7_TPP4 *
X_M_IP7    + F_IP8_TPP4 * X_M_IP8    ;
X_CHCL_IN_TPP4 + X_M_IN_TPP4 <= 1 ; !JUST ADD TO EASE CALCULATION IN
LINGO, DO NOT INCLUDE IN FORMULATION.;

!----;
F_IN_TPP5 = F_IP1_TPP5 + F_IP2_TPP5 + F_IP3_TPP5 + F_IP4_TPP5 +
F_IP5_TPP5 + F_IP6_TPP5 + F_IP7_TPP5 + F_IP8_TPP5 ; !kg/s = kg/s ;
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F_IN_TPP5 * X_CHCL_IN_TPP5  = F_IP1_TPP5 * X_CHCL_IP1  + F_IP2_TPP5 *
X_CHCL_IP2  + F_IP3_TPP5 * X_CHCL_IP3  + F_IP4_TPP5 * X_CHCL_IP4  +
F_IP5_TPP5 * X_CHCL_IP5  + F_IP6_TPP5 * X_CHCL_IP6  + F_IP7_TPP5 *
X_CHCL_IP7 + F_IP8_TPP5 * X_CHCL_IP8 ;
F_IN_TPP5 * X_M_IN_TPP5     = F_IP1_TPP5 * X_M_IP1     + F_IP2_TPP5 *
X_M_IP2     + F_IP3_TPP5 * X_M_IP3     + F_IP4_TPP5 * X_M_IP4     +
F_IP5_TPP5 * X_M_IP5     + F_IP6_TPP5 * X_M_IP6     + F_IP7_TPP5 *
X_M_IP7    + F_IP8_TPP5 * X_M_IP8    ;
X_CHCL_IN_TPP5 + X_M_IN_TPP5 <= 1 ; !JUST ADD TO EASE CALCULATION IN
LINGO, DO NOT INCLUDE IN FORMULATION.;

!----;
F_IN_TPP6 = F_IP1_TPP6 + F_IP2_TPP6 + F_IP3_TPP6 + F_IP4_TPP6 +
F_IP5_TPP6 + F_IP6_TPP6 + F_IP7_TPP6 + F_IP8_TPP6 ; !kg/s = kg/s ;
F_IN_TPP6 * X_CHCL_IN_TPP6  = F_IP1_TPP6 * X_CHCL_IP1 + F_IP2_TPP6  *
X_CHCL_IP2 + F_IP3_TPP6  * X_CHCL_IP3  + F_IP4_TPP6 * X_CHCL_IP4  +
F_IP5_TPP6 * X_CHCL_IP5  + F_IP6_TPP6 * X_CHCL_IP6  + F_IP7_TPP6 *
X_CHCL_IP7 + F_IP8_TPP6 * X_CHCL_IP8 ;
F_IN_TPP6 * X_M_IN_TPP6     = F_IP1_TPP6 * X_M_IP1    + F_IP2_TPP6  *
X_M_IP2    + F_IP3_TPP6  * X_M_IP3     + F_IP4_TPP6 * X_M_IP4     +
F_IP5_TPP6 * X_M_IP5     + F_IP6_TPP6 * X_M_IP6     + F_IP7_TPP6 *
X_M_IP7    + F_IP8_TPP6 * X_M_IP8    ;
X_CHCL_IN_TPP6 + X_M_IN_TPP6 <= 1 ; !JUST ADD TO EASE CALCULATION IN
LINGO, DO NOT INCLUDE IN FORMULATION.;

!----;
F_IN_TPP7 = F_IP1_TPP7 + F_IP2_TPP7 + F_IP3_TPP7 + F_IP4_TPP7 +
F_IP5_TPP7 + F_IP6_TPP7 + F_IP7_TPP7 + F_IP8_TPP7 ; !kg/s = kg/s ;
F_IN_TPP7 * X_CHCL_IN_TPP7  = F_IP1_TPP7 * X_CHCL_IP1 + F_IP2_TPP7  *
X_CHCL_IP2 + F_IP3_TPP7  * X_CHCL_IP3  + F_IP4_TPP7 * X_CHCL_IP4  +
F_IP5_TPP7 * X_CHCL_IP5  + F_IP6_TPP7 * X_CHCL_IP6  + F_IP7_TPP7 *
X_CHCL_IP7 + F_IP8_TPP7 * X_CHCL_IP8 ;
F_IN_TPP7 * X_M_IN_TPP7     = F_IP1_TPP7 * X_M_IP1    + F_IP2_TPP7  *
X_M_IP2    + F_IP3_TPP7  * X_M_IP3     + F_IP4_TPP7 * X_M_IP4     +
F_IP5_TPP7 * X_M_IP5     + F_IP6_TPP7 * X_M_IP6     + F_IP7_TPP7 *
X_M_IP7    + F_IP8_TPP7 * X_M_IP8    ;
X_CHCL_IN_TPP7 + X_M_IN_TPP7 <= 1 ; !JUST ADD TO EASE CALCULATION IN
LINGO, DO NOT INCLUDE IN FORMULATION.;

!----;
F_IN_BLANK3 = F_IP1_BLANK3 + F_IP2_BLANK3 + F_IP3_BLANK3 +
F_IP4_BLANK3 + F_IP5_BLANK3 + F_IP6_BLANK3 + F_IP7_BLANK3 +
F_IP8_BLANK3 ; !kg/s = kg/s ;
F_IN_BLANK3 * X_CHCL_IN_BLANK3  = F_IP1_BLANK3 * X_CHCL_IP1  +
F_IP2_BLANK3 * X_CHCL_IP2  + F_IP3_BLANK3 * X_CHCL_IP3  +
F_IP4_BLANK3 * X_CHCL_IP4  + F_IP5_BLANK3 * X_CHCL_IP5  +
F_IP6_BLANK3 * X_CHCL_IP6  + F_IP7_BLANK3 * X_CHCL_IP7 + F_IP8_BLANK3
* X_CHCL_IP8 ;
F_IN_BLANK3 * X_M_IN_BLANK3     = F_IP1_BLANK3 * X_M_IP1     +
F_IP2_BLANK3 * X_M_IP2     + F_IP3_BLANK3 * X_M_IP3     +
F_IP4_BLANK3 * X_M_IP4     + F_IP5_BLANK3 * X_M_IP5     +
F_IP6_BLANK3 * X_M_IP6     + F_IP7_BLANK3 * X_M_IP7    + F_IP8_BLANK3
* X_M_IP8    ;
X_CHCL_IN_BLANK3 + X_M_IN_BLANK3 <= 1 ; !JUST ADD TO EASE CALCULATION
IN LINGO, DO NOT INCLUDE IN FORMULATION.;
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F_IN_TPP1 + F_IN_TPP2 + F_IN_TPP3 + F_IN_TPP4 + F_IN_TPP5 + F_IN_TPP6
+ F_IN_TPP7 + F_IN_BLANK3 = F_IN_TPP_TOTAL ;
F_IN_TPP1 <= TOTAL_BIOMASS_AVAILABLE ;
F_IN_TPP2 <= TOTAL_BIOMASS_AVAILABLE ;
F_IN_TPP3 <= TOTAL_BIOMASS_AVAILABLE ;
F_IN_TPP4 <= TOTAL_BIOMASS_AVAILABLE ;
F_IN_TPP5 <= TOTAL_BIOMASS_AVAILABLE ;
F_IN_TPP6 <= TOTAL_BIOMASS_AVAILABLE ;
F_IN_TPP7 <= TOTAL_BIOMASS_AVAILABLE ;
F_IN_BLANK3 <= TOTAL_BIOMASS_AVAILABLE ;
F_IN_TPP_TOTAL <= TOTAL_BIOMASS_AVAILABLE ;

(F_IN_TPP1/TOTAL_BIOMASS_AVAILABLE) <= I_TPP1 ;
(F_IN_TPP2/TOTAL_BIOMASS_AVAILABLE) <= I_TPP2 ;
(F_IN_TPP3/TOTAL_BIOMASS_AVAILABLE) <= I_TPP3 ;
(F_IN_TPP4/TOTAL_BIOMASS_AVAILABLE) <= I_TPP4 ;
(F_IN_TPP5/TOTAL_BIOMASS_AVAILABLE) <= I_TPP5 ;
(F_IN_TPP6/TOTAL_BIOMASS_AVAILABLE) <= I_TPP6 ;
(F_IN_TPP7/TOTAL_BIOMASS_AVAILABLE) <= I_TPP7 ;
(F_IN_BLANK3/TOTAL_BIOMASS_AVAILABLE) <= I_BLANK3 ;
@BIN(I_TPP1); @BIN(I_TPP2);
@BIN(I_TPP3); @BIN(I_TPP4);
@BIN(I_TPP5); @BIN(I_TPP6);
@BIN(I_TPP7); @BIN(I_BLANK3);

(0.25 * I_TPP1) <= (X_M_IN_TPP1 * I_TPP1) ;
(X_M_IN_TPP1 * I_TPP1) <= (0.65 * I_TPP1) ;
(0.25 * I_TPP2) <= (X_M_IN_TPP2 * I_TPP2) ;
(X_M_IN_TPP2 * I_TPP2) <= (0.65 * I_TPP2) ;
(0.25 * I_TPP3) <= (X_M_IN_TPP3 * I_TPP3) ;
(X_M_IN_TPP3 * I_TPP3) <= (0.65 * I_TPP3) ;
(0.25 * I_TPP4) <= (X_M_IN_TPP4 * I_TPP4) ;
(X_M_IN_TPP4 * I_TPP4) <= (0.72 * I_TPP4) ;
(0.04 * I_TPP5) <= (X_M_IN_TPP5 * I_TPP5) ;
(X_M_IN_TPP5 * I_TPP5) <= (0.07 * I_TPP5) ;
(0.04 * I_TPP6) <= (X_M_IN_TPP6 * I_TPP6) ;
(X_M_IN_TPP6 * I_TPP6) <= (0.12 * I_TPP6) ;
(0 * I_TPP7)    <= (X_M_IN_TPP7 * I_TPP7) ;
(X_M_IN_TPP7 * I_TPP7) <= (1 * I_TPP7) ;
(0 * I_BLANK3)  <= (X_M_IN_BLANK3 * I_BLANK3) ;
(X_M_IN_BLANK3 * I_BLANK3) <= (1 * I_BLANK3) ;


(25 * I_TPP1)  <= (S_3 * I_TPP1) ;
(S_3 * I_TPP1) <= (125 * I_TPP1) ;
(0.5 * I_TPP2) <= (S_3 * I_TPP2) ;
(S_3 * I_TPP2) <= (50  * I_TPP2) ;
(0 * I_TPP3)   <= (S_3 * I_TPP3) ;
(S_3 * I_TPP3) <= (100 * I_TPP3) ;
(0 * I_TPP4)   <= (S_3 * I_TPP4) ;
(S_3 * I_TPP4) <= (150 * I_TPP4) ;
(25 * I_TPP5)  <= (S_3 * I_TPP5) ;
(S_3 * I_TPP5) <= (150 * I_TPP5) ;
(25 * I_TPP6)  <= (S_3 * I_TPP6) ;
(S_3 * I_TPP6) <= (150 * I_TPP6) ;
(0 * I_TPP7)   <= (S_3 * I_TPP7) ;
(S_3 * I_TPP7) <= (150 * I_TPP7) ;
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```
(0 * I_BLANK3) <= (S_3 * I_BLANK3) ;

 (S_3 * I_BLANK3) <= (150 * I_BLANK3) ;

F_OUTCHCL_TPP1 = F_IN_TPP1 * X_CHCL_IN_TPP1 ;
F_OUTCHCL_TPP2 = F_IN_TPP2 * X_CHCL_IN_TPP2 ;
F_OUTCHCL_TPP3 = F_IN_TPP3 * X_CHCL_IN_TPP3 ;
F_OUTCHCL_TPP4 = F_IN_TPP4 * X_CHCL_IN_TPP4 ;
F_OUTCHCL_TPP5 = F_IN_TPP5 * X_CHCL_IN_TPP5 ;
F_OUTCHCL_TPP6 = F_IN_TPP6 * X_CHCL_IN_TPP6 ;
F_OUTCHCL_TPP7 = F_IN_TPP7 * X_CHCL_IN_TPP7 ;
F_OUTCHCL_BLANK3 = F_IN_BLANK3 * X_CHCL_IN_BLANK3 ;

F_OUTCHCL_TPP1 <= TOTAL_CHCL_AVAILABLE ;
F_OUTCHCL_TPP2 <= TOTAL_CHCL_AVAILABLE ;
F_OUTCHCL_TPP3 <= TOTAL_CHCL_AVAILABLE ;
F_OUTCHCL_TPP4 <= TOTAL_CHCL_AVAILABLE ;
F_OUTCHCL_TPP5 <= TOTAL_CHCL_AVAILABLE ;
F_OUTCHCL_TPP6 <= TOTAL_CHCL_AVAILABLE ;
F_OUTCHCL_TPP7 <= TOTAL_CHCL_AVAILABLE ;
F_OUTCHCL_BLANK3 <= TOTAL_CHCL_AVAILABLE;
F_OUTCHCL_TPP_TOTAL = F_OUTCHCL_TPP1 + F_OUTCHCL_TPP2 +
F_OUTCHCL_TPP3 + F_OUTCHCL_TPP4 + F_OUTCHCL_TPP5 + F_OUTCHCL_TPP6 +
F_OUTCHCL_TPP7 + F_OUTCHCL_BLANK3 ;
F_OUTCHCL_TPP_TOTAL <= TOTAL_CHCL_AVAILABLE ;

F_OUTM_TPP1 = F_IN_TPP1 * X_M_IN_TPP1 - F_MR_TPP1 ;
F_OUTM_TPP2 = F_IN_TPP2 * X_M_IN_TPP2 - F_MR_TPP2 ;
F_OUTM_TPP3 = F_IN_TPP3 * X_M_IN_TPP3 - F_MR_TPP3 ;
F_OUTM_TPP4 = F_IN_TPP4 * X_M_IN_TPP4 - F_MR_TPP4 ;
F_OUTM_TPP5 = F_IN_TPP5 * X_M_IN_TPP5 - F_MR_TPP5 ;
F_OUTM_TPP6 = F_IN_TPP6 * X_M_IN_TPP6 - F_MR_TPP6 ;
F_OUTM_TPP7 = F_IN_TPP7 * X_M_IN_TPP7 - F_MR_TPP7 ;
F_OUTM_BLANK3 = F_IN_BLANK3 * X_M_IN_BLANK3 - F_MR_BLANK3 ;

F_MR_TPP1 = F_IN_TPP1 * X_M_IN_TPP1 * MRR_TPP1 ;
0.56 <= MRR_TPP1 ;
MRR_TPP1 <= 0.86 ;
TR_TPP1 = 0.67 ; !kWhr/kg ;
EF_TPP1 = 0.6 ;
P_D_TPP1 * EF_TPP1 * 3600 = TR_TPP1 * F_MR_TPP1  ; !kWhr/s * 3600
s/hr = kWhr/kg * kg/s ;

F_MR_TPP2 = F_IN_TPP2 * X_M_IN_TPP2 * MRR_TPP2 ;
0.56 <= MRR_TPP2 ;
MRR_TPP2 <= 0.86 ;
TR_TPP2 = 0.67 ; !kWhr/kg ;
EF_TPP2 = 0.86 ;
P_D_TPP2 * EF_TPP2 * 3600 = TR_TPP2 * F_MR_TPP2  ; !kWhr/s * 3600
s/hr = kWhr/kg * kg/s ;

F_MR_TPp3 = F_IN_TPp3 * X_M_IN_TPP3 * MRR_TPp3 ;
0.56 <= MRR_TPP3 ;
MRR_TPP3 <= 0.86 ;
TR_TPP3 = 0.67 ; !kWhr/kg ;
EF_TPP3 = 0.87 ;
```

```
P_D_TPP3 * EF_TPp3 * 3600 = TR_TPP3 * F_MR_TPP3 ; !kWhr/s * 3600 s/hr
= kWhr/kg * kg/s ;

F_MR_TPp4 = F_IN_TPp4 * X_M_IN_TPP4 * MRR_TPP4 ;
0.64 <= MRR_TPP4 ;
MRR_TPp4 <= 0.81 ;
TR_TPp4 = 0.67 ; !kWhr/kg ;
EF_TPp4 = 0.7 ;
P_D_TPp4 * EF_TPP4 * 3600 = TR_TPP4 * F_MR_TPP4 ; !kWhr/s * 3600 s/hr
= kWhr/kg * kg/s ;

F_MR_TPp5 = F_IN_TPp5 * X_M_IN_TPP5 * MRR_TPP5 ;
MRR_TPp5 = 0.15 ;
TR_TPp5 = 0 ; !kWhr/kg ;
EF_TPp5 = 1 ;
P_D_TPp5 * EF_TPp5 * 3600  = TR_TpP5 * F_MR_TPp5 ; !kWhr/s * 3600
s/hr = kWhr/kg * kg/s ;

F_MR_TPp6 = F_IN_TpP6 * X_M_IN_TpP6 * MRR_TpP6 ;
MRR_TPp6 = 0.15 ;
TR_TPp6 = 0 ; !kWhr/kg ;
EF_TPp6 = 1 ;
P_D_TPp6 * EF_TPp6 * 3600 = TR_TpP6 * F_MR_TpP6 ; !kWhr/s * 3600 s/hr
= kWhr/kg * kg/s ;

F_MR_TPp7 = F_IN_TpP7 * X_M_IN_TpP7 * MRR_TpP7 ;
MRR_TPp7 = 0.15 ;
TR_TPp7 = 0 ; !kWhr/kg ;
EF_TPp7 = 1 ;
P_D_TPp7 * EF_TPp7 * 3600 = TR_TpP7 * F_MR_TpP7 ; !kWhr/s * 3600 s/hr
= kWhr/kg * kg/s ;

F_MR_BLANK3 = F_IN_BLANK3 * X_M_IN_BLANK3 * MRR_BLANK3 ;
MRR_BLANK3 = 0 ;
TR_BLANK3 = 0 ; !kWhr/kg ;
EF_BLANK3 = 1;
P_D_BLANK3 * EF_BLANK3 * 3600 = TR_BLANK3 * F_MR_BLANK3 ; !kWhr/s *
3600 s/hr  = kWhr/kg * kg/s ;

P_D_TPP1 + P_D_TPP2 + P_D_TPP3 + P_D_TPP4 + P_D_TPP5 + P_D_TPP6 +
P_D_TPP7 + P_D_BLANK3 = P_D_TPP_TOTAL ;

                                                F_OUTM_TPP_TOTAL =
F_OUTM_TPP1 + F_OUTM_TPP2 + F_OUTM_TPP3 + F_OUTM_TPP4 + F_OUTM_TPP5 +
F_OUTM_TPP6 + F_OUTM_TPP7 + F_OUTM_BLANK3 ;
                                                F_OUTM_TPP_TOTAL <=
TOTAL_M_AVAILABLE ;

S_IN_TPP1 = S_3 ; S_IN_TPP2 = S_3 ;
S_IN_TPP3 = S_3 ; S_IN_TPP4 = S_3 ;
S_IN_TPP5 = S_3 ; S_IN_TPP6 = S_3 ;
S_IN_TPP7 = S_3 ; S_IN_BLANK3 = S_3 ;

(S_IN_TPP1/SRR_TPP1) * I_TPP1 = S_IPP1 ;
S_IPP1 <= 10000 * I_TPP1 ;
SRR_TPP1 = 1 ;
```

```
P_SR_TPP1 = I_TPP1 * @LOG10 (SRR_TPP1) * F_IN_TPP1 ; !kW = kW/kgs-1 *
kgs-1 ;
@FREE (K_TPP1);
@FREE (P_SR_TPP1);

(S_IN_TPP2/SRR_TPP2) * I_TPP2 = S_IPP2 ;
S_IPP2 <= 10000 * I_TPP2 ;
SRR_TPP2 = 1 ;
P_SR_TPP2 = I_TPP2 * @LOG10 (SRR_TPP2) * F_IN_TPP2 ; !kW = kW/kgs-1 *
kgs-1 ;
@FREE (K_TPP2);
@FREE (P_SR_TPP2);

(S_IN_TPP3/SRR_TPP3) * I_TPP3 = S_IPP3 ;
S_IPP3 <= 10000 * I_TPP3 ;
SRR_TPP3 = 1 ;
P_SR_TPP3 = I_TPP3 * @LOG10 (SRR_TPP3) * F_IN_TPP3 ; !kW = kW/kgs-1 *
kgs-1 ;
@FREE (K_TPP3);
@FREE (P_SR_TPP3);

(S_IN_TPP4/SRR_TPP4) * I_TPP4 = S_IPP4 ;
S_IPP4 <= 10000 * I_TPP4 ;
SRR_TPP4 = 1 ;
P_SR_TPP4 = I_TPP4 * @LOG10 (SRR_TPP4) * F_IN_TPP4 ; !kW = kW/kgs-1 *
kgs-1 ;
@FREE (K_TPP4);
@FREE (P_SR_TPP4);

(S_IN_TPP5/SRR_TPP5) * I_TPP5 = S_IPP5 ;
S_IPP5 <= 10000 * I_TPP5 ;
2 <= SRR_TPP5 ;
SRR_TPP5 <= 14 ;
A_TPP5 = @LOG10(SRR_TPP5);
B_TPP5 = X_M_IN_TPP5 ;
K_TPP5 = 339.9 - 1109*A_TPP5 - 7.529*B_TPP5  + 947.4*(A_TPP5^2) +
170.5*(A_TPP5)*(B_TPP5) - 16.53*(B_TPP5^2) - 362.7*(A_TPP5^3)
      - 76.75*(A_TPP5^2)*(B_TPP5)  - 5.958*(A_TPP5)*(B_TPP5^2) +
1.836*(B_TPP5 ^3) + 56.16*(A_TPP5^4) + 3.813*(A_TPP5^3)*(B_TPP5) +
4.932*(A_TPP5^2)*(B_TPP5^2) - 0.7026*A_TPP5*(B_TPP5^3) ;
P_SR_TPP5 = I_TPP5 * K_TPP5 * @LOG10 (SRR_TPP5) * F_IN_TPP5 ; !kW =
kW/kgs-1 * kgs-1 ;
@FREE (K_TPP5);
@FREE (P_SR_TPP5);

(S_IN_TPP6/SRR_TPP6) * I_TPP6 = S_IPP6 ;
S_IPP6 <= 10000 * I_TPP6 ;
2.23 <= SRR_TPP6 ;
SRR_TPP6 <= 12.825 ;
A_TPP6 = @LOG10(SRR_TPP6);
B_TPP6 = X_M_IN_TPP6 ;
K_TPP6 = 49.02 + 10.04 *A_TPP6 - 72.54*B_TPP6  + 11.03*(A_TPP6^2) +
2.03*(A_TPP6)*(B_TPP6) + 96.17*(B_TPP6^2) +0.7976*(A_TPP6^3)
      +2.241*(A_TPP6^2)*(B_TPP6)  - 4.248*(A_TPP6)*(B_TPP6^2) -
18.67*(B_TPP6^3) + 2.451*(A_TPP6^4) + 6.563*(A_TPP6^3)*(B_TPP6) -
```

```
0.3381*(A_TPP6^2)*(B_TPP6^2) - 9.35*A_TPP6*(B_TPP6^3) -
43.85*(B_TPP6^4) ;
P_SR_TPP6 = I_TPP6 * K_TPP6 * @LOG10 (SRR_TPP6) * F_IN_TPP6 ; !kW =
kW/kgs-1 * kgs-1 ;
@FREE (K_TPP6);
@FREE (P_SR_TPP6);

(S_IN_TPP7/SRR_TPP7) * I_TPP7 = S_IPP7 ;
S_IPP7 <= 10000 * I_TPP7 ;
2.03 <= SRR_TPP7 ;
SRR_TPP7 <= 4.06 ;
A_TPP7 = @LOG10(SRR_TPP7);
K_TPP7 = 1.0633 * A_TPP7 + 0.0203 ;
P_SR_TPP7 = I_TPP7 * K_TPP7 * @LOG10 (SRR_TPP7) * F_IN_TPP7 ; !kW =
kW/kgs-1 * kgs-1 ;
@FREE (K_TPP7);
@FREE (P_SR_TPP7);

(S_IN_BLANK3/SRR_BLANK3) * I_BLANK3 = S_IPP8 ;
S_IPP8 <= 10000 * I_BLANK3 ;
SRR_BLANK3 = 1 ;
P_SR_BLANK3 = I_BLANK3 * @LOG10 (SRR_BLANK3) * F_IN_BLANK3; !kW =
kW/kgs-1 * kgs-1 ;
@FREE (K_BLANK3);
@FREE (P_SR_BLANK3);

P_SR_TPP1 + P_SR_TPP2 + P_SR_TPP3 + P_SR_TPP4 + P_SR_TPP5 + P_SR_TPP6
+ P_SR_TPP7 + P_SR_BLANK3 = P_SR_TPP_TOTAL ;

!TECHNOLOGY COST;
C_TPP1 = ((2.9*3*18^0.63)*1000)*(((F_IN_T1*3600/1000)/1)^0.6);
C_TPP2 = ((2.23*1.75*46^0.6)*1000)*(((F_IN_TPP2*3600/1000)/1)^0.6);
C_TPP3 = ((45*1^0.7)*1000)*(((F_IN_TPP3*3600/1000)/1)^0.6);
C_TPP4 = ((1.4*5^0.77)*1000)*(((F_IN_TPP4*3600/1000)/1)^0.6);
C_TPP5 = ((27.5*1*0.39)*1000)*(((F_IN_TPP5*3600/1000)/1)^0.6);
C_TPP6 = ((2.97*(F_IN_TPP6*3600/1000)^0.78)*1000);
C_TPP7 = ((7.7*1^0.57)*1000)*(((F_IN_TPP7*3600/1000)/1)^0.6);
C_BLANK3 = F_IN_BLANK3 * 0;

C_TPP_TOTAL = C_TPP1 + C_TPP2 + C_TPP3 + C_TPP4 + C_TPP5 + C_TPP6 +
C_TPP7 + C_BLANK3 ;

F_IPP1 = F_OUTCHCL_TPP1 + F_OUTM_TPP1 ; !kg/s = kg/s ;
F_IPP2 = F_OUTCHCL_TPP2 + F_OUTM_TPP2 ; !kg/s = kg/s ;
F_IPP3 = F_OUTCHCL_TPP3 + F_OUTM_TPP3 ; !kg/s = kg/s ;
F_IPP4 = F_OUTCHCL_TPP4 + F_OUTM_TPP4 ; !kg/s = kg/s ;
F_IPP5 = F_OUTCHCL_TPP5 + F_OUTM_TPP5 ; !kg/s = kg/s ;
F_IPP6 = F_OUTCHCL_TPP6 + F_OUTM_TPP6 ; !kg/s = kg/s ;
F_IPP7 = F_OUTCHCL_TPP7 + F_OUTM_TPP7 ; !kg/s = kg/s ;
F_IPP8 = F_OUTCHCL_BLANK3 + F_OUTM_BLANK3 ; !kg/s = kg/s ;

F_IPP1 <= TOTAL_BIOMASS_AVAILABLE ;
F_IPP2 <= TOTAL_BIOMASS_AVAILABLE ;
F_IPP3 <= TOTAL_BIOMASS_AVAILABLE ;
F_IPP4 <= TOTAL_BIOMASS_AVAILABLE ;
F_IPP5 <= TOTAL_BIOMASS_AVAILABLE ;
F_IPP6 <= TOTAL_BIOMASS_AVAILABLE ;
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F_IPP7 <= TOTAL_BIOMASS_AVAILABLE ;
F_IPP8 <= TOTAL_BIOMASS_AVAILABLE ;
F_IPP_TOTAL = F_IPP1 + F_IPP2 + F_IPP3 + F_IPP4 + F_IPP5 + F_IPP6 +
F_IPP7 + F_IPP8 ;
F_IPP_TOTAL <= TOTAL_BIOMASS_AVAILABLE ;

F_OUTCHCL_TPP1   = F_IPP1 * X_CHCL_IPP1 ;
F_OUTM_TPP1      = F_IPP1 * X_M_IPP1    ;
X_CHCL_IPP1 + X_M_IPP1 <= 1 ; !JUST ADD TO EASE CALCULATION IN LINGO,
DO NOT INCLUDE IN FORMULATION.;

F_OUTCHCL_TPP2   = F_IPP2 * X_CHCL_IPP2 ;
F_OUTM_TPP2      = F_IPP2 * X_M_IPP2    ;
X_CHCL_IPP2 + X_M_IPP2 <= 1 ; !JUST ADD TO EASE CALCULATION IN LINGO,
DO NOT INCLUDE IN FORMULATION.;

F_OUTCHCL_TPP3   = F_IPP3 * X_CHCL_IPP3 ;
F_OUTM_TPP3      = F_IPP3 * X_M_IPP3    ;
X_CHCL_IPP3 + X_M_IPP3 <= 1 ; !JUST ADD TO EASE CALCULATION IN LINGO,
DO NOT INCLUDE IN FORMULATION.;

F_OUTCHCL_TPP4   = F_IPP4 * X_CHCL_IPP4 ;
F_OUTM_TPP4      = F_IPP4 * X_M_IPP4    ;
X_CHCL_IPP4 + X_M_IPP4 <= 1 ; !JUST ADD TO EASE CALCULATION IN LINGO,
DO NOT INCLUDE IN FORMULATION.;

F_OUTCHCL_TPP5   = F_IPP5 * X_CHCL_IPP5 ;
F_OUTM_TPP5      = F_IPP5 * X_M_IPP5    ;
X_CHCL_IPP5 + X_M_IPP5 <= 1 ; !JUST ADD TO EASE CALCULATION IN LINGO,
DO NOT INCLUDE IN FORMULATION.;

F_OUTCHCL_TPP6   = F_IPP6 * X_CHCL_IPP6 ;
F_OUTM_TPP6      = F_IPP6 * X_M_IPP6    ;
X_CHCL_IPP6 + X_M_IPP6 <= 1 ; !JUST ADD TO EASE CALCULATION IN LINGO,
DO NOT INCLUDE IN FORMULATION.;

F_OUTCHCL_TPP7   = F_IPP7 * X_CHCL_IPP7 ;
F_OUTM_TPP7      = F_IPP7 * X_M_IPP7    ;
X_CHCL_IPP7 + X_M_IPP7 <= 1 ; !JUST ADD TO EASE CALCULATION IN LINGO,
DO NOT INCLUDE IN FORMULATION.;

F_OUTCHCL_BLANK3 = F_IPP8 * X_CHCL_IPP8 ;
F_OUTM_BLANK3    = F_IPP8 * X_M_IPP8    ;
X_CHCL_IPP8 + X_M_IPP8 <= 1 ; !JUST ADD TO EASE CALCULATION IN LINGO,
DO NOT INCLUDE IN FORMULATION.;

I_TPP1 + I_TPP2 + I_TPP3 + I_TPP4 + I_TPP5 + I_TPP6 + I_TPP7 +
I_BLANK3 = I_TPP_TOTAL;

I_T_TOTAL + I_TP_TOTAL + I_TPP_TOTAL = I_TOTAL ;

P_TOTAL = (P_D_T_TOTAL + P_D_TP_TOTAL + P_D_TPP_TOTAL) +
(P_SR_T_TOTAL + P_SR_TP_TOTAL + P_SR_TPP_TOTAL);

C_TOTAL = C_T_TOTAL + C_TP_TOTAL + C_TPP_TOTAL ;

MAX = F_IPP_TOTAL -(0.00001 * I_TOTAL) ;
```

```
X_M_IPP1 <= 0.15 ;
X_M_IPP2 <= 0.15 ;
X_M_IPP3 <= 0.15 ;
X_M_IPP4 <= 0.15 ;
X_M_IPP5 <= 0.15 ;
X_M_IPP6 <= 0.15 ;
X_M_IPP7 <= 0.15 ;
X_M_IPP8 <= 0.15 ;

S_IPP1 <= 15 ;
S_IPP2 <= 15 ;
S_IPP3 <= 15 ;
S_IPP4 <= 15 ;
S_IPP5 <= 15 ;
S_IPP6 <= 15 ;
S_IPP7 <= 15 ;
S_IPP8 <= 15 ;
```

APPENDIX A2

Lingo File

For minimising energy requirement

```
!INFORMATION;
F_AVAILABLE_EFB = 3.9 ; !kg/s;
X_CHCL_EFB  = 0.55;  X_M_EFB  = 0.45;  S_EFB  = 150 ; !mm;

F_AVAILABLE_PKS = 1.2 ; !kg/s;
X_CHCL_PKS  = 0.73 ; X_M_PKS  = 0.27 ; S_PKS = 20 ; !mm;

F_AVAILABLE_PMF = 2.2 ; !kg/s;
X_CHCL_PMF  = 0.77 ; X_M_PMF  = 0.23 ; S_PMF = 30 ; !mm;

!PROBLEM SIZE DEFINITION FOR EASIER SOLVING;
TOTAL_BIOMASS_AVAILABLE = F_AVAILABLE_EFB + F_AVAILABLE_PKS +
F_AVAILABLE_PMF ;
TOTAL_CHCL_AVAILABLE    = F_AVAILABLE_EFB * X_CHCL_EFB +
F_AVAILABLE_PKS * X_CHCL_PKS + F_AVAILABLE_PMF * X_CHCL_PMF ;
TOTAL_M_AVAILABLE       = F_AVAILABLE_EFB * X_M_EFB    +
F_AVAILABLE_PKS * X_M_PKS    + F_AVAILABLE_PMF * X_M_PMF    ;
F_EFB <= F_AVAILABLE_EFB ;
F_PKS <= F_AVAILABLE_PKS ;
F_PMF <= F_AVAILABLE_PMF ;

!MODEL STARTS;
!STAGE 1;
S_1 >= S_EFB ;
S_1 >= S_PKS ;
S_1 >= S_PMF ;

F_EFB = F_EFB_T1 + F_EFB_T2 + F_EFB_T3 + F_EFB_T4 + F_EFB_T5 +
F_EFB_T6 + F_EFB_T7 + F_EFB_BLANK1 ;  !kg/s = kg/s ;
F_PKS = F_PKS_T1 + F_PKS_T2 + F_PKS_T3 + F_PKS_T4 + F_PKS_T5 +
F_PKS_T6 + F_PKS_T7 + F_PKS_BLANK1 ;  !kg/s = kg/s ;
F_PMF = F_PMF_T1 + F_PMF_T2 + F_PMF_T3 + F_PMF_T4 + F_PMF_T5 +
F_PMF_T6 + F_PMF_T7 + F_PMF_BLANK1 ;  !kg/s = kg/s ;
```

```
F_IN_T1 = F_EFB_T1 + F_PKS_T1 + F_PMF_T1 ; !kg/s = kg/s ;
F_IN_T1 * X_CHCL_IN_T1 = F_EFB_T1 * X_CHCL_EFB + F_PKS_T1 *
X_CHCL_PKS + F_PMF_T1 * X_CHCL_PMF ;
F_IN_T1 * X_M_IN_T1    = F_EFB_T1 * X_M_EFB    + F_PKS_T1 * X_M_PKS
+ F_PMF_T1 * X_M_PMF    ;
X_CHCL_IN_T1 + X_M_IN_T1 <= 1;

F_IN_T2 = F_EFB_T2 + F_PKS_T2 + F_PMF_T2 ; !kg/s = kg/s ;
F_IN_T2 * X_CHCL_IN_T2 = F_EFB_T2 * X_CHCL_EFB + F_PKS_T2 *
X_CHCL_PKS + F_PMF_T2 * X_CHCL_PMF ;
F_IN_T2 * X_M_IN_T2    = F_EFB_T2 * X_M_EFB    + F_PKS_T2 * X_M_PKS
+ F_PMF_T2 * X_M_PMF    ;
X_CHCL_IN_T2 + X_M_IN_T2 <= 1;

F_IN_T3 = F_EFB_T3 + F_PKS_T3 + F_PMF_T3 ; !kg/s = kg/s ;
F_IN_T3 * X_CHCL_IN_T3 = F_EFB_T3 * X_CHCL_EFB + F_PKS_T3 *
X_CHCL_PKS + F_PMF_T3 * X_CHCL_PMF ;
F_IN_T3 * X_M_IN_T3    = F_EFB_T3 * X_M_EFB    + F_PKS_T3 * X_M_PKS
+ F_PMF_T3 * X_M_PMF    ;
X_CHCL_IN_T3 + X_M_IN_T3 <= 1;

F_IN_T4 = F_EFB_T4 + F_PKS_T4 + F_PMF_T4 ;
F_IN_T4 * X_CHCL_IN_T4 = F_EFB_T4 * X_CHCL_EFB + F_PKS_T4 *
X_CHCL_PKS + F_PMF_T4 * X_CHCL_PMF ;
F_IN_T4 * X_M_IN_T4    = F_EFB_T4 * X_M_EFB    + F_PKS_T4 * X_M_PKS
+ F_PMF_T4 * X_M_PMF    ;
X_CHCL_IN_T4 + X_M_IN_T4 <= 1;

F_IN_T5 = F_EFB_T5 + F_PKS_T5 + F_PMF_T5 ; !kg/s = kg/s ;
F_IN_T5 * X_CHCL_IN_T5 = F_EFB_T5 * X_CHCL_EFB + F_PKS_T5 *
X_CHCL_PKS + F_PMF_T5 * X_CHCL_PMF ;
F_IN_T5 * X_M_IN_T5    = F_EFB_T5 * X_M_EFB    + F_PKS_T5 * X_M_PKS
+ F_PMF_T5 * X_M_PMF    ;
X_CHCL_IN_T5 + X_M_IN_T5 <= 1;

F_IN_T6 = F_EFB_T6 + F_PKS_T6 + F_PMF_T6 ; !kg/s = kg/s ;
F_IN_T6 * X_CHCL_IN_T6 = F_EFB_T6 * X_CHCL_EFB + F_PKS_T6 *
X_CHCL_PKS + F_PMF_T6 * X_CHCL_PMF ;
F_IN_T6 * X_M_IN_T6    = F_EFB_T6 * X_M_EFB    + F_PKS_T6 * X_M_PKS
+ F_PMF_T6 * X_M_PMF    ;
X_CHCL_IN_T6 + X_M_IN_T6 <= 1;

F_IN_T7 = F_EFB_T7 + F_PKS_T7 + F_PMF_T7 ; !kg/s = kg/s ;
F_IN_T7 * X_CHCL_IN_T7 = F_EFB_T7 * X_CHCL_EFB + F_PKS_T7 *
X_CHCL_PKS + F_PMF_T7 * X_CHCL_PMF ;
F_IN_T7 * X_M_IN_T7    = F_EFB_T7 * X_M_EFB    + F_PKS_T7 * X_M_PKS
+ F_PMF_T7 * X_M_PMF    ;
X_CHCL_IN_T7 + X_M_IN_T7 <= 1;

F_IN_BLANK1 = F_EFB_BLANK1 + F_PKS_BLANK1 + F_PMF_BLANK1 ;
F_IN_BLANK1 * X_CHCL_IN_BLANK1 = F_EFB_BLANK1 * X_CHCL_EFB +
F_PKS_BLANK1 * X_CHCL_PKS + F_PMF_BLANK1 * X_CHCL_PMF ;
F_IN_BLANK1 * X_M_IN_BLANK1    = F_EFB_BLANK1 * X_M_EFB    +
F_PKS_BLANK1 * X_M_PKS    + F_PMF_BLANK1 * X_M_PMF    ;
X_CHCL_IN_BLANK1 + X_M_IN_BLANK1 <= 1;
```

```
F_IN_T1 + F_IN_T2 + F_IN_T3 + F_IN_T4 + F_IN_T5 + F_IN_T6 + F_IN_T7 +
F_IN_BLANK1 = F_IN_T_TOTAL ;
F_IN_T1 <= TOTAL_BIOMASS_AVAILABLE ;
F_IN_T2 <= TOTAL_BIOMASS_AVAILABLE ;
F_IN_T3 <= TOTAL_BIOMASS_AVAILABLE ;
F_IN_T4 <= TOTAL_BIOMASS_AVAILABLE ;
F_IN_T5 <= TOTAL_BIOMASS_AVAILABLE ;
F_IN_T6 <= TOTAL_BIOMASS_AVAILABLE ;
F_IN_T7 <= TOTAL_BIOMASS_AVAILABLE ;
F_IN_BLANK1 <= TOTAL_BIOMASS_AVAILABLE ;
F_IN_T_TOTAL <= TOTAL_BIOMASS_AVAILABLE ;

(F_IN_T1/TOTAL_BIOMASS_AVAILABLE) <= I_T1 ;
(F_IN_T2/TOTAL_BIOMASS_AVAILABLE) <= I_T2 ;
(F_IN_T3/TOTAL_BIOMASS_AVAILABLE) <= I_T3 ;
(F_IN_T4/TOTAL_BIOMASS_AVAILABLE) <= I_T4 ;
(F_IN_T5/TOTAL_BIOMASS_AVAILABLE) <= I_T5 ;
(F_IN_T6/TOTAL_BIOMASS_AVAILABLE) <= I_T6 ;
(F_IN_T7/TOTAL_BIOMASS_AVAILABLE) <= I_T7 ;
(F_IN_BLANK1/TOTAL_BIOMASS_AVAILABLE) <= I_BLANK1 ;
@BIN(I_T1); @BIN(I_T2);
@BIN(I_T3); @BIN(I_T4);
@BIN(I_T5); @BIN(I_T6);
@BIN(I_T7); @BIN(I_BLANK1);

(0.25 * I_T1)  <= (X_M_IN_T1 * I_T1)          ;
(X_M_IN_T1 * I_T1)          <= (0.65 * I_T1)  ;
(0.25 * I_T2)  <= (X_M_IN_T2 * I_T2)          ;
(X_M_IN_T2 * I_T2)          <= (0.65 * I_T2)  ;
(0.25 * I_T3)  <= (X_M_IN_T3 * I_T3)          ;
(X_M_IN_T3 * I_T3)          <= (0.65 * I_T3)  ;
(0.25 * I_T4)  <= (X_M_IN_T4 * I_T4)          ;
(X_M_IN_T4 * I_T4)          <= (0.72 * I_T4)  ;
(0.04 * I_T5)  <= (X_M_IN_T5 * I_T5)          ;
(X_M_IN_T5 * I_T5)          <= (0.07 * I_T5)  ;
(0.04 * I_T6)  <= (X_M_IN_T6 * I_T6)          ;
(X_M_IN_T6 * I_T6)          <= (0.12 * I_T6)  ;
(0 * I_T7)     <= (X_M_IN_T7 * I_T7)          ;
(X_M_IN_T7 * I_T7)          <= (1 * I_T7)     ;
(0 * I_BLANK1) <= (X_M_IN_BLANK1 * I_BLANK1) ; (X_M_IN_BLANK1 *
I_BLANK1) <= (1 * I_BLANK1) ;

(25  * I_T1)     <= (S_1 * I_T1)     ;
(S_1 * I_T1)     <= (125 * I_T1)     ;
(0.5 * I_T2)     <= (S_1 * I_T2)     ;
(S_1 * I_T2)     <= (50  * I_T2)     ;
(0   * I_T3)     <= (S_1 * I_T3)     ;
(S_1 * I_T3)     <= (100 * I_T3)     ;
(0   * I_T4)     <= (S_1 * I_T4)     ;
(S_1 * I_T4)     <= (150 * I_T4)     ;
(25  * I_T5)     <= (S_1 * I_T5)     ;
(S_1 * I_T5)     <= (150 * I_T5)     ;
(25  * I_T6)     <= (S_1 * I_T6)     ;
(S_1 * I_T6)     <= (150 * I_T6)     ;
(0   * I_T7)     <= (S_1 * I_T7)     ;
(S_1 * I_T7)     <= (150 * I_T7)     ;
   (0   * I_BLANK1) <= (S_1 * I_BLANK1) ;
```

```
   (1    (S_1 * I_BLANK1) <= (150 * I_BLANK1) ;

F_OUTCHCL_T1 = F_IN_T1 * X_CHCL_IN_T1 ;
F_OUTCHCL_T2 = F_IN_T2 * X_CHCL_IN_T2 ;
F_OUTCHCL_T3 = F_IN_T3 * X_CHCL_IN_T3 ;
F_OUTCHCL_T4 = F_IN_T4 * X_CHCL_IN_T4 ;
F_OUTCHCL_T5 = F_IN_T5 * X_CHCL_IN_T5 ;
F_OUTCHCL_T6 = F_IN_T6 * X_CHCL_IN_T6 ;
F_OUTCHCL_T7 = F_IN_T7 * X_CHCL_IN_T7 ;
F_OUTCHCL_BLANK1 = F_IN_BLANK1 * X_CHCL_IN_BLANK1;

F_OUTCHCL_T1 <= TOTAL_CHCL_AVAILABLE ;
F_OUTCHCL_T2 <= TOTAL_CHCL_AVAILABLE ;
F_OUTCHCL_T3 <= TOTAL_CHCL_AVAILABLE ;
F_OUTCHCL_T4 <= TOTAL_CHCL_AVAILABLE ;
F_OUTCHCL_T5 <= TOTAL_CHCL_AVAILABLE ;
F_OUTCHCL_T6 <= TOTAL_CHCL_AVAILABLE ;
F_OUTCHCL_T7 <= TOTAL_CHCL_AVAILABLE ;
F_OUTCHCL_BLANK1 <= TOTAL_CHCL_AVAILABLE ;
F_OUTCHCL_T_TOTAL = F_OUTCHCL_T1 + F_OUTCHCL_T2 + F_OUTCHCL_T3 +
F_OUTCHCL_T4 + F_OUTCHCL_T5 + F_OUTCHCL_T6 + F_OUTCHCL_T7 +
F_OUTCHCL_BLANK1 ;
F_OUTCHCL_T_TOTAL <= TOTAL_CHCL_AVAILABLE ;

F_MR_T1 = F_IN_T1 * X_M_IN_T1 * MRR_T1 ; !kg/s = kg/s;
0.56 <= MRR_T1 ;
MRR_T1 <= 0.86 ;
TR_T1 = 0.67 ;!kWhr/kg ;
EF_T1 = 0.6 ;
P_D_T1 * EF_T1 * 3600 = TR_T1 * F_MR_T1 ; !kWhr/s * 3600 s/hr =
kWhr/kg * kg/s ;

F_MR_T2 = F_IN_T2 * X_M_IN_T2 * MRR_T2 ; !kg/s = kg/s;
0.56 <= MRR_T2 ;
MRR_T2 <= 0.86 ;
TR_T2 = 0.67 ; !kWhr/kg ;
EF_T2 = 0.86 ;
P_D_T2 * EF_T2 * 3600 = TR_T2 * F_MR_T2  ; !kWhr/s * 3600 s/hr =
kWhr/kg * kg/s ;

F_MR_T3 = F_IN_T3 * X_M_IN_T3 * MRR_T3;
0.56 <= MRR_T3 ;
MRR_T3 <= 0.86 ;
TR_T3 = 0.67 ; !kWhr/kg ;
EF_T3 = 0.87 ;
P_D_T3 * EF_T3 * 3600 = TR_T3 * F_MR_T3 ; !kWhr/s * 3600 s/hr =
kWhr/kg * kg/s ;

F_MR_T4 = F_IN_T4 * X_M_IN_T4 * MRR_T4;
0.64 <= MRR_T4 ;
MRR_T4 <= 0.81 ;
TR_T4 = 0.67 ; !kWhr/kg ;
EF_T4 = 0.7 ;
P_D_T4 * EF_T4 * 3600 = TR_T4 * F_MR_T4 ; !kWhr/s * 3600 s/hr =
kWhr/kg * kg/s ;

F_MR_T5 = F_IN_T5 * X_M_IN_T5 * MRR_T5;
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```
MRR_T5 = 0.15 ;
TR_T5 = 0 ; !kWhr/kg ;
EF_T5 = 1 ;
P_D_T5 * EF_T5 * 3600  = TR_T5 * F_MR_T5 ; !kWhr/s * 3600 s/hr =
kWhr/kg * kg/s ;

F_MR_T6 = F_IN_T6 * X_M_IN_T6 * MRR_T6;
MRR_T6 = 0.15 ;
TR_T6 = 0 ; !kWhr/kg ;
EF_T6 = 1 ;
P_D_T6 * EF_T6 * 3600 = TR_T6 * F_MR_T6 ; !kWhr/s * 3600 s/hr =
kWhr/kg * kg/s ;

F_MR_T7 = F_IN_T7 * X_M_IN_T7 * MRR_T7;
MRR_T7 = 0.15 ;
TR_T7 = 0 ; !kWhr/kg ;
EF_T7 = 1 ;
P_D_T7 * EF_T7 * 3600 = TR_T7 * F_MR_T7 ; !kWhr/s * 3600 s/hr =
kWhr/kg * kg/s ;

F_MR_BLANK1 = F_IN_BLANK1 * X_M_IN_BLANK1 * MRR_BLANK1 ;
MRR_BLANK1 = 0 ;
TR_BLANK1 = 0 ; !kWhr/kg ;
EF_BLANK1 = 1 ;
P_D_BLANK1 * EF_BLANK1 * 3600 = TR_BLANK1 * F_MR_BLANK1 ; !kWhr/s *
3600 s/hr = kWhr/kg * kg/s ;

F_OUTM_T1 = F_IN_T1 * X_M_IN_T1 - F_MR_T1 ; !kg/s = kg/s ;
F_OUTM_T2 = F_IN_T2 * X_M_IN_T2 - F_MR_T2 ; !kg/s = kg/s ;
F_OUTM_T3 = F_IN_T3 * X_M_IN_T3 - F_MR_T3 ; !kg/s = kg/s ;
F_OUTM_T4 = F_IN_T4 * X_M_IN_T4 - F_MR_T4 ; !kg/s = kg/s ;
F_OUTM_T5 = F_IN_T5 * X_M_IN_T5 - F_MR_T5 ; !kg/s = kg/s ;
F_OUTM_T6 = F_IN_T6 * X_M_IN_T6 - F_MR_T6 ; !kg/s = kg/s ;
F_OUTM_T7 = F_IN_T7 * X_M_IN_T7 - F_MR_T7 ; !kg/s = kg/s ;
F_OUTM_BLANK1 = F_IN_BLANK1 * X_M_IN_BLANK1 - F_MR_BLANK1 ; !kg/s =
kg/s
F_OUTM_T_TOTAL = F_OUTM_T1 + F_OUTM_T2 + F_OUTM_T3 + F_OUTM_T4 +
F_OUTM_T5 + F_OUTM_T6 + F_OUTM_T7 + F_OUTM_BLANK1 ;
F_OUTM_T_TOTAL <= TOTAL_M_AVAILABLE ;

P_D_T1 + P_D_T2 + P_D_T3 + P_D_T4 + P_D_T5 + P_D_T6 + P_D_T7 +
P_D_BLANK1 = P_D_T_TOTAL ;

S_IN_T1 = S_1 ; S_IN_T2 = S_1;
S_IN_T3 = S_1 ; S_IN_T4 = S_1 ;
S_IN_T5 = S_1 ; S_IN_T6 = S_1 ;
S_IN_T7 = S_1 ; S_IN_BLANK1 = S_1 ;

(S_IN_T1/SRR_T1) * I_T1 = S_I1 ;
S_I1 <= 10000 * I_T1 ;
SRR_T1 = 1 ;
P_SR_T1 = I_T1 * @LOG10 (SRR_T1) * F_IN_T1 ; !kW = kW/kgs-1 * kgs-1 ;
@FREE (K_T1);
@FREE (P_SR_T1);

(S_IN_T2/SRR_T2) * I_T2 = S_I2 ;
S_I2 <= 10000 * I_T2 ;
```

```
SRR_T2 = 1 ;
P_SR_T2 = I_T2 * @LOG10 (SRR_T2) * F_IN_T2 ; !kW = kW/kgs-1 * kgs-1 ;
@FREE (K_T2);
@FREE (P_SR_T2);

(S_IN_T3/SRR_T3) * I_T3 = S_I3 ;
S_I3 <= 10000 * I_T3 ;
SRR_T3 = 1 ;
P_SR_T3 = I_T3 * @LOG10 (SRR_T3) * F_IN_T3 ; !kW = kW/kgs-1 * kgs-1 ;
@FREE (K_T3);
@FREE (P_SR_T3);

(S_IN_T4/SRR_T4) * I_T4 = S_I4 ;
S_I4 <= 10000 * I_T4 ;
SRR_T4 = 1 ;
P_SR_T4 = I_T4 * @LOG10 (SRR_T4) * F_IN_T4 ; !kW = kW/kgs-1 * kgs-1 ;
@FREE (K_T4);
@FREE (P_SR_T4);

(S_IN_T5/SRR_T5) * I_T5 = S_I5 ;
S_I5 <= 10000 * I_T5 ;
2 <= SRR_T5 ;
SRR_T5 <= 14 ;
A_T5 = @LOG10(SRR_T5);
B_T5 = X_M_IN_T5 ;
K_T5 = 339.9 - 1109*A_T5 - 7.529*B_T5  + 947.4*(A_T5^2) +
170.5*(A_T5)*(B_T5) - 16.53*(B_T5^2) - 362.7*(A_T5^3)
      - 76.75*(A_T5^2)*(B_T5)  - 5.958*(A_T5)*(B_T5^2) + 1.836*(B_T5
^3) + 56.16*(A_T5^4) + 3.813*(A_T5^3)*(B_T5) +
4.932*(A_T5^2)*(B_T5^2) - 0.7026*A_T5*(B_T5^3) ;
P_SR_T5 = I_T5 * K_T5 * @LOG10 (SRR_T5) * F_IN_T5 ; !kW = kW/kgs-1 *
kgs-1 ;
@FREE (K_T5);
@FREE (P_SR_T5);

(S_IN_T6/SRR_T6) * I_T6 = S_I6 ;
S_I6 <= 10000 * I_T6 ;
2.23 <= SRR_T6 ;
SRR_T6 <= 12.825 ;
A_T6 = @LOG10(SRR_T6);
B_T6 = X_M_IN_T6 ;
K_T6 = 49.02 + 10.04 *A_T6 - 72.54*B_T6  + 11.03*(A_T6^2) +
2.03*(A_T6)*(B_T6) + 96.17*(B_T6^2) +0.7976*(A_T6^3)
      +2.241*(A_T6^2)*(B_T6)  - 4.248*(A_T6)*(B_T6^2) -
18.67*(B_T6^3) + 2.451*(A_T6^4) + 6.563*(A_T6^3)*(B_T6) -
0.3381*(A_T6^2)*(B_T6^2) - 9.35*A_T6*(B_T6^3) -43.85*(B_T6^4) ;
P_SR_T6 = I_T6 * K_T6 * @LOG10 (SRR_T6) * F_IN_T6; !kW = kW/kgs-1 *
kgs-1 ;
@FREE (K_T6);
@FREE (P_SR_T6);

(S_IN_T7/SRR_T7) * I_T7 = S_I7 ;
S_I7 <= 10000 * I_T7 ;
2.03 <= SRR_T7 ;
SRR_T7 <= 4.06 ;
A_T7 = @LOG10(SRR_T7);! NEED TO CHANGE;
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```
B_T7 = X_M_IN_T7 ; ! NEED TO CHANGE;
K_T7 = 1.0633 * A_T7 + 0.0203 ;
P_SR_T7 = I_T7 * K_T7 * @LOG10 (SRR_T7) * F_IN_T7; !kW = kW/kgs-1 *
kgs-1 ;
@FREE (K_T7);
@FREE (P_SR_T7);

(S_IN_BLANK1/SRR_BLANK1) * I_BLANK1 = S_I8 ;
S_I8 <= 10000 * I_BLANK1 ;
SRR_BLANK1 = 1 ;
P_SR_BLANK1 = I_BLANK1 * @LOG10 (SRR_BLANK1) * F_IN_BLANK1 ; !kW =
kW/kgs-1 * kgs-1 ;
@FREE (K_BLANK1);
@FREE (P_SR_BLANK1);

P_SR_T1 + P_SR_T2 + P_SR_T3 + P_SR_T4 + P_SR_T5 + P_SR_T6 + P_SR_T7 +
P_SR_BLANK1 = P_SR_T_TOTAL ;

!TECHNOLOGY COST;
C_T1 = ((2.9*3*18^0.63)*1000)*(((F_IN_T1*3600/1000)/1)^0.6);
C_T2 = ((2.23*1.75*46^0.6)*1000)*(((F_IN_T2*3600/1000)/1)^0.6);
C_T3 = ((45*1^0.7)*1000)*(((F_IN_T3*3600/1000)/1)^0.6);
C_T4 = ((1.4*5^0.77)*1000)*(((F_IN_T4*3600/1000)/1)^0.6);
C_T5 = ((27.5*1*0.39)*1000)*(((F_IN_T5*3600/1000)/1)^0.6);
C_T6 = ((2.97*(F_IN_T6*3600/1000)^0.78)*1000);
C_T7 = ((7.7*1^0.57)*1000)*(((F_IN_T7*3600/1000)/1)^0.6);
C_BLANK1 = F_IN_BLANK1 * 0;

C_T_TOTAL = C_T1 + C_T2 + C_T3 + C_T4 + C_T5 + C_T6 + C_T7 +
C_BLANK1 ;

F_I1 = F_OUTCHCL_T1 + F_OUTM_T1 ; !kg/s = kg/s ;
F_I2 = F_OUTCHCL_T2 + F_OUTM_T2 ; !kg/s = kg/s ;
F_I3 = F_OUTCHCL_T3 + F_OUTM_T3 ; !kg/s = kg/s ;
F_I4 = F_OUTCHCL_T4 + F_OUTM_T4 ; !kg/s = kg/s ;
F_I5 = F_OUTCHCL_T5 + F_OUTM_T5 ; !kg/s = kg/s ;
F_I6 = F_OUTCHCL_T6 + F_OUTM_T6 ; !kg/s = kg/s ;
F_I7 = F_OUTCHCL_T7 + F_OUTM_T7 ; !kg/s = kg/s ;
F_I8 = F_OUTCHCL_BLANK1 + F_OUTM_BLANK1 ; !kg/s = kg/s ;

F_I1 <= TOTAL_BIOMASS_AVAILABLE ;
F_I2 <= TOTAL_BIOMASS_AVAILABLE ;
F_I3 <= TOTAL_BIOMASS_AVAILABLE ;
F_I4 <= TOTAL_BIOMASS_AVAILABLE ;
F_I5 <= TOTAL_BIOMASS_AVAILABLE ;
F_I6 <= TOTAL_BIOMASS_AVAILABLE ;
F_I7 <= TOTAL_BIOMASS_AVAILABLE ;
F_I8 <= TOTAL_BIOMASS_AVAILABLE ;
F_I_TOTAL = F_I1 + F_I2 + F_I3 + F_I4 + F_I5 + F_I6 + F_I7 + F_I8 ;
F_I_TOTAL <= TOTAL_BIOMASS_AVAILABLE ;

F_OUTCHCL_T1  = F_I1 * X_CHCL_I1 ;
F_OUTM_T1     = F_I1 * X_M_I1    ;
X_CHCL_I1 + X_M_I1 <= 1 ; !JUST ADD TO EASE CALCULATION IN LINGO, DO
NOT INCLUDE IN FORMULATION.;
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F_OUTCHCL_T2  = F_I2 * X_CHCL_I2 ;
F_OUTM_T2     = F_I2 * X_M_I2    ;
X_CHCL_I2 + X_M_I2 <= 1 ; !JUST ADD TO EASE CALCULATION IN LINGO, DO
NOT INCLUDE IN FORMULATION.;

F_OUTCHCL_T3  = F_I3 * X_CHCL_I3 ;
F_OUTM_T3     = F_I3 * X_M_I3    ;
X_CHCL_I3 + X_M_I3 <= 1 ; !JUST ADD TO EASE CALCULATION IN LINGO, DO
NOT INCLUDE IN FORMULATION.;

F_OUTCHCL_T4  = F_I4 * X_CHCL_I4 ;
F_OUTM_T4     = F_I4 * X_M_I4    ;
X_CHCL_I4 + X_M_I4 <= 1 ; !JUST ADD TO EASE CALCULATION IN LINGO, DO
NOT INCLUDE IN FORMULATION.;

F_OUTCHCL_T5  = F_I5 * X_CHCL_I5 ;
F_OUTM_T5     = F_I1 * X_M_I5    ;
X_CHCL_I5 + X_M_I5 <= 1 ; !JUST ADD TO EASE CALCULATION IN LINGO, DO
NOT INCLUDE IN FORMULATION.;

F_OUTCHCL_T6  = F_I6 * X_CHCL_I6 ;
F_OUTM_T6     = F_I6 * X_M_I6    ;
X_CHCL_I6 + X_M_I6 <= 1 ; !JUST ADD TO EASE CALCULATION IN LINGO, DO
NOT INCLUDE IN FORMULATION.;

F_OUTCHCL_T7  = F_I7 * X_CHCL_I7 ;
F_OUTM_T7     = F_I7 * X_M_I7    ;
X_CHCL_I7 + X_M_I7 <= 1 ; !JUST ADD TO EASE CALCULATION IN LINGO, DO
NOT INCLUDE IN FORMULATION.;

F_OUTCHCL_BLANK1 = F_I8 * X_CHCL_I8 ;
F_OUTM_BLANK1    = F_I8 * X_M_I8    ;
X_CHCL_I8 + X_M_I8 <= 1 ; !JUST ADD TO EASE CALCULATION IN LINGO, DO
NOT INCLUDE IN FORMULATION.;

I_T1 + I_T2 + I_T3 + I_T4 + I_T5 + I_T6 + I_T7 + I_BLANK1 =
I_T_TOTAL ;

!STAGE 2;
S_2 >= S_I1 ; S_2 >= S_I2 ;
S_2 >= S_I3 ; S_2 >= S_I4 ;
S_2 >= S_I5 ; S_2 >= S_I6 ;
S_2 >= S_I7 ; S_2 >= S_I8 ;

F_I1 = F_I1_TP1 + F_I1_TP2 + F_I1_TP3 + F_I1_TP4 + F_I1_TP5 +
F_I1_TP6 + F_I1_TP7 + F_I1_BLANK2 ; !kg/s = kg/s ;
F_I2 = F_I2_TP1 + F_I2_TP2 + F_I2_TP3 + F_I2_TP4 + F_I2_TP5 +
F_I2_TP6 + F_I2_TP7 + F_I2_BLANK2 ; !kg/s = kg/s ;
F_I3 = F_I3_TP1 + F_I3_TP2 + F_I3_TP3 + F_I3_TP4 + F_I3_TP5 +
F_I3_TP6 + F_I3_TP7 + F_I3_BLANK2 ; !kg/s = kg/s ;
F_I4 = F_I4_TP1 + F_I4_TP2 + F_I4_TP3 + F_I4_TP4 + F_I4_TP5 +
F_I4_TP6 + F_I4_TP7 + F_I4_BLANK2 ; !kg/s = kg/s ;
F_I5 = F_I5_TP1 + F_I5_TP2 + F_I5_TP3 + F_I5_TP4 + F_I5_TP5 +
F_I5_TP6 + F_I5_TP7 + F_I5_BLANK2 ; !kg/s = kg/s ;
F_I6 = F_I6_TP1 + F_I6_TP2 + F_I6_TP3 + F_I6_TP4 + F_I6_TP5 +
F_I6_TP6 + F_I6_TP7 + F_I6_BLANK2 ; !kg/s = kg/s ;
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F_I7 = F_I7_TP1 + F_I7_TP2 + F_I7_TP3 + F_I7_TP4 + F_I7_TP5 +
F_I7_TP6 + F_I7_TP7 + F_I7_BLANK2 ; !kg/s = kg/s ;
F_I8 = F_I8_TP1 + F_I8_TP2 + F_I8_TP3 + F_I8_TP4 + F_I8_TP5 +
F_I8_TP6 + F_I8_TP7 + F_I8_BLANK2 ; !kg/s = kg/s ;

F_IN_TP1 = F_I1_TP1 + F_I2_TP1 + F_I3_TP1 + F_I4_TP1 + F_I5_TP1 +
F_I6_TP1 + F_I7_TP1 + F_I8_TP1 ; !kg/s = kg/s ;
F_IN_TP1 * X_CHCL_IN_TP1  = F_I1_TP1 * X_CHCL_I1  + F_I2_TP1 *
X_CHCL_I2  + F_I3_TP1 * X_CHCL_I3  + F_I4_TP1 * X_CHCL_I4  + F_I5_TP1
* X_CHCL_I5  + F_I6_TP1 * X_CHCL_I6  + F_I7_TP1 * X_CHCL_I7 +
F_I8_TP1 * X_CHCL_I8 ;
F_IN_TP1 * X_M_IN_TP1     = F_I1_TP1 * X_M_I1     + F_I2_TP1 * X_M_I2
+ F_I3_TP1 * X_M_I3     + F_I4_TP1 * X_M_I4     + F_I5_TP1 * X_M_I5
+ F_I6_TP1 * X_M_I6     + F_I7_TP1 * X_M_I7    + F_I8_TP1 *
X_M_I8    ;
X_CHCL_IN_TP1 + X_M_IN_TP1 <=1 ;

F_IN_TP2 = F_I1_TP2 + F_I2_TP2 + F_I3_TP2 + F_I4_TP2 + F_I5_TP2 +
F_I6_TP2 + F_I7_TP2 + F_I8_TP2 ; !kg/s = kg/s ;
F_IN_TP2 * X_CHCL_IN_TP2  = F_I1_TP2 * X_CHCL_I1  + F_I2_TP2 *
X_CHCL_I2  + F_I3_TP2 * X_CHCL_I3  + F_I4_TP2 * X_CHCL_I4  + F_I5_TP2
* X_CHCL_I5  + F_I6_TP2 * X_CHCL_I6  + F_I7_TP2 * X_CHCL_I7 +
F_I8_TP2 * X_CHCL_I8 ;
F_IN_TP2 * X_M_IN_TP2     = F_I1_TP2 * X_M_I1     + F_I2_TP2 * X_M_I2
+ F_I3_TP2 * X_M_I3     + F_I4_TP2 * X_M_I4     + F_I5_TP2 * X_M_I5
+ F_I6_TP2 * X_M_I6     + F_I7_TP2 * X_M_I7    + F_I8_TP2 *
X_M_I8    ;
X_CHCL_IN_Tp2 + X_M_IN_TP2 <=1 ;

F_IN_TP3 = F_I1_TP3 + F_I2_TP3 + F_I3_TP3 + F_I4_TP3 + F_I5_TP3 +
F_I6_TP3 + F_I7_TP3 + F_I8_TP3 ; !kg/s = kg/s ;
F_IN_TP3 * X_CHCL_IN_TP3  = F_I1_TP3 * X_CHCL_I1  + F_I2_TP3 *
X_CHCL_I2  + F_I3_TP3 * X_CHCL_I3  + F_I4_TP3 * X_CHCL_I4  + F_I5_TP3
* X_CHCL_I5  + F_I6_TP3 * X_CHCL_I6  + F_I7_TP3 * X_CHCL_I7 +
F_I8_TP3 * X_CHCL_I8 ;
F_IN_TP3 * X_M_IN_TP3     = F_I1_TP3 * X_M_I1     + F_I2_TP3 * X_M_I2
+ F_I3_TP3 * X_M_I3     + F_I4_TP3 * X_M_I4     + F_I5_TP3 * X_M_I5
+ F_I6_TP3 * X_M_I6     + F_I7_TP3 * X_M_I7    + F_I8_TP3 *
X_M_I8    ;
X_CHCL_IN_TP3 + X_M_IN_TP3 <=1 ;

F_IN_TP4 = F_I1_TP4 + F_I2_TP4 + F_I3_TP4 + F_I4_TP4 + F_I5_TP4 +
F_I6_TP4 + F_I7_TP4 + F_I8_TP4 ; !kg/s = kg/s ;
F_IN_TP4 * X_CHCL_IN_TP4  = F_I1_TP4 * X_CHCL_I1  + F_I2_TP4 *
X_CHCL_I2  + F_I3_TP4 * X_CHCL_I3  + F_I4_TP4 * X_CHCL_I4  + F_I5_TP4
* X_CHCL_I5  + F_I6_TP4 * X_CHCL_I6  + F_I7_TP4 * X_CHCL_I7 +
F_I8_TP4 * X_CHCL_I8 ;
F_IN_TP4 * X_M_IN_TP4     = F_I1_TP4 * X_M_I1     + F_I2_TP4 * X_M_I2
+ F_I3_TP4 * X_M_I3     + F_I4_TP4 * X_M_I4     + F_I5_TP4 * X_M_I5
+ F_I6_TP4 * X_M_I6     + F_I7_TP4 * X_M_I7    + F_I8_TP4 *
X_M_I8    ;
X_CHCL_IN_TP4 + X_M_IN_TP4 <=1 ;

F_IN_TP5 = F_I1_TP5 + F_I2_TP5 + F_I3_TP5 + F_I4_TP5 + F_I5_TP5 +
F_I6_TP5 + F_I7_TP5 + F_I8_TP5 ; !kg/s = kg/s ;
F_IN_TP5 * X_CHCL_IN_TP5  = F_I1_TP5 * X_CHCL_I1  + F_I2_TP5 *
X_CHCL_I2  + F_I3_TP5 * X_CHCL_I3  + F_I4_TP5 * X_CHCL_I4  + F_I5_TP5
```

```
* X_CHCL_I5  + F_I6_TP5 * X_CHCL_I6  + F_I7_TP5 * X_CHCL_I7 +
F_I8_TP5 * X_CHCL_I8 ;
F_IN_TP5 * X_M_IN_TP5     = F_I1_TP5 * X_M_I1     + F_I2_TP5 * X_M_I2
+ F_I3_TP5 * X_M_I3     + F_I4_TP5 * X_M_I4     + F_I5_TP5 * X_M_I5
+ F_I6_TP5 * X_M_I6     + F_I7_TP5 * X_M_I7    + F_I8_TP5 *
X_M_I8    ;
X_CHCL_IN_TP5 + X_M_IN_TP5 <=1 ;

F_IN_TP6 = F_I1_TP6 + F_I2_TP6 + F_I3_TP6 + F_I4_TP6 + F_I5_TP6 +
F_I6_TP6 + F_I7_TP6 + F_I8_TP6 ; !kg/s = kg/s ;
F_IN_TP6 * X_CHCL_IN_TP6  = F_I1_TP6 * X_CHCL_I1  + F_I2_TP6 *
X_CHCL_I2  + F_I3_TP6 * X_CHCL_I3  + F_I4_TP6 * X_CHCL_I4  + F_I5_TP6
* X_CHCL_I5  + F_I6_TP6 * X_CHCL_I6  + F_I7_TP6 * X_CHCL_I7 +
F_I8_TP6 * X_CHCL_I8 ;
F_IN_TP6 * X_M_IN_TP6     = F_I1_TP6 * X_M_I1     + F_I2_TP6 * X_M_I2
+ F_I3_TP6 * X_M_I3     + F_I4_TP6 * X_M_I4     + F_I5_TP6 * X_M_I5
+ F_I6_TP6 * X_M_I6     + F_I7_TP6 * X_M_I7    + F_I8_TP6 *
X_M_I8    ;
X_CHCL_IN_TP6 + X_M_IN_TP6 <=1 ;

F_IN_TP7 = F_I1_TP7 + F_I2_TP7 + F_I3_TP7 + F_I4_TP7 + F_I5_TP7 +
F_I6_TP7 + F_I7_TP7 + F_I8_TP7 ; !kg/s = kg/s ;
F_IN_TP7 * X_CHCL_IN_TP7  = F_I1_TP7 * X_CHCL_I1  + F_I2_TP7 *
X_CHCL_I2  + F_I3_TP7 * X_CHCL_I3  + F_I4_TP7 * X_CHCL_I4  + F_I5_TP7
* X_CHCL_I5  + F_I6_TP7 * X_CHCL_I6  + F_I7_TP7 * X_CHCL_I7 +
F_I8_TP7 * X_CHCL_I8 ;
F_IN_TP7 * X_M_IN_TP7     = F_I1_TP7 * X_M_I1     + F_I2_TP7 * X_M_I2
+ F_I3_TP7 * X_M_I3     + F_I4_TP7 * X_M_I4     + F_I5_TP7 * X_M_I5
+ F_I6_TP7 * X_M_I6     + F_I7_TP7 * X_M_I7    + F_I8_TP7 *
X_M_I8    ;
X_CHCL_IN_TP7 + X_M_IN_TP7 <=1 ;

F_IN_BLANK2 = F_I1_BLANK2 + F_I2_BLANK2 + F_I3_BLANK2 + F_I4_BLANK2 +
F_I5_BLANK2 + F_I6_BLANK2 + F_I7_BLANK2 + F_I8_BLANK2 ; !kg/s =
kg/s ;
F_IN_BLANK2 * X_CHCL_IN_BLANK2  = F_I1_BLANK2 * X_CHCL_I1  +
F_I2_BLANK2 * X_CHCL_I2  + F_I3_BLANK2 * X_CHCL_I3  + F_I4_BLANK2 *
X_CHCL_I4  + F_I5_BLANK2 * X_CHCL_I5  + F_I6_BLANK2 * X_CHCL_I6  +
F_I7_BLANK2 * X_CHCL_I7 + F_I8_BLANK2 * X_CHCL_I8 ;
F_IN_BLANK2 * X_M_IN_BLANK2     = F_I1_BLANK2 * X_M_I1     +
F_I2_BLANK2 * X_M_I2     + F_I3_BLANK2 * X_M_I3     + F_I4_BLANK2 *
X_M_I4     + F_I5_BLANK2 * X_M_I5     + F_I6_BLANK2 * X_M_I6     +
F_I7_BLANK2 * X_M_I7    + F_I8_BLANK2 * X_M_I8    ;
X_CHCL_IN_BLANK2 + X_M_IN_BLANK2 <=1 ;

F_IN_TP1 + F_IN_TP2 + F_IN_TP3 + F_IN_TP4 + F_IN_TP5 + F_IN_TP6 +
F_IN_TP7 + F_IN_BLANK2 = F_IN_TP_TOTAL ;
F_IN_TP1 <= TOTAL_BIOMASS_AVAILABLE ;
F_IN_TP2 <= TOTAL_BIOMASS_AVAILABLE ;
F_IN_TP3 <= TOTAL_BIOMASS_AVAILABLE ;
F_IN_TP4 <= TOTAL_BIOMASS_AVAILABLE ;
F_IN_TP5 <= TOTAL_BIOMASS_AVAILABLE ;
F_IN_TP6 <= TOTAL_BIOMASS_AVAILABLE ;
F_IN_TP7 <= TOTAL_BIOMASS_AVAILABLE ;
F_IN_BLANK2 <= TOTAL_BIOMASS_AVAILABLE ;
F_IN_TP_TOTAL <= TOTAL_BIOMASS_AVAILABLE ;
```

```
(F_IN_TP1/TOTAL_BIOMASS_AVAILABLE) <= I_TP1 ;
(F_IN_TP2/TOTAL_BIOMASS_AVAILABLE) <= I_TP2 ;
(F_IN_TP3/TOTAL_BIOMASS_AVAILABLE) <= I_TP3 ;
(F_IN_TP4/TOTAL_BIOMASS_AVAILABLE) <= I_TP4 ;
(F_IN_TP5/TOTAL_BIOMASS_AVAILABLE) <= I_TP5 ;
(F_IN_TP6/TOTAL_BIOMASS_AVAILABLE) <= I_TP6 ;
(F_IN_TP7/TOTAL_BIOMASS_AVAILABLE) <= I_TP7 ;
(F_IN_BLANK2/TOTAL_BIOMASS_AVAILABLE) <= I_BLANK2 ;
@BIN(I_TP1); @BIN(I_TP2);
@BIN(I_TP3); @BIN(I_TP4);
@BIN(I_TP5); @BIN(I_TP6);
@BIN(I_TP7); @BIN(I_BLANK2);

(0.25 * I_TP1) <= (X_M_IN_TP1 * I_TP1)       ;
(X_M_IN_TP1 * I_TP1)       <= (0.65 * I_TP1) ;
(0.25 * I_TP2) <= (X_M_IN_TP2 * I_TP2)       ;
(X_M_IN_TP2 * I_TP2)       <= (0.65 * I_TP2) ;
(0.25 * I_TP3) <= (X_M_IN_TP3 * I_TP3)       ;
(X_M_IN_TP3 * I_TP3)       <= (0.65 * I_TP3) ;
(0.25 * I_TP4) <= (X_M_IN_TP4 * I_TP4)       ;
(X_M_IN_TP4 * I_TP4)       <= (0.72 * I_TP4) ;
(0.04 * I_TP5) <= (X_M_IN_TP5 * I_TP5)       ;
(X_M_IN_TP5 * I_TP5)       <= (0.07 * I_TP5) ;
(0.04 * I_TP6) <= (X_M_IN_TP6 * I_TP6)       ;
(X_M_IN_TP6 * I_TP6)       <= (0.12 * I_TP6) ;
(0 * I_TP7)    <= (X_M_IN_TP7 * I_TP7)       ;
(X_M_IN_TP7 * I_TP7)       <= (1 * I_TP7)    ;
(0 * I_BLANK2) <= (X_M_IN_BLANK2 * I_BLANK2) ;
(X_M_IN_BLANK2 * I_BLANK2) <= (1 * I_BLANK2) ;

(25  * I_TP1)    <= (S_2 * I_TP1)    ;
(S_2 * I_TP1)    <= (125 * I_TP1)    ;
(0.5 * I_TP2)    <= (S_2 * I_TP2)    ;
(S_2 * I_TP2)    <= (50  * I_TP2)    ;
(0   * I_TP3)    <= (S_2 * I_TP3)    ;
(S_2 * I_TP3)    <= (100 * I_TP3)    ;
(0   * I_TP4)    <= (S_2 * I_TP4)    ;
(S_2 * I_TP4)    <= (150 * I_TP4)    ;
(25  * I_TP5)    <= (S_2 * I_TP5)    ;
(S_2 * I_TP5)    <= (150 * I_TP5)    ;
(25  * I_TP6)    <= (S_2 * I_TP6)    ;
(S_2 * I_TP6)    <= (150 * I_TP6)    ;
(0   * I_TP7)    <= (S_2 * I_TP7)    ;
(S_2 * I_TP7)    <= (150 * I_TP7)    ;
   (0   * I_BLANK2) <= (S_2 * I_BLANK2) ;
   (1   (S_2 * I_BLANK2) <= (150 * I_BLANK2) ;


F_OUTCHCL_TP1 = (F_IN_TP1 * X_CHCL_IN_TP1)  ;
F_OUTCHCL_TP2 = (F_IN_TP2 * X_CHCL_IN_TP2)  ;
F_OUTCHCL_TP3 = (F_IN_TP3 * X_CHCL_IN_TP3)  ;
F_OUTCHCL_TP4 = (F_IN_TP4 * X_CHCL_IN_TP4)  ;
F_OUTCHCL_TP5 = (F_IN_TP5 * X_CHCL_IN_TP5)  ;
F_OUTCHCL_TP6 = (F_IN_TP6 * X_CHCL_IN_TP6)  ;
F_OUTCHCL_TP7 = (F_IN_TP7 * X_CHCL_IN_TP7)  ;
F_OUTCHCL_BLANK2 = (F_IN_BLANK2 * X_CHCL_IN_BLANK2)  ;
```

```
F_OUTCHCL_TP1 <= TOTAL_CHCL_AVAILABLE ;
F_OUTCHCL_TP2 <= TOTAL_CHCL_AVAILABLE ;
F_OUTCHCL_TP3 <= TOTAL_CHCL_AVAILABLE ;
F_OUTCHCL_TP4 <= TOTAL_CHCL_AVAILABLE ;
F_OUTCHCL_TP5 <= TOTAL_CHCL_AVAILABLE ;
F_OUTCHCL_TP6 <= TOTAL_CHCL_AVAILABLE ;
F_OUTCHCL_TP7 <= TOTAL_CHCL_AVAILABLE ;
F_OUTCHCL_BLANK2 <= TOTAL_CHCL_AVAILABLE ;
F_OUTCHCL_TP_TOTAL = F_OUTCHCL_TP1 + F_OUTCHCL_TP2 + F_OUTCHCL_TP3 +
F_OUTCHCL_TP4 + F_OUTCHCL_TP5 + F_OUTCHCL_TP6 + F_OUTCHCL_TP7 +
F_OUTCHCL_BLANK2 ;
F_OUTCHCL_TP_TOTAL <= TOTAL_CHCL_AVAILABLE ;

F_MR_TP1 = F_IN_TP1 * X_M_IN_TP1 * MRR_TP1 ;
0.56 <= MRR_TP1 ;
MRR_TP1 <= 0.86 ;
TR_TP1 = 0.67 ; !kWhr/kg ;
EF_TP1 = 0.6 ;
P_D_TP1 * EF_TP1 * 3600 = TR_TP1 * F_MR_TP1  ; !kWhr/s * 3600 s/hr =
kWhr/kg * kg/s ;

F_MR_TP2 = F_IN_TP2 * X_M_IN_TP2 * MRR_TP2 ;
0.56 <= MRR_TP2 ;
MRR_TP2 <= 0.86 ;
TR_TP2 = 0.67 ; !kWhr/kg ;
EF_TP2 = 0.86 ;
P_D_TP2 * EF_TP2 * 3600 = TR_TP2 * F_MR_TP2  ; !kWhr/s * 3600 s/hr =
kWhr/kg * kg/s ;

F_MR_TP3 = F_IN_TP3 * X_M_IN_TP3 * MRR_TP3 ;
0.56 <= MRR_TP3 ;
MRR_TP3 <= 0.86 ;
TR_TP3 = 0.67 ; !kWhr/kg ;
EF_TP3 = 0.87 ;
P_D_TP3 * EF_TP3 * 3600 = TR_TP3 * F_MR_TP3 ; !kWhr/s * 3600 s/hr =
kWhr/kg * kg/s ;

F_MR_TP4 = F_IN_TP4 * X_M_IN_TP4 * MRR_TP4 ;
0.64 <= MRR_TP4 ;
MRR_TP4 <= 0.81 ;
TR_TP4 = 0.67 ; !kWhr/kg ;
EF_TP4 = 0.7 ;
P_D_TP4 * EF_TP4 * 3600 = TR_TP4 * F_MR_TP4 ; !kWhr/s * 3600 s/hr =
kWhr/kg * kg/s ;

F_MR_TP5 = F_IN_TP5 * X_M_IN_TP5 * MRR_TP5 ;
MRR_TP5 = 0.15 ;
TR_TP5 = 0 ; !kWhr/kg ;
EF_TP5 = 1 ;
P_D_TP5 * EF_TP5 * 3600  = TR_TP5 * F_MR_TP5 ; !kWhr/s * 3600 s/hr =
kWhr/kg * kg/s ;

F_MR_TP6 = F_IN_TP6 * X_M_IN_TP6 * MRR_TP6 ;
MRR_TP6 = 0.15 ;
TR_TP6 = 0 ; !kWhr/kg ;
EF_TP6 = 1 ;
```

```
P_D_TP6 * EF_TP6 * 3600 = TR_TP6 * F_MR_TP6 ; !kWhr/s * 3600 s/hr =
kWhr/kg * kg/s ;

F_MR_TP7 = F_IN_TP7 * X_M_IN_TP7 * MRR_TP7 ;
MRR_TP7 = 0.15 ;
TR_TP7 = 0 ; !kWhr/kg ;
EF_TP7 = 1 ;
P_D_TP7 * EF_TP7 * 3600 = TR_TP7 * F_MR_TP7 ; !kWhr/s * 3600 s/hr =
kWhr/kg * kg/s ;

F_MR_BLANK2 = F_IN_BLANK2 * X_M_IN_BLANK2 * MRR_BLANK2 ;
MRR_BLANK2 = 0 ;
TR_BLANK2 = 0 ; !kWhr/kg ;
EF_BLANK2 = 1;
P_D_BLANK2 * EF_BLANK2 * 3600 = TR_BLANK2 * F_MR_BLANK2 ; !kWhr/s *
3600 s/hr  = kWhr/kg * kg/s ;

P_D_TP1 + P_D_TP2 + P_D_TP3 + P_D_TP4 + P_D_TP5 + P_D_TP6 + P_D_TP7 +
P_D_BLANK2 = P_D_TP_TOTAL ;

F_OUTM_TP1 = F_IN_TP1 * X_M_IN_TP1 - F_MR_TP1 ;
F_OUTM_TP2 = F_IN_TP2 * X_M_IN_TP2 - F_MR_TP2 ;
F_OUTM_TP3 = F_IN_TP3 * X_M_IN_TP3 - F_MR_TP3 ;
F_OUTM_TP4 = F_IN_TP4 * X_M_IN_TP4 - F_MR_TP4 ;
F_OUTM_TP5 = F_IN_TP5 * X_M_IN_TP5 - F_MR_TP5 ;
F_OUTM_TP6 = F_IN_TP6 * X_M_IN_TP6 - F_MR_TP6 ;
F_OUTM_TP7 = F_IN_TP7 * X_M_IN_TP7 - F_MR_TP7 ;
F_OUTM_BLANK2 = F_IN_BLANK2 * X_M_IN_BLANK2 - F_MR_BLANK2 ;

F_OUTM_TP_TOTAL = F_OUTM_TP1 + F_OUTM_TP2 + F_OUTM_TP3 + F_OUTM_TP4 +
F_OUTM_TP5 + F_OUTM_TP6 + F_OUTM_TP7 + F_OUTM_BLANK2 ;
F_OUTM_TP_TOTAL <= TOTAL_M_AVAILABLE;

S_IN_TP1 = S_2 ; S_IN_TP2 = S_2 ;
S_IN_TP3 = S_2 ; S_IN_TP4 = S_2 ;
S_IN_TP5 = S_2 ; S_IN_TP6 = S_2 ;
S_IN_TP7 = S_2 ; S_IN_BLANK2 = S_2 ;

(S_IN_TP1/SRR_TP1) * I_TP1 = S_IP1 ;
S_IP1 <= 10000 * I_TP1 ;
SRR_TP1 = 1 ;
P_SR_TP1 = I_TP1 * @LOG10 (SRR_TP1) * F_IN_TP1 ; !kW = kW/kgs-1 *
kgs-1 ;
@FREE (K_TP1);
@FREE (P_SR_TP1);

(S_IN_TP2/SRR_TP2) * I_TP2 = S_IP2 ;
S_IP2 <= 10000 * I_TP2 ;
SRR_TP2 = 1 ;
P_SR_TP2 = I_TP2 * @LOG10 (SRR_TP2) * F_IN_TP2 ; !kW = kW/kgs-1 *
kgs-1 ;
@FREE (K_TP2);
@FREE (P_SR_TP2);

(S_IN_TP3/SRR_TP3) * I_TP3 = S_IP3 ;
S_IP3 <= 10000 * I_TP3 ;
SRR_TP3 = 1 ;
```

```
P_SR_TP3 = I_TP3 * @LOG10 (SRR_TP3) * F_IN_TP3 ; !kW = kW/kgs-1 *
kgs-1 ;
@FREE (K_TP3);
@FREE (P_SR_TP3);

(S_IN_TP4/SRR_TP4) * I_TP4 = S_IP4 ;
S_IP4 <= 10000 * I_TP4 ;
SRR_TP4 = 1 ;
P_SR_TP4 = I_TP4 * @LOG10 (SRR_TP4) * F_IN_TP4 ; !kW = kW/kgs-1 *
kgs-1 ;
@FREE (K_TP4);
@FREE (P_SR_TP4);

(S_IN_TP5/SRR_TP5) * I_TP5 = S_IP5 ;
S_IP5 <= 10000 * I_TP5 ;
2 <= SRR_TP5 ;
SRR_TP5 <= 14 ;
A_TP5 = @LOG10(SRR_TP5);
B_TP5 = X_M_IN_TP5 ;
K_TP5 = 339.9 - 1109*A_TP5 - 7.529*B_TP5  + 947.4*(A_TP5^2) +
170.5*(A_TP5)*(B_TP5) - 16.53*(B_TP5^2) - 362.7*(A_TP5^3)
      - 76.75*(A_TP5^2)*(B_TP5)  - 5.958*(A_TP5)*(B_TP5^2) +
1.836*(B_TP5 ^3) + 56.16*(A_TP5^4) + 3.813*(A_TP5^3)*(B_TP5) +
4.932*(A_TP5^2)*(B_TP5^2) - 0.7026*A_TP5*(B_TP5^3) ;
P_SR_TP5 = I_TP5 * K_TP5 * @LOG10 (SRR_TP5) * F_IN_TP5 ; !kW =
kW/kgs-1 * kgs-1 ;
@FREE (K_TP5);
@FREE (P_SR_TP5);

(S_IN_TP6/SRR_TP6) * I_TP6 = S_IP6 ;
S_IP6 <= 10000 * I_TP6 ;
2.23 <= SRR_TP6 ;
SRR_TP6 <= 12.825 ;
A_TP6 = @LOG10(SRR_TP6);
B_TP6 = X_M_IN_TP6 ;
K_TP6 = 49.02 + 10.04 *A_TP6 - 72.54*B_TP6  + 11.03*(A_TP6^2) +
2.03*(A_TP6)*(B_TP6) + 96.17*(B_TP6^2) +0.7976*(A_TP6^3)
      +2.241*(A_T6^2)*(B_TP6)  - 4.248*(A_TP6)*(B_TP6^2) -
18.67*(B_TP6^3) + 2.451*(A_TP6^4) + 6.563*(A_TP6^3)*(B_TP6) -
0.3381*(A_TP6^2)*(B_TP6^2) - 9.35*A_TP6*(B_TP6^3) -43.85*(B_TP6^4) ;
P_SR_TP6 = I_TP6 * K_TP6 * @LOG10 (SRR_TP6) * F_IN_TP6 ; !kW =
kW/kgs-1 * kgs-1 ;
@FREE (K_TP6);
@FREE (P_SR_TP6);

(S_IN_TP7/SRR_TP7) * I_TP7 = S_IP7 ;
S_IP7 <= 10000 * I_TP7 ;
2.03 <= SRR_TP7 ;
SRR_TP7 <= 4.06 ;
A_TP7 = @LOG10(SRR_TP7);
K_TP7 = 1.0633 * A_TP7 + 0.0203 ;
P_SR_TP7 = I_TP7 * K_TP7 * @LOG10 (SRR_TP7) * F_IN_TP7 ; !kW =
kW/kgs-1 * kgs-1 ;

(S_IN_BLANK2/SRR_BLANK2) * I_BLANK2 = S_IP8 ;
```

```
S_IP8 <= 10000 * I_BLANK2 ;
SRR_BLANK2 = 1 ;
P_SR_BLANK2 = I_BLANK2 * @LOG10 (SRR_BLANK2) * F_IN_BLANK2 ; !kW =
kW/kgs-1 * kgs-1 ;
@FREE (K_BLANK2);
@FREE (P_SR_BLANK2);

P_SR_TP1 + P_SR_TP2 + P_SR_TP3 + P_SR_TP4 + P_SR_TP5 + P_SR_TP6 +
P_SR_TP7 + P_SR_BLANK2 = P_SR_TP_TOTAL ;

!TECHNOLOGY COST;
C_TP1 = ((2.9*3*18^0.63)*1000)*(((F_IN_TP1*3600/1000)/1)^0.6);
C_TP2 = ((2.23*1.75*46^0.6)*1000)*(((F_IN_TP2*3600/1000)/1)^0.6);
C_TP3 = ((45*1^0.7)*1000)*(((F_IN_TP3*3600/1000)/1)^0.6);
C_TP4 = ((1.4*5^0.77)*1000)*(((F_IN_TP4*3600/1000)/1)^0.6);
C_TP5 = ((27.5*1*0.39)*1000)*(((F_IN_TP5*3600/1000)/1)^0.6);
C_TP6 = ((2.97*(F_IN_T6*3600/1000)^0.78)*1000);
C_TP7 = ((7.7*1^0.57)*1000)*(((F_IN_TP7*3600/1000)/1)^0.6);
C_BLANK2 = F_IN_BLANK1 * 0;

C_TP_TOTAL = C_TP1 + C_TP2 + C_TP3 + C_TP4 + C_TP5 + C_TP6 + C_TP7 +
C_BLANK2 ;

F_IP1 = F_OUTCHCL_TP1 + F_OUTM_TP1 ; !kg/s = kg/s ;
F_IP2 = F_OUTCHCL_TP2 + F_OUTM_TP2 ; !kg/s = kg/s ;
F_IP3 = F_OUTCHCL_TP3 + F_OUTM_TP3 ; !kg/s = kg/s ;
F_IP4 = F_OUTCHCL_TP4 + F_OUTM_TP4 ; !kg/s = kg/s ;
F_IP5 = F_OUTCHCL_TP5 + F_OUTM_TP5 ; !kg/s = kg/s ;
F_IP6 = F_OUTCHCL_TP6 + F_OUTM_TP6 ; !kg/s = kg/s ;
F_IP7 = F_OUTCHCL_TP7 + F_OUTM_TP7 ; !kg/s = kg/s ;
F_IP8 = F_OUTCHCL_BLANK2 + F_OUTM_BLANK2 ; !kg/s = kg/s ;

F_IP1 <= TOTAL_BIOMASS_AVAILABLE;
F_IP2 <= TOTAL_BIOMASS_AVAILABLE;
F_IP3 <= TOTAL_BIOMASS_AVAILABLE;
F_IP4 <= TOTAL_BIOMASS_AVAILABLE;
F_IP5 <= TOTAL_BIOMASS_AVAILABLE;
F_IP6 <= TOTAL_BIOMASS_AVAILABLE;
F_IP7 <= TOTAL_BIOMASS_AVAILABLE;
F_IP8 <= TOTAL_BIOMASS_AVAILABLE;
F_IP_TOTAL = F_IP1 + F_IP2 + F_IP3 + F_IP4 + F_IP5 + F_IP6 + F_IP7 +
F_IP8 ;
F_IP_TOTAL <= TOTAL_BIOMASS_AVAILABLE;

F_OUTCHCL_TP1  = F_IP1 * X_CHCL_IP1 ;
F_OUTM_TP1     = F_IP1 * X_M_IP1    ;
X_CHCL_IP1 + X_M_IP1 <= 1 ; !JUST ADD TO EASE CALCULATION IN LINGO,
DO NOT INCLUDE IN FORMULATION.;

F_OUTCHCL_TP2  = F_IP2 * X_CHCL_IP2 ;
F_OUTM_TP2     = F_IP2 * X_M_IP2    ; X_CHCL_IP2 + X_M_IP2 <=
1 ; !JUST ADD TO EASE CALCULATION IN LINGO, DO NOT INCLUDE IN
FORMULATION.;


F_OUTCHCL_TP3  = F_IP3 * X_CHCL_IP3 ;
F_OUTM_TP3     = F_IP3 * X_M_IP3    ;
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X_CHCL_IP3 + X_M_IP3 <= 1 ; !JUST ADD TO EASE CALCULATION IN LINGO,
DO NOT INCLUDE IN FORMULATION.;

F_OUTCHCL_TP4  = F_IP4 * X_CHCL_IP4 ;
F_OUTM_TP4     = F_IP4 * X_M_IP4    ;
X_CHCL_IP4 + X_M_IP4 <= 1 ; !JUST ADD TO EASE CALCULATION IN LINGO,
DO NOT INCLUDE IN FORMULATION.;

F_OUTCHCL_TP5  = F_IP5 * X_CHCL_IP5 ;
F_OUTM_TP5     = F_IP5 * X_M_IP5    ;
X_CHCL_IP5 + X_M_IP5 <= 1 ; !JUST ADD TO EASE CALCULATION IN LINGO,
DO NOT INCLUDE IN FORMULATION.;

F_OUTCHCL_TP6  = F_IP6 * X_CHCL_IP6 ;
F_OUTM_TP6     = F_IP6 * X_M_IP6    ;
X_CHCL_IP6 + X_M_IP6 <= 1 ; !JUST ADD TO EASE CALCULATION IN LINGO,
DO NOT INCLUDE IN FORMULATION.;

F_OUTCHCL_TP7  = F_IP7 * X_CHCL_IP7 ;
F_OUTM_TP7     = F_IP7 * X_M_IP7    ;
X_CHCL_IP7 + X_M_IP7 <= 1 ; !JUST ADD TO EASE CALCULATION IN LINGO,
DO NOT INCLUDE IN FORMULATION.;

F_OUTCHCL_BLANK2 = F_IP8 * X_CHCL_IP8 ;
F_OUTM_BLANK2    = F_IP8 * X_M_IP8    ;
X_CHCL_IP8 + X_M_IP8 <= 1 ; !JUST ADD TO EASE CALCULATION IN LINGO,
DO NOT INCLUDE IN FORMULATION.;

I_TP1 + I_TP2 + I_TP3 + I_TP4 + I_TP5 + I_TP6 + I_TP7 + I_BLANK2 =
I_TP_TOTAL ;


!STAGE 3;
S_3 >= S_IP1 ; S_3 >= S_IP2 ;
S_3 >= S_IP3 ; S_3 >= S_IP4 ;
S_3 >= S_IP5 ; S_3 >= S_IP6 ;
S_3 >= S_IP7 ; S_3 >= S_IP8 ;

F_IP1 = F_IP1_TPP1 + F_IP1_TPP2 + F_IP1_TPP3 + F_IP1_TPP4 +
F_IP1_TPP5 + F_IP1_TPP6 + F_IP1_TPP7 + F_IP1_BLANK3 ; !kg/s = kg/s ;
F_IP2 = F_IP2_TPP1 + F_IP2_TPP2 + F_IP2_TPP3 + F_IP2_TPP4 +
F_IP2_TPP5 + F_IP2_TPP6 + F_IP2_TPP7 + F_IP2_BLANK3 ; !kg/s = kg/s ;
F_IP3 = F_IP3_TPP1 + F_IP3_TPP2 + F_IP3_TPP3 + F_IP3_TPP4 +
F_IP3_TPP5 + F_IP3_TPP6 + F_IP3_TPP7 + F_IP3_BLANK3 ; !kg/s = kg/s ;
F_IP4 = F_IP4_TPP1 + F_IP4_TPP2 + F_IP4_TPP3 + F_IP4_TPP4 +
F_IP4_TPP5 + F_IP4_TPP6 + F_IP4_TPP7 + F_IP4_BLANK3 ; !kg/s = kg/s ;
F_IP5 = F_IP5_TPP1 + F_IP5_TPP2 + F_IP5_TPP3 + F_IP5_TPP4 +
F_IP5_TPP5 + F_IP5_TPP6 + F_IP5_TPP7 + F_IP5_BLANK3 ; !kg/s = kg/s ;
F_IP6 = F_IP6_TPP1 + F_IP6_TPP2 + F_IP6_TPP3 + F_IP6_TPP4 +
F_IP6_TPP5 + F_IP6_TPP6 + F_IP6_TPP7 + F_IP6_BLANK3 ; !kg/s = kg/s ;
F_IP7 = F_IP7_TPP1 + F_IP7_TPP2 + F_IP7_TPP3 + F_IP7_TPP4 +
F_IP7_TPP5 + F_IP7_TPP6 + F_IP7_TPP7 + F_IP7_BLANK3 ; !kg/s = kg/s ;
F_IP8 = F_IP8_TPP1 + F_IP8_TPP2 + F_IP8_TPP3 + F_IP8_TPP4 +
F_IP8_TPP5 + F_IP8_TPP6 + F_IP8_TPP7 + F_IP8_BLANK3 ; !kg/s = kg/s ;

!----;
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F_IN_TPP1 = F_IP1_TPP1 + F_IP2_TPP1 + F_IP3_TPP1 + F_IP4_TPP1 +
F_IP5_TPP1 + F_IP6_TPP1 + F_IP7_TPP1 + F_IP8_TPP1; !kg/s = kg/s ;
F_IN_TPP1 * X_CHCL_IN_TPP1  = F_IP1_TPP1 * X_CHCL_IP1  + F_IP2_TPP1 *
X_CHCL_IP2  + F_IP3_TPP1 * X_CHCL_IP3  + F_IP4_TPP1 * X_CHCL_IP4  +
F_IP5_TPP1 * X_CHCL_IP5  + F_IP6_TPP1 * X_CHCL_IP6  + F_IP7_TPP1 *
X_CHCL_IP7 + F_IP8_TPP1 * X_CHCL_IP8 ;
F_IN_TPP1 * X_M_IN_TPP1     = F_IP1_TPP1 * X_M_IP1     + F_IP2_TPP1 *
X_M_IP2     + F_IP3_TPP1 * X_M_IP3     + F_IP4_TPP1 * X_M_IP4     +
F_IP5_TPP1 * X_M_IP5     + F_IP6_TPP1 * X_M_IP6     + F_IP7_TPP1 *
X_M_IP7    + F_IP8_TPP1 * X_M_IP8    ;
X_CHCL_IN_TPP1 + X_M_IN_TPP1 <= 1 ; !JUST ADD TO EASE CALCULATION IN
LINGO, DO NOT INCLUDE IN FORMULATION.;

!----;
F_IN_TPP2 = F_IP1_TPP2 + F_IP2_TPP2 + F_IP3_TPP2 + F_IP4_TPP2 +
F_IP5_TPP2 + F_IP6_TPP2 + F_IP7_TPP2 + F_IP8_TPP2 ; !kg/s = kg/s ;
F_IN_TPP2 * X_CHCL_IN_TPP2  = F_IP1_TPP2 * X_CHCL_IP1  + F_IP2_TPP2 *
X_CHCL_IP2  + F_IP3_TPP2 * X_CHCL_IP3  + F_IP4_TPP2 * X_CHCL_IP4  +
F_IP5_TPP2 * X_CHCL_IP5  + F_IP6_TPP2 * X_CHCL_IP6  + F_IP7_TPP2 *
X_CHCL_IP7 + F_IP8_TPP2 * X_CHCL_IP8 ;
F_IN_TPP2 * X_M_IN_TPP2     = F_IP1_TPP2 * X_M_IP1     + F_IP2_TPP2 *
X_M_IP2     + F_IP3_TPP2 * X_M_IP3     + F_IP4_TPP2 * X_M_IP4     +
F_IP5_TPP2 * X_M_IP5     + F_IP6_TPP2 * X_M_IP6     + F_IP7_TPP2 *
X_M_IP7    + F_IP8_TPP2 * X_M_IP8    ;
X_CHCL_IN_TPP2 + X_M_IN_TPP2 <= 1 ; !JUST ADD TO EASE CALCULATION IN
LINGO, DO NOT INCLUDE IN FORMULATION.;

!----;
F_IN_TPP3 = F_IP1_TPP3 + F_IP2_TPP3 + F_IP3_TPP3 + F_IP4_TPP3 +
F_IP5_TPP3 + F_IP6_TPP3 + F_IP7_TPP3 + F_IP8_TPP3 ; !kg/s = kg/s ;
F_IN_TPP3 * X_CHCL_IN_TPP3  = F_IP1_TPP3 * X_CHCL_IP1  + F_IP2_TPP3 *
X_CHCL_IP2  + F_IP3_TPP3 * X_CHCL_IP3  + F_IP4_TPP3 * X_CHCL_IP4  +
F_IP5_TPP3 * X_CHCL_IP5  + F_IP6_TPP3 * X_CHCL_IP6  + F_IP7_TPP3 *
X_CHCL_IP7 + F_IP8_TPP3 * X_CHCL_IP8 ;
F_IN_TPP3 * X_M_IN_TPP3     = F_IP1_TPP3 * X_M_IP1     + F_IP2_TPP3 *
X_M_IP2     + F_IP3_TPP3 * X_M_IP3     + F_IP4_TPP3 * X_M_IP4     +
F_IP5_TPP3 * X_M_IP5     + F_IP6_TPP3 * X_M_IP6     + F_IP7_TPP3 *
X_M_IP7    + F_IP8_TPP3 * X_M_IP8    ;
X_CHCL_IN_TPP3 + X_M_IN_TPP3 <= 1 ; !JUST ADD TO EASE CALCULATION IN
LINGO, DO NOT INCLUDE IN FORMULATION.;

!----;
F_IN_TPP4 = F_IP1_TPP4 + F_IP2_TPP4 + F_IP3_TPP4 + F_IP4_TPP4 +
F_IP5_TPP4 + F_IP6_TPP4 + F_IP7_TPP4 + F_IP8_TPP4 ; !kg/s = kg/s ;
F_IN_TPP4 * X_CHCL_IN_TPP4  = F_IP1_TPP4 * X_CHCL_IP1  + F_IP2_TPP4 *
X_CHCL_IP2  + F_IP3_TPP4 * X_CHCL_IP3  + F_IP4_TPP4 * X_CHCL_IP4  +
F_IP5_TPP4 * X_CHCL_IP5  + F_IP6_TPP4 * X_CHCL_IP6  + F_IP7_TPP4 *
X_CHCL_IP7 + F_IP8_TPP4 * X_CHCL_IP8 ;
F_IN_TPP4 * X_M_IN_TPP4     = F_IP1_TPP4 * X_M_IP1     + F_IP2_TPP4 *
X_M_IP2     + F_IP3_TPP4 * X_M_IP3     + F_IP4_TPP4 * X_M_IP4     +
F_IP5_TPP4 * X_M_IP5     + F_IP6_TPP4 * X_M_IP6     + F_IP7_TPP4 *
X_M_IP7    + F_IP8_TPP4 * X_M_IP8    ;
X_CHCL_IN_TPP4 + X_M_IN_TPP4 <= 1 ; !JUST ADD TO EASE CALCULATION IN
LINGO, DO NOT INCLUDE IN FORMULATION.;

!----;
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F_IN_TPP5 = F_IP1_TPP5 + F_IP2_TPP5 + F_IP3_TPP5 + F_IP4_TPP5 +
F_IP5_TPP5 + F_IP6_TPP5 + F_IP7_TPP5 + F_IP8_TPP5 ; !kg/s = kg/s ;
F_IN_TPP5 * X_CHCL_IN_TPP5  = F_IP1_TPP5 * X_CHCL_IP1  + F_IP2_TPP5 *
X_CHCL_IP2  + F_IP3_TPP5 * X_CHCL_IP3  + F_IP4_TPP5 * X_CHCL_IP4  +
F_IP5_TPP5 * X_CHCL_IP5  + F_IP6_TPP5 * X_CHCL_IP6  + F_IP7_TPP5 *
X_CHCL_IP7 + F_IP8_TPP5 * X_CHCL_IP8 ;
F_IN_TPP5 * X_M_IN_TPP5     = F_IP1_TPP5 * X_M_IP1     + F_IP2_TPP5 *
X_M_IP2     + F_IP3_TPP5 * X_M_IP3     + F_IP4_TPP5 * X_M_IP4     +
F_IP5_TPP5 * X_M_IP5     + F_IP6_TPP5 * X_M_IP6     + F_IP7_TPP5 *
X_M_IP7    + F_IP8_TPP5 * X_M_IP8    ;
X_CHCL_IN_TPP5 + X_M_IN_TPP5 <= 1 ; !JUST ADD TO EASE CALCULATION IN
LINGO, DO NOT INCLUDE IN FORMULATION.;

!----;
F_IN_TPP6 = F_IP1_TPP6 + F_IP2_TPP6 + F_IP3_TPP6 + F_IP4_TPP6 +
F_IP5_TPP6 + F_IP6_TPP6 + F_IP7_TPP6 + F_IP8_TPP6 ; !kg/s = kg/s ;
F_IN_TPP6 * X_CHCL_IN_TPP6  = F_IP1_TPP6 * X_CHCL_IP1 + F_IP2_TPP6  *
X_CHCL_IP2 + F_IP3_TPP6  * X_CHCL_IP3  + F_IP4_TPP6 * X_CHCL_IP4  +
F_IP5_TPP6 * X_CHCL_IP5  + F_IP6_TPP6 * X_CHCL_IP6  + F_IP7_TPP6 *
X_CHCL_IP7 + F_IP8_TPP6 * X_CHCL_IP8 ;
F_IN_TPP6 * X_M_IN_TPP6     = F_IP1_TPP6 * X_M_IP1    + F_IP2_TPP6  *
X_M_IP2    + F_IP3_TPP6  * X_M_IP3     + F_IP4_TPP6 * X_M_IP4     +
F_IP5_TPP6 * X_M_IP5     + F_IP6_TPP6 * X_M_IP6     + F_IP7_TPP6 *
X_M_IP7    + F_IP8_TPP6 * X_M_IP8    ;
X_CHCL_IN_TPP6 + X_M_IN_TPP6 <= 1 ; !JUST ADD TO EASE CALCULATION IN
LINGO, DO NOT INCLUDE IN FORMULATION.;

!----;
F_IN_TPP7 = F_IP1_TPP7 + F_IP2_TPP7 + F_IP3_TPP7 + F_IP4_TPP7 +
F_IP5_TPP7 + F_IP6_TPP7 + F_IP7_TPP7 + F_IP8_TPP7 ; !kg/s = kg/s ;
F_IN_TPP7 * X_CHCL_IN_TPP7  = F_IP1_TPP7 * X_CHCL_IP1 + F_IP2_TPP7  *
X_CHCL_IP2 + F_IP3_TPP7  * X_CHCL_IP3  + F_IP4_TPP7 * X_CHCL_IP4  +
F_IP5_TPP7 * X_CHCL_IP5  + F_IP6_TPP7 * X_CHCL_IP6  + F_IP7_TPP7 *
X_CHCL_IP7 + F_IP8_TPP7 * X_CHCL_IP8 ;
F_IN_TPP7 * X_M_IN_TPP7     = F_IP1_TPP7 * X_M_IP1    + F_IP2_TPP7  *
X_M_IP2    + F_IP3_TPP7  * X_M_IP3     + F_IP4_TPP7 * X_M_IP4     +
F_IP5_TPP7 * X_M_IP5     + F_IP6_TPP7 * X_M_IP6     + F_IP7_TPP7 *
X_M_IP7    + F_IP8_TPP7 * X_M_IP8    ;
X_CHCL_IN_TPP7 + X_M_IN_TPP7 <= 1 ; !JUST ADD TO EASE CALCULATION IN
LINGO, DO NOT INCLUDE IN FORMULATION.;

!----;
F_IN_BLANK3 = F_IP1_BLANK3 + F_IP2_BLANK3 + F_IP3_BLANK3 +
F_IP4_BLANK3 + F_IP5_BLANK3 + F_IP6_BLANK3 + F_IP7_BLANK3 +
F_IP8_BLANK3 ; !kg/s = kg/s ;
F_IN_BLANK3 * X_CHCL_IN_BLANK3  = F_IP1_BLANK3 * X_CHCL_IP1  +
F_IP2_BLANK3 * X_CHCL_IP2  + F_IP3_BLANK3 * X_CHCL_IP3  +
F_IP4_BLANK3 * X_CHCL_IP4  + F_IP5_BLANK3 * X_CHCL_IP5  +
F_IP6_BLANK3 * X_CHCL_IP6  + F_IP7_BLANK3 * X_CHCL_IP7 + F_IP8_BLANK3
* X_CHCL_IP8 ;
F_IN_BLANK3 * X_M_IN_BLANK3     = F_IP1_BLANK3 * X_M_IP1     +
F_IP2_BLANK3 * X_M_IP2     + F_IP3_BLANK3 * X_M_IP3     +
F_IP4_BLANK3 * X_M_IP4     + F_IP5_BLANK3 * X_M_IP5     +
F_IP6_BLANK3 * X_M_IP6     + F_IP7_BLANK3 * X_M_IP7    + F_IP8_BLANK3
* X_M_IP8    ;
X_CHCL_IN_BLANK3 + X_M_IN_BLANK3 <= 1 ; !JUST ADD TO EASE CALCULATION
IN LINGO, DO NOT INCLUDE IN FORMULATION.;
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F_IN_TPP1 + F_IN_TPP2 + F_IN_TPP3 + F_IN_TPP4 + F_IN_TPP5 + F_IN_TPP6
+ F_IN_TPP7 + F_IN_BLANK3 = F_IN_TPP_TOTAL ;
F_IN_TPP1 <= TOTAL_BIOMASS_AVAILABLE ;
F_IN_TPP2 <= TOTAL_BIOMASS_AVAILABLE ;
F_IN_TPP3 <= TOTAL_BIOMASS_AVAILABLE ;
F_IN_TPP4 <= TOTAL_BIOMASS_AVAILABLE ;
F_IN_TPP5 <= TOTAL_BIOMASS_AVAILABLE ;
F_IN_TPP6 <= TOTAL_BIOMASS_AVAILABLE ;
F_IN_TPP7 <= TOTAL_BIOMASS_AVAILABLE ;
F_IN_BLANK3 <= TOTAL_BIOMASS_AVAILABLE ;
F_IN_TPP_TOTAL <= TOTAL_BIOMASS_AVAILABLE ;

(F_IN_TPP1/TOTAL_BIOMASS_AVAILABLE) <= I_TPP1 ;
(F_IN_TPP2/TOTAL_BIOMASS_AVAILABLE) <= I_TPP2 ;
(F_IN_TPP3/TOTAL_BIOMASS_AVAILABLE) <= I_TPP3 ;
(F_IN_TPP4/TOTAL_BIOMASS_AVAILABLE) <= I_TPP4 ;
(F_IN_TPP5/TOTAL_BIOMASS_AVAILABLE) <= I_TPP5 ;
(F_IN_TPP6/TOTAL_BIOMASS_AVAILABLE) <= I_TPP6 ;
(F_IN_TPP7/TOTAL_BIOMASS_AVAILABLE) <= I_TPP7 ;
(F_IN_BLANK3/TOTAL_BIOMASS_AVAILABLE) <= I_BLANK3 ;
@BIN(I_TPP1); @BIN(I_TPP2);
@BIN(I_TPP3); @BIN(I_TPP4);
@BIN(I_TPP5); @BIN(I_TPP6);
@BIN(I_TPP7); @BIN(I_BLANK3);

(0.25 * I_TPP1) <= (X_M_IN_TPP1 * I_TPP1) ;
(X_M_IN_TPP1 * I_TPP1) <= (0.65 * I_TPP1) ;
(0.25 * I_TPP2) <= (X_M_IN_TPP2 * I_TPP2) ;
(X_M_IN_TPP2 * I_TPP2) <= (0.65 * I_TPP2) ;
(0.25 * I_TPP3) <= (X_M_IN_TPP3 * I_TPP3) ;
(X_M_IN_TPP3 * I_TPP3) <= (0.65 * I_TPP3) ;
(0.25 * I_TPP4) <= (X_M_IN_TPP4 * I_TPP4) ;
(X_M_IN_TPP4 * I_TPP4) <= (0.72 * I_TPP4) ;
(0.04 * I_TPP5) <= (X_M_IN_TPP5 * I_TPP5) ;
(X_M_IN_TPP5 * I_TPP5) <= (0.07 * I_TPP5) ;
(0.04 * I_TPP6) <= (X_M_IN_TPP6 * I_TPP6) ;
(X_M_IN_TPP6 * I_TPP6) <= (0.12 * I_TPP6) ;
(0 * I_TPP7)    <= (X_M_IN_TPP7 * I_TPP7) ;
(X_M_IN_TPP7 * I_TPP7) <= (1 * I_TPP7) ;
(0 * I_BLANK3)  <= (X_M_IN_BLANK3 * I_BLANK3) ;
(X_M_IN_BLANK3 * I_BLANK3) <= (1 * I_BLANK3) ;


(25 * I_TPP1)  <= (S_3 * I_TPP1) ;
(S_3 * I_TPP1) <= (125 * I_TPP1) ;
(0.5 * I_TPP2) <= (S_3 * I_TPP2) ;
(S_3 * I_TPP2) <= (50  * I_TPP2) ;
(0 * I_TPP3)   <= (S_3 * I_TPP3) ;
(S_3 * I_TPP3) <= (100 * I_TPP3) ;
(0 * I_TPP4)   <= (S_3 * I_TPP4) ;
(S_3 * I_TPP4) <= (150 * I_TPP4) ;
(25 * I_TPP5)  <= (S_3 * I_TPP5) ;
(S_3 * I_TPP5) <= (150 * I_TPP5) ;
(25 * I_TPP6)  <= (S_3 * I_TPP6) ;
(S_3 * I_TPP6) <= (150 * I_TPP6) ;
(0 * I_TPP7)   <= (S_3 * I_TPP7) ;
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(S_3 * I_TPP7) <= (150 * I_TPP7) ;
(0 * I_BLANK3) <= (S_3 * I_BLANK3) ;

 (S_3 * I_BLANK3) <= (150 * I_BLANK3) ;

F_OUTCHCL_TPP1 = F_IN_TPP1 * X_CHCL_IN_TPP1 ;
F_OUTCHCL_TPP2 = F_IN_TPP2 * X_CHCL_IN_TPP2 ;
F_OUTCHCL_TPP3 = F_IN_TPP3 * X_CHCL_IN_TPP3 ;
F_OUTCHCL_TPP4 = F_IN_TPP4 * X_CHCL_IN_TPP4 ;
F_OUTCHCL_TPP5 = F_IN_TPP5 * X_CHCL_IN_TPP5 ;
F_OUTCHCL_TPP6 = F_IN_TPP6 * X_CHCL_IN_TPP6 ;
F_OUTCHCL_TPP7 = F_IN_TPP7 * X_CHCL_IN_TPP7 ;
F_OUTCHCL_BLANK3 = F_IN_BLANK3 * X_CHCL_IN_BLANK3 ;

F_OUTCHCL_TPP1 <= TOTAL_CHCL_AVAILABLE ;
F_OUTCHCL_TPP2 <= TOTAL_CHCL_AVAILABLE ;
F_OUTCHCL_TPP3 <= TOTAL_CHCL_AVAILABLE ;
F_OUTCHCL_TPP4 <= TOTAL_CHCL_AVAILABLE ;
F_OUTCHCL_TPP5 <= TOTAL_CHCL_AVAILABLE ;
F_OUTCHCL_TPP6 <= TOTAL_CHCL_AVAILABLE ;
F_OUTCHCL_TPP7 <= TOTAL_CHCL_AVAILABLE ;
F_OUTCHCL_BLANK3 <= TOTAL_CHCL_AVAILABLE;
F_OUTCHCL_TPP_TOTAL = F_OUTCHCL_TPP1 + F_OUTCHCL_TPP2 +
F_OUTCHCL_TPP3 + F_OUTCHCL_TPP4 + F_OUTCHCL_TPP5 + F_OUTCHCL_TPP6 +
F_OUTCHCL_TPP7 + F_OUTCHCL_BLANK3 ;
F_OUTCHCL_TPP_TOTAL <= TOTAL_CHCL_AVAILABLE ;

F_OUTM_TPP1 = F_IN_TPP1 * X_M_IN_TPP1 - F_MR_TPP1 ;
F_OUTM_TPP2 = F_IN_TPP2 * X_M_IN_TPP2 - F_MR_TPP2 ;
F_OUTM_TPP3 = F_IN_TPP3 * X_M_IN_TPP3 - F_MR_TPP3 ;
F_OUTM_TPP4 = F_IN_TPP4 * X_M_IN_TPP4 - F_MR_TPP4 ;
F_OUTM_TPP5 = F_IN_TPP5 * X_M_IN_TPP5 - F_MR_TPP5 ;
F_OUTM_TPP6 = F_IN_TPP6 * X_M_IN_TPP6 - F_MR_TPP6 ;
F_OUTM_TPP7 = F_IN_TPP7 * X_M_IN_TPP7 - F_MR_TPP7 ;
F_OUTM_BLANK3 = F_IN_BLANK3 * X_M_IN_BLANK3 - F_MR_BLANK3 ;

F_MR_TPP1 = F_IN_TPP1 * X_M_IN_TPP1 * MRR_TPP1 ;
0.56 <= MRR_TPP1 ;
MRR_TPP1 <= 0.86 ;
TR_TPP1 = 0.67 ; !kWhr/kg ;
EF_TPP1 = 0.6 ;
P_D_TPP1 * EF_TPP1 * 3600 = TR_TPP1 * F_MR_TPP1  ; !kWhr/s * 3600
s/hr = kWhr/kg * kg/s ;

F_MR_TPP2 = F_IN_TPP2 * X_M_IN_TPP2 * MRR_TPP2 ;
0.56 <= MRR_TPP2 ;
MRR_TPP2 <= 0.86 ;
TR_TPP2 = 0.67 ; !kWhr/kg ;
EF_TPP2 = 0.86 ;
P_D_TPP2 * EF_TPP2 * 3600 = TR_TPP2 * F_MR_TPP2  ; !kWhr/s * 3600
s/hr = kWhr/kg * kg/s ;

F_MR_TPp3 = F_IN_TPp3 * X_M_IN_TPP3 * MRR_TPp3 ;
0.56 <= MRR_TPP3 ;
MRR_TPP3 <= 0.86 ;
TR_TPP3 = 0.67 ; !kWhr/kg ;
EF_TPP3 = 0.87 ;
```

```
P_D_TPP3 * EF_TPp3 * 3600 = TR_TPP3 * F_MR_TPP3 ; !kWhr/s * 3600 s/hr
= kWhr/kg * kg/s ;

F_MR_TPp4 = F_IN_TPp4 * X_M_IN_TPP4 * MRR_TPP4 ;
0.64 <= MRR_TPP4 ;
MRR_TPp4 <= 0.81 ;
TR_TPp4 = 0.67 ; !kWhr/kg ;
EF_TPp4 = 0.7 ;
P_D_TPp4 * EF_TPP4 * 3600 = TR_TPP4 * F_MR_TPP4 ; !kWhr/s * 3600 s/hr
= kWhr/kg * kg/s ;

F_MR_TPp5 = F_IN_TPp5 * X_M_IN_TPP5 * MRR_TPP5 ;
MRR_TPp5 = 0.15 ;
TR_TPp5 = 0 ; !kWhr/kg ;
EF_TPp5 = 1 ;
P_D_TPp5 * EF_TPp5 * 3600  = TR_TpP5 * F_MR_TPp5 ; !kWhr/s * 3600
s/hr = kWhr/kg * kg/s ;

F_MR_TPp6 = F_IN_TpP6 * X_M_IN_TpP6 * MRR_TpP6 ;
MRR_TPp6 = 0.15 ;
TR_TPp6 = 0 ; !kWhr/kg ;
EF_TPp6 = 1 ;
P_D_TPp6 * EF_TPp6 * 3600 = TR_TpP6 * F_MR_TpP6 ; !kWhr/s * 3600 s/hr
= kWhr/kg * kg/s ;

F_MR_TPp7 = F_IN_TpP7 * X_M_IN_TpP7 * MRR_TpP7 ;
MRR_TPp7 = 0.15 ;
TR_TPp7 = 0 ; !kWhr/kg ;
EF_TPp7 = 1 ;
P_D_TPp7 * EF_TPp7 * 3600 = TR_TpP7 * F_MR_TpP7 ; !kWhr/s * 3600 s/hr
= kWhr/kg * kg/s ;

F_MR_BLANK3 = F_IN_BLANK3 * X_M_IN_BLANK3 * MRR_BLANK3 ;
MRR_BLANK3 = 0 ;
TR_BLANK3 = 0 ; !kWhr/kg ;
EF_BLANK3 = 1;
P_D_BLANK3 * EF_BLANK3 * 3600 = TR_BLANK3 * F_MR_BLANK3 ; !kWhr/s *
3600 s/hr  = kWhr/kg * kg/s ;

P_D_TPP1 + P_D_TPP2 + P_D_TPP3 + P_D_TPP4 + P_D_TPP5 + P_D_TPP6 +
P_D_TPP7 + P_D_BLANK3 = P_D_TPP_TOTAL ;

                                                F_OUTM_TPP_TOTAL =
F_OUTM_TPP1 + F_OUTM_TPP2 + F_OUTM_TPP3 + F_OUTM_TPP4 + F_OUTM_TPP5 +
F_OUTM_TPP6 + F_OUTM_TPP7 + F_OUTM_BLANK3 ;
                                                F_OUTM_TPP_TOTAL <=
TOTAL_M_AVAILABLE ;

S_IN_TPP1 = S_3 ; S_IN_TPP2 = S_3 ;
S_IN_TPP3 = S_3 ; S_IN_TPP4 = S_3 ;
S_IN_TPP5 = S_3 ; S_IN_TPP6 = S_3 ;
S_IN_TPP7 = S_3 ; S_IN_BLANK3 = S_3 ;

(S_IN_TPP1/SRR_TPP1) * I_TPP1 = S_IPP1 ;
S_IPP1 <= 10000 * I_TPP1 ;
SRR_TPP1 = 1 ;
```

```
P_SR_TPP1 = I_TPP1 * @LOG10 (SRR_TPP1) * F_IN_TPP1 ; !kW = kW/kgs-1 *
kgs-1 ;
@FREE (K_TPP1);
@FREE (P_SR_TPP1);

(S_IN_TPP2/SRR_TPP2) * I_TPP2 = S_IPP2 ;
S_IPP2 <= 10000 * I_TPP2 ;
SRR_TPP2 = 1 ;
P_SR_TPP2 = I_TPP2 * @LOG10 (SRR_TPP2) * F_IN_TPP2 ; !kW = kW/kgs-1 *
kgs-1 ;
@FREE (K_TPP2);
@FREE (P_SR_TPP2);

(S_IN_TPP3/SRR_TPP3) * I_TPP3 = S_IPP3 ;
S_IPP3 <= 10000 * I_TPP3 ;
SRR_TPP3 = 1 ;
P_SR_TPP3 = I_TPP3 * @LOG10 (SRR_TPP3) * F_IN_TPP3 ; !kW = kW/kgs-1 *
kgs-1 ;
@FREE (K_TPP3);
@FREE (P_SR_TPP3);

(S_IN_TPP4/SRR_TPP4) * I_TPP4 = S_IPP4 ;
S_IPP4 <= 10000 * I_TPP4 ;
SRR_TPP4 = 1 ;
P_SR_TPP4 = I_TPP4 * @LOG10 (SRR_TPP4) * F_IN_TPP4 ; !kW = kW/kgs-1 *
kgs-1 ;
@FREE (K_TPP4);
@FREE (P_SR_TPP4);

(S_IN_TPP5/SRR_TPP5) * I_TPP5 = S_IPP5 ;
S_IPP5 <= 10000 * I_TPP5 ;
2 <= SRR_TPP5 ;
SRR_TPP5 <= 14 ;
A_TPP5 = @LOG10(SRR_TPP5);
B_TPP5 = X_M_IN_TPP5 ;
K_TPP5 = 339.9 - 1109*A_TPP5 - 7.529*B_TPP5  + 947.4*(A_TPP5^2) +
170.5*(A_TPP5)*(B_TPP5) - 16.53*(B_TPP5^2) - 362.7*(A_TPP5^3)
      - 76.75*(A_TPP5^2)*(B_TPP5)  - 5.958*(A_TPP5)*(B_TPP5^2) +
1.836*(B_TPP5 ^3) + 56.16*(A_TPP5^4) + 3.813*(A_TPP5^3)*(B_TPP5) +
4.932*(A_TPP5^2)*(B_TPP5^2) - 0.7026*A_TPP5*(B_TPP5^3) ;
P_SR_TPP5 = I_TPP5 * K_TPP5 * @LOG10 (SRR_TPP5) * F_IN_TPP5 ; !kW =
kW/kgs-1 * kgs-1 ;
@FREE (K_TPP5);
@FREE (P_SR_TPP5);

(S_IN_TPP6/SRR_TPP6) * I_TPP6 = S_IPP6 ;
S_IPP6 <= 10000 * I_TPP6 ;
2.23 <= SRR_TPP6 ;
SRR_TPP6 <= 12.825 ;
A_TPP6 = @LOG10(SRR_TPP6);
B_TPP6 = X_M_IN_TPP6 ;
K_TPP6 = 49.02 + 10.04 *A_TPP6 - 72.54*B_TPP6  + 11.03*(A_TPP6^2) +
2.03*(A_TPP6)*(B_TPP6) + 96.17*(B_TPP6^2) +0.7976*(A_TPP6^3)
      +2.241*(A_TPP6^2)*(B_TPP6)  - 4.248*(A_TPP6)*(B_TPP6^2) -
18.67*(B_TPP6^3) + 2.451*(A_TPP6^4) + 6.563*(A_TPP6^3)*(B_TPP6) -
```

```
0.3381*(A_TPP6^2)*(B_TPP6^2) - 9.35*A_TPP6*(B_TPP6^3) -
43.85*(B_TPP6^4) ;
P_SR_TPP6 = I_TPP6 * K_TPP6 * @LOG10 (SRR_TPP6) * F_IN_TPP6 ; !kW =
kW/kgs-1 * kgs-1 ;
@FREE (K_TPP6);
@FREE (P_SR_TPP6);

(S_IN_TPP7/SRR_TPP7) * I_TPP7 = S_IPP7 ;
S_IPP7 <= 10000 * I_TPP7 ;
2.03 <= SRR_TPP7 ;
SRR_TPP7 <= 4.06 ;
A_TPP7 = @LOG10(SRR_TPP7);
K_TPP7 = 1.0633 * A_TPP7 + 0.0203 ;
P_SR_TPP7 = I_TPP7 * K_TPP7 * @LOG10 (SRR_TPP7) * F_IN_TPP7 ; !kW =
kW/kgs-1 * kgs-1 ;
@FREE (K_TPP7);
@FREE (P_SR_TPP7);

(S_IN_BLANK3/SRR_BLANK3) * I_BLANK3 = S_IPP8 ;
S_IPP8 <= 10000 * I_BLANK3 ;
SRR_BLANK3 = 1 ;
P_SR_BLANK3 = I_BLANK3 * @LOG10 (SRR_BLANK3) * F_IN_BLANK3; !kW =
kW/kgs-1 * kgs-1 ;
@FREE (K_BLANK3);
@FREE (P_SR_BLANK3);

P_SR_TPP1 + P_SR_TPP2 + P_SR_TPP3 + P_SR_TPP4 + P_SR_TPP5 + P_SR_TPP6
+ P_SR_TPP7 + P_SR_BLANK3 = P_SR_TPP_TOTAL ;

!TECHNOLOGY COST;
C_TPP1 = ((2.9*3*18^0.63)*1000)*(((F_IN_T1*3600/1000)/1)^0.6);
C_TPP2 = ((2.23*1.75*46^0.6)*1000)*(((F_IN_TPP2*3600/1000)/1)^0.6);
C_TPP3 = ((45*1^0.7)*1000)*(((F_IN_TPP3*3600/1000)/1)^0.6);
C_TPP4 = ((1.4*5^0.77)*1000)*(((F_IN_TPP4*3600/1000)/1)^0.6);
C_TPP5 = ((27.5*1*0.39)*1000)*(((F_IN_TPP5*3600/1000)/1)^0.6);
C_TPP6 = ((2.97*(F_IN_TPP6*3600/1000)^0.78)*1000);
C_TPP7 = ((7.7*1^0.57)*1000)*(((F_IN_TPP7*3600/1000)/1)^0.6);
C_BLANK3 = F_IN_BLANK3 * 0;

C_TPP_TOTAL = C_TPP1 + C_TPP2 + C_TPP3 + C_TPP4 + C_TPP5 + C_TPP6 +
C_TPP7 + C_BLANK3 ;

F_IPP1 = F_OUTCHCL_TPP1 + F_OUTM_TPP1 ; !kg/s = kg/s ;
F_IPP2 = F_OUTCHCL_TPP2 + F_OUTM_TPP2 ; !kg/s = kg/s ;
F_IPP3 = F_OUTCHCL_TPP3 + F_OUTM_TPP3 ; !kg/s = kg/s ;
F_IPP4 = F_OUTCHCL_TPP4 + F_OUTM_TPP4 ; !kg/s = kg/s ;
F_IPP5 = F_OUTCHCL_TPP5 + F_OUTM_TPP5 ; !kg/s = kg/s ;
F_IPP6 = F_OUTCHCL_TPP6 + F_OUTM_TPP6 ; !kg/s = kg/s ;
F_IPP7 = F_OUTCHCL_TPP7 + F_OUTM_TPP7 ; !kg/s = kg/s ;
F_IPP8 = F_OUTCHCL_BLANK3 + F_OUTM_BLANK3 ; !kg/s = kg/s ;

F_IPP1 <= TOTAL_BIOMASS_AVAILABLE ;
F_IPP2 <= TOTAL_BIOMASS_AVAILABLE ;
F_IPP3 <= TOTAL_BIOMASS_AVAILABLE ;
F_IPP4 <= TOTAL_BIOMASS_AVAILABLE ;
F_IPP5 <= TOTAL_BIOMASS_AVAILABLE ;
F_IPP6 <= TOTAL_BIOMASS_AVAILABLE ;
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F_IPP7 <= TOTAL_BIOMASS_AVAILABLE ;
F_IPP8 <= TOTAL_BIOMASS_AVAILABLE ;
F_IPP_TOTAL = F_IPP1 + F_IPP2 + F_IPP3 + F_IPP4 + F_IPP5 + F_IPP6 +
F_IPP7 + F_IPP8 ;
F_IPP_TOTAL <= TOTAL_BIOMASS_AVAILABLE ;

F_OUTCHCL_TPP1   = F_IPP1 * X_CHCL_IPP1 ;
F_OUTM_TPP1      = F_IPP1 * X_M_IPP1    ;
X_CHCL_IPP1 + X_M_IPP1 <= 1 ; !JUST ADD TO EASE CALCULATION IN LINGO,
DO NOT INCLUDE IN FORMULATION.;

F_OUTCHCL_TPP2   = F_IPP2 * X_CHCL_IPP2 ;
F_OUTM_TPP2      = F_IPP2 * X_M_IPP2    ;
X_CHCL_IPP2 + X_M_IPP2 <= 1 ; !JUST ADD TO EASE CALCULATION IN LINGO,
DO NOT INCLUDE IN FORMULATION.;

F_OUTCHCL_TPP3   = F_IPP3 * X_CHCL_IPP3 ;
F_OUTM_TPP3      = F_IPP3 * X_M_IPP3    ;
X_CHCL_IPP3 + X_M_IPP3 <= 1 ; !JUST ADD TO EASE CALCULATION IN LINGO,
DO NOT INCLUDE IN FORMULATION.;

F_OUTCHCL_TPP4   = F_IPP4 * X_CHCL_IPP4 ;
F_OUTM_TPP4      = F_IPP4 * X_M_IPP4    ;
X_CHCL_IPP4 + X_M_IPP4 <= 1 ; !JUST ADD TO EASE CALCULATION IN LINGO,
DO NOT INCLUDE IN FORMULATION.;

F_OUTCHCL_TPP5   = F_IPP5 * X_CHCL_IPP5 ;
F_OUTM_TPP5      = F_IPP5 * X_M_IPP5    ;
X_CHCL_IPP5 + X_M_IPP5 <= 1 ; !JUST ADD TO EASE CALCULATION IN LINGO,
DO NOT INCLUDE IN FORMULATION.;

F_OUTCHCL_TPP6   = F_IPP6 * X_CHCL_IPP6 ;
F_OUTM_TPP6      = F_IPP6 * X_M_IPP6    ;
X_CHCL_IPP6 + X_M_IPP6 <= 1 ; !JUST ADD TO EASE CALCULATION IN LINGO,
DO NOT INCLUDE IN FORMULATION.;

F_OUTCHCL_TPP7   = F_IPP7 * X_CHCL_IPP7 ;
F_OUTM_TPP7      = F_IPP7 * X_M_IPP7    ;
X_CHCL_IPP7 + X_M_IPP7 <= 1 ; !JUST ADD TO EASE CALCULATION IN LINGO,
DO NOT INCLUDE IN FORMULATION.;

F_OUTCHCL_BLANK3 = F_IPP8 * X_CHCL_IPP8 ;
F_OUTM_BLANK3    = F_IPP8 * X_M_IPP8    ;
X_CHCL_IPP8 + X_M_IPP8 <= 1 ; !JUST ADD TO EASE CALCULATION IN LINGO,
DO NOT INCLUDE IN FORMULATION.;

I_TPP1 + I_TPP2 + I_TPP3 + I_TPP4 + I_TPP5 + I_TPP6 + I_TPP7 +
I_BLANK3 = I_TPP_TOTAL;

I_T_TOTAL + I_TP_TOTAL + I_TPP_TOTAL = I_TOTAL ;

P_TOTAL = (P_D_T_TOTAL + P_D_TP_TOTAL + P_D_TPP_TOTAL) +
(P_SR_T_TOTAL + P_SR_TP_TOTAL + P_SR_TPP_TOTAL);

C_TOTAL = C_T_TOTAL + C_TP_TOTAL + C_TPP_TOTAL ;

MIN = p_total + (0.00001 * I_TOTAL)
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```
f_ipp_total >= 5.547059 ;
f_ipp_total >= 5.547019 ;


X_M_IPP1 <= 0.15 ;
X_M_IPP2 <= 0.15 ;
X_M_IPP3 <= 0.15 ;
X_M_IPP4 <= 0.15 ;
X_M_IPP5 <= 0.15 ;
X_M_IPP6 <= 0.15 ;
X_M_IPP7 <= 0.15 ;
X_M_IPP8 <= 0.15 ;

S_IPP1 <= 15 ;
S_IPP2 <= 15 ;
S_IPP3 <= 15 ;
S_IPP4 <= 15 ;
S_IPP5 <= 15 ;
S_IPP6 <= 15 ;
S_IPP7 <= 15 ;
S_IPP8 <= 15 ;
```

APPENDIX A3

Lingo File

For sensitivity analysis (16.5wt% and 16.5mm)

```
!INFORMATION;
F_AVAILABLE_EFB = 3.9 ; !kg/s;
X_CHCL_EFB  = 0.55;  X_M_EFB  = 0.45;  S_EFB  = 150 ; !mm;

F_AVAILABLE_PKS = 1.2 ; !kg/s;
X_CHCL_PKS  = 0.73 ; X_M_PKS  = 0.27 ; S_PKS = 20 ; !mm;

F_AVAILABLE_PMF = 2.2 ; !kg/s;
X_CHCL_PMF  = 0.77 ; X_M_PMF  = 0.23 ; S_PMF = 30 ; !mm;

!PROBLEM SIZE DEFINITION FOR EASIER SOLVING;
TOTAL_BIOMASS_AVAILABLE = F_AVAILABLE_EFB + F_AVAILABLE_PKS +
F_AVAILABLE_PMF ;
TOTAL_CHCL_AVAILABLE    = F_AVAILABLE_EFB * X_CHCL_EFB +
F_AVAILABLE_PKS * X_CHCL_PKS + F_AVAILABLE_PMF * X_CHCL_PMF ;
TOTAL_M_AVAILABLE       = F_AVAILABLE_EFB * X_M_EFB    +
F_AVAILABLE_PKS * X_M_PKS    + F_AVAILABLE_PMF * X_M_PMF    ;
F_EFB <= F_AVAILABLE_EFB ;
F_PKS <= F_AVAILABLE_PKS ;
F_PMF <= F_AVAILABLE_PMF ;

!MODEL STARTS;
!STAGE 1;
S_1 >= S_EFB ;
S_1 >= S_PKS ;
S_1 >= S_PMF ;

F_EFB = F_EFB_T1 + F_EFB_T2 + F_EFB_T3 + F_EFB_T4 + F_EFB_T5 +
F_EFB_T6 + F_EFB_T7 + F_EFB_BLANK1 ;  !kg/s = kg/s ;
F_PKS = F_PKS_T1 + F_PKS_T2 + F_PKS_T3 + F_PKS_T4 + F_PKS_T5 +
F_PKS_T6 + F_PKS_T7 + F_PKS_BLANK1 ;  !kg/s = kg/s ;
F_PMF = F_PMF_T1 + F_PMF_T2 + F_PMF_T3 + F_PMF_T4 + F_PMF_T5 +
F_PMF_T6 + F_PMF_T7 + F_PMF_BLANK1 ;  !kg/s = kg/s ;

F_IN_T1 = F_EFB_T1 + F_PKS_T1 + F_PMF_T1 ; !kg/s = kg/s ;
F_IN_T1 * X_CHCL_IN_T1 = F_EFB_T1 * X_CHCL_EFB + F_PKS_T1 *
X_CHCL_PKS + F_PMF_T1 * X_CHCL_PMF ;
F_IN_T1 * X_M_IN_T1    = F_EFB_T1 * X_M_EFB    + F_PKS_T1 * X_M_PKS
+ F_PMF_T1 * X_M_PMF    ;
X_CHCL_IN_T1 + X_M_IN_T1 <= 1;
```

```
F_IN_T2 = F_EFB_T2 + F_PKS_T2 + F_PMF_T2 ; !kg/s = kg/s ;
F_IN_T2 * X_CHCL_IN_T2 = F_EFB_T2 * X_CHCL_EFB + F_PKS_T2 *
X_CHCL_PKS + F_PMF_T2 * X_CHCL_PMF ;
F_IN_T2 * X_M_IN_T2    = F_EFB_T2 * X_M_EFB    + F_PKS_T2 * X_M_PKS
+ F_PMF_T2 * X_M_PMF    ;
X_CHCL_IN_T2 + X_M_IN_T2 <= 1;

F_IN_T3 = F_EFB_T3 + F_PKS_T3 + F_PMF_T3 ; !kg/s = kg/s ;
F_IN_T3 * X_CHCL_IN_T3 = F_EFB_T3 * X_CHCL_EFB + F_PKS_T3 *
X_CHCL_PKS + F_PMF_T3 * X_CHCL_PMF ;
F_IN_T3 * X_M_IN_T3    = F_EFB_T3 * X_M_EFB    + F_PKS_T3 * X_M_PKS
+ F_PMF_T3 * X_M_PMF    ;
X_CHCL_IN_T3 + X_M_IN_T3 <= 1;

F_IN_T4 = F_EFB_T4 + F_PKS_T4 + F_PMF_T4 ;
F_IN_T4 * X_CHCL_IN_T4 = F_EFB_T4 * X_CHCL_EFB + F_PKS_T4 *
X_CHCL_PKS + F_PMF_T4 * X_CHCL_PMF ;
F_IN_T4 * X_M_IN_T4    = F_EFB_T4 * X_M_EFB    + F_PKS_T4 * X_M_PKS
+ F_PMF_T4 * X_M_PMF    ;
X_CHCL_IN_T4 + X_M_IN_T4 <= 1;

F_IN_T5 = F_EFB_T5 + F_PKS_T5 + F_PMF_T5 ; !kg/s = kg/s ;
F_IN_T5 * X_CHCL_IN_T5 = F_EFB_T5 * X_CHCL_EFB + F_PKS_T5 *
X_CHCL_PKS + F_PMF_T5 * X_CHCL_PMF ;
F_IN_T5 * X_M_IN_T5    = F_EFB_T5 * X_M_EFB    + F_PKS_T5 * X_M_PKS
+ F_PMF_T5 * X_M_PMF    ;
X_CHCL_IN_T5 + X_M_IN_T5 <= 1;

F_IN_T6 = F_EFB_T6 + F_PKS_T6 + F_PMF_T6 ; !kg/s = kg/s ;
F_IN_T6 * X_CHCL_IN_T6 = F_EFB_T6 * X_CHCL_EFB + F_PKS_T6 *
X_CHCL_PKS + F_PMF_T6 * X_CHCL_PMF ;
F_IN_T6 * X_M_IN_T6    = F_EFB_T6 * X_M_EFB    + F_PKS_T6 * X_M_PKS
+ F_PMF_T6 * X_M_PMF    ;
X_CHCL_IN_T6 + X_M_IN_T6 <= 1;

F_IN_T7 = F_EFB_T7 + F_PKS_T7 + F_PMF_T7 ; !kg/s = kg/s ;
F_IN_T7 * X_CHCL_IN_T7 = F_EFB_T7 * X_CHCL_EFB + F_PKS_T7 *
X_CHCL_PKS + F_PMF_T7 * X_CHCL_PMF ;
F_IN_T7 * X_M_IN_T7    = F_EFB_T7 * X_M_EFB    + F_PKS_T7 * X_M_PKS
+ F_PMF_T7 * X_M_PMF    ;
X_CHCL_IN_T7 + X_M_IN_T7 <= 1;

F_IN_BLANK1 = F_EFB_BLANK1 + F_PKS_BLANK1 + F_PMF_BLANK1 ;
F_IN_BLANK1 * X_CHCL_IN_BLANK1 = F_EFB_BLANK1 * X_CHCL_EFB +
F_PKS_BLANK1 * X_CHCL_PKS + F_PMF_BLANK1 * X_CHCL_PMF ;
F_IN_BLANK1 * X_M_IN_BLANK1    = F_EFB_BLANK1 * X_M_EFB    +
F_PKS_BLANK1 * X_M_PKS    + F_PMF_BLANK1 * X_M_PMF    ;
X_CHCL_IN_BLANK1 + X_M_IN_BLANK1 <= 1;

F_IN_T1 + F_IN_T2 + F_IN_T3 + F_IN_T4 + F_IN_T5 + F_IN_T6 + F_IN_T7 +
F_IN_BLANK1 = F_IN_T_TOTAL ;
F_IN_T1 <= TOTAL_BIOMASS_AVAILABLE ;
F_IN_T2 <= TOTAL_BIOMASS_AVAILABLE ;
F_IN_T3 <= TOTAL_BIOMASS_AVAILABLE ;
F_IN_T4 <= TOTAL_BIOMASS_AVAILABLE ;
F_IN_T5 <= TOTAL_BIOMASS_AVAILABLE ;
F_IN_T6 <= TOTAL_BIOMASS_AVAILABLE ;
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F_IN_T7 <= TOTAL_BIOMASS_AVAILABLE ;
F_IN_BLANK1 <= TOTAL_BIOMASS_AVAILABLE ;
F_IN_T_TOTAL <= TOTAL_BIOMASS_AVAILABLE ;

(F_IN_T1/TOTAL_BIOMASS_AVAILABLE) <= I_T1 ;
(F_IN_T2/TOTAL_BIOMASS_AVAILABLE) <= I_T2 ;
(F_IN_T3/TOTAL_BIOMASS_AVAILABLE) <= I_T3 ;
(F_IN_T4/TOTAL_BIOMASS_AVAILABLE) <= I_T4 ;
(F_IN_T5/TOTAL_BIOMASS_AVAILABLE) <= I_T5 ;
(F_IN_T6/TOTAL_BIOMASS_AVAILABLE) <= I_T6 ;
(F_IN_T7/TOTAL_BIOMASS_AVAILABLE) <= I_T7 ;
(F_IN_BLANK1/TOTAL_BIOMASS_AVAILABLE) <= I_BLANK1 ;
@BIN(I_T1); @BIN(I_T2);
@BIN(I_T3); @BIN(I_T4);
@BIN(I_T5); @BIN(I_T6);
@BIN(I_T7); @BIN(I_BLANK1);

(0.25 * I_T1)  <= (X_M_IN_T1 * I_T1)          ;
(X_M_IN_T1 * I_T1)          <= (0.65 * I_T1)  ;
(0.25 * I_T2)  <= (X_M_IN_T2 * I_T2)          ;
(X_M_IN_T2 * I_T2)          <= (0.65 * I_T2)  ;
(0.25 * I_T3)  <= (X_M_IN_T3 * I_T3)          ;
(X_M_IN_T3 * I_T3)          <= (0.65 * I_T3)  ;
(0.25 * I_T4)  <= (X_M_IN_T4 * I_T4)          ;
(X_M_IN_T4 * I_T4)          <= (0.72 * I_T4)  ;
(0.04 * I_T5)  <= (X_M_IN_T5 * I_T5)          ;
(X_M_IN_T5 * I_T5)          <= (0.07 * I_T5)  ;
(0.04 * I_T6)  <= (X_M_IN_T6 * I_T6)          ;
(X_M_IN_T6 * I_T6)          <= (0.12 * I_T6)  ;
(0 * I_T7)     <= (X_M_IN_T7 * I_T7)          ;
(X_M_IN_T7 * I_T7)          <= (1 * I_T7)     ;
(0 * I_BLANK1) <= (X_M_IN_BLANK1 * I_BLANK1) ; (X_M_IN_BLANK1 *
I_BLANK1) <= (1 * I_BLANK1) ;

(25  * I_T1)      <= (S_1 * I_T1)      ;
(S_1 * I_T1)      <= (125 * I_T1)      ;
(0.5 * I_T2)      <= (S_1 * I_T2)      ;
(S_1 * I_T2)      <= (50  * I_T2)      ;
(0   * I_T3)      <= (S_1 * I_T3)      ;
(S_1 * I_T3)      <= (100 * I_T3)      ;
(0   * I_T4)      <= (S_1 * I_T4)      ;
(S_1 * I_T4)      <= (150 * I_T4)      ;
(25  * I_T5)      <= (S_1 * I_T5)      ;
(S_1 * I_T5)      <= (150 * I_T5)      ;
(25  * I_T6)      <= (S_1 * I_T6)      ;
(S_1 * I_T6)      <= (150 * I_T6)      ;
(0   * I_T7)      <= (S_1 * I_T7)      ;
(S_1 * I_T7)      <= (150 * I_T7)      ;
   (2   * I_BLANK1) <= (S_1 * I_BLANK1) ;
   (3   (S_1 * I_BLANK1) <= (150 * I_BLANK1) ;

F_OUTCHCL_T1 = F_IN_T1 * X_CHCL_IN_T1 ;
F_OUTCHCL_T2 = F_IN_T2 * X_CHCL_IN_T2 ;
F_OUTCHCL_T3 = F_IN_T3 * X_CHCL_IN_T3 ;
F_OUTCHCL_T4 = F_IN_T4 * X_CHCL_IN_T4 ;
F_OUTCHCL_T5 = F_IN_T5 * X_CHCL_IN_T5 ;
F_OUTCHCL_T6 = F_IN_T6 * X_CHCL_IN_T6 ;
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F_OUTCHCL_T7 = F_IN_T7 * X_CHCL_IN_T7 ;
F_OUTCHCL_BLANK1 = F_IN_BLANK1 * X_CHCL_IN_BLANK1;

F_OUTCHCL_T1 <= TOTAL_CHCL_AVAILABLE ;
F_OUTCHCL_T2 <= TOTAL_CHCL_AVAILABLE ;
F_OUTCHCL_T3 <= TOTAL_CHCL_AVAILABLE ;
F_OUTCHCL_T4 <= TOTAL_CHCL_AVAILABLE ;
F_OUTCHCL_T5 <= TOTAL_CHCL_AVAILABLE ;
F_OUTCHCL_T6 <= TOTAL_CHCL_AVAILABLE ;
F_OUTCHCL_T7 <= TOTAL_CHCL_AVAILABLE ;
F_OUTCHCL_BLANK1 <= TOTAL_CHCL_AVAILABLE ;
F_OUTCHCL_T_TOTAL = F_OUTCHCL_T1 + F_OUTCHCL_T2 + F_OUTCHCL_T3 +
F_OUTCHCL_T4 + F_OUTCHCL_T5 + F_OUTCHCL_T6 + F_OUTCHCL_T7 +
F_OUTCHCL_BLANK1 ;
F_OUTCHCL_T_TOTAL <= TOTAL_CHCL_AVAILABLE ;

F_MR_T1 = F_IN_T1 * X_M_IN_T1 * MRR_T1 ; !kg/s = kg/s;
0.56 <= MRR_T1 ;
MRR_T1 <= 0.86 ;
TR_T1 = 0.67 ;!kWhr/kg ;
EF_T1 = 0.6 ;
P_D_T1 * EF_T1 * 3600 = TR_T1 * F_MR_T1 ; !kWhr/s * 3600 s/hr =
kWhr/kg * kg/s ;

F_MR_T2 = F_IN_T2 * X_M_IN_T2 * MRR_T2 ; !kg/s = kg/s;
0.56 <= MRR_T2 ;
MRR_T2 <= 0.86 ;
TR_T2 = 0.67 ; !kWhr/kg ;
EF_T2 = 0.86 ;
P_D_T2 * EF_T2 * 3600 = TR_T2 * F_MR_T2  ; !kWhr/s * 3600 s/hr =
kWhr/kg * kg/s ;

F_MR_T3 = F_IN_T3 * X_M_IN_T3 * MRR_T3;
0.56 <= MRR_T3 ;
MRR_T3 <= 0.86 ;
TR_T3 = 0.67 ; !kWhr/kg ;
EF_T3 = 0.87 ;
P_D_T3 * EF_T3 * 3600 = TR_T3 * F_MR_T3 ; !kWhr/s * 3600 s/hr =
kWhr/kg * kg/s ;

F_MR_T4 = F_IN_T4 * X_M_IN_T4 * MRR_T4;
0.64 <= MRR_T4 ;
MRR_T4 <= 0.81 ;
TR_T4 = 0.67 ; !kWhr/kg ;
EF_T4 = 0.7 ;
P_D_T4 * EF_T4 * 3600 = TR_T4 * F_MR_T4 ; !kWhr/s * 3600 s/hr =
kWhr/kg * kg/s ;

F_MR_T5 = F_IN_T5 * X_M_IN_T5 * MRR_T5;
MRR_T5 = 0.15 ;
TR_T5 = 0 ; !kWhr/kg ;
EF_T5 = 1 ;
P_D_T5 * EF_T5 * 3600  = TR_T5 * F_MR_T5 ; !kWhr/s * 3600 s/hr =
kWhr/kg * kg/s ;

F_MR_T6 = F_IN_T6 * X_M_IN_T6 * MRR_T6;
MRR_T6 = 0.15 ;
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TR_T6 = 0 ; !kWhr/kg ;
EF_T6 = 1 ;
P_D_T6 * EF_T6 * 3600 = TR_T6 * F_MR_T6 ; !kWhr/s * 3600 s/hr =
kWhr/kg * kg/s ;

F_MR_T7 = F_IN_T7 * X_M_IN_T7 * MRR_T7;
MRR_T7 = 0.15 ;
TR_T7 = 0 ; !kWhr/kg ;
EF_T7 = 1 ;
P_D_T7 * EF_T7 * 3600 = TR_T7 * F_MR_T7 ; !kWhr/s * 3600 s/hr =
kWhr/kg * kg/s ;

F_MR_BLANK1 = F_IN_BLANK1 * X_M_IN_BLANK1 * MRR_BLANK1 ;
MRR_BLANK1 = 0 ;
TR_BLANK1 = 0 ; !kWhr/kg ;
EF_BLANK1 = 1 ;
P_D_BLANK1 * EF_BLANK1 * 3600 = TR_BLANK1 * F_MR_BLANK1 ; !kWhr/s *
3600 s/hr = kWhr/kg * kg/s ;

F_OUTM_T1 = F_IN_T1 * X_M_IN_T1 - F_MR_T1 ; !kg/s = kg/s ;
F_OUTM_T2 = F_IN_T2 * X_M_IN_T2 - F_MR_T2 ; !kg/s = kg/s ;
F_OUTM_T3 = F_IN_T3 * X_M_IN_T3 - F_MR_T3 ; !kg/s = kg/s ;
F_OUTM_T4 = F_IN_T4 * X_M_IN_T4 - F_MR_T4 ; !kg/s = kg/s ;
F_OUTM_T5 = F_IN_T5 * X_M_IN_T5 - F_MR_T5 ; !kg/s = kg/s ;
F_OUTM_T6 = F_IN_T6 * X_M_IN_T6 - F_MR_T6 ; !kg/s = kg/s ;
F_OUTM_T7 = F_IN_T7 * X_M_IN_T7 - F_MR_T7 ; !kg/s = kg/s ;
F_OUTM_BLANK1 = F_IN_BLANK1 * X_M_IN_BLANK1 - F_MR_BLANK1 ; !kg/s =
kg/s
F_OUTM_T_TOTAL = F_OUTM_T1 + F_OUTM_T2 + F_OUTM_T3 + F_OUTM_T4 +
F_OUTM_T5 + F_OUTM_T6 + F_OUTM_T7 + F_OUTM_BLANK1 ;
F_OUTM_T_TOTAL <= TOTAL_M_AVAILABLE ;

P_D_T1 + P_D_T2 + P_D_T3 + P_D_T4 + P_D_T5 + P_D_T6 + P_D_T7 +
P_D_BLANK1 = P_D_T_TOTAL ;

S_IN_T1 = S_1 ; S_IN_T2 = S_1;
S_IN_T3 = S_1 ; S_IN_T4 = S_1 ;
S_IN_T5 = S_1 ; S_IN_T6 = S_1 ;
S_IN_T7 = S_1 ; S_IN_BLANK1 = S_1 ;

(S_IN_T1/SRR_T1) * I_T1 = S_I1 ;
S_I1 <= 10000 * I_T1 ;
SRR_T1 = 1 ;
P_SR_T1 = I_T1 * @LOG10 (SRR_T1) * F_IN_T1 ; !kW = kW/kgs-1 * kgs-1 ;
@FREE (K_T1);
@FREE (P_SR_T1);

(S_IN_T2/SRR_T2) * I_T2 = S_I2 ;
S_I2 <= 10000 * I_T2 ;
SRR_T2 = 1 ;
P_SR_T2 = I_T2 * @LOG10 (SRR_T2) * F_IN_T2 ; !kW = kW/kgs-1 * kgs-1 ;
@FREE (K_T2);
@FREE (P_SR_T2);

(S_IN_T3/SRR_T3) * I_T3 = S_I3 ;
S_I3 <= 10000 * I_T3 ;
SRR_T3 = 1 ;
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P_SR_T3 = I_T3 * @LOG10 (SRR_T3) * F_IN_T3 ; !kW = kW/kgs-1 * kgs-1 ;
@FREE (K_T3);
@FREE (P_SR_T3);

(S_IN_T4/SRR_T4) * I_T4 = S_I4 ;
S_I4 <= 10000 * I_T4 ;
SRR_T4 = 1 ;
P_SR_T4 = I_T4 * @LOG10 (SRR_T4) * F_IN_T4 ; !kW = kW/kgs-1 * kgs-1 ;
@FREE (K_T4);
@FREE (P_SR_T4);

(S_IN_T5/SRR_T5) * I_T5 = S_I5 ;
S_I5 <= 10000 * I_T5 ;
2 <= SRR_T5 ;
SRR_T5 <= 14 ;
A_T5 = @LOG10(SRR_T5);
B_T5 = X_M_IN_T5 ;
K_T5 = 339.9 - 1109*A_T5 - 7.529*B_T5  + 947.4*(A_T5^2) +
170.5*(A_T5)*(B_T5) - 16.53*(B_T5^2) - 362.7*(A_T5^3)
      - 76.75*(A_T5^2)*(B_T5)  - 5.958*(A_T5)*(B_T5^2) + 1.836*(B_T5
^3) + 56.16*(A_T5^4) + 3.813*(A_T5^3)*(B_T5) +
4.932*(A_T5^2)*(B_T5^2) - 0.7026*A_T5*(B_T5^3) ;
P_SR_T5 = I_T5 * K_T5 * @LOG10 (SRR_T5) * F_IN_T5 ; !kW = kW/kgs-1 *
kgs-1 ;
@FREE (K_T5);
@FREE (P_SR_T5);

(S_IN_T6/SRR_T6) * I_T6 = S_I6 ;
S_I6 <= 10000 * I_T6 ;
2.23 <= SRR_T6 ;
SRR_T6 <= 12.825 ;
A_T6 = @LOG10(SRR_T6);
B_T6 = X_M_IN_T6 ;
K_T6 = 49.02 + 10.04 *A_T6 - 72.54*B_T6  + 11.03*(A_T6^2) +
2.03*(A_T6)*(B_T6) + 96.17*(B_T6^2) +0.7976*(A_T6^3)
      +2.241*(A_T6^2)*(B_T6)  - 4.248*(A_T6)*(B_T6^2) -
18.67*(B_T6^3) + 2.451*(A_T6^4) + 6.563*(A_T6^3)*(B_T6) -
0.3381*(A_T6^2)*(B_T6^2) - 9.35*A_T6*(B_T6^3) -43.85*(B_T6^4) ;
P_SR_T6 = I_T6 * K_T6 * @LOG10 (SRR_T6) * F_IN_T6; !kW = kW/kgs-1 *
kgs-1 ;
@FREE (K_T6);
@FREE (P_SR_T6);

(S_IN_T7/SRR_T7) * I_T7 = S_I7 ;
S_I7 <= 10000 * I_T7 ;
2.03 <= SRR_T7 ;
SRR_T7 <= 4.06 ;
A_T7 = @LOG10(SRR_T7);! NEED TO CHANGE;
B_T7 = X_M_IN_T7 ; ! NEED TO CHANGE;
K_T7 = 1.0633 * A_T7 + 0.0203 ;
P_SR_T7 = I_T7 * K_T7 * @LOG10 (SRR_T7) * F_IN_T7; !kW = kW/kgs-1 *
kgs-1 ;
@FREE (K_T7);
@FREE (P_SR_T7);
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(S_IN_BLANK1/SRR_BLANK1) * I_BLANK1 = S_I8 ;
S_I8 <= 10000 * I_BLANK1 ;
SRR_BLANK1 = 1 ;
P_SR_BLANK1 = I_BLANK1 * @LOG10 (SRR_BLANK1) * F_IN_BLANK1 ; !kW =
kW/kgs-1 * kgs-1 ;
@FREE (K_BLANK1);
@FREE (P_SR_BLANK1);

P_SR_T1 + P_SR_T2 + P_SR_T3 + P_SR_T4 + P_SR_T5 + P_SR_T6 + P_SR_T7 +
P_SR_BLANK1 = P_SR_T_TOTAL ;

!TECHNOLOGY COST;
C_T1 = ((2.9*3*18^0.63)*1000)*(((F_IN_T1*3600/1000)/1)^0.6);
C_T2 = ((2.23*1.75*46^0.6)*1000)*(((F_IN_T2*3600/1000)/1)^0.6);
C_T3 = ((45*1^0.7)*1000)*(((F_IN_T3*3600/1000)/1)^0.6);
C_T4 = ((1.4*5^0.77)*1000)*(((F_IN_T4*3600/1000)/1)^0.6);
C_T5 = ((27.5*1*0.39)*1000)*(((F_IN_T5*3600/1000)/1)^0.6);
C_T6 = ((2.97*(F_IN_T6*3600/1000)^0.78)*1000);
C_T7 = ((7.7*1^0.57)*1000)*(((F_IN_T7*3600/1000)/1)^0.6);
C_BLANK1 = F_IN_BLANK1 * 0;

C_T_TOTAL = C_T1 + C_T2 + C_T3 + C_T4 + C_T5 + C_T6 + C_T7 +
C_BLANK1 ;

F_I1 = F_OUTCHCL_T1 + F_OUTM_T1 ; !kg/s = kg/s ;
F_I2 = F_OUTCHCL_T2 + F_OUTM_T2 ; !kg/s = kg/s ;
F_I3 = F_OUTCHCL_T3 + F_OUTM_T3 ; !kg/s = kg/s ;
F_I4 = F_OUTCHCL_T4 + F_OUTM_T4 ; !kg/s = kg/s ;
F_I5 = F_OUTCHCL_T5 + F_OUTM_T5 ; !kg/s = kg/s ;
F_I6 = F_OUTCHCL_T6 + F_OUTM_T6 ; !kg/s = kg/s ;
F_I7 = F_OUTCHCL_T7 + F_OUTM_T7 ; !kg/s = kg/s ;
F_I8 = F_OUTCHCL_BLANK1 + F_OUTM_BLANK1 ; !kg/s = kg/s ;

F_I1 <= TOTAL_BIOMASS_AVAILABLE ;
F_I2 <= TOTAL_BIOMASS_AVAILABLE ;
F_I3 <= TOTAL_BIOMASS_AVAILABLE ;
F_I4 <= TOTAL_BIOMASS_AVAILABLE ;
F_I5 <= TOTAL_BIOMASS_AVAILABLE ;
F_I6 <= TOTAL_BIOMASS_AVAILABLE ;
F_I7 <= TOTAL_BIOMASS_AVAILABLE ;
F_I8 <= TOTAL_BIOMASS_AVAILABLE ;
F_I_TOTAL = F_I1 + F_I2 + F_I3 + F_I4 + F_I5 + F_I6 + F_I7 + F_I8 ;
F_I_TOTAL <= TOTAL_BIOMASS_AVAILABLE ;

F_OUTCHCL_T1  = F_I1 * X_CHCL_I1 ;
F_OUTM_T1     = F_I1 * X_M_I1    ;
X_CHCL_I1 + X_M_I1 <= 1 ; !JUST ADD TO EASE CALCULATION IN LINGO, DO
NOT INCLUDE IN FORMULATION.;

F_OUTCHCL_T2  = F_I2 * X_CHCL_I2 ;
F_OUTM_T2     = F_I2 * X_M_I2    ;
X_CHCL_I2 + X_M_I2 <= 1 ; !JUST ADD TO EASE CALCULATION IN LINGO, DO
NOT INCLUDE IN FORMULATION.;

F_OUTCHCL_T3  = F_I3 * X_CHCL_I3 ;
F_OUTM_T3     = F_I3 * X_M_I3    ;
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X_CHCL_I3 + X_M_I3 <= 1 ; !JUST ADD TO EASE CALCULATION IN LINGO, DO
NOT INCLUDE IN FORMULATION.;

F_OUTCHCL_T4  = F_I4 * X_CHCL_I4 ;
F_OUTM_T4     = F_I4 * X_M_I4    ;
X_CHCL_I4 + X_M_I4 <= 1 ; !JUST ADD TO EASE CALCULATION IN LINGO, DO
NOT INCLUDE IN FORMULATION.;

F_OUTCHCL_T5  = F_I5 * X_CHCL_I5 ;
F_OUTM_T5     = F_I1 * X_M_I5    ;
X_CHCL_I5 + X_M_I5 <= 1 ; !JUST ADD TO EASE CALCULATION IN LINGO, DO
NOT INCLUDE IN FORMULATION.;

F_OUTCHCL_T6  = F_I6 * X_CHCL_I6 ;
F_OUTM_T6     = F_I6 * X_M_I6    ;
X_CHCL_I6 + X_M_I6 <= 1 ; !JUST ADD TO EASE CALCULATION IN LINGO, DO
NOT INCLUDE IN FORMULATION.;

F_OUTCHCL_T7  = F_I7 * X_CHCL_I7 ;
F_OUTM_T7     = F_I7 * X_M_I7    ;
X_CHCL_I7 + X_M_I7 <= 1 ; !JUST ADD TO EASE CALCULATION IN LINGO, DO
NOT INCLUDE IN FORMULATION.;

F_OUTCHCL_BLANK1 = F_I8 * X_CHCL_I8 ;
F_OUTM_BLANK1    = F_I8 * X_M_I8    ;
X_CHCL_I8 + X_M_I8 <= 1 ; !JUST ADD TO EASE CALCULATION IN LINGO, DO
NOT INCLUDE IN FORMULATION.;

I_T1 + I_T2 + I_T3 + I_T4 + I_T5 + I_T6 + I_T7 + I_BLANK1 =
I_T_TOTAL ;

!STAGE 2;
S_2 >= S_I1 ; S_2 >= S_I2 ;
S_2 >= S_I3 ; S_2 >= S_I4 ;
S_2 >= S_I5 ; S_2 >= S_I6 ;
S_2 >= S_I7 ; S_2 >= S_I8 ;

F_I1 = F_I1_TP1 + F_I1_TP2 + F_I1_TP3 + F_I1_TP4 + F_I1_TP5 +
F_I1_TP6 + F_I1_TP7 + F_I1_BLANK2 ; !kg/s = kg/s ;
F_I2 = F_I2_TP1 + F_I2_TP2 + F_I2_TP3 + F_I2_TP4 + F_I2_TP5 +
F_I2_TP6 + F_I2_TP7 + F_I2_BLANK2 ; !kg/s = kg/s ;
F_I3 = F_I3_TP1 + F_I3_TP2 + F_I3_TP3 + F_I3_TP4 + F_I3_TP5 +
F_I3_TP6 + F_I3_TP7 + F_I3_BLANK2 ; !kg/s = kg/s ;
F_I4 = F_I4_TP1 + F_I4_TP2 + F_I4_TP3 + F_I4_TP4 + F_I4_TP5 +
F_I4_TP6 + F_I4_TP7 + F_I4_BLANK2 ; !kg/s = kg/s ;
F_I5 = F_I5_TP1 + F_I5_TP2 + F_I5_TP3 + F_I5_TP4 + F_I5_TP5 +
F_I5_TP6 + F_I5_TP7 + F_I5_BLANK2 ; !kg/s = kg/s ;
F_I6 = F_I6_TP1 + F_I6_TP2 + F_I6_TP3 + F_I6_TP4 + F_I6_TP5 +
F_I6_TP6 + F_I6_TP7 + F_I6_BLANK2 ; !kg/s = kg/s ;
F_I7 = F_I7_TP1 + F_I7_TP2 + F_I7_TP3 + F_I7_TP4 + F_I7_TP5 +
F_I7_TP6 + F_I7_TP7 + F_I7_BLANK2 ; !kg/s = kg/s ;
F_I8 = F_I8_TP1 + F_I8_TP2 + F_I8_TP3 + F_I8_TP4 + F_I8_TP5 +
F_I8_TP6 + F_I8_TP7 + F_I8_BLANK2 ; !kg/s = kg/s ;

F_IN_TP1 = F_I1_TP1 + F_I2_TP1 + F_I3_TP1 + F_I4_TP1 + F_I5_TP1 +
F_I6_TP1 + F_I7_TP1 + F_I8_TP1 ; !kg/s = kg/s ;
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F_IN_TP1 * X_CHCL_IN_TP1  = F_I1_TP1 * X_CHCL_I1  + F_I2_TP1 *
X_CHCL_I2  + F_I3_TP1 * X_CHCL_I3  + F_I4_TP1 * X_CHCL_I4  + F_I5_TP1
* X_CHCL_I5  + F_I6_TP1 * X_CHCL_I6  + F_I7_TP1 * X_CHCL_I7 +
F_I8_TP1 * X_CHCL_I8 ;
F_IN_TP1 * X_M_IN_TP1     = F_I1_TP1 * X_M_I1     + F_I2_TP1 * X_M_I2
+ F_I3_TP1 * X_M_I3     + F_I4_TP1 * X_M_I4     + F_I5_TP1 * X_M_I5
+ F_I6_TP1 * X_M_I6     + F_I7_TP1 * X_M_I7    + F_I8_TP1 *
X_M_I8    ;
X_CHCL_IN_TP1 + X_M_IN_TP1 <=1 ;

F_IN_TP2 = F_I1_TP2 + F_I2_TP2 + F_I3_TP2 + F_I4_TP2 + F_I5_TP2 +
F_I6_TP2 + F_I7_TP2 + F_I8_TP2 ; !kg/s = kg/s ;
F_IN_TP2 * X_CHCL_IN_TP2  = F_I1_TP2 * X_CHCL_I1  + F_I2_TP2 *
X_CHCL_I2  + F_I3_TP2 * X_CHCL_I3  + F_I4_TP2 * X_CHCL_I4  + F_I5_TP2
* X_CHCL_I5  + F_I6_TP2 * X_CHCL_I6  + F_I7_TP2 * X_CHCL_I7 +
F_I8_TP2 * X_CHCL_I8 ;
F_IN_TP2 * X_M_IN_TP2     = F_I1_TP2 * X_M_I1     + F_I2_TP2 * X_M_I2
+ F_I3_TP2 * X_M_I3     + F_I4_TP2 * X_M_I4     + F_I5_TP2 * X_M_I5
+ F_I6_TP2 * X_M_I6     + F_I7_TP2 * X_M_I7    + F_I8_TP2 *
X_M_I8    ;
X_CHCL_IN_Tp2 + X_M_IN_TP2 <=1 ;

F_IN_TP3 = F_I1_TP3 + F_I2_TP3 + F_I3_TP3 + F_I4_TP3 + F_I5_TP3 +
F_I6_TP3 + F_I7_TP3 + F_I8_TP3 ; !kg/s = kg/s ;
F_IN_TP3 * X_CHCL_IN_TP3  = F_I1_TP3 * X_CHCL_I1  + F_I2_TP3 *
X_CHCL_I2  + F_I3_TP3 * X_CHCL_I3  + F_I4_TP3 * X_CHCL_I4  + F_I5_TP3
* X_CHCL_I5  + F_I6_TP3 * X_CHCL_I6  + F_I7_TP3 * X_CHCL_I7 +
F_I8_TP3 * X_CHCL_I8 ;
F_IN_TP3 * X_M_IN_TP3     = F_I1_TP3 * X_M_I1     + F_I2_TP3 * X_M_I2
+ F_I3_TP3 * X_M_I3     + F_I4_TP3 * X_M_I4     + F_I5_TP3 * X_M_I5
+ F_I6_TP3 * X_M_I6     + F_I7_TP3 * X_M_I7    + F_I8_TP3 *
X_M_I8    ;
X_CHCL_IN_TP3 + X_M_IN_TP3 <=1 ;

F_IN_TP4 = F_I1_TP4 + F_I2_TP4 + F_I3_TP4 + F_I4_TP4 + F_I5_TP4 +
F_I6_TP4 + F_I7_TP4 + F_I8_TP4 ; !kg/s = kg/s ;
F_IN_TP4 * X_CHCL_IN_TP4  = F_I1_TP4 * X_CHCL_I1  + F_I2_TP4 *
X_CHCL_I2  + F_I3_TP4 * X_CHCL_I3  + F_I4_TP4 * X_CHCL_I4  + F_I5_TP4
* X_CHCL_I5  + F_I6_TP4 * X_CHCL_I6  + F_I7_TP4 * X_CHCL_I7 +
F_I8_TP4 * X_CHCL_I8 ;
F_IN_TP4 * X_M_IN_TP4     = F_I1_TP4 * X_M_I1     + F_I2_TP4 * X_M_I2
+ F_I3_TP4 * X_M_I3     + F_I4_TP4 * X_M_I4     + F_I5_TP4 * X_M_I5
+ F_I6_TP4 * X_M_I6     + F_I7_TP4 * X_M_I7    + F_I8_TP4 *
X_M_I8    ;
X_CHCL_IN_TP4 + X_M_IN_TP4 <=1 ;

F_IN_TP5 = F_I1_TP5 + F_I2_TP5 + F_I3_TP5 + F_I4_TP5 + F_I5_TP5 +
F_I6_TP5 + F_I7_TP5 + F_I8_TP5 ; !kg/s = kg/s ;
F_IN_TP5 * X_CHCL_IN_TP5  = F_I1_TP5 * X_CHCL_I1  + F_I2_TP5 *
X_CHCL_I2  + F_I3_TP5 * X_CHCL_I3  + F_I4_TP5 * X_CHCL_I4  + F_I5_TP5
* X_CHCL_I5  + F_I6_TP5 * X_CHCL_I6  + F_I7_TP5 * X_CHCL_I7 +
F_I8_TP5 * X_CHCL_I8 ;
F_IN_TP5 * X_M_IN_TP5     = F_I1_TP5 * X_M_I1     + F_I2_TP5 * X_M_I2
+ F_I3_TP5 * X_M_I3     + F_I4_TP5 * X_M_I4     + F_I5_TP5 * X_M_I5
+ F_I6_TP5 * X_M_I6     + F_I7_TP5 * X_M_I7    + F_I8_TP5 *
X_M_I8    ;
X_CHCL_IN_TP5 + X_M_IN_TP5 <=1 ;
```

```
F_IN_TP6 = F_I1_TP6 + F_I2_TP6 + F_I3_TP6 + F_I4_TP6 + F_I5_TP6 +
F_I6_TP6 + F_I7_TP6 + F_I8_TP6 ; !kg/s = kg/s ;
F_IN_TP6 * X_CHCL_IN_TP6  = F_I1_TP6 * X_CHCL_I1  + F_I2_TP6 *
X_CHCL_I2  + F_I3_TP6 * X_CHCL_I3  + F_I4_TP6 * X_CHCL_I4  + F_I5_TP6
* X_CHCL_I5  + F_I6_TP6 * X_CHCL_I6  + F_I7_TP6 * X_CHCL_I7 +
F_I8_TP6 * X_CHCL_I8 ;
F_IN_TP6 * X_M_IN_TP6     = F_I1_TP6 * X_M_I1     + F_I2_TP6 * X_M_I2
+ F_I3_TP6 * X_M_I3     + F_I4_TP6 * X_M_I4     + F_I5_TP6 * X_M_I5
+ F_I6_TP6 * X_M_I6     + F_I7_TP6 * X_M_I7    + F_I8_TP6 *
X_M_I8    ;
X_CHCL_IN_TP6 + X_M_IN_TP6 <=1 ;

F_IN_TP7 = F_I1_TP7 + F_I2_TP7 + F_I3_TP7 + F_I4_TP7 + F_I5_TP7 +
F_I6_TP7 + F_I7_TP7 + F_I8_TP7 ; !kg/s = kg/s ;
F_IN_TP7 * X_CHCL_IN_TP7  = F_I1_TP7 * X_CHCL_I1  + F_I2_TP7 *
X_CHCL_I2  + F_I3_TP7 * X_CHCL_I3  + F_I4_TP7 * X_CHCL_I4  + F_I5_TP7
* X_CHCL_I5  + F_I6_TP7 * X_CHCL_I6  + F_I7_TP7 * X_CHCL_I7 +
F_I8_TP7 * X_CHCL_I8 ;
F_IN_TP7 * X_M_IN_TP7     = F_I1_TP7 * X_M_I1     + F_I2_TP7 * X_M_I2
+ F_I3_TP7 * X_M_I3     + F_I4_TP7 * X_M_I4     + F_I5_TP7 * X_M_I5
+ F_I6_TP7 * X_M_I6     + F_I7_TP7 * X_M_I7    + F_I8_TP7 *
X_M_I8    ;
X_CHCL_IN_TP7 + X_M_IN_TP7 <=1 ;

F_IN_BLANK2 = F_I1_BLANK2 + F_I2_BLANK2 + F_I3_BLANK2 + F_I4_BLANK2 +
F_I5_BLANK2 + F_I6_BLANK2 + F_I7_BLANK2 + F_I8_BLANK2 ; !kg/s =
kg/s ;
F_IN_BLANK2 * X_CHCL_IN_BLANK2  = F_I1_BLANK2 * X_CHCL_I1  +
F_I2_BLANK2 * X_CHCL_I2  + F_I3_BLANK2 * X_CHCL_I3  + F_I4_BLANK2 *
X_CHCL_I4  + F_I5_BLANK2 * X_CHCL_I5  + F_I6_BLANK2 * X_CHCL_I6  +
F_I7_BLANK2 * X_CHCL_I7 + F_I8_BLANK2 * X_CHCL_I8 ;
F_IN_BLANK2 * X_M_IN_BLANK2     = F_I1_BLANK2 * X_M_I1     +
F_I2_BLANK2 * X_M_I2     + F_I3_BLANK2 * X_M_I3     + F_I4_BLANK2 *
X_M_I4     + F_I5_BLANK2 * X_M_I5     + F_I6_BLANK2 * X_M_I6     +
F_I7_BLANK2 * X_M_I7    + F_I8_BLANK2 * X_M_I8    ;
X_CHCL_IN_BLANK2 + X_M_IN_BLANK2 <=1 ;

F_IN_TP1 + F_IN_TP2 + F_IN_TP3 + F_IN_TP4 + F_IN_TP5 + F_IN_TP6 +
F_IN_TP7 + F_IN_BLANK2 = F_IN_TP_TOTAL ;
F_IN_TP1 <= TOTAL_BIOMASS_AVAILABLE ;
F_IN_TP2 <= TOTAL_BIOMASS_AVAILABLE ;
F_IN_TP3 <= TOTAL_BIOMASS_AVAILABLE ;
F_IN_TP4 <= TOTAL_BIOMASS_AVAILABLE ;
F_IN_TP5 <= TOTAL_BIOMASS_AVAILABLE ;
F_IN_TP6 <= TOTAL_BIOMASS_AVAILABLE ;
F_IN_TP7 <= TOTAL_BIOMASS_AVAILABLE ;
F_IN_BLANK2 <= TOTAL_BIOMASS_AVAILABLE ;
F_IN_TP_TOTAL <= TOTAL_BIOMASS_AVAILABLE ;

(F_IN_TP1/TOTAL_BIOMASS_AVAILABLE) <= I_TP1 ;
(F_IN_TP2/TOTAL_BIOMASS_AVAILABLE) <= I_TP2 ;
(F_IN_TP3/TOTAL_BIOMASS_AVAILABLE) <= I_TP3 ;
(F_IN_TP4/TOTAL_BIOMASS_AVAILABLE) <= I_TP4 ;
(F_IN_TP5/TOTAL_BIOMASS_AVAILABLE) <= I_TP5 ;
(F_IN_TP6/TOTAL_BIOMASS_AVAILABLE) <= I_TP6 ;
(F_IN_TP7/TOTAL_BIOMASS_AVAILABLE) <= I_TP7 ;
```

```
(F_IN_BLANK2/TOTAL_BIOMASS_AVAILABLE) <= I_BLANK2 ;
@BIN(I_TP1); @BIN(I_TP2);
@BIN(I_TP3); @BIN(I_TP4);
@BIN(I_TP5); @BIN(I_TP6);
@BIN(I_TP7); @BIN(I_BLANK2);

(0.25 * I_TP1) <= (X_M_IN_TP1 * I_TP1)       ;
(X_M_IN_TP1 * I_TP1)       <= (0.65 * I_TP1) ;
(0.25 * I_TP2) <= (X_M_IN_TP2 * I_TP2)       ;
(X_M_IN_TP2 * I_TP2)       <= (0.65 * I_TP2) ;
(0.25 * I_TP3) <= (X_M_IN_TP3 * I_TP3)       ;
(X_M_IN_TP3 * I_TP3)       <= (0.65 * I_TP3) ;
(0.25 * I_TP4) <= (X_M_IN_TP4 * I_TP4)       ;
(X_M_IN_TP4 * I_TP4)       <= (0.72 * I_TP4) ;
(0.04 * I_TP5) <= (X_M_IN_TP5 * I_TP5)       ;
(X_M_IN_TP5 * I_TP5)       <= (0.07 * I_TP5) ;
(0.04 * I_TP6) <= (X_M_IN_TP6 * I_TP6)       ;
(X_M_IN_TP6 * I_TP6)       <= (0.12 * I_TP6) ;
(0 * I_TP7)    <= (X_M_IN_TP7 * I_TP7)       ;
(X_M_IN_TP7 * I_TP7)       <= (1 * I_TP7)    ;
(0 * I_BLANK2) <= (X_M_IN_BLANK2 * I_BLANK2) ;
(X_M_IN_BLANK2 * I_BLANK2) <= (1 * I_BLANK2) ;

(25  * I_TP1)    <= (S_2 * I_TP1)    ;
(S_2 * I_TP1)    <= (125 * I_TP1)    ;
(0.5 * I_TP2)    <= (S_2 * I_TP2)    ;
(S_2 * I_TP2)    <= (50  * I_TP2)    ;
(0   * I_TP3)    <= (S_2 * I_TP3)    ;
(S_2 * I_TP3)    <= (100 * I_TP3)    ;
(0   * I_TP4)    <= (S_2 * I_TP4)    ;
(S_2 * I_TP4)    <= (150 * I_TP4)    ;
(25  * I_TP5)    <= (S_2 * I_TP5)    ;
(S_2 * I_TP5)    <= (150 * I_TP5)    ;
(25  * I_TP6)    <= (S_2 * I_TP6)    ;
(S_2 * I_TP6)    <= (150 * I_TP6)    ;
(0   * I_TP7)    <= (S_2 * I_TP7)    ;
(S_2 * I_TP7)    <= (150 * I_TP7)    ;
   (2   * I_BLANK2) <= (S_2 * I_BLANK2) ;
   (3   (S_2 * I_BLANK2) <= (150 * I_BLANK2) ;


F_OUTCHCL_TP1 = (F_IN_TP1 * X_CHCL_IN_TP1)  ;
F_OUTCHCL_TP2 = (F_IN_TP2 * X_CHCL_IN_TP2)  ;
F_OUTCHCL_TP3 = (F_IN_TP3 * X_CHCL_IN_TP3)  ;
F_OUTCHCL_TP4 = (F_IN_TP4 * X_CHCL_IN_TP4)  ;
F_OUTCHCL_TP5 = (F_IN_TP5 * X_CHCL_IN_TP5)  ;
F_OUTCHCL_TP6 = (F_IN_TP6 * X_CHCL_IN_TP6)  ;
F_OUTCHCL_TP7 = (F_IN_TP7 * X_CHCL_IN_TP7)  ;
F_OUTCHCL_BLANK2 = (F_IN_BLANK2 * X_CHCL_IN_BLANK2)  ;

F_OUTCHCL_TP1 <= TOTAL_CHCL_AVAILABLE ;
F_OUTCHCL_TP2 <= TOTAL_CHCL_AVAILABLE ;
F_OUTCHCL_TP3 <= TOTAL_CHCL_AVAILABLE ;
F_OUTCHCL_TP4 <= TOTAL_CHCL_AVAILABLE ;
F_OUTCHCL_TP5 <= TOTAL_CHCL_AVAILABLE ;
F_OUTCHCL_TP6 <= TOTAL_CHCL_AVAILABLE ;
F_OUTCHCL_TP7 <= TOTAL_CHCL_AVAILABLE ;
```

```
F_OUTCHCL_BLANK2 <= TOTAL_CHCL_AVAILABLE ;
F_OUTCHCL_TP_TOTAL = F_OUTCHCL_TP1 + F_OUTCHCL_TP2 + F_OUTCHCL_TP3 +
F_OUTCHCL_TP4 + F_OUTCHCL_TP5 + F_OUTCHCL_TP6 + F_OUTCHCL_TP7 +
F_OUTCHCL_BLANK2 ;
F_OUTCHCL_TP_TOTAL <= TOTAL_CHCL_AVAILABLE ;

F_MR_TP1 = F_IN_TP1 * X_M_IN_TP1 * MRR_TP1 ;
0.56 <= MRR_TP1 ;
MRR_TP1 <= 0.86 ;
TR_TP1 = 0.67 ; !kWhr/kg ;
EF_TP1 = 0.6 ;
P_D_TP1 * EF_TP1 * 3600 = TR_TP1 * F_MR_TP1  ; !kWhr/s * 3600 s/hr =
kWhr/kg * kg/s ;

F_MR_TP2 = F_IN_TP2 * X_M_IN_TP2 * MRR_TP2 ;
0.56 <= MRR_TP2 ;
MRR_TP2 <= 0.86 ;
TR_TP2 = 0.67 ; !kWhr/kg ;
EF_TP2 = 0.86 ;
P_D_TP2 * EF_TP2 * 3600 = TR_TP2 * F_MR_TP2  ; !kWhr/s * 3600 s/hr =
kWhr/kg * kg/s ;

F_MR_TP3 = F_IN_TP3 * X_M_IN_TP3 * MRR_TP3 ;
0.56 <= MRR_TP3 ;
MRR_TP3 <= 0.86 ;
TR_TP3 = 0.67 ; !kWhr/kg ;
EF_TP3 = 0.87 ;
P_D_TP3 * EF_TP3 * 3600 = TR_TP3 * F_MR_TP3 ; !kWhr/s * 3600 s/hr =
kWhr/kg * kg/s ;

F_MR_TP4 = F_IN_TP4 * X_M_IN_TP4 * MRR_TP4 ;
0.64 <= MRR_TP4 ;
MRR_TP4 <= 0.81 ;
TR_TP4 = 0.67 ; !kWhr/kg ;
EF_TP4 = 0.7 ;
P_D_TP4 * EF_TP4 * 3600 = TR_TP4 * F_MR_TP4 ; !kWhr/s * 3600 s/hr =
kWhr/kg * kg/s ;

F_MR_TP5 = F_IN_TP5 * X_M_IN_TP5 * MRR_TP5 ;
MRR_TP5 = 0.15 ;
TR_TP5 = 0 ; !kWhr/kg ;
EF_TP5 = 1 ;
P_D_TP5 * EF_TP5 * 3600  = TR_TP5 * F_MR_TP5 ; !kWhr/s * 3600 s/hr =
kWhr/kg * kg/s ;

F_MR_TP6 = F_IN_TP6 * X_M_IN_TP6 * MRR_TP6 ;
MRR_TP6 = 0.15 ;
TR_TP6 = 0 ; !kWhr/kg ;
EF_TP6 = 1 ;
P_D_TP6 * EF_TP6 * 3600 = TR_TP6 * F_MR_TP6 ; !kWhr/s * 3600 s/hr =
kWhr/kg * kg/s ;

F_MR_TP7 = F_IN_TP7 * X_M_IN_TP7 * MRR_TP7 ;
MRR_TP7 = 0.15 ;
TR_TP7 = 0 ; !kWhr/kg ;
EF_TP7 = 1 ;
```

```
P_D_TP7 * EF_TP7 * 3600 = TR_TP7 * F_MR_TP7 ; !kWhr/s * 3600 s/hr =
kWhr/kg * kg/s ;

F_MR_BLANK2 = F_IN_BLANK2 * X_M_IN_BLANK2 * MRR_BLANK2 ;
MRR_BLANK2 = 0 ;
TR_BLANK2 = 0 ; !kWhr/kg ;
EF_BLANK2 = 1;
P_D_BLANK2 * EF_BLANK2 * 3600 = TR_BLANK2 * F_MR_BLANK2 ; !kWhr/s *
3600 s/hr  = kWhr/kg * kg/s ;

P_D_TP1 + P_D_TP2 + P_D_TP3 + P_D_TP4 + P_D_TP5 + P_D_TP6 + P_D_TP7 +
P_D_BLANK2 = P_D_TP_TOTAL ;

F_OUTM_TP1 = F_IN_TP1 * X_M_IN_TP1 - F_MR_TP1 ;
F_OUTM_TP2 = F_IN_TP2 * X_M_IN_TP2 - F_MR_TP2 ;
F_OUTM_TP3 = F_IN_TP3 * X_M_IN_TP3 - F_MR_TP3 ;
F_OUTM_TP4 = F_IN_TP4 * X_M_IN_TP4 - F_MR_TP4 ;
F_OUTM_TP5 = F_IN_TP5 * X_M_IN_TP5 - F_MR_TP5 ;
F_OUTM_TP6 = F_IN_TP6 * X_M_IN_TP6 - F_MR_TP6 ;
F_OUTM_TP7 = F_IN_TP7 * X_M_IN_TP7 - F_MR_TP7 ;
F_OUTM_BLANK2 = F_IN_BLANK2 * X_M_IN_BLANK2 - F_MR_BLANK2 ;

F_OUTM_TP_TOTAL = F_OUTM_TP1 + F_OUTM_TP2 + F_OUTM_TP3 + F_OUTM_TP4 +
F_OUTM_TP5 + F_OUTM_TP6 + F_OUTM_TP7 + F_OUTM_BLANK2 ;
F_OUTM_TP_TOTAL <= TOTAL_M_AVAILABLE;

S_IN_TP1 = S_2 ; S_IN_TP2 = S_2 ;
S_IN_TP3 = S_2 ; S_IN_TP4 = S_2 ;
S_IN_TP5 = S_2 ; S_IN_TP6 = S_2 ;
S_IN_TP7 = S_2 ; S_IN_BLANK2 = S_2 ;

(S_IN_TP1/SRR_TP1) * I_TP1 = S_IP1 ;
S_IP1 <= 10000 * I_TP1 ;
SRR_TP1 = 1 ;
P_SR_TP1 = I_TP1 * @LOG10 (SRR_TP1) * F_IN_TP1 ; !kW = kW/kgs-1 *
kgs-1 ;
@FREE (K_TP1);
@FREE (P_SR_TP1);

(S_IN_TP2/SRR_TP2) * I_TP2 = S_IP2 ;
S_IP2 <= 10000 * I_TP2 ;
SRR_TP2 = 1 ;
P_SR_TP2 = I_TP2 * @LOG10 (SRR_TP2) * F_IN_TP2 ; !kW = kW/kgs-1 *
kgs-1 ;
@FREE (K_TP2);
@FREE (P_SR_TP2);

(S_IN_TP3/SRR_TP3) * I_TP3 = S_IP3 ;
S_IP3 <= 10000 * I_TP3 ;
SRR_TP3 = 1 ;
P_SR_TP3 = I_TP3 * @LOG10 (SRR_TP3) * F_IN_TP3 ; !kW = kW/kgs-1 *
kgs-1 ;
@FREE (K_TP3);
@FREE (P_SR_TP3);

(S_IN_TP4/SRR_TP4) * I_TP4 = S_IP4 ;
```

```
S_IP4 <= 10000 * I_TP4 ;
SRR_TP4 = 1 ;
P_SR_TP4 = I_TP4 * @LOG10 (SRR_TP4) * F_IN_TP4 ; !kW = kW/kgs-1 *
kgs-1 ;
@FREE (K_TP4);
@FREE (P_SR_TP4);

(S_IN_TP5/SRR_TP5) * I_TP5 = S_IP5 ;
S_IP5 <= 10000 * I_TP5 ;
2 <= SRR_TP5 ;
SRR_TP5 <= 14 ;
A_TP5 = @LOG10(SRR_TP5);
B_TP5 = X_M_IN_TP5 ;
K_TP5 = 339.9 - 1109*A_TP5 - 7.529*B_TP5  + 947.4*(A_TP5^2) +
170.5*(A_TP5)*(B_TP5) - 16.53*(B_TP5^2) - 362.7*(A_TP5^3)
      - 76.75*(A_TP5^2)*(B_TP5)  - 5.958*(A_TP5)*(B_TP5^2) +
1.836*(B_TP5 ^3) + 56.16*(A_TP5^4) + 3.813*(A_TP5^3)*(B_TP5) +
4.932*(A_TP5^2)*(B_TP5^2) - 0.7026*A_TP5*(B_TP5^3) ;
P_SR_TP5 = I_TP5 * K_TP5 * @LOG10 (SRR_TP5) * F_IN_TP5 ; !kW =
kW/kgs-1 * kgs-1 ;
@FREE (K_TP5);
@FREE (P_SR_TP5);

(S_IN_TP6/SRR_TP6) * I_TP6 = S_IP6 ;
S_IP6 <= 10000 * I_TP6 ;
2.23 <= SRR_TP6 ;
SRR_TP6 <= 12.825 ;
A_TP6 = @LOG10(SRR_TP6);
B_TP6 = X_M_IN_TP6 ;
K_TP6 = 49.02 + 10.04 *A_TP6 - 72.54*B_TP6  + 11.03*(A_TP6^2) +
2.03*(A_TP6)*(B_TP6) + 96.17*(B_TP6^2) +0.7976*(A_TP6^3)
      +2.241*(A_T6^2)*(B_TP6)  - 4.248*(A_TP6)*(B_TP6^2) -
18.67*(B_TP6^3) + 2.451*(A_TP6^4) + 6.563*(A_TP6^3)*(B_TP6) -
0.3381*(A_TP6^2)*(B_TP6^2) - 9.35*A_TP6*(B_TP6^3) -43.85*(B_TP6^4) ;
P_SR_TP6 = I_TP6 * K_TP6 * @LOG10 (SRR_TP6) * F_IN_TP6 ; !kW =
kW/kgs-1 * kgs-1 ;
@FREE (K_TP6);
@FREE (P_SR_TP6);

(S_IN_TP7/SRR_TP7) * I_TP7 = S_IP7 ;
S_IP7 <= 10000 * I_TP7 ;
2.03 <= SRR_TP7 ;
SRR_TP7 <= 4.06 ;
A_TP7 = @LOG10(SRR_TP7);
K_TP7 = 1.0633 * A_TP7 + 0.0203 ;
P_SR_TP7 = I_TP7 * K_TP7 * @LOG10 (SRR_TP7) * F_IN_TP7 ; !kW =
kW/kgs-1 * kgs-1 ;

(S_IN_BLANK2/SRR_BLANK2) * I_BLANK2 = S_IP8 ;
S_IP8 <= 10000 * I_BLANK2 ;
SRR_BLANK2 = 1 ;
P_SR_BLANK2 = I_BLANK2 * @LOG10 (SRR_BLANK2) * F_IN_BLANK2 ; !kW =
kW/kgs-1 * kgs-1 ;
@FREE (K_BLANK2);
@FREE (P_SR_BLANK2);
```

```
P_SR_TP1 + P_SR_TP2 + P_SR_TP3 + P_SR_TP4 + P_SR_TP5 + P_SR_TP6 +
P_SR_TP7 + P_SR_BLANK2 = P_SR_TP_TOTAL ;

!TECHNOLOGY COST;
C_TP1 = ((2.9*3*18^0.63)*1000)*(((F_IN_TP1*3600/1000)/1)^0.6);
C_TP2 = ((2.23*1.75*46^0.6)*1000)*(((F_IN_TP2*3600/1000)/1)^0.6);
C_TP3 = ((45*1^0.7)*1000)*(((F_IN_TP3*3600/1000)/1)^0.6);
C_TP4 = ((1.4*5^0.77)*1000)*(((F_IN_TP4*3600/1000)/1)^0.6);
C_TP5 = ((27.5*1*0.39)*1000)*(((F_IN_TP5*3600/1000)/1)^0.6);
C_TP6 = ((2.97*(F_IN_T6*3600/1000)^0.78)*1000);
C_TP7 = ((7.7*1^0.57)*1000)*(((F_IN_TP7*3600/1000)/1)^0.6);
C_BLANK2 = F_IN_BLANK1 * 0;

C_TP_TOTAL = C_TP1 + C_TP2 + C_TP3 + C_TP4 + C_TP5 + C_TP6 + C_TP7 +
C_BLANK2 ;

F_IP1 = F_OUTCHCL_TP1 + F_OUTM_TP1 ; !kg/s = kg/s ;
F_IP2 = F_OUTCHCL_TP2 + F_OUTM_TP2 ; !kg/s = kg/s ;
F_IP3 = F_OUTCHCL_TP3 + F_OUTM_TP3 ; !kg/s = kg/s ;
F_IP4 = F_OUTCHCL_TP4 + F_OUTM_TP4 ; !kg/s = kg/s ;
F_IP5 = F_OUTCHCL_TP5 + F_OUTM_TP5 ; !kg/s = kg/s ;
F_IP6 = F_OUTCHCL_TP6 + F_OUTM_TP6 ; !kg/s = kg/s ;
F_IP7 = F_OUTCHCL_TP7 + F_OUTM_TP7 ; !kg/s = kg/s ;
F_IP8 = F_OUTCHCL_BLANK2 + F_OUTM_BLANK2 ; !kg/s = kg/s ;

F_IP1 <= TOTAL_BIOMASS_AVAILABLE;
F_IP2 <= TOTAL_BIOMASS_AVAILABLE;
F_IP3 <= TOTAL_BIOMASS_AVAILABLE;
F_IP4 <= TOTAL_BIOMASS_AVAILABLE;
F_IP5 <= TOTAL_BIOMASS_AVAILABLE;
F_IP6 <= TOTAL_BIOMASS_AVAILABLE;
F_IP7 <= TOTAL_BIOMASS_AVAILABLE;
F_IP8 <= TOTAL_BIOMASS_AVAILABLE;
F_IP_TOTAL = F_IP1 + F_IP2 + F_IP3 + F_IP4 + F_IP5 + F_IP6 + F_IP7 +
F_IP8 ;
F_IP_TOTAL <= TOTAL_BIOMASS_AVAILABLE;

F_OUTCHCL_TP1  = F_IP1 * X_CHCL_IP1 ;
F_OUTM_TP1     = F_IP1 * X_M_IP1    ;
X_CHCL_IP1 + X_M_IP1 <= 1 ; !JUST ADD TO EASE CALCULATION IN LINGO,
DO NOT INCLUDE IN FORMULATION.;

F_OUTCHCL_TP2  = F_IP2 * X_CHCL_IP2 ;
F_OUTM_TP2     = F_IP2 * X_M_IP2    ; X_CHCL_IP2 + X_M_IP2 <=
1 ; !JUST ADD TO EASE CALCULATION IN LINGO, DO NOT INCLUDE IN
FORMULATION.;


F_OUTCHCL_TP3  = F_IP3 * X_CHCL_IP3 ;
F_OUTM_TP3     = F_IP3 * X_M_IP3    ;
X_CHCL_IP3 + X_M_IP3 <= 1 ; !JUST ADD TO EASE CALCULATION IN LINGO,
DO NOT INCLUDE IN FORMULATION.;

F_OUTCHCL_TP4  = F_IP4 * X_CHCL_IP4 ;
F_OUTM_TP4     = F_IP4 * X_M_IP4    ;
```

```
X_CHCL_IP4 + X_M_IP4 <= 1 ; !JUST ADD TO EASE CALCULATION IN LINGO,
DO NOT INCLUDE IN FORMULATION.;

F_OUTCHCL_TP5  = F_IP5 * X_CHCL_IP5 ;
F_OUTM_TP5     = F_IP5 * X_M_IP5    ;
X_CHCL_IP5 + X_M_IP5 <= 1 ; !JUST ADD TO EASE CALCULATION IN LINGO,
DO NOT INCLUDE IN FORMULATION.;

F_OUTCHCL_TP6  = F_IP6 * X_CHCL_IP6 ;
F_OUTM_TP6     = F_IP6 * X_M_IP6    ;
X_CHCL_IP6 + X_M_IP6 <= 1 ; !JUST ADD TO EASE CALCULATION IN LINGO,
DO NOT INCLUDE IN FORMULATION.;

F_OUTCHCL_TP7  = F_IP7 * X_CHCL_IP7 ;
F_OUTM_TP7     = F_IP7 * X_M_IP7    ;
X_CHCL_IP7 + X_M_IP7 <= 1 ; !JUST ADD TO EASE CALCULATION IN LINGO,
DO NOT INCLUDE IN FORMULATION.;

F_OUTCHCL_BLANK2 = F_IP8 * X_CHCL_IP8 ;
F_OUTM_BLANK2    = F_IP8 * X_M_IP8    ;
X_CHCL_IP8 + X_M_IP8 <= 1 ; !JUST ADD TO EASE CALCULATION IN LINGO,
DO NOT INCLUDE IN FORMULATION.;

I_TP1 + I_TP2 + I_TP3 + I_TP4 + I_TP5 + I_TP6 + I_TP7 + I_BLANK2 =
I_TP_TOTAL ;


!STAGE 3;
S_3 >= S_IP1 ; S_3 >= S_IP2 ;
S_3 >= S_IP3 ; S_3 >= S_IP4 ;
S_3 >= S_IP5 ; S_3 >= S_IP6 ;
S_3 >= S_IP7 ; S_3 >= S_IP8 ;

F_IP1 = F_IP1_TPP1 + F_IP1_TPP2 + F_IP1_TPP3 + F_IP1_TPP4 +
F_IP1_TPP5 + F_IP1_TPP6 + F_IP1_TPP7 + F_IP1_BLANK3 ; !kg/s = kg/s ;
F_IP2 = F_IP2_TPP1 + F_IP2_TPP2 + F_IP2_TPP3 + F_IP2_TPP4 +
F_IP2_TPP5 + F_IP2_TPP6 + F_IP2_TPP7 + F_IP2_BLANK3 ; !kg/s = kg/s ;
F_IP3 = F_IP3_TPP1 + F_IP3_TPP2 + F_IP3_TPP3 + F_IP3_TPP4 +
F_IP3_TPP5 + F_IP3_TPP6 + F_IP3_TPP7 + F_IP3_BLANK3 ; !kg/s = kg/s ;
F_IP4 = F_IP4_TPP1 + F_IP4_TPP2 + F_IP4_TPP3 + F_IP4_TPP4 +
F_IP4_TPP5 + F_IP4_TPP6 + F_IP4_TPP7 + F_IP4_BLANK3 ; !kg/s = kg/s ;
F_IP5 = F_IP5_TPP1 + F_IP5_TPP2 + F_IP5_TPP3 + F_IP5_TPP4 +
F_IP5_TPP5 + F_IP5_TPP6 + F_IP5_TPP7 + F_IP5_BLANK3 ; !kg/s = kg/s ;
F_IP6 = F_IP6_TPP1 + F_IP6_TPP2 + F_IP6_TPP3 + F_IP6_TPP4 +
F_IP6_TPP5 + F_IP6_TPP6 + F_IP6_TPP7 + F_IP6_BLANK3 ; !kg/s = kg/s ;
F_IP7 = F_IP7_TPP1 + F_IP7_TPP2 + F_IP7_TPP3 + F_IP7_TPP4 +
F_IP7_TPP5 + F_IP7_TPP6 + F_IP7_TPP7 + F_IP7_BLANK3 ; !kg/s = kg/s ;
F_IP8 = F_IP8_TPP1 + F_IP8_TPP2 + F_IP8_TPP3 + F_IP8_TPP4 +
F_IP8_TPP5 + F_IP8_TPP6 + F_IP8_TPP7 + F_IP8_BLANK3 ; !kg/s = kg/s ;

!----;
F_IN_TPP1 = F_IP1_TPP1 + F_IP2_TPP1 + F_IP3_TPP1 + F_IP4_TPP1 +
F_IP5_TPP1 + F_IP6_TPP1 + F_IP7_TPP1 + F_IP8_TPP1; !kg/s = kg/s ;
F_IN_TPP1 * X_CHCL_IN_TPP1  = F_IP1_TPP1 * X_CHCL_IP1  + F_IP2_TPP1 *
X_CHCL_IP2  + F_IP3_TPP1 * X_CHCL_IP3  + F_IP4_TPP1 * X_CHCL_IP4  +
F_IP5_TPP1 * X_CHCL_IP5  + F_IP6_TPP1 * X_CHCL_IP6  + F_IP7_TPP1 *
X_CHCL_IP7 + F_IP8_TPP1 * X_CHCL_IP8 ;
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F_IN_TPP1 * X_M_IN_TPP1     = F_IP1_TPP1 * X_M_IP1     + F_IP2_TPP1 *
X_M_IP2     + F_IP3_TPP1 * X_M_IP3     + F_IP4_TPP1 * X_M_IP4     +
F_IP5_TPP1 * X_M_IP5     + F_IP6_TPP1 * X_M_IP6     + F_IP7_TPP1 *
X_M_IP7    + F_IP8_TPP1 * X_M_IP8    ;
X_CHCL_IN_TPP1 + X_M_IN_TPP1 <= 1 ; !JUST ADD TO EASE CALCULATION IN
LINGO, DO NOT INCLUDE IN FORMULATION.;

!----;
F_IN_TPP2 = F_IP1_TPP2 + F_IP2_TPP2 + F_IP3_TPP2 + F_IP4_TPP2 +
F_IP5_TPP2 + F_IP6_TPP2 + F_IP7_TPP2 + F_IP8_TPP2 ; !kg/s = kg/s ;
F_IN_TPP2 * X_CHCL_IN_TPP2  = F_IP1_TPP2 * X_CHCL_IP1  + F_IP2_TPP2 *
X_CHCL_IP2  + F_IP3_TPP2 * X_CHCL_IP3  + F_IP4_TPP2 * X_CHCL_IP4  +
F_IP5_TPP2 * X_CHCL_IP5  + F_IP6_TPP2 * X_CHCL_IP6  + F_IP7_TPP2 *
X_CHCL_IP7 + F_IP8_TPP2 * X_CHCL_IP8 ;
F_IN_TPP2 * X_M_IN_TPP2     = F_IP1_TPP2 * X_M_IP1     + F_IP2_TPP2 *
X_M_IP2     + F_IP3_TPP2 * X_M_IP3     + F_IP4_TPP2 * X_M_IP4     +
F_IP5_TPP2 * X_M_IP5     + F_IP6_TPP2 * X_M_IP6     + F_IP7_TPP2 *
X_M_IP7    + F_IP8_TPP2 * X_M_IP8    ;
X_CHCL_IN_TPP2 + X_M_IN_TPP2 <= 1 ; !JUST ADD TO EASE CALCULATION IN
LINGO, DO NOT INCLUDE IN FORMULATION.;

!----;
F_IN_TPP3 = F_IP1_TPP3 + F_IP2_TPP3 + F_IP3_TPP3 + F_IP4_TPP3 +
F_IP5_TPP3 + F_IP6_TPP3 + F_IP7_TPP3 + F_IP8_TPP3 ; !kg/s = kg/s ;
F_IN_TPP3 * X_CHCL_IN_TPP3  = F_IP1_TPP3 * X_CHCL_IP1  + F_IP2_TPP3 *
X_CHCL_IP2  + F_IP3_TPP3 * X_CHCL_IP3  + F_IP4_TPP3 * X_CHCL_IP4  +
F_IP5_TPP3 * X_CHCL_IP5  + F_IP6_TPP3 * X_CHCL_IP6  + F_IP7_TPP3 *
X_CHCL_IP7 + F_IP8_TPP3 * X_CHCL_IP8 ;
F_IN_TPP3 * X_M_IN_TPP3     = F_IP1_TPP3 * X_M_IP1     + F_IP2_TPP3 *
X_M_IP2     + F_IP3_TPP3 * X_M_IP3     + F_IP4_TPP3 * X_M_IP4     +
F_IP5_TPP3 * X_M_IP5     + F_IP6_TPP3 * X_M_IP6     + F_IP7_TPP3 *
X_M_IP7    + F_IP8_TPP3 * X_M_IP8    ;
X_CHCL_IN_TPP3 + X_M_IN_TPP3 <= 1 ; !JUST ADD TO EASE CALCULATION IN
LINGO, DO NOT INCLUDE IN FORMULATION.;

!----;
F_IN_TPP4 = F_IP1_TPP4 + F_IP2_TPP4 + F_IP3_TPP4 + F_IP4_TPP4 +
F_IP5_TPP4 + F_IP6_TPP4 + F_IP7_TPP4 + F_IP8_TPP4 ; !kg/s = kg/s ;
F_IN_TPP4 * X_CHCL_IN_TPP4  = F_IP1_TPP4 * X_CHCL_IP1  + F_IP2_TPP4 *
X_CHCL_IP2  + F_IP3_TPP4 * X_CHCL_IP3  + F_IP4_TPP4 * X_CHCL_IP4  +
F_IP5_TPP4 * X_CHCL_IP5  + F_IP6_TPP4 * X_CHCL_IP6  + F_IP7_TPP4 *
X_CHCL_IP7 + F_IP8_TPP4 * X_CHCL_IP8 ;
F_IN_TPP4 * X_M_IN_TPP4     = F_IP1_TPP4 * X_M_IP1     + F_IP2_TPP4 *
X_M_IP2     + F_IP3_TPP4 * X_M_IP3     + F_IP4_TPP4 * X_M_IP4     +
F_IP5_TPP4 * X_M_IP5     + F_IP6_TPP4 * X_M_IP6     + F_IP7_TPP4 *
X_M_IP7    + F_IP8_TPP4 * X_M_IP8    ;
X_CHCL_IN_TPP4 + X_M_IN_TPP4 <= 1 ; !JUST ADD TO EASE CALCULATION IN
LINGO, DO NOT INCLUDE IN FORMULATION.;

!----;
F_IN_TPP5 = F_IP1_TPP5 + F_IP2_TPP5 + F_IP3_TPP5 + F_IP4_TPP5 +
F_IP5_TPP5 + F_IP6_TPP5 + F_IP7_TPP5 + F_IP8_TPP5 ; !kg/s = kg/s ;
F_IN_TPP5 * X_CHCL_IN_TPP5  = F_IP1_TPP5 * X_CHCL_IP1  + F_IP2_TPP5 *
X_CHCL_IP2  + F_IP3_TPP5 * X_CHCL_IP3  + F_IP4_TPP5 * X_CHCL_IP4  +
F_IP5_TPP5 * X_CHCL_IP5  + F_IP6_TPP5 * X_CHCL_IP6  + F_IP7_TPP5 *
X_CHCL_IP7 + F_IP8_TPP5 * X_CHCL_IP8 ;
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F_IN_TPP5 * X_M_IN_TPP5     = F_IP1_TPP5 * X_M_IP1     + F_IP2_TPP5 *
X_M_IP2     + F_IP3_TPP5 * X_M_IP3     + F_IP4_TPP5 * X_M_IP4     +
F_IP5_TPP5 * X_M_IP5     + F_IP6_TPP5 * X_M_IP6     + F_IP7_TPP5 *
X_M_IP7    + F_IP8_TPP5 * X_M_IP8    ;
X_CHCL_IN_TPP5 + X_M_IN_TPP5 <= 1 ; !JUST ADD TO EASE CALCULATION IN
LINGO, DO NOT INCLUDE IN FORMULATION.;

!----;
F_IN_TPP6 = F_IP1_TPP6 + F_IP2_TPP6 + F_IP3_TPP6 + F_IP4_TPP6 +
F_IP5_TPP6 + F_IP6_TPP6 + F_IP7_TPP6 + F_IP8_TPP6 ; !kg/s = kg/s ;
F_IN_TPP6 * X_CHCL_IN_TPP6  = F_IP1_TPP6 * X_CHCL_IP1 + F_IP2_TPP6  *
X_CHCL_IP2 + F_IP3_TPP6  * X_CHCL_IP3  + F_IP4_TPP6 * X_CHCL_IP4  +
F_IP5_TPP6 * X_CHCL_IP5  + F_IP6_TPP6 * X_CHCL_IP6  + F_IP7_TPP6 *
X_CHCL_IP7 + F_IP8_TPP6 * X_CHCL_IP8 ;
F_IN_TPP6 * X_M_IN_TPP6     = F_IP1_TPP6 * X_M_IP1    + F_IP2_TPP6  *
X_M_IP2    + F_IP3_TPP6  * X_M_IP3     + F_IP4_TPP6 * X_M_IP4     +
F_IP5_TPP6 * X_M_IP5     + F_IP6_TPP6 * X_M_IP6     + F_IP7_TPP6 *
X_M_IP7    + F_IP8_TPP6 * X_M_IP8    ;
X_CHCL_IN_TPP6 + X_M_IN_TPP6 <= 1 ; !JUST ADD TO EASE CALCULATION IN
LINGO, DO NOT INCLUDE IN FORMULATION.;

!----;
F_IN_TPP7 = F_IP1_TPP7 + F_IP2_TPP7 + F_IP3_TPP7 + F_IP4_TPP7 +
F_IP5_TPP7 + F_IP6_TPP7 + F_IP7_TPP7 + F_IP8_TPP7 ; !kg/s = kg/s ;
F_IN_TPP7 * X_CHCL_IN_TPP7  = F_IP1_TPP7 * X_CHCL_IP1 + F_IP2_TPP7  *
X_CHCL_IP2 + F_IP3_TPP7  * X_CHCL_IP3  + F_IP4_TPP7 * X_CHCL_IP4  +
F_IP5_TPP7 * X_CHCL_IP5  + F_IP6_TPP7 * X_CHCL_IP6  + F_IP7_TPP7 *
X_CHCL_IP7 + F_IP8_TPP7 * X_CHCL_IP8 ;
F_IN_TPP7 * X_M_IN_TPP7     = F_IP1_TPP7 * X_M_IP1    + F_IP2_TPP7  *
X_M_IP2    + F_IP3_TPP7  * X_M_IP3     + F_IP4_TPP7 * X_M_IP4     +
F_IP5_TPP7 * X_M_IP5     + F_IP6_TPP7 * X_M_IP6     + F_IP7_TPP7 *
X_M_IP7    + F_IP8_TPP7 * X_M_IP8    ;
X_CHCL_IN_TPP7 + X_M_IN_TPP7 <= 1 ; !JUST ADD TO EASE CALCULATION IN
LINGO, DO NOT INCLUDE IN FORMULATION.;

!----;
F_IN_BLANK3 = F_IP1_BLANK3 + F_IP2_BLANK3 + F_IP3_BLANK3 +
F_IP4_BLANK3 + F_IP5_BLANK3 + F_IP6_BLANK3 + F_IP7_BLANK3 +
F_IP8_BLANK3 ; !kg/s = kg/s ;
F_IN_BLANK3 * X_CHCL_IN_BLANK3  = F_IP1_BLANK3 * X_CHCL_IP1  +
F_IP2_BLANK3 * X_CHCL_IP2  + F_IP3_BLANK3 * X_CHCL_IP3  +
F_IP4_BLANK3 * X_CHCL_IP4  + F_IP5_BLANK3 * X_CHCL_IP5  +
F_IP6_BLANK3 * X_CHCL_IP6  + F_IP7_BLANK3 * X_CHCL_IP7 + F_IP8_BLANK3
* X_CHCL_IP8 ;
F_IN_BLANK3 * X_M_IN_BLANK3     = F_IP1_BLANK3 * X_M_IP1     +
F_IP2_BLANK3 * X_M_IP2     + F_IP3_BLANK3 * X_M_IP3     +
F_IP4_BLANK3 * X_M_IP4     + F_IP5_BLANK3 * X_M_IP5     +
F_IP6_BLANK3 * X_M_IP6     + F_IP7_BLANK3 * X_M_IP7    + F_IP8_BLANK3
* X_M_IP8    ;
X_CHCL_IN_BLANK3 + X_M_IN_BLANK3 <= 1 ; !JUST ADD TO EASE CALCULATION
IN LINGO, DO NOT INCLUDE IN FORMULATION.;

F_IN_TPP1 + F_IN_TPP2 + F_IN_TPP3 + F_IN_TPP4 + F_IN_TPP5 + F_IN_TPP6
+ F_IN_TPP7 + F_IN_BLANK3 = F_IN_TPP_TOTAL ;
F_IN_TPP1 <= TOTAL_BIOMASS_AVAILABLE ;
F_IN_TPP2 <= TOTAL_BIOMASS_AVAILABLE ;
F_IN_TPP3 <= TOTAL_BIOMASS_AVAILABLE ;
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F_IN_TPP4 <= TOTAL_BIOMASS_AVAILABLE ;
F_IN_TPP5 <= TOTAL_BIOMASS_AVAILABLE ;
F_IN_TPP6 <= TOTAL_BIOMASS_AVAILABLE ;
F_IN_TPP7 <= TOTAL_BIOMASS_AVAILABLE ;
F_IN_BLANK3 <= TOTAL_BIOMASS_AVAILABLE ;
F_IN_TPP_TOTAL <= TOTAL_BIOMASS_AVAILABLE ;

(F_IN_TPP1/TOTAL_BIOMASS_AVAILABLE) <= I_TPP1 ;
(F_IN_TPP2/TOTAL_BIOMASS_AVAILABLE) <= I_TPP2 ;
(F_IN_TPP3/TOTAL_BIOMASS_AVAILABLE) <= I_TPP3 ;
(F_IN_TPP4/TOTAL_BIOMASS_AVAILABLE) <= I_TPP4 ;
(F_IN_TPP5/TOTAL_BIOMASS_AVAILABLE) <= I_TPP5 ;
(F_IN_TPP6/TOTAL_BIOMASS_AVAILABLE) <= I_TPP6 ;
(F_IN_TPP7/TOTAL_BIOMASS_AVAILABLE) <= I_TPP7 ;
(F_IN_BLANK3/TOTAL_BIOMASS_AVAILABLE) <= I_BLANK3 ;
@BIN(I_TPP1); @BIN(I_TPP2);
@BIN(I_TPP3); @BIN(I_TPP4);
@BIN(I_TPP5); @BIN(I_TPP6);
@BIN(I_TPP7); @BIN(I_BLANK3);

(0.25 * I_TPP1) <= (X_M_IN_TPP1 * I_TPP1) ;
(X_M_IN_TPP1 * I_TPP1) <= (0.65 * I_TPP1) ;
(0.25 * I_TPP2) <= (X_M_IN_TPP2 * I_TPP2) ;
(X_M_IN_TPP2 * I_TPP2) <= (0.65 * I_TPP2) ;
(0.25 * I_TPP3) <= (X_M_IN_TPP3 * I_TPP3) ;
(X_M_IN_TPP3 * I_TPP3) <= (0.65 * I_TPP3) ;
(0.25 * I_TPP4) <= (X_M_IN_TPP4 * I_TPP4) ;
(X_M_IN_TPP4 * I_TPP4) <= (0.72 * I_TPP4) ;
(0.04 * I_TPP5) <= (X_M_IN_TPP5 * I_TPP5) ;
(X_M_IN_TPP5 * I_TPP5) <= (0.07 * I_TPP5) ;
(0.04 * I_TPP6) <= (X_M_IN_TPP6 * I_TPP6) ;
(X_M_IN_TPP6 * I_TPP6) <= (0.12 * I_TPP6) ;
(0 * I_TPP7)    <= (X_M_IN_TPP7 * I_TPP7) ;
(X_M_IN_TPP7 * I_TPP7) <= (1 * I_TPP7) ;
(0 * I_BLANK3)  <= (X_M_IN_BLANK3 * I_BLANK3) ;
(X_M_IN_BLANK3 * I_BLANK3) <= (1 * I_BLANK3) ;


(25 * I_TPP1)  <= (S_3 * I_TPP1) ;
(S_3 * I_TPP1) <= (125 * I_TPP1) ;
(0.5 * I_TPP2) <= (S_3 * I_TPP2) ;
(S_3 * I_TPP2) <= (50  * I_TPP2) ;
(0 * I_TPP3)   <= (S_3 * I_TPP3) ;
(S_3 * I_TPP3) <= (100 * I_TPP3) ;
(0 * I_TPP4)   <= (S_3 * I_TPP4) ;
(S_3 * I_TPP4) <= (150 * I_TPP4) ;
(25 * I_TPP5)  <= (S_3 * I_TPP5) ;
(S_3 * I_TPP5) <= (150 * I_TPP5) ;
(25 * I_TPP6)  <= (S_3 * I_TPP6) ;
(S_3 * I_TPP6) <= (150 * I_TPP6) ;
(0 * I_TPP7)   <= (S_3 * I_TPP7) ;
(S_3 * I_TPP7) <= (150 * I_TPP7) ;
(0 * I_BLANK3) <= (S_3 * I_BLANK3) ;

 (S_3 * I_BLANK3) <= (150 * I_BLANK3) ;

F_OUTCHCL_TPP1 = F_IN_TPP1 * X_CHCL_IN_TPP1 ;
F_OUTCHCL_TPP2 = F_IN_TPP2 * X_CHCL_IN_TPP2 ;
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F_OUTCHCL_TPP3 = F_IN_TPP3 * X_CHCL_IN_TPP3 ;
F_OUTCHCL_TPP4 = F_IN_TPP4 * X_CHCL_IN_TPP4 ;
F_OUTCHCL_TPP5 = F_IN_TPP5 * X_CHCL_IN_TPP5 ;
F_OUTCHCL_TPP6 = F_IN_TPP6 * X_CHCL_IN_TPP6 ;
F_OUTCHCL_TPP7 = F_IN_TPP7 * X_CHCL_IN_TPP7 ;
F_OUTCHCL_BLANK3 = F_IN_BLANK3 * X_CHCL_IN_BLANK3 ;

F_OUTCHCL_TPP1 <= TOTAL_CHCL_AVAILABLE ;
F_OUTCHCL_TPP2 <= TOTAL_CHCL_AVAILABLE ;
F_OUTCHCL_TPP3 <= TOTAL_CHCL_AVAILABLE ;
F_OUTCHCL_TPP4 <= TOTAL_CHCL_AVAILABLE ;
F_OUTCHCL_TPP5 <= TOTAL_CHCL_AVAILABLE ;
F_OUTCHCL_TPP6 <= TOTAL_CHCL_AVAILABLE ;
F_OUTCHCL_TPP7 <= TOTAL_CHCL_AVAILABLE ;
F_OUTCHCL_BLANK3 <= TOTAL_CHCL_AVAILABLE;
F_OUTCHCL_TPP_TOTAL = F_OUTCHCL_TPP1 + F_OUTCHCL_TPP2 +
F_OUTCHCL_TPP3 + F_OUTCHCL_TPP4 + F_OUTCHCL_TPP5 + F_OUTCHCL_TPP6 +
F_OUTCHCL_TPP7 + F_OUTCHCL_BLANK3 ;
F_OUTCHCL_TPP_TOTAL <= TOTAL_CHCL_AVAILABLE ;

F_OUTM_TPP1 = F_IN_TPP1 * X_M_IN_TPP1 - F_MR_TPP1 ;
F_OUTM_TPP2 = F_IN_TPP2 * X_M_IN_TPP2 - F_MR_TPP2 ;
F_OUTM_TPP3 = F_IN_TPP3 * X_M_IN_TPP3 - F_MR_TPP3 ;
F_OUTM_TPP4 = F_IN_TPP4 * X_M_IN_TPP4 - F_MR_TPP4 ;
F_OUTM_TPP5 = F_IN_TPP5 * X_M_IN_TPP5 - F_MR_TPP5 ;
F_OUTM_TPP6 = F_IN_TPP6 * X_M_IN_TPP6 - F_MR_TPP6 ;
F_OUTM_TPP7 = F_IN_TPP7 * X_M_IN_TPP7 - F_MR_TPP7 ;
F_OUTM_BLANK3 = F_IN_BLANK3 * X_M_IN_BLANK3 - F_MR_BLANK3 ;

F_MR_TPP1 = F_IN_TPP1 * X_M_IN_TPP1 * MRR_TPP1 ;
0.56 <= MRR_TPP1 ;
MRR_TPP1 <= 0.86 ;
TR_TPP1 = 0.67 ; !kWhr/kg ;
EF_TPP1 = 0.6 ;
P_D_TPP1 * EF_TPP1 * 3600 = TR_TPP1 * F_MR_TPP1  ; !kWhr/s * 3600
s/hr = kWhr/kg * kg/s ;

F_MR_TPP2 = F_IN_TPP2 * X_M_IN_TPP2 * MRR_TPP2 ;
0.56 <= MRR_TPP2 ;
MRR_TPP2 <= 0.86 ;
TR_TPP2 = 0.67 ; !kWhr/kg ;
EF_TPP2 = 0.86 ;
P_D_TPP2 * EF_TPP2 * 3600 = TR_TPP2 * F_MR_TPP2  ; !kWhr/s * 3600
s/hr = kWhr/kg * kg/s ;

F_MR_TPp3 = F_IN_TPp3 * X_M_IN_TPP3 * MRR_TPp3 ;
0.56 <= MRR_TPP3 ;
MRR_TPP3 <= 0.86 ;
TR_TPP3 = 0.67 ; !kWhr/kg ;
EF_TPP3 = 0.87 ;
P_D_TPP3 * EF_TPp3 * 3600 = TR_TPP3 * F_MR_TPP3 ; !kWhr/s * 3600 s/hr
= kWhr/kg * kg/s ;

F_MR_TPp4 = F_IN_TPp4 * X_M_IN_TPP4 * MRR_TPP4 ;
0.64 <= MRR_TPP4 ;
MRR_TPp4 <= 0.81 ;
TR_TPp4 = 0.67 ; !kWhr/kg ;
```

```
EF_TPp4 = 0.7 ;
P_D_TPp4 * EF_TPP4 * 3600 = TR_TPP4 * F_MR_TPP4 ; !kWhr/s * 3600 s/hr
= kWhr/kg * kg/s ;

F_MR_TPp5 = F_IN_TPp5 * X_M_IN_TPP5 * MRR_TPP5 ;
MRR_TPp5 = 0.15 ;
TR_TPp5 = 0 ; !kWhr/kg ;
EF_TPp5 = 1 ;
P_D_TPp5 * EF_TPp5 * 3600  = TR_TpP5 * F_MR_TPp5 ; !kWhr/s * 3600
s/hr = kWhr/kg * kg/s ;

F_MR_TPp6 = F_IN_TpP6 * X_M_IN_TpP6 * MRR_TpP6 ;
MRR_TPp6 = 0.15 ;
TR_TPp6 = 0 ; !kWhr/kg ;
EF_TPp6 = 1 ;
P_D_TPp6 * EF_TPp6 * 3600 = TR_TpP6 * F_MR_TpP6 ; !kWhr/s * 3600 s/hr
= kWhr/kg * kg/s ;

F_MR_TPp7 = F_IN_TpP7 * X_M_IN_TpP7 * MRR_TpP7 ;
MRR_TPp7 = 0.15 ;
TR_TPp7 = 0 ; !kWhr/kg ;
EF_TPp7 = 1 ;
P_D_TPp7 * EF_TPp7 * 3600 = TR_TpP7 * F_MR_TpP7 ; !kWhr/s * 3600 s/hr
= kWhr/kg * kg/s ;

F_MR_BLANK3 = F_IN_BLANK3 * X_M_IN_BLANK3 * MRR_BLANK3 ;
MRR_BLANK3 = 0 ;
TR_BLANK3 = 0 ; !kWhr/kg ;
EF_BLANK3 = 1;
P_D_BLANK3 * EF_BLANK3 * 3600 = TR_BLANK3 * F_MR_BLANK3 ; !kWhr/s *
3600 s/hr  = kWhr/kg * kg/s ;

P_D_TPP1 + P_D_TPP2 + P_D_TPP3 + P_D_TPP4 + P_D_TPP5 + P_D_TPP6 +
P_D_TPP7 + P_D_BLANK3 = P_D_TPP_TOTAL ;

                                                F_OUTM_TPP_TOTAL =
F_OUTM_TPP1 + F_OUTM_TPP2 + F_OUTM_TPP3 + F_OUTM_TPP4 + F_OUTM_TPP5 +
F_OUTM_TPP6 + F_OUTM_TPP7 + F_OUTM_BLANK3 ;
                                                F_OUTM_TPP_TOTAL <=
TOTAL_M_AVAILABLE ;

S_IN_TPP1 = S_3 ; S_IN_TPP2 = S_3 ;
S_IN_TPP3 = S_3 ; S_IN_TPP4 = S_3 ;
S_IN_TPP5 = S_3 ; S_IN_TPP6 = S_3 ;
S_IN_TPP7 = S_3 ; S_IN_BLANK3 = S_3 ;

(S_IN_TPP1/SRR_TPP1) * I_TPP1 = S_IPP1 ;
S_IPP1 <= 10000 * I_TPP1 ;
SRR_TPP1 = 1 ;
P_SR_TPP1 = I_TPP1 * @LOG10 (SRR_TPP1) * F_IN_TPP1 ; !kW = kW/kgs-1 *
kgs-1 ;
@FREE (K_TPP1);
@FREE (P_SR_TPP1);

(S_IN_TPP2/SRR_TPP2) * I_TPP2 = S_IPP2 ;
S_IPP2 <= 10000 * I_TPP2 ;
SRR_TPP2 = 1 ;
```

```
P_SR_TPP2 = I_TPP2 * @LOG10 (SRR_TPP2) * F_IN_TPP2 ; !kW = kW/kgs-1 *
kgs-1 ;
@FREE (K_TPP2);
@FREE (P_SR_TPP2);

(S_IN_TPP3/SRR_TPP3) * I_TPP3 = S_IPP3 ;
S_IPP3 <= 10000 * I_TPP3 ;
SRR_TPP3 = 1 ;
P_SR_TPP3 = I_TPP3 * @LOG10 (SRR_TPP3) * F_IN_TPP3 ; !kW = kW/kgs-1 *
kgs-1 ;
@FREE (K_TPP3);
@FREE (P_SR_TPP3);

(S_IN_TPP4/SRR_TPP4) * I_TPP4 = S_IPP4 ;
S_IPP4 <= 10000 * I_TPP4 ;
SRR_TPP4 = 1 ;
P_SR_TPP4 = I_TPP4 * @LOG10 (SRR_TPP4) * F_IN_TPP4 ; !kW = kW/kgs-1 *
kgs-1 ;
@FREE (K_TPP4);
@FREE (P_SR_TPP4);

(S_IN_TPP5/SRR_TPP5) * I_TPP5 = S_IPP5 ;
S_IPP5 <= 10000 * I_TPP5 ;
2 <= SRR_TPP5 ;
SRR_TPP5 <= 14 ;
A_TPP5 = @LOG10(SRR_TPP5);
B_TPP5 = X_M_IN_TPP5 ;
K_TPP5 = 339.9 - 1109*A_TPP5 - 7.529*B_TPP5  + 947.4*(A_TPP5^2) +
170.5*(A_TPP5)*(B_TPP5) - 16.53*(B_TPP5^2) - 362.7*(A_TPP5^3)
      - 76.75*(A_TPP5^2)*(B_TPP5)  - 5.958*(A_TPP5)*(B_TPP5^2) +
1.836*(B_TPP5 ^3) + 56.16*(A_TPP5^4) + 3.813*(A_TPP5^3)*(B_TPP5) +
4.932*(A_TPP5^2)*(B_TPP5^2) - 0.7026*A_TPP5*(B_TPP5^3) ;
P_SR_TPP5 = I_TPP5 * K_TPP5 * @LOG10 (SRR_TPP5) * F_IN_TPP5 ; !kW =
kW/kgs-1 * kgs-1 ;
@FREE (K_TPP5);
@FREE (P_SR_TPP5);

(S_IN_TPP6/SRR_TPP6) * I_TPP6 = S_IPP6 ;
S_IPP6 <= 10000 * I_TPP6 ;
2.23 <= SRR_TPP6 ;
SRR_TPP6 <= 12.825 ;
A_TPP6 = @LOG10(SRR_TPP6);
B_TPP6 = X_M_IN_TPP6 ;
K_TPP6 = 49.02 + 10.04 *A_TPP6 - 72.54*B_TPP6  + 11.03*(A_TPP6^2) +
2.03*(A_TPP6)*(B_TPP6) + 96.17*(B_TPP6^2) +0.7976*(A_TPP6^3)
      +2.241*(A_TPP6^2)*(B_TPP6)  - 4.248*(A_TPP6)*(B_TPP6^2) -
18.67*(B_TPP6^3) + 2.451*(A_TPP6^4) + 6.563*(A_TPP6^3)*(B_TPP6) -
0.3381*(A_TPP6^2)*(B_TPP6^2) - 9.35*A_TPP6*(B_TPP6^3) -
43.85*(B_TPP6^4) ;
P_SR_TPP6 = I_TPP6 * K_TPP6 * @LOG10 (SRR_TPP6) * F_IN_TPP6 ; !kW =
kW/kgs-1 * kgs-1 ;
@FREE (K_TPP6);
@FREE (P_SR_TPP6);

(S_IN_TPP7/SRR_TPP7) * I_TPP7 = S_IPP7 ;
```

```
S_IPP7 <= 10000 * I_TPP7 ;
2.03 <= SRR_TPP7 ;
SRR_TPP7 <= 4.06 ;
A_TPP7 = @LOG10(SRR_TPP7);
K_TPP7 = 1.0633 * A_TPP7 + 0.0203 ;
P_SR_TPP7 = I_TPP7 * K_TPP7 * @LOG10 (SRR_TPP7) * F_IN_TPP7 ; !kW =
kW/kgs-1 * kgs-1 ;
@FREE (K_TPP7);
@FREE (P_SR_TPP7);

(S_IN_BLANK3/SRR_BLANK3) * I_BLANK3 = S_IPP8 ;
S_IPP8 <= 10000 * I_BLANK3 ;
SRR_BLANK3 = 1 ;
P_SR_BLANK3 = I_BLANK3 * @LOG10 (SRR_BLANK3) * F_IN_BLANK3; !kW =
kW/kgs-1 * kgs-1 ;
@FREE (K_BLANK3);
@FREE (P_SR_BLANK3);

P_SR_TPP1 + P_SR_TPP2 + P_SR_TPP3 + P_SR_TPP4 + P_SR_TPP5 + P_SR_TPP6
+ P_SR_TPP7 + P_SR_BLANK3 = P_SR_TPP_TOTAL ;

!TECHNOLOGY COST;
C_TPP1 = ((2.9*3*18^0.63)*1000)*(((F_IN_T1*3600/1000)/1)^0.6);
C_TPP2 = ((2.23*1.75*46^0.6)*1000)*(((F_IN_TPP2*3600/1000)/1)^0.6);
C_TPP3 = ((45*1^0.7)*1000)*(((F_IN_TPP3*3600/1000)/1)^0.6);
C_TPP4 = ((1.4*5^0.77)*1000)*(((F_IN_TPP4*3600/1000)/1)^0.6);
C_TPP5 = ((27.5*1*0.39)*1000)*(((F_IN_TPP5*3600/1000)/1)^0.6);
C_TPP6 = ((2.97*(F_IN_TPP6*3600/1000)^0.78)*1000);
C_TPP7 = ((7.7*1^0.57)*1000)*(((F_IN_TPP7*3600/1000)/1)^0.6);
C_BLANK3 = F_IN_BLANK3 * 0;

C_TPP_TOTAL = C_TPP1 + C_TPP2 + C_TPP3 + C_TPP4 + C_TPP5 + C_TPP6 +
C_TPP7 + C_BLANK3 ;

F_IPP1 = F_OUTCHCL_TPP1 + F_OUTM_TPP1 ; !kg/s = kg/s ;
F_IPP2 = F_OUTCHCL_TPP2 + F_OUTM_TPP2 ; !kg/s = kg/s ;
F_IPP3 = F_OUTCHCL_TPP3 + F_OUTM_TPP3 ; !kg/s = kg/s ;
F_IPP4 = F_OUTCHCL_TPP4 + F_OUTM_TPP4 ; !kg/s = kg/s ;
F_IPP5 = F_OUTCHCL_TPP5 + F_OUTM_TPP5 ; !kg/s = kg/s ;
F_IPP6 = F_OUTCHCL_TPP6 + F_OUTM_TPP6 ; !kg/s = kg/s ;
F_IPP7 = F_OUTCHCL_TPP7 + F_OUTM_TPP7 ; !kg/s = kg/s ;
F_IPP8 = F_OUTCHCL_BLANK3 + F_OUTM_BLANK3 ; !kg/s = kg/s ;

F_IPP1 <= TOTAL_BIOMASS_AVAILABLE ;
F_IPP2 <= TOTAL_BIOMASS_AVAILABLE ;
F_IPP3 <= TOTAL_BIOMASS_AVAILABLE ;
F_IPP4 <= TOTAL_BIOMASS_AVAILABLE ;
F_IPP5 <= TOTAL_BIOMASS_AVAILABLE ;
F_IPP6 <= TOTAL_BIOMASS_AVAILABLE ;
F_IPP7 <= TOTAL_BIOMASS_AVAILABLE ;
F_IPP8 <= TOTAL_BIOMASS_AVAILABLE ;
F_IPP_TOTAL = F_IPP1 + F_IPP2 + F_IPP3 + F_IPP4 + F_IPP5 + F_IPP6 +
F_IPP7 + F_IPP8 ;
F_IPP_TOTAL <= TOTAL_BIOMASS_AVAILABLE ;

F_OUTCHCL_TPP1   = F_IPP1 * X_CHCL_IPP1 ;
F_OUTM_TPP1      = F_IPP1 * X_M_IPP1    ;
```

```
X_CHCL_IPP1 + X_M_IPP1 <= 1 ; !JUST ADD TO EASE CALCULATION IN LINGO,
DO NOT INCLUDE IN FORMULATION.;

F_OUTCHCL_TPP2   = F_IPP2 * X_CHCL_IPP2 ;
F_OUTM_TPP2      = F_IPP2 * X_M_IPP2    ;
X_CHCL_IPP2 + X_M_IPP2 <= 1 ; !JUST ADD TO EASE CALCULATION IN LINGO,
DO NOT INCLUDE IN FORMULATION.;

F_OUTCHCL_TPP3   = F_IPP3 * X_CHCL_IPP3 ;
F_OUTM_TPP3      = F_IPP3 * X_M_IPP3    ;
X_CHCL_IPP3 + X_M_IPP3 <= 1 ; !JUST ADD TO EASE CALCULATION IN LINGO,
DO NOT INCLUDE IN FORMULATION.;

F_OUTCHCL_TPP4   = F_IPP4 * X_CHCL_IPP4 ;
F_OUTM_TPP4      = F_IPP4 * X_M_IPP4    ;
X_CHCL_IPP4 + X_M_IPP4 <= 1 ; !JUST ADD TO EASE CALCULATION IN LINGO,
DO NOT INCLUDE IN FORMULATION.;

F_OUTCHCL_TPP5   = F_IPP5 * X_CHCL_IPP5 ;
F_OUTM_TPP5      = F_IPP5 * X_M_IPP5    ;
X_CHCL_IPP5 + X_M_IPP5 <= 1 ; !JUST ADD TO EASE CALCULATION IN LINGO,
DO NOT INCLUDE IN FORMULATION.;

F_OUTCHCL_TPP6   = F_IPP6 * X_CHCL_IPP6 ;
F_OUTM_TPP6      = F_IPP6 * X_M_IPP6    ;
X_CHCL_IPP6 + X_M_IPP6 <= 1 ; !JUST ADD TO EASE CALCULATION IN LINGO,
DO NOT INCLUDE IN FORMULATION.;

F_OUTCHCL_TPP7   = F_IPP7 * X_CHCL_IPP7 ;
F_OUTM_TPP7      = F_IPP7 * X_M_IPP7    ;
X_CHCL_IPP7 + X_M_IPP7 <= 1 ; !JUST ADD TO EASE CALCULATION IN LINGO,
DO NOT INCLUDE IN FORMULATION.;

F_OUTCHCL_BLANK3 = F_IPP8 * X_CHCL_IPP8 ;
F_OUTM_BLANK3    = F_IPP8 * X_M_IPP8    ;
X_CHCL_IPP8 + X_M_IPP8 <= 1 ; !JUST ADD TO EASE CALCULATION IN LINGO,
DO NOT INCLUDE IN FORMULATION.;

I_TPP1 + I_TPP2 + I_TPP3 + I_TPP4 + I_TPP5 + I_TPP6 + I_TPP7 +
I_BLANK3 = I_TPP_TOTAL;

I_T_TOTAL + I_TP_TOTAL + I_TPP_TOTAL = I_TOTAL ;

P_TOTAL = (P_D_T_TOTAL + P_D_TP_TOTAL + P_D_TPP_TOTAL) +
(P_SR_T_TOTAL + P_SR_TP_TOTAL + P_SR_TPP_TOTAL);

C_TOTAL = C_T_TOTAL + C_TP_TOTAL + C_TPP_TOTAL ;

MAX = F_IPP_TOTAL -(0.00001 * I_TOTAL) ;

X_M_IPP1 <= 0.165 ;
X_M_IPP2 <= 0.165 ;
X_M_IPP3 <= 0.165 ;
X_M_IPP4 <= 0.165 ;
X_M_IPP5 <= 0.165 ;
X_M_IPP6 <= 0.165 ;
X_M_IPP7 <= 0.165 ;
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```
X_M_IPP8 <= 0.165 ;

S_IPP1 <= 16.5 ;
S_IPP2 <= 16.5 ;
S_IPP3 <= 16.5 ;
S_IPP4 <= 16.5 ;
S_IPP5 <= 16.5 ;
S_IPP6 <= 16.5 ;
S_IPP7 <= 16.5 ;
S_IPP8 <= 16.5 ;
```

APPENDIX A4

Lingo File

For sensitivity analysis (13.5wt% and 13.5mm)

```
!INFORMATION;
F_AVAILABLE_EFB = 3.9 ; !kg/s;
X_CHCL_EFB  = 0.55;  X_M_EFB  = 0.45;  S_EFB  = 150 ; !mm;

F_AVAILABLE_PKS = 1.2 ; !kg/s;
X_CHCL_PKS  = 0.73 ; X_M_PKS  = 0.27 ; S_PKS = 20 ; !mm;

F_AVAILABLE_PMF = 2.2 ; !kg/s;
X_CHCL_PMF  = 0.77 ; X_M_PMF  = 0.23 ; S_PMF = 30 ; !mm;

!PROBLEM SIZE DEFINITION FOR EASIER SOLVING;
TOTAL_BIOMASS_AVAILABLE = F_AVAILABLE_EFB + F_AVAILABLE_PKS +
F_AVAILABLE_PMF ;
TOTAL_CHCL_AVAILABLE    = F_AVAILABLE_EFB * X_CHCL_EFB +
F_AVAILABLE_PKS * X_CHCL_PKS + F_AVAILABLE_PMF * X_CHCL_PMF ;
TOTAL_M_AVAILABLE       = F_AVAILABLE_EFB * X_M_EFB    +
F_AVAILABLE_PKS * X_M_PKS    + F_AVAILABLE_PMF * X_M_PMF    ;
F_EFB <= F_AVAILABLE_EFB ;
F_PKS <= F_AVAILABLE_PKS ;
F_PMF <= F_AVAILABLE_PMF ;

!MODEL STARTS;
!STAGE 1;
S_1 >= S_EFB ;
S_1 >= S_PKS ;
S_1 >= S_PMF ;

F_EFB = F_EFB_T1 + F_EFB_T2 + F_EFB_T3 + F_EFB_T4 + F_EFB_T5 +
F_EFB_T6 + F_EFB_T7 + F_EFB_BLANK1 ;  !kg/s = kg/s ;
F_PKS = F_PKS_T1 + F_PKS_T2 + F_PKS_T3 + F_PKS_T4 + F_PKS_T5 +
F_PKS_T6 + F_PKS_T7 + F_PKS_BLANK1 ;  !kg/s = kg/s ;
F_PMF = F_PMF_T1 + F_PMF_T2 + F_PMF_T3 + F_PMF_T4 + F_PMF_T5 +
F_PMF_T6 + F_PMF_T7 + F_PMF_BLANK1 ;  !kg/s = kg/s ;

F_IN_T1 = F_EFB_T1 + F_PKS_T1 + F_PMF_T1 ; !kg/s = kg/s ;
F_IN_T1 * X_CHCL_IN_T1 = F_EFB_T1 * X_CHCL_EFB + F_PKS_T1 *
X_CHCL_PKS + F_PMF_T1 * X_CHCL_PMF ;
F_IN_T1 * X_M_IN_T1    = F_EFB_T1 * X_M_EFB    + F_PKS_T1 * X_M_PKS
+ F_PMF_T1 * X_M_PMF    ;
X_CHCL_IN_T1 + X_M_IN_T1 <= 1;
```

```
F_IN_T2 = F_EFB_T2 + F_PKS_T2 + F_PMF_T2 ; !kg/s = kg/s ;
F_IN_T2 * X_CHCL_IN_T2 = F_EFB_T2 * X_CHCL_EFB + F_PKS_T2 *
X_CHCL_PKS + F_PMF_T2 * X_CHCL_PMF ;
F_IN_T2 * X_M_IN_T2    = F_EFB_T2 * X_M_EFB    + F_PKS_T2 * X_M_PKS
+ F_PMF_T2 * X_M_PMF    ;
X_CHCL_IN_T2 + X_M_IN_T2 <= 1;

F_IN_T3 = F_EFB_T3 + F_PKS_T3 + F_PMF_T3 ; !kg/s = kg/s ;
F_IN_T3 * X_CHCL_IN_T3 = F_EFB_T3 * X_CHCL_EFB + F_PKS_T3 *
X_CHCL_PKS + F_PMF_T3 * X_CHCL_PMF ;
F_IN_T3 * X_M_IN_T3    = F_EFB_T3 * X_M_EFB    + F_PKS_T3 * X_M_PKS
+ F_PMF_T3 * X_M_PMF    ;
X_CHCL_IN_T3 + X_M_IN_T3 <= 1;

F_IN_T4 = F_EFB_T4 + F_PKS_T4 + F_PMF_T4 ;
F_IN_T4 * X_CHCL_IN_T4 = F_EFB_T4 * X_CHCL_EFB + F_PKS_T4 *
X_CHCL_PKS + F_PMF_T4 * X_CHCL_PMF ;
F_IN_T4 * X_M_IN_T4    = F_EFB_T4 * X_M_EFB    + F_PKS_T4 * X_M_PKS
+ F_PMF_T4 * X_M_PMF    ;
X_CHCL_IN_T4 + X_M_IN_T4 <= 1;

F_IN_T5 = F_EFB_T5 + F_PKS_T5 + F_PMF_T5 ; !kg/s = kg/s ;
F_IN_T5 * X_CHCL_IN_T5 = F_EFB_T5 * X_CHCL_EFB + F_PKS_T5 *
X_CHCL_PKS + F_PMF_T5 * X_CHCL_PMF ;
F_IN_T5 * X_M_IN_T5    = F_EFB_T5 * X_M_EFB    + F_PKS_T5 * X_M_PKS
+ F_PMF_T5 * X_M_PMF    ;
X_CHCL_IN_T5 + X_M_IN_T5 <= 1;

F_IN_T6 = F_EFB_T6 + F_PKS_T6 + F_PMF_T6 ; !kg/s = kg/s ;
F_IN_T6 * X_CHCL_IN_T6 = F_EFB_T6 * X_CHCL_EFB + F_PKS_T6 *
X_CHCL_PKS + F_PMF_T6 * X_CHCL_PMF ;
F_IN_T6 * X_M_IN_T6    = F_EFB_T6 * X_M_EFB    + F_PKS_T6 * X_M_PKS
+ F_PMF_T6 * X_M_PMF    ;
X_CHCL_IN_T6 + X_M_IN_T6 <= 1;

F_IN_T7 = F_EFB_T7 + F_PKS_T7 + F_PMF_T7 ; !kg/s = kg/s ;
F_IN_T7 * X_CHCL_IN_T7 = F_EFB_T7 * X_CHCL_EFB + F_PKS_T7 *
X_CHCL_PKS + F_PMF_T7 * X_CHCL_PMF ;
F_IN_T7 * X_M_IN_T7    = F_EFB_T7 * X_M_EFB    + F_PKS_T7 * X_M_PKS
+ F_PMF_T7 * X_M_PMF    ;
X_CHCL_IN_T7 + X_M_IN_T7 <= 1;

F_IN_BLANK1 = F_EFB_BLANK1 + F_PKS_BLANK1 + F_PMF_BLANK1 ;
F_IN_BLANK1 * X_CHCL_IN_BLANK1 = F_EFB_BLANK1 * X_CHCL_EFB +
F_PKS_BLANK1 * X_CHCL_PKS + F_PMF_BLANK1 * X_CHCL_PMF ;
F_IN_BLANK1 * X_M_IN_BLANK1    = F_EFB_BLANK1 * X_M_EFB    +
F_PKS_BLANK1 * X_M_PKS    + F_PMF_BLANK1 * X_M_PMF    ;
X_CHCL_IN_BLANK1 + X_M_IN_BLANK1 <= 1;

F_IN_T1 + F_IN_T2 + F_IN_T3 + F_IN_T4 + F_IN_T5 + F_IN_T6 + F_IN_T7 +
F_IN_BLANK1 = F_IN_T_TOTAL ;
F_IN_T1 <= TOTAL_BIOMASS_AVAILABLE ;
F_IN_T2 <= TOTAL_BIOMASS_AVAILABLE ;
F_IN_T3 <= TOTAL_BIOMASS_AVAILABLE ;
F_IN_T4 <= TOTAL_BIOMASS_AVAILABLE ;
F_IN_T5 <= TOTAL_BIOMASS_AVAILABLE ;
F_IN_T6 <= TOTAL_BIOMASS_AVAILABLE ;
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F_IN_T7 <= TOTAL_BIOMASS_AVAILABLE ;
F_IN_BLANK1 <= TOTAL_BIOMASS_AVAILABLE ;
F_IN_T_TOTAL <= TOTAL_BIOMASS_AVAILABLE ;

(F_IN_T1/TOTAL_BIOMASS_AVAILABLE) <= I_T1 ;
(F_IN_T2/TOTAL_BIOMASS_AVAILABLE) <= I_T2 ;
(F_IN_T3/TOTAL_BIOMASS_AVAILABLE) <= I_T3 ;
(F_IN_T4/TOTAL_BIOMASS_AVAILABLE) <= I_T4 ;
(F_IN_T5/TOTAL_BIOMASS_AVAILABLE) <= I_T5 ;
(F_IN_T6/TOTAL_BIOMASS_AVAILABLE) <= I_T6 ;
(F_IN_T7/TOTAL_BIOMASS_AVAILABLE) <= I_T7 ;
(F_IN_BLANK1/TOTAL_BIOMASS_AVAILABLE) <= I_BLANK1 ;
@BIN(I_T1); @BIN(I_T2);
@BIN(I_T3); @BIN(I_T4);
@BIN(I_T5); @BIN(I_T6);
@BIN(I_T7); @BIN(I_BLANK1);

(0.25 * I_T1)  <= (X_M_IN_T1 * I_T1)         ;
(X_M_IN_T1 * I_T1)         <= (0.65 * I_T1)  ;
(0.25 * I_T2)  <= (X_M_IN_T2 * I_T2)         ;
(X_M_IN_T2 * I_T2)         <= (0.65 * I_T2)  ;
(0.25 * I_T3)  <= (X_M_IN_T3 * I_T3)         ;
(X_M_IN_T3 * I_T3)         <= (0.65 * I_T3)  ;
(0.25 * I_T4)  <= (X_M_IN_T4 * I_T4)         ;
(X_M_IN_T4 * I_T4)         <= (0.72 * I_T4)  ;
(0.04 * I_T5)  <= (X_M_IN_T5 * I_T5)         ;
(X_M_IN_T5 * I_T5)         <= (0.07 * I_T5)  ;
(0.04 * I_T6)  <= (X_M_IN_T6 * I_T6)         ;
(X_M_IN_T6 * I_T6)         <= (0.12 * I_T6)  ;
(0 * I_T7)     <= (X_M_IN_T7 * I_T7)         ;
(X_M_IN_T7 * I_T7)         <= (1 * I_T7)     ;
(0 * I_BLANK1) <= (X_M_IN_BLANK1 * I_BLANK1) ; (X_M_IN_BLANK1 *
I_BLANK1) <= (1 * I_BLANK1) ;

(25  * I_T1)     <= (S_1 * I_T1)     ;
(S_1 * I_T1)     <= (125 * I_T1)     ;
(0.5 * I_T2)     <= (S_1 * I_T2)     ;
(S_1 * I_T2)     <= (50  * I_T2)     ;
(0   * I_T3)     <= (S_1 * I_T3)     ;
(S_1 * I_T3)     <= (100 * I_T3)     ;
(0   * I_T4)     <= (S_1 * I_T4)     ;
(S_1 * I_T4)     <= (150 * I_T4)     ;
(25  * I_T5)     <= (S_1 * I_T5)     ;
(S_1 * I_T5)     <= (150 * I_T5)     ;
(25  * I_T6)     <= (S_1 * I_T6)     ;
(S_1 * I_T6)     <= (150 * I_T6)     ;
(0   * I_T7)     <= (S_1 * I_T7)     ;
(S_1 * I_T7)     <= (150 * I_T7)     ;
   (4   * I_BLANK1) <= (S_1 * I_BLANK1) ;
   (5   (S_1 * I_BLANK1) <= (150 * I_BLANK1) ;

F_OUTCHCL_T1 = F_IN_T1 * X_CHCL_IN_T1 ;
F_OUTCHCL_T2 = F_IN_T2 * X_CHCL_IN_T2 ;
F_OUTCHCL_T3 = F_IN_T3 * X_CHCL_IN_T3 ;
F_OUTCHCL_T4 = F_IN_T4 * X_CHCL_IN_T4 ;
F_OUTCHCL_T5 = F_IN_T5 * X_CHCL_IN_T5 ;
F_OUTCHCL_T6 = F_IN_T6 * X_CHCL_IN_T6 ;
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F_OUTCHCL_T7 = F_IN_T7 * X_CHCL_IN_T7 ;
F_OUTCHCL_BLANK1 = F_IN_BLANK1 * X_CHCL_IN_BLANK1;

F_OUTCHCL_T1 <= TOTAL_CHCL_AVAILABLE ;
F_OUTCHCL_T2 <= TOTAL_CHCL_AVAILABLE ;
F_OUTCHCL_T3 <= TOTAL_CHCL_AVAILABLE ;
F_OUTCHCL_T4 <= TOTAL_CHCL_AVAILABLE ;
F_OUTCHCL_T5 <= TOTAL_CHCL_AVAILABLE ;
F_OUTCHCL_T6 <= TOTAL_CHCL_AVAILABLE ;
F_OUTCHCL_T7 <= TOTAL_CHCL_AVAILABLE ;
F_OUTCHCL_BLANK1 <= TOTAL_CHCL_AVAILABLE ;
F_OUTCHCL_T_TOTAL = F_OUTCHCL_T1 + F_OUTCHCL_T2 + F_OUTCHCL_T3 +
F_OUTCHCL_T4 + F_OUTCHCL_T5 + F_OUTCHCL_T6 + F_OUTCHCL_T7 +
F_OUTCHCL_BLANK1 ;
F_OUTCHCL_T_TOTAL <= TOTAL_CHCL_AVAILABLE ;

F_MR_T1 = F_IN_T1 * X_M_IN_T1 * MRR_T1 ; !kg/s = kg/s;
0.56 <= MRR_T1 ;
MRR_T1 <= 0.86 ;
TR_T1 = 0.67 ;!kWhr/kg ;
EF_T1 = 0.6 ;
P_D_T1 * EF_T1 * 3600 = TR_T1 * F_MR_T1 ; !kWhr/s * 3600 s/hr =
kWhr/kg * kg/s ;

F_MR_T2 = F_IN_T2 * X_M_IN_T2 * MRR_T2 ; !kg/s = kg/s;
0.56 <= MRR_T2 ;
MRR_T2 <= 0.86 ;
TR_T2 = 0.67 ; !kWhr/kg ;
EF_T2 = 0.86 ;
P_D_T2 * EF_T2 * 3600 = TR_T2 * F_MR_T2  ; !kWhr/s * 3600 s/hr =
kWhr/kg * kg/s ;

F_MR_T3 = F_IN_T3 * X_M_IN_T3 * MRR_T3;
0.56 <= MRR_T3 ;
MRR_T3 <= 0.86 ;
TR_T3 = 0.67 ; !kWhr/kg ;
EF_T3 = 0.87 ;
P_D_T3 * EF_T3 * 3600 = TR_T3 * F_MR_T3 ; !kWhr/s * 3600 s/hr =
kWhr/kg * kg/s ;

F_MR_T4 = F_IN_T4 * X_M_IN_T4 * MRR_T4;
0.64 <= MRR_T4 ;
MRR_T4 <= 0.81 ;
TR_T4 = 0.67 ; !kWhr/kg ;
EF_T4 = 0.7 ;
P_D_T4 * EF_T4 * 3600 = TR_T4 * F_MR_T4 ; !kWhr/s * 3600 s/hr =
kWhr/kg * kg/s ;

F_MR_T5 = F_IN_T5 * X_M_IN_T5 * MRR_T5;
MRR_T5 = 0.15 ;
TR_T5 = 0 ; !kWhr/kg ;
EF_T5 = 1 ;
P_D_T5 * EF_T5 * 3600  = TR_T5 * F_MR_T5 ; !kWhr/s * 3600 s/hr =
kWhr/kg * kg/s ;

F_MR_T6 = F_IN_T6 * X_M_IN_T6 * MRR_T6;
MRR_T6 = 0.15 ;
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TR_T6 = 0 ; !kWhr/kg ;
EF_T6 = 1 ;
P_D_T6 * EF_T6 * 3600 = TR_T6 * F_MR_T6 ; !kWhr/s * 3600 s/hr =
kWhr/kg * kg/s ;

F_MR_T7 = F_IN_T7 * X_M_IN_T7 * MRR_T7;
MRR_T7 = 0.15 ;
TR_T7 = 0 ; !kWhr/kg ;
EF_T7 = 1 ;
P_D_T7 * EF_T7 * 3600 = TR_T7 * F_MR_T7 ; !kWhr/s * 3600 s/hr =
kWhr/kg * kg/s ;

F_MR_BLANK1 = F_IN_BLANK1 * X_M_IN_BLANK1 * MRR_BLANK1 ;
MRR_BLANK1 = 0 ;
TR_BLANK1 = 0 ; !kWhr/kg ;
EF_BLANK1 = 1 ;
P_D_BLANK1 * EF_BLANK1 * 3600 = TR_BLANK1 * F_MR_BLANK1 ; !kWhr/s *
3600 s/hr = kWhr/kg * kg/s ;

F_OUTM_T1 = F_IN_T1 * X_M_IN_T1 - F_MR_T1 ; !kg/s = kg/s ;
F_OUTM_T2 = F_IN_T2 * X_M_IN_T2 - F_MR_T2 ; !kg/s = kg/s ;
F_OUTM_T3 = F_IN_T3 * X_M_IN_T3 - F_MR_T3 ; !kg/s = kg/s ;
F_OUTM_T4 = F_IN_T4 * X_M_IN_T4 - F_MR_T4 ; !kg/s = kg/s ;
F_OUTM_T5 = F_IN_T5 * X_M_IN_T5 - F_MR_T5 ; !kg/s = kg/s ;
F_OUTM_T6 = F_IN_T6 * X_M_IN_T6 - F_MR_T6 ; !kg/s = kg/s ;
F_OUTM_T7 = F_IN_T7 * X_M_IN_T7 - F_MR_T7 ; !kg/s = kg/s ;
F_OUTM_BLANK1 = F_IN_BLANK1 * X_M_IN_BLANK1 - F_MR_BLANK1 ; !kg/s =
kg/s
F_OUTM_T_TOTAL = F_OUTM_T1 + F_OUTM_T2 + F_OUTM_T3 + F_OUTM_T4 +
F_OUTM_T5 + F_OUTM_T6 + F_OUTM_T7 + F_OUTM_BLANK1 ;
F_OUTM_T_TOTAL <= TOTAL_M_AVAILABLE ;

P_D_T1 + P_D_T2 + P_D_T3 + P_D_T4 + P_D_T5 + P_D_T6 + P_D_T7 +
P_D_BLANK1 = P_D_T_TOTAL ;

S_IN_T1 = S_1 ; S_IN_T2 = S_1;
S_IN_T3 = S_1 ; S_IN_T4 = S_1 ;
S_IN_T5 = S_1 ; S_IN_T6 = S_1 ;
S_IN_T7 = S_1 ; S_IN_BLANK1 = S_1 ;

(S_IN_T1/SRR_T1) * I_T1 = S_I1 ;
S_I1 <= 10000 * I_T1 ;
SRR_T1 = 1 ;
P_SR_T1 = I_T1 * @LOG10 (SRR_T1) * F_IN_T1 ; !kW = kW/kgs-1 * kgs-1 ;
@FREE (K_T1);
@FREE (P_SR_T1);

(S_IN_T2/SRR_T2) * I_T2 = S_I2 ;
S_I2 <= 10000 * I_T2 ;
SRR_T2 = 1 ;
P_SR_T2 = I_T2 * @LOG10 (SRR_T2) * F_IN_T2 ; !kW = kW/kgs-1 * kgs-1 ;
@FREE (K_T2);
@FREE (P_SR_T2);

(S_IN_T3/SRR_T3) * I_T3 = S_I3 ;
S_I3 <= 10000 * I_T3 ;
SRR_T3 = 1 ;
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```
P_SR_T3 = I_T3 * @LOG10 (SRR_T3) * F_IN_T3 ; !kW = kW/kgs-1 * kgs-1 ;
@FREE (K_T3);
@FREE (P_SR_T3);

(S_IN_T4/SRR_T4) * I_T4 = S_I4 ;
S_I4 <= 10000 * I_T4 ;
SRR_T4 = 1 ;
P_SR_T4 = I_T4 * @LOG10 (SRR_T4) * F_IN_T4 ; !kW = kW/kgs-1 * kgs-1 ;
@FREE (K_T4);
@FREE (P_SR_T4);

(S_IN_T5/SRR_T5) * I_T5 = S_I5 ;
S_I5 <= 10000 * I_T5 ;
2 <= SRR_T5 ;
SRR_T5 <= 14 ;
A_T5 = @LOG10(SRR_T5);
B_T5 = X_M_IN_T5 ;
K_T5 = 339.9 - 1109*A_T5 - 7.529*B_T5  + 947.4*(A_T5^2) +
170.5*(A_T5)*(B_T5) - 16.53*(B_T5^2) - 362.7*(A_T5^3)
      - 76.75*(A_T5^2)*(B_T5)  - 5.958*(A_T5)*(B_T5^2) + 1.836*(B_T5
^3) + 56.16*(A_T5^4) + 3.813*(A_T5^3)*(B_T5) +
4.932*(A_T5^2)*(B_T5^2) - 0.7026*A_T5*(B_T5^3) ;
P_SR_T5 = I_T5 * K_T5 * @LOG10 (SRR_T5) * F_IN_T5 ; !kW = kW/kgs-1 *
kgs-1 ;
@FREE (K_T5);
@FREE (P_SR_T5);

(S_IN_T6/SRR_T6) * I_T6 = S_I6 ;
S_I6 <= 10000 * I_T6 ;
2.23 <= SRR_T6 ;
SRR_T6 <= 12.825 ;
A_T6 = @LOG10(SRR_T6);
B_T6 = X_M_IN_T6 ;
K_T6 = 49.02 + 10.04 *A_T6 - 72.54*B_T6  + 11.03*(A_T6^2) +
2.03*(A_T6)*(B_T6) + 96.17*(B_T6^2) +0.7976*(A_T6^3)
      +2.241*(A_T6^2)*(B_T6)  - 4.248*(A_T6)*(B_T6^2) -
18.67*(B_T6^3) + 2.451*(A_T6^4) + 6.563*(A_T6^3)*(B_T6) -
0.3381*(A_T6^2)*(B_T6^2) - 9.35*A_T6*(B_T6^3) -43.85*(B_T6^4) ;
P_SR_T6 = I_T6 * K_T6 * @LOG10 (SRR_T6) * F_IN_T6; !kW = kW/kgs-1 *
kgs-1 ;
@FREE (K_T6);
@FREE (P_SR_T6);

(S_IN_T7/SRR_T7) * I_T7 = S_I7 ;
S_I7 <= 10000 * I_T7 ;
2.03 <= SRR_T7 ;
SRR_T7 <= 4.06 ;
A_T7 = @LOG10(SRR_T7);! NEED TO CHANGE;
B_T7 = X_M_IN_T7 ; ! NEED TO CHANGE;
K_T7 = 1.0633 * A_T7 + 0.0203 ;
P_SR_T7 = I_T7 * K_T7 * @LOG10 (SRR_T7) * F_IN_T7; !kW = kW/kgs-1 *
kgs-1 ;
@FREE (K_T7);
@FREE (P_SR_T7);
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(S_IN_BLANK1/SRR_BLANK1) * I_BLANK1 = S_I8 ;
S_I8 <= 10000 * I_BLANK1 ;
SRR_BLANK1 = 1 ;
P_SR_BLANK1 = I_BLANK1 * @LOG10 (SRR_BLANK1) * F_IN_BLANK1 ; !kW =
kW/kgs-1 * kgs-1 ;
@FREE (K_BLANK1);
@FREE (P_SR_BLANK1);

P_SR_T1 + P_SR_T2 + P_SR_T3 + P_SR_T4 + P_SR_T5 + P_SR_T6 + P_SR_T7 +
P_SR_BLANK1 = P_SR_T_TOTAL ;

!TECHNOLOGY COST;
C_T1 = ((2.9*3*18^0.63)*1000)*(((F_IN_T1*3600/1000)/1)^0.6);
C_T2 = ((2.23*1.75*46^0.6)*1000)*(((F_IN_T2*3600/1000)/1)^0.6);
C_T3 = ((45*1^0.7)*1000)*(((F_IN_T3*3600/1000)/1)^0.6);
C_T4 = ((1.4*5^0.77)*1000)*(((F_IN_T4*3600/1000)/1)^0.6);
C_T5 = ((27.5*1*0.39)*1000)*(((F_IN_T5*3600/1000)/1)^0.6);
C_T6 = ((2.97*(F_IN_T6*3600/1000)^0.78)*1000);
C_T7 = ((7.7*1^0.57)*1000)*(((F_IN_T7*3600/1000)/1)^0.6);
C_BLANK1 = F_IN_BLANK1 * 0;

C_T_TOTAL = C_T1 + C_T2 + C_T3 + C_T4 + C_T5 + C_T6 + C_T7 +
C_BLANK1 ;

F_I1 = F_OUTCHCL_T1 + F_OUTM_T1 ; !kg/s = kg/s ;
F_I2 = F_OUTCHCL_T2 + F_OUTM_T2 ; !kg/s = kg/s ;
F_I3 = F_OUTCHCL_T3 + F_OUTM_T3 ; !kg/s = kg/s ;
F_I4 = F_OUTCHCL_T4 + F_OUTM_T4 ; !kg/s = kg/s ;
F_I5 = F_OUTCHCL_T5 + F_OUTM_T5 ; !kg/s = kg/s ;
F_I6 = F_OUTCHCL_T6 + F_OUTM_T6 ; !kg/s = kg/s ;
F_I7 = F_OUTCHCL_T7 + F_OUTM_T7 ; !kg/s = kg/s ;
F_I8 = F_OUTCHCL_BLANK1 + F_OUTM_BLANK1 ; !kg/s = kg/s ;

F_I1 <= TOTAL_BIOMASS_AVAILABLE ;
F_I2 <= TOTAL_BIOMASS_AVAILABLE ;
F_I3 <= TOTAL_BIOMASS_AVAILABLE ;
F_I4 <= TOTAL_BIOMASS_AVAILABLE ;
F_I5 <= TOTAL_BIOMASS_AVAILABLE ;
F_I6 <= TOTAL_BIOMASS_AVAILABLE ;
F_I7 <= TOTAL_BIOMASS_AVAILABLE ;
F_I8 <= TOTAL_BIOMASS_AVAILABLE ;
F_I_TOTAL = F_I1 + F_I2 + F_I3 + F_I4 + F_I5 + F_I6 + F_I7 + F_I8 ;
F_I_TOTAL <= TOTAL_BIOMASS_AVAILABLE ;

F_OUTCHCL_T1  = F_I1 * X_CHCL_I1 ;
F_OUTM_T1     = F_I1 * X_M_I1    ;
X_CHCL_I1 + X_M_I1 <= 1 ; !JUST ADD TO EASE CALCULATION IN LINGO, DO
NOT INCLUDE IN FORMULATION.;

F_OUTCHCL_T2  = F_I2 * X_CHCL_I2 ;
F_OUTM_T2     = F_I2 * X_M_I2    ;
X_CHCL_I2 + X_M_I2 <= 1 ; !JUST ADD TO EASE CALCULATION IN LINGO, DO
NOT INCLUDE IN FORMULATION.;

F_OUTCHCL_T3  = F_I3 * X_CHCL_I3 ;
F_OUTM_T3     = F_I3 * X_M_I3    ;
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X_CHCL_I3 + X_M_I3 <= 1 ; !JUST ADD TO EASE CALCULATION IN LINGO, DO
NOT INCLUDE IN FORMULATION.;

F_OUTCHCL_T4  = F_I4 * X_CHCL_I4 ;
F_OUTM_T4     = F_I4 * X_M_I4    ;
X_CHCL_I4 + X_M_I4 <= 1 ; !JUST ADD TO EASE CALCULATION IN LINGO, DO
NOT INCLUDE IN FORMULATION.;

F_OUTCHCL_T5  = F_I5 * X_CHCL_I5 ;
F_OUTM_T5     = F_I1 * X_M_I5    ;
X_CHCL_I5 + X_M_I5 <= 1 ; !JUST ADD TO EASE CALCULATION IN LINGO, DO
NOT INCLUDE IN FORMULATION.;

F_OUTCHCL_T6  = F_I6 * X_CHCL_I6 ;
F_OUTM_T6     = F_I6 * X_M_I6    ;
X_CHCL_I6 + X_M_I6 <= 1 ; !JUST ADD TO EASE CALCULATION IN LINGO, DO
NOT INCLUDE IN FORMULATION.;

F_OUTCHCL_T7  = F_I7 * X_CHCL_I7 ;
F_OUTM_T7     = F_I7 * X_M_I7    ;
X_CHCL_I7 + X_M_I7 <= 1 ; !JUST ADD TO EASE CALCULATION IN LINGO, DO
NOT INCLUDE IN FORMULATION.;

F_OUTCHCL_BLANK1 = F_I8 * X_CHCL_I8 ;
F_OUTM_BLANK1    = F_I8 * X_M_I8    ;
X_CHCL_I8 + X_M_I8 <= 1 ; !JUST ADD TO EASE CALCULATION IN LINGO, DO
NOT INCLUDE IN FORMULATION.;

I_T1 + I_T2 + I_T3 + I_T4 + I_T5 + I_T6 + I_T7 + I_BLANK1 =
I_T_TOTAL ;

!STAGE 2;
S_2 >= S_I1 ; S_2 >= S_I2 ;
S_2 >= S_I3 ; S_2 >= S_I4 ;
S_2 >= S_I5 ; S_2 >= S_I6 ;
S_2 >= S_I7 ; S_2 >= S_I8 ;

F_I1 = F_I1_TP1 + F_I1_TP2 + F_I1_TP3 + F_I1_TP4 + F_I1_TP5 +
F_I1_TP6 + F_I1_TP7 + F_I1_BLANK2 ; !kg/s = kg/s ;
F_I2 = F_I2_TP1 + F_I2_TP2 + F_I2_TP3 + F_I2_TP4 + F_I2_TP5 +
F_I2_TP6 + F_I2_TP7 + F_I2_BLANK2 ; !kg/s = kg/s ;
F_I3 = F_I3_TP1 + F_I3_TP2 + F_I3_TP3 + F_I3_TP4 + F_I3_TP5 +
F_I3_TP6 + F_I3_TP7 + F_I3_BLANK2 ; !kg/s = kg/s ;
F_I4 = F_I4_TP1 + F_I4_TP2 + F_I4_TP3 + F_I4_TP4 + F_I4_TP5 +
F_I4_TP6 + F_I4_TP7 + F_I4_BLANK2 ; !kg/s = kg/s ;
F_I5 = F_I5_TP1 + F_I5_TP2 + F_I5_TP3 + F_I5_TP4 + F_I5_TP5 +
F_I5_TP6 + F_I5_TP7 + F_I5_BLANK2 ; !kg/s = kg/s ;
F_I6 = F_I6_TP1 + F_I6_TP2 + F_I6_TP3 + F_I6_TP4 + F_I6_TP5 +
F_I6_TP6 + F_I6_TP7 + F_I6_BLANK2 ; !kg/s = kg/s ;
F_I7 = F_I7_TP1 + F_I7_TP2 + F_I7_TP3 + F_I7_TP4 + F_I7_TP5 +
F_I7_TP6 + F_I7_TP7 + F_I7_BLANK2 ; !kg/s = kg/s ;
F_I8 = F_I8_TP1 + F_I8_TP2 + F_I8_TP3 + F_I8_TP4 + F_I8_TP5 +
F_I8_TP6 + F_I8_TP7 + F_I8_BLANK2 ; !kg/s = kg/s ;

F_IN_TP1 = F_I1_TP1 + F_I2_TP1 + F_I3_TP1 + F_I4_TP1 + F_I5_TP1 +
F_I6_TP1 + F_I7_TP1 + F_I8_TP1 ; !kg/s = kg/s ;
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```
F_IN_TP1 * X_CHCL_IN_TP1  = F_I1_TP1 * X_CHCL_I1  + F_I2_TP1 *
X_CHCL_I2  + F_I3_TP1 * X_CHCL_I3  + F_I4_TP1 * X_CHCL_I4  + F_I5_TP1
* X_CHCL_I5  + F_I6_TP1 * X_CHCL_I6  + F_I7_TP1 * X_CHCL_I7 +
F_I8_TP1 * X_CHCL_I8 ;
F_IN_TP1 * X_M_IN_TP1     = F_I1_TP1 * X_M_I1     + F_I2_TP1 * X_M_I2
+ F_I3_TP1 * X_M_I3     + F_I4_TP1 * X_M_I4     + F_I5_TP1 * X_M_I5
+ F_I6_TP1 * X_M_I6     + F_I7_TP1 * X_M_I7    + F_I8_TP1 *
X_M_I8    ;
X_CHCL_IN_TP1 + X_M_IN_TP1 <=1 ;

F_IN_TP2 = F_I1_TP2 + F_I2_TP2 + F_I3_TP2 + F_I4_TP2 + F_I5_TP2 +
F_I6_TP2 + F_I7_TP2 + F_I8_TP2 ; !kg/s = kg/s ;
F_IN_TP2 * X_CHCL_IN_TP2  = F_I1_TP2 * X_CHCL_I1  + F_I2_TP2 *
X_CHCL_I2  + F_I3_TP2 * X_CHCL_I3  + F_I4_TP2 * X_CHCL_I4  + F_I5_TP2
* X_CHCL_I5  + F_I6_TP2 * X_CHCL_I6  + F_I7_TP2 * X_CHCL_I7 +
F_I8_TP2 * X_CHCL_I8 ;
F_IN_TP2 * X_M_IN_TP2     = F_I1_TP2 * X_M_I1     + F_I2_TP2 * X_M_I2
+ F_I3_TP2 * X_M_I3     + F_I4_TP2 * X_M_I4     + F_I5_TP2 * X_M_I5
+ F_I6_TP2 * X_M_I6     + F_I7_TP2 * X_M_I7    + F_I8_TP2 *
X_M_I8    ;
X_CHCL_IN_Tp2 + X_M_IN_TP2 <=1 ;

F_IN_TP3 = F_I1_TP3 + F_I2_TP3 + F_I3_TP3 + F_I4_TP3 + F_I5_TP3 +
F_I6_TP3 + F_I7_TP3 + F_I8_TP3 ; !kg/s = kg/s ;
F_IN_TP3 * X_CHCL_IN_TP3  = F_I1_TP3 * X_CHCL_I1  + F_I2_TP3 *
X_CHCL_I2  + F_I3_TP3 * X_CHCL_I3  + F_I4_TP3 * X_CHCL_I4  + F_I5_TP3
* X_CHCL_I5  + F_I6_TP3 * X_CHCL_I6  + F_I7_TP3 * X_CHCL_I7 +
F_I8_TP3 * X_CHCL_I8 ;
F_IN_TP3 * X_M_IN_TP3     = F_I1_TP3 * X_M_I1     + F_I2_TP3 * X_M_I2
+ F_I3_TP3 * X_M_I3     + F_I4_TP3 * X_M_I4     + F_I5_TP3 * X_M_I5
+ F_I6_TP3 * X_M_I6     + F_I7_TP3 * X_M_I7    + F_I8_TP3 *
X_M_I8    ;
X_CHCL_IN_TP3 + X_M_IN_TP3 <=1 ;

F_IN_TP4 = F_I1_TP4 + F_I2_TP4 + F_I3_TP4 + F_I4_TP4 + F_I5_TP4 +
F_I6_TP4 + F_I7_TP4 + F_I8_TP4 ; !kg/s = kg/s ;
F_IN_TP4 * X_CHCL_IN_TP4  = F_I1_TP4 * X_CHCL_I1  + F_I2_TP4 *
X_CHCL_I2  + F_I3_TP4 * X_CHCL_I3  + F_I4_TP4 * X_CHCL_I4  + F_I5_TP4
* X_CHCL_I5  + F_I6_TP4 * X_CHCL_I6  + F_I7_TP4 * X_CHCL_I7 +
F_I8_TP4 * X_CHCL_I8 ;
F_IN_TP4 * X_M_IN_TP4     = F_I1_TP4 * X_M_I1     + F_I2_TP4 * X_M_I2
+ F_I3_TP4 * X_M_I3     + F_I4_TP4 * X_M_I4     + F_I5_TP4 * X_M_I5
+ F_I6_TP4 * X_M_I6     + F_I7_TP4 * X_M_I7    + F_I8_TP4 *
X_M_I8    ;
X_CHCL_IN_TP4 + X_M_IN_TP4 <=1 ;

F_IN_TP5 = F_I1_TP5 + F_I2_TP5 + F_I3_TP5 + F_I4_TP5 + F_I5_TP5 +
F_I6_TP5 + F_I7_TP5 + F_I8_TP5 ; !kg/s = kg/s ;
F_IN_TP5 * X_CHCL_IN_TP5  = F_I1_TP5 * X_CHCL_I1  + F_I2_TP5 *
X_CHCL_I2  + F_I3_TP5 * X_CHCL_I3  + F_I4_TP5 * X_CHCL_I4  + F_I5_TP5
* X_CHCL_I5  + F_I6_TP5 * X_CHCL_I6  + F_I7_TP5 * X_CHCL_I7 +
F_I8_TP5 * X_CHCL_I8 ;
F_IN_TP5 * X_M_IN_TP5     = F_I1_TP5 * X_M_I1     + F_I2_TP5 * X_M_I2
+ F_I3_TP5 * X_M_I3     + F_I4_TP5 * X_M_I4     + F_I5_TP5 * X_M_I5
+ F_I6_TP5 * X_M_I6     + F_I7_TP5 * X_M_I7    + F_I8_TP5 *
X_M_I8    ;
X_CHCL_IN_TP5 + X_M_IN_TP5 <=1 ;
```

```
F_IN_TP6 = F_I1_TP6 + F_I2_TP6 + F_I3_TP6 + F_I4_TP6 + F_I5_TP6 +
F_I6_TP6 + F_I7_TP6 + F_I8_TP6 ; !kg/s = kg/s ;
F_IN_TP6 * X_CHCL_IN_TP6  = F_I1_TP6 * X_CHCL_I1  + F_I2_TP6 *
X_CHCL_I2  + F_I3_TP6 * X_CHCL_I3  + F_I4_TP6 * X_CHCL_I4  + F_I5_TP6
* X_CHCL_I5  + F_I6_TP6 * X_CHCL_I6  + F_I7_TP6 * X_CHCL_I7 +
F_I8_TP6 * X_CHCL_I8 ;
F_IN_TP6 * X_M_IN_TP6     = F_I1_TP6 * X_M_I1     + F_I2_TP6 * X_M_I2
+ F_I3_TP6 * X_M_I3     + F_I4_TP6 * X_M_I4     + F_I5_TP6 * X_M_I5
+ F_I6_TP6 * X_M_I6     + F_I7_TP6 * X_M_I7    + F_I8_TP6 *
X_M_I8    ;
X_CHCL_IN_TP6 + X_M_IN_TP6 <=1 ;

F_IN_TP7 = F_I1_TP7 + F_I2_TP7 + F_I3_TP7 + F_I4_TP7 + F_I5_TP7 +
F_I6_TP7 + F_I7_TP7 + F_I8_TP7 ; !kg/s = kg/s ;
F_IN_TP7 * X_CHCL_IN_TP7  = F_I1_TP7 * X_CHCL_I1  + F_I2_TP7 *
X_CHCL_I2  + F_I3_TP7 * X_CHCL_I3  + F_I4_TP7 * X_CHCL_I4  + F_I5_TP7
* X_CHCL_I5  + F_I6_TP7 * X_CHCL_I6  + F_I7_TP7 * X_CHCL_I7 +
F_I8_TP7 * X_CHCL_I8 ;
F_IN_TP7 * X_M_IN_TP7     = F_I1_TP7 * X_M_I1     + F_I2_TP7 * X_M_I2
+ F_I3_TP7 * X_M_I3     + F_I4_TP7 * X_M_I4     + F_I5_TP7 * X_M_I5
+ F_I6_TP7 * X_M_I6     + F_I7_TP7 * X_M_I7    + F_I8_TP7 *
X_M_I8    ;
X_CHCL_IN_TP7 + X_M_IN_TP7 <=1 ;

F_IN_BLANK2 = F_I1_BLANK2 + F_I2_BLANK2 + F_I3_BLANK2 + F_I4_BLANK2 +
F_I5_BLANK2 + F_I6_BLANK2 + F_I7_BLANK2 + F_I8_BLANK2 ; !kg/s =
kg/s ;
F_IN_BLANK2 * X_CHCL_IN_BLANK2  = F_I1_BLANK2 * X_CHCL_I1  +
F_I2_BLANK2 * X_CHCL_I2  + F_I3_BLANK2 * X_CHCL_I3  + F_I4_BLANK2 *
X_CHCL_I4  + F_I5_BLANK2 * X_CHCL_I5  + F_I6_BLANK2 * X_CHCL_I6  +
F_I7_BLANK2 * X_CHCL_I7 + F_I8_BLANK2 * X_CHCL_I8 ;
F_IN_BLANK2 * X_M_IN_BLANK2     = F_I1_BLANK2 * X_M_I1     +
F_I2_BLANK2 * X_M_I2     + F_I3_BLANK2 * X_M_I3     + F_I4_BLANK2 *
X_M_I4     + F_I5_BLANK2 * X_M_I5     + F_I6_BLANK2 * X_M_I6     +
F_I7_BLANK2 * X_M_I7    + F_I8_BLANK2 * X_M_I8    ;
X_CHCL_IN_BLANK2 + X_M_IN_BLANK2 <=1 ;

F_IN_TP1 + F_IN_TP2 + F_IN_TP3 + F_IN_TP4 + F_IN_TP5 + F_IN_TP6 +
F_IN_TP7 + F_IN_BLANK2 = F_IN_TP_TOTAL ;
F_IN_TP1 <= TOTAL_BIOMASS_AVAILABLE ;
F_IN_TP2 <= TOTAL_BIOMASS_AVAILABLE ;
F_IN_TP3 <= TOTAL_BIOMASS_AVAILABLE ;
F_IN_TP4 <= TOTAL_BIOMASS_AVAILABLE ;
F_IN_TP5 <= TOTAL_BIOMASS_AVAILABLE ;
F_IN_TP6 <= TOTAL_BIOMASS_AVAILABLE ;
F_IN_TP7 <= TOTAL_BIOMASS_AVAILABLE ;
F_IN_BLANK2 <= TOTAL_BIOMASS_AVAILABLE ;
F_IN_TP_TOTAL <= TOTAL_BIOMASS_AVAILABLE ;

(F_IN_TP1/TOTAL_BIOMASS_AVAILABLE) <= I_TP1 ;
(F_IN_TP2/TOTAL_BIOMASS_AVAILABLE) <= I_TP2 ;
(F_IN_TP3/TOTAL_BIOMASS_AVAILABLE) <= I_TP3 ;
(F_IN_TP4/TOTAL_BIOMASS_AVAILABLE) <= I_TP4 ;
(F_IN_TP5/TOTAL_BIOMASS_AVAILABLE) <= I_TP5 ;
(F_IN_TP6/TOTAL_BIOMASS_AVAILABLE) <= I_TP6 ;
(F_IN_TP7/TOTAL_BIOMASS_AVAILABLE) <= I_TP7 ;
```

```
(F_IN_BLANK2/TOTAL_BIOMASS_AVAILABLE) <= I_BLANK2 ;
@BIN(I_TP1); @BIN(I_TP2);
@BIN(I_TP3); @BIN(I_TP4);
@BIN(I_TP5); @BIN(I_TP6);
@BIN(I_TP7); @BIN(I_BLANK2);

(0.25 * I_TP1) <= (X_M_IN_TP1 * I_TP1)       ;
(X_M_IN_TP1 * I_TP1)       <= (0.65 * I_TP1) ;
(0.25 * I_TP2) <= (X_M_IN_TP2 * I_TP2)       ;
(X_M_IN_TP2 * I_TP2)       <= (0.65 * I_TP2) ;
(0.25 * I_TP3) <= (X_M_IN_TP3 * I_TP3)       ;
(X_M_IN_TP3 * I_TP3)       <= (0.65 * I_TP3) ;
(0.25 * I_TP4) <= (X_M_IN_TP4 * I_TP4)       ;
(X_M_IN_TP4 * I_TP4)       <= (0.72 * I_TP4) ;
(0.04 * I_TP5) <= (X_M_IN_TP5 * I_TP5)       ;
(X_M_IN_TP5 * I_TP5)       <= (0.07 * I_TP5) ;
(0.04 * I_TP6) <= (X_M_IN_TP6 * I_TP6)       ;
(X_M_IN_TP6 * I_TP6)       <= (0.12 * I_TP6) ;
(0 * I_TP7)    <= (X_M_IN_TP7 * I_TP7)       ;
(X_M_IN_TP7 * I_TP7)       <= (1 * I_TP7)    ;
(0 * I_BLANK2) <= (X_M_IN_BLANK2 * I_BLANK2) ;
(X_M_IN_BLANK2 * I_BLANK2) <= (1 * I_BLANK2) ;

(25  * I_TP1)    <= (S_2 * I_TP1)    ;
(S_2 * I_TP1)    <= (125 * I_TP1)    ;
(0.5 * I_TP2)    <= (S_2 * I_TP2)    ;
(S_2 * I_TP2)    <= (50  * I_TP2)    ;
(0   * I_TP3)    <= (S_2 * I_TP3)    ;
(S_2 * I_TP3)    <= (100 * I_TP3)    ;
(0   * I_TP4)    <= (S_2 * I_TP4)    ;
(S_2 * I_TP4)    <= (150 * I_TP4)    ;
(25  * I_TP5)    <= (S_2 * I_TP5)    ;
(S_2 * I_TP5)    <= (150 * I_TP5)    ;
(25  * I_TP6)    <= (S_2 * I_TP6)    ;
(S_2 * I_TP6)    <= (150 * I_TP6)    ;
(0   * I_TP7)    <= (S_2 * I_TP7)    ;
(S_2 * I_TP7)    <= (150 * I_TP7)    ;
   (4   * I_BLANK2) <= (S_2 * I_BLANK2) ;
   (5   (S_2 * I_BLANK2) <= (150 * I_BLANK2) ;


F_OUTCHCL_TP1 = (F_IN_TP1 * X_CHCL_IN_TP1)  ;
F_OUTCHCL_TP2 = (F_IN_TP2 * X_CHCL_IN_TP2)  ;
F_OUTCHCL_TP3 = (F_IN_TP3 * X_CHCL_IN_TP3)  ;
F_OUTCHCL_TP4 = (F_IN_TP4 * X_CHCL_IN_TP4)  ;
F_OUTCHCL_TP5 = (F_IN_TP5 * X_CHCL_IN_TP5)  ;
F_OUTCHCL_TP6 = (F_IN_TP6 * X_CHCL_IN_TP6)  ;
F_OUTCHCL_TP7 = (F_IN_TP7 * X_CHCL_IN_TP7)  ;
F_OUTCHCL_BLANK2 = (F_IN_BLANK2 * X_CHCL_IN_BLANK2)  ;

F_OUTCHCL_TP1 <= TOTAL_CHCL_AVAILABLE ;
F_OUTCHCL_TP2 <= TOTAL_CHCL_AVAILABLE ;
F_OUTCHCL_TP3 <= TOTAL_CHCL_AVAILABLE ;
F_OUTCHCL_TP4 <= TOTAL_CHCL_AVAILABLE ;
F_OUTCHCL_TP5 <= TOTAL_CHCL_AVAILABLE ;
F_OUTCHCL_TP6 <= TOTAL_CHCL_AVAILABLE ;
F_OUTCHCL_TP7 <= TOTAL_CHCL_AVAILABLE ;
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F_OUTCHCL_BLANK2 <= TOTAL_CHCL_AVAILABLE ;
F_OUTCHCL_TP_TOTAL = F_OUTCHCL_TP1 + F_OUTCHCL_TP2 + F_OUTCHCL_TP3 +
F_OUTCHCL_TP4 + F_OUTCHCL_TP5 + F_OUTCHCL_TP6 + F_OUTCHCL_TP7 +
F_OUTCHCL_BLANK2 ;
F_OUTCHCL_TP_TOTAL <= TOTAL_CHCL_AVAILABLE ;

F_MR_TP1 = F_IN_TP1 * X_M_IN_TP1 * MRR_TP1 ;
0.56 <= MRR_TP1 ;
MRR_TP1 <= 0.86 ;
TR_TP1 = 0.67 ; !kWhr/kg ;
EF_TP1 = 0.6 ;
P_D_TP1 * EF_TP1 * 3600 = TR_TP1 * F_MR_TP1  ; !kWhr/s * 3600 s/hr =
kWhr/kg * kg/s ;

F_MR_TP2 = F_IN_TP2 * X_M_IN_TP2 * MRR_TP2 ;
0.56 <= MRR_TP2 ;
MRR_TP2 <= 0.86 ;
TR_TP2 = 0.67 ; !kWhr/kg ;
EF_TP2 = 0.86 ;
P_D_TP2 * EF_TP2 * 3600 = TR_TP2 * F_MR_TP2  ; !kWhr/s * 3600 s/hr =
kWhr/kg * kg/s ;

F_MR_TP3 = F_IN_TP3 * X_M_IN_TP3 * MRR_TP3 ;
0.56 <= MRR_TP3 ;
MRR_TP3 <= 0.86 ;
TR_TP3 = 0.67 ; !kWhr/kg ;
EF_TP3 = 0.87 ;
P_D_TP3 * EF_TP3 * 3600 = TR_TP3 * F_MR_TP3 ; !kWhr/s * 3600 s/hr =
kWhr/kg * kg/s ;

F_MR_TP4 = F_IN_TP4 * X_M_IN_TP4 * MRR_TP4 ;
0.64 <= MRR_TP4 ;
MRR_TP4 <= 0.81 ;
TR_TP4 = 0.67 ; !kWhr/kg ;
EF_TP4 = 0.7 ;
P_D_TP4 * EF_TP4 * 3600 = TR_TP4 * F_MR_TP4 ; !kWhr/s * 3600 s/hr =
kWhr/kg * kg/s ;

F_MR_TP5 = F_IN_TP5 * X_M_IN_TP5 * MRR_TP5 ;
MRR_TP5 = 0.15 ;
TR_TP5 = 0 ; !kWhr/kg ;
EF_TP5 = 1 ;
P_D_TP5 * EF_TP5 * 3600  = TR_TP5 * F_MR_TP5 ; !kWhr/s * 3600 s/hr =
kWhr/kg * kg/s ;

F_MR_TP6 = F_IN_TP6 * X_M_IN_TP6 * MRR_TP6 ;
MRR_TP6 = 0.15 ;
TR_TP6 = 0 ; !kWhr/kg ;
EF_TP6 = 1 ;
P_D_TP6 * EF_TP6 * 3600 = TR_TP6 * F_MR_TP6 ; !kWhr/s * 3600 s/hr =
kWhr/kg * kg/s ;

F_MR_TP7 = F_IN_TP7 * X_M_IN_TP7 * MRR_TP7 ;
MRR_TP7 = 0.15 ;
TR_TP7 = 0 ; !kWhr/kg ;
EF_TP7 = 1 ;
```

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P_D_TP7 * EF_TP7 * 3600 = TR_TP7 * F_MR_TP7 ; !kWhr/s * 3600 s/hr =
kWhr/kg * kg/s ;

F_MR_BLANK2 = F_IN_BLANK2 * X_M_IN_BLANK2 * MRR_BLANK2 ;
MRR_BLANK2 = 0 ;
TR_BLANK2 = 0 ; !kWhr/kg ;
EF_BLANK2 = 1;
P_D_BLANK2 * EF_BLANK2 * 3600 = TR_BLANK2 * F_MR_BLANK2 ; !kWhr/s *
3600 s/hr  = kWhr/kg * kg/s ;

P_D_TP1 + P_D_TP2 + P_D_TP3 + P_D_TP4 + P_D_TP5 + P_D_TP6 + P_D_TP7 +
P_D_BLANK2 = P_D_TP_TOTAL ;

F_OUTM_TP1 = F_IN_TP1 * X_M_IN_TP1 - F_MR_TP1 ;
F_OUTM_TP2 = F_IN_TP2 * X_M_IN_TP2 - F_MR_TP2 ;
F_OUTM_TP3 = F_IN_TP3 * X_M_IN_TP3 - F_MR_TP3 ;
F_OUTM_TP4 = F_IN_TP4 * X_M_IN_TP4 - F_MR_TP4 ;
F_OUTM_TP5 = F_IN_TP5 * X_M_IN_TP5 - F_MR_TP5 ;
F_OUTM_TP6 = F_IN_TP6 * X_M_IN_TP6 - F_MR_TP6 ;
F_OUTM_TP7 = F_IN_TP7 * X_M_IN_TP7 - F_MR_TP7 ;
F_OUTM_BLANK2 = F_IN_BLANK2 * X_M_IN_BLANK2 - F_MR_BLANK2 ;

F_OUTM_TP_TOTAL = F_OUTM_TP1 + F_OUTM_TP2 + F_OUTM_TP3 + F_OUTM_TP4 +
F_OUTM_TP5 + F_OUTM_TP6 + F_OUTM_TP7 + F_OUTM_BLANK2 ;
F_OUTM_TP_TOTAL <= TOTAL_M_AVAILABLE;

S_IN_TP1 = S_2 ; S_IN_TP2 = S_2 ;
S_IN_TP3 = S_2 ; S_IN_TP4 = S_2 ;
S_IN_TP5 = S_2 ; S_IN_TP6 = S_2 ;
S_IN_TP7 = S_2 ; S_IN_BLANK2 = S_2 ;

(S_IN_TP1/SRR_TP1) * I_TP1 = S_IP1 ;
S_IP1 <= 10000 * I_TP1 ;
SRR_TP1 = 1 ;
P_SR_TP1 = I_TP1 * @LOG10 (SRR_TP1) * F_IN_TP1 ; !kW = kW/kgs-1 *
kgs-1 ;
@FREE (K_TP1);
@FREE (P_SR_TP1);

(S_IN_TP2/SRR_TP2) * I_TP2 = S_IP2 ;
S_IP2 <= 10000 * I_TP2 ;
SRR_TP2 = 1 ;
P_SR_TP2 = I_TP2 * @LOG10 (SRR_TP2) * F_IN_TP2 ; !kW = kW/kgs-1 *
kgs-1 ;
@FREE (K_TP2);
@FREE (P_SR_TP2);

(S_IN_TP3/SRR_TP3) * I_TP3 = S_IP3 ;
S_IP3 <= 10000 * I_TP3 ;
SRR_TP3 = 1 ;
P_SR_TP3 = I_TP3 * @LOG10 (SRR_TP3) * F_IN_TP3 ; !kW = kW/kgs-1 *
kgs-1 ;
@FREE (K_TP3);
@FREE (P_SR_TP3);

(S_IN_TP4/SRR_TP4) * I_TP4 = S_IP4 ;
```

```
S_IP4 <= 10000 * I_TP4 ;
SRR_TP4 = 1 ;
P_SR_TP4 = I_TP4 * @LOG10 (SRR_TP4) * F_IN_TP4 ; !kW = kW/kgs-1 *
kgs-1 ;
@FREE (K_TP4);
@FREE (P_SR_TP4);

(S_IN_TP5/SRR_TP5) * I_TP5 = S_IP5 ;
S_IP5 <= 10000 * I_TP5 ;
2 <= SRR_TP5 ;
SRR_TP5 <= 14 ;
A_TP5 = @LOG10(SRR_TP5);
B_TP5 = X_M_IN_TP5 ;
K_TP5 = 339.9 - 1109*A_TP5 - 7.529*B_TP5  + 947.4*(A_TP5^2) +
170.5*(A_TP5)*(B_TP5) - 16.53*(B_TP5^2) - 362.7*(A_TP5^3)
      - 76.75*(A_TP5^2)*(B_TP5)  - 5.958*(A_TP5)*(B_TP5^2) +
1.836*(B_TP5 ^3) + 56.16*(A_TP5^4) + 3.813*(A_TP5^3)*(B_TP5) +
4.932*(A_TP5^2)*(B_TP5^2) - 0.7026*A_TP5*(B_TP5^3) ;
P_SR_TP5 = I_TP5 * K_TP5 * @LOG10 (SRR_TP5) * F_IN_TP5 ; !kW =
kW/kgs-1 * kgs-1 ;
@FREE (K_TP5);
@FREE (P_SR_TP5);

(S_IN_TP6/SRR_TP6) * I_TP6 = S_IP6 ;
S_IP6 <= 10000 * I_TP6 ;
2.23 <= SRR_TP6 ;
SRR_TP6 <= 12.825 ;
A_TP6 = @LOG10(SRR_TP6);
B_TP6 = X_M_IN_TP6 ;
K_TP6 = 49.02 + 10.04 *A_TP6 - 72.54*B_TP6  + 11.03*(A_TP6^2) +
2.03*(A_TP6)*(B_TP6) + 96.17*(B_TP6^2) +0.7976*(A_TP6^3)
      +2.241*(A_T6^2)*(B_TP6)  - 4.248*(A_TP6)*(B_TP6^2) -
18.67*(B_TP6^3) + 2.451*(A_TP6^4) + 6.563*(A_TP6^3)*(B_TP6) -
0.3381*(A_TP6^2)*(B_TP6^2) - 9.35*A_TP6*(B_TP6^3) -43.85*(B_TP6^4) ;
P_SR_TP6 = I_TP6 * K_TP6 * @LOG10 (SRR_TP6) * F_IN_TP6 ; !kW =
kW/kgs-1 * kgs-1 ;
@FREE (K_TP6);
@FREE (P_SR_TP6);

(S_IN_TP7/SRR_TP7) * I_TP7 = S_IP7 ;
S_IP7 <= 10000 * I_TP7 ;
2.03 <= SRR_TP7 ;
SRR_TP7 <= 4.06 ;
A_TP7 = @LOG10(SRR_TP7);
K_TP7 = 1.0633 * A_TP7 + 0.0203 ;
P_SR_TP7 = I_TP7 * K_TP7 * @LOG10 (SRR_TP7) * F_IN_TP7 ; !kW =
kW/kgs-1 * kgs-1 ;

(S_IN_BLANK2/SRR_BLANK2) * I_BLANK2 = S_IP8 ;
S_IP8 <= 10000 * I_BLANK2 ;
SRR_BLANK2 = 1 ;
P_SR_BLANK2 = I_BLANK2 * @LOG10 (SRR_BLANK2) * F_IN_BLANK2 ; !kW =
kW/kgs-1 * kgs-1 ;
@FREE (K_BLANK2);
@FREE (P_SR_BLANK2);
```

```
P_SR_TP1 + P_SR_TP2 + P_SR_TP3 + P_SR_TP4 + P_SR_TP5 + P_SR_TP6 +
P_SR_TP7 + P_SR_BLANK2 = P_SR_TP_TOTAL ;

!TECHNOLOGY COST;
C_TP1 = ((2.9*3*18^0.63)*1000)*(((F_IN_TP1*3600/1000)/1)^0.6);
C_TP2 = ((2.23*1.75*46^0.6)*1000)*(((F_IN_TP2*3600/1000)/1)^0.6);
C_TP3 = ((45*1^0.7)*1000)*(((F_IN_TP3*3600/1000)/1)^0.6);
C_TP4 = ((1.4*5^0.77)*1000)*(((F_IN_TP4*3600/1000)/1)^0.6);
C_TP5 = ((27.5*1*0.39)*1000)*(((F_IN_TP5*3600/1000)/1)^0.6);
C_TP6 = ((2.97*(F_IN_T6*3600/1000)^0.78)*1000);
C_TP7 = ((7.7*1^0.57)*1000)*(((F_IN_TP7*3600/1000)/1)^0.6);
C_BLANK2 = F_IN_BLANK1 * 0;

C_TP_TOTAL = C_TP1 + C_TP2 + C_TP3 + C_TP4 + C_TP5 + C_TP6 + C_TP7 +
C_BLANK2 ;

F_IP1 = F_OUTCHCL_TP1 + F_OUTM_TP1 ; !kg/s = kg/s ;
F_IP2 = F_OUTCHCL_TP2 + F_OUTM_TP2 ; !kg/s = kg/s ;
F_IP3 = F_OUTCHCL_TP3 + F_OUTM_TP3 ; !kg/s = kg/s ;
F_IP4 = F_OUTCHCL_TP4 + F_OUTM_TP4 ; !kg/s = kg/s ;
F_IP5 = F_OUTCHCL_TP5 + F_OUTM_TP5 ; !kg/s = kg/s ;
F_IP6 = F_OUTCHCL_TP6 + F_OUTM_TP6 ; !kg/s = kg/s ;
F_IP7 = F_OUTCHCL_TP7 + F_OUTM_TP7 ; !kg/s = kg/s ;
F_IP8 = F_OUTCHCL_BLANK2 + F_OUTM_BLANK2 ; !kg/s = kg/s ;

F_IP1 <= TOTAL_BIOMASS_AVAILABLE;
F_IP2 <= TOTAL_BIOMASS_AVAILABLE;
F_IP3 <= TOTAL_BIOMASS_AVAILABLE;
F_IP4 <= TOTAL_BIOMASS_AVAILABLE;
F_IP5 <= TOTAL_BIOMASS_AVAILABLE;
F_IP6 <= TOTAL_BIOMASS_AVAILABLE;
F_IP7 <= TOTAL_BIOMASS_AVAILABLE;
F_IP8 <= TOTAL_BIOMASS_AVAILABLE;
F_IP_TOTAL = F_IP1 + F_IP2 + F_IP3 + F_IP4 + F_IP5 + F_IP6 + F_IP7 +
F_IP8 ;
F_IP_TOTAL <= TOTAL_BIOMASS_AVAILABLE;

F_OUTCHCL_TP1  = F_IP1 * X_CHCL_IP1 ;
F_OUTM_TP1     = F_IP1 * X_M_IP1    ;
X_CHCL_IP1 + X_M_IP1 <= 1 ; !JUST ADD TO EASE CALCULATION IN LINGO,
DO NOT INCLUDE IN FORMULATION.;

F_OUTCHCL_TP2  = F_IP2 * X_CHCL_IP2 ;
F_OUTM_TP2     = F_IP2 * X_M_IP2    ; X_CHCL_IP2 + X_M_IP2 <=
1 ; !JUST ADD TO EASE CALCULATION IN LINGO, DO NOT INCLUDE IN
FORMULATION.;


F_OUTCHCL_TP3  = F_IP3 * X_CHCL_IP3 ;
F_OUTM_TP3     = F_IP3 * X_M_IP3    ;
X_CHCL_IP3 + X_M_IP3 <= 1 ; !JUST ADD TO EASE CALCULATION IN LINGO,
DO NOT INCLUDE IN FORMULATION.;

F_OUTCHCL_TP4  = F_IP4 * X_CHCL_IP4 ;
F_OUTM_TP4     = F_IP4 * X_M_IP4    ;
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X_CHCL_IP4 + X_M_IP4 <= 1 ; !JUST ADD TO EASE CALCULATION IN LINGO,
DO NOT INCLUDE IN FORMULATION.;

F_OUTCHCL_TP5  = F_IP5 * X_CHCL_IP5 ;
F_OUTM_TP5     = F_IP5 * X_M_IP5    ;
X_CHCL_IP5 + X_M_IP5 <= 1 ; !JUST ADD TO EASE CALCULATION IN LINGO,
DO NOT INCLUDE IN FORMULATION.;

F_OUTCHCL_TP6  = F_IP6 * X_CHCL_IP6 ;
F_OUTM_TP6     = F_IP6 * X_M_IP6    ;
X_CHCL_IP6 + X_M_IP6 <= 1 ; !JUST ADD TO EASE CALCULATION IN LINGO,
DO NOT INCLUDE IN FORMULATION.;

F_OUTCHCL_TP7  = F_IP7 * X_CHCL_IP7 ;
F_OUTM_TP7     = F_IP7 * X_M_IP7    ;
X_CHCL_IP7 + X_M_IP7 <= 1 ; !JUST ADD TO EASE CALCULATION IN LINGO,
DO NOT INCLUDE IN FORMULATION.;

F_OUTCHCL_BLANK2 = F_IP8 * X_CHCL_IP8 ;
F_OUTM_BLANK2    = F_IP8 * X_M_IP8    ;
X_CHCL_IP8 + X_M_IP8 <= 1 ; !JUST ADD TO EASE CALCULATION IN LINGO,
DO NOT INCLUDE IN FORMULATION.;

I_TP1 + I_TP2 + I_TP3 + I_TP4 + I_TP5 + I_TP6 + I_TP7 + I_BLANK2 =
I_TP_TOTAL ;


!STAGE 3;
S_3 >= S_IP1 ; S_3 >= S_IP2 ;
S_3 >= S_IP3 ; S_3 >= S_IP4 ;
S_3 >= S_IP5 ; S_3 >= S_IP6 ;
S_3 >= S_IP7 ; S_3 >= S_IP8 ;

F_IP1 = F_IP1_TPP1 + F_IP1_TPP2 + F_IP1_TPP3 + F_IP1_TPP4 +
F_IP1_TPP5 + F_IP1_TPP6 + F_IP1_TPP7 + F_IP1_BLANK3 ; !kg/s = kg/s ;
F_IP2 = F_IP2_TPP1 + F_IP2_TPP2 + F_IP2_TPP3 + F_IP2_TPP4 +
F_IP2_TPP5 + F_IP2_TPP6 + F_IP2_TPP7 + F_IP2_BLANK3 ; !kg/s = kg/s ;
F_IP3 = F_IP3_TPP1 + F_IP3_TPP2 + F_IP3_TPP3 + F_IP3_TPP4 +
F_IP3_TPP5 + F_IP3_TPP6 + F_IP3_TPP7 + F_IP3_BLANK3 ; !kg/s = kg/s ;
F_IP4 = F_IP4_TPP1 + F_IP4_TPP2 + F_IP4_TPP3 + F_IP4_TPP4 +
F_IP4_TPP5 + F_IP4_TPP6 + F_IP4_TPP7 + F_IP4_BLANK3 ; !kg/s = kg/s ;
F_IP5 = F_IP5_TPP1 + F_IP5_TPP2 + F_IP5_TPP3 + F_IP5_TPP4 +
F_IP5_TPP5 + F_IP5_TPP6 + F_IP5_TPP7 + F_IP5_BLANK3 ; !kg/s = kg/s ;
F_IP6 = F_IP6_TPP1 + F_IP6_TPP2 + F_IP6_TPP3 + F_IP6_TPP4 +
F_IP6_TPP5 + F_IP6_TPP6 + F_IP6_TPP7 + F_IP6_BLANK3 ; !kg/s = kg/s ;
F_IP7 = F_IP7_TPP1 + F_IP7_TPP2 + F_IP7_TPP3 + F_IP7_TPP4 +
F_IP7_TPP5 + F_IP7_TPP6 + F_IP7_TPP7 + F_IP7_BLANK3 ; !kg/s = kg/s ;
F_IP8 = F_IP8_TPP1 + F_IP8_TPP2 + F_IP8_TPP3 + F_IP8_TPP4 +
F_IP8_TPP5 + F_IP8_TPP6 + F_IP8_TPP7 + F_IP8_BLANK3 ; !kg/s = kg/s ;

!----;
F_IN_TPP1 = F_IP1_TPP1 + F_IP2_TPP1 + F_IP3_TPP1 + F_IP4_TPP1 +
F_IP5_TPP1 + F_IP6_TPP1 + F_IP7_TPP1 + F_IP8_TPP1; !kg/s = kg/s ;
F_IN_TPP1 * X_CHCL_IN_TPP1  = F_IP1_TPP1 * X_CHCL_IP1  + F_IP2_TPP1 *
X_CHCL_IP2  + F_IP3_TPP1 * X_CHCL_IP3  + F_IP4_TPP1 * X_CHCL_IP4  +
F_IP5_TPP1 * X_CHCL_IP5  + F_IP6_TPP1 * X_CHCL_IP6  + F_IP7_TPP1 *
X_CHCL_IP7 + F_IP8_TPP1 * X_CHCL_IP8 ;
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F_IN_TPP1 * X_M_IN_TPP1     = F_IP1_TPP1 * X_M_IP1     + F_IP2_TPP1 *
X_M_IP2     + F_IP3_TPP1 * X_M_IP3     + F_IP4_TPP1 * X_M_IP4     +
F_IP5_TPP1 * X_M_IP5     + F_IP6_TPP1 * X_M_IP6     + F_IP7_TPP1 *
X_M_IP7    + F_IP8_TPP1 * X_M_IP8    ;
X_CHCL_IN_TPP1 + X_M_IN_TPP1 <= 1 ; !JUST ADD TO EASE CALCULATION IN
LINGO, DO NOT INCLUDE IN FORMULATION.;

!----;
F_IN_TPP2 = F_IP1_TPP2 + F_IP2_TPP2 + F_IP3_TPP2 + F_IP4_TPP2 +
F_IP5_TPP2 + F_IP6_TPP2 + F_IP7_TPP2 + F_IP8_TPP2 ; !kg/s = kg/s ;
F_IN_TPP2 * X_CHCL_IN_TPP2  = F_IP1_TPP2 * X_CHCL_IP1  + F_IP2_TPP2 *
X_CHCL_IP2  + F_IP3_TPP2 * X_CHCL_IP3  + F_IP4_TPP2 * X_CHCL_IP4  +
F_IP5_TPP2 * X_CHCL_IP5  + F_IP6_TPP2 * X_CHCL_IP6  + F_IP7_TPP2 *
X_CHCL_IP7 + F_IP8_TPP2 * X_CHCL_IP8 ;
F_IN_TPP2 * X_M_IN_TPP2     = F_IP1_TPP2 * X_M_IP1     + F_IP2_TPP2 *
X_M_IP2     + F_IP3_TPP2 * X_M_IP3     + F_IP4_TPP2 * X_M_IP4     +
F_IP5_TPP2 * X_M_IP5     + F_IP6_TPP2 * X_M_IP6     + F_IP7_TPP2 *
X_M_IP7    + F_IP8_TPP2 * X_M_IP8    ;
X_CHCL_IN_TPP2 + X_M_IN_TPP2 <= 1 ; !JUST ADD TO EASE CALCULATION IN
LINGO, DO NOT INCLUDE IN FORMULATION.;

!----;
F_IN_TPP3 = F_IP1_TPP3 + F_IP2_TPP3 + F_IP3_TPP3 + F_IP4_TPP3 +
F_IP5_TPP3 + F_IP6_TPP3 + F_IP7_TPP3 + F_IP8_TPP3 ; !kg/s = kg/s ;
F_IN_TPP3 * X_CHCL_IN_TPP3  = F_IP1_TPP3 * X_CHCL_IP1  + F_IP2_TPP3 *
X_CHCL_IP2  + F_IP3_TPP3 * X_CHCL_IP3  + F_IP4_TPP3 * X_CHCL_IP4  +
F_IP5_TPP3 * X_CHCL_IP5  + F_IP6_TPP3 * X_CHCL_IP6  + F_IP7_TPP3 *
X_CHCL_IP7 + F_IP8_TPP3 * X_CHCL_IP8 ;
F_IN_TPP3 * X_M_IN_TPP3     = F_IP1_TPP3 * X_M_IP1     + F_IP2_TPP3 *
X_M_IP2     + F_IP3_TPP3 * X_M_IP3     + F_IP4_TPP3 * X_M_IP4     +
F_IP5_TPP3 * X_M_IP5     + F_IP6_TPP3 * X_M_IP6     + F_IP7_TPP3 *
X_M_IP7    + F_IP8_TPP3 * X_M_IP8    ;
X_CHCL_IN_TPP3 + X_M_IN_TPP3 <= 1 ; !JUST ADD TO EASE CALCULATION IN
LINGO, DO NOT INCLUDE IN FORMULATION.;

!----;
F_IN_TPP4 = F_IP1_TPP4 + F_IP2_TPP4 + F_IP3_TPP4 + F_IP4_TPP4 +
F_IP5_TPP4 + F_IP6_TPP4 + F_IP7_TPP4 + F_IP8_TPP4 ; !kg/s = kg/s ;
F_IN_TPP4 * X_CHCL_IN_TPP4  = F_IP1_TPP4 * X_CHCL_IP1  + F_IP2_TPP4 *
X_CHCL_IP2  + F_IP3_TPP4 * X_CHCL_IP3  + F_IP4_TPP4 * X_CHCL_IP4  +
F_IP5_TPP4 * X_CHCL_IP5  + F_IP6_TPP4 * X_CHCL_IP6  + F_IP7_TPP4 *
X_CHCL_IP7 + F_IP8_TPP4 * X_CHCL_IP8 ;
F_IN_TPP4 * X_M_IN_TPP4     = F_IP1_TPP4 * X_M_IP1     + F_IP2_TPP4 *
X_M_IP2     + F_IP3_TPP4 * X_M_IP3     + F_IP4_TPP4 * X_M_IP4     +
F_IP5_TPP4 * X_M_IP5     + F_IP6_TPP4 * X_M_IP6     + F_IP7_TPP4 *
X_M_IP7    + F_IP8_TPP4 * X_M_IP8    ;
X_CHCL_IN_TPP4 + X_M_IN_TPP4 <= 1 ; !JUST ADD TO EASE CALCULATION IN
LINGO, DO NOT INCLUDE IN FORMULATION.;

!----;
F_IN_TPP5 = F_IP1_TPP5 + F_IP2_TPP5 + F_IP3_TPP5 + F_IP4_TPP5 +
F_IP5_TPP5 + F_IP6_TPP5 + F_IP7_TPP5 + F_IP8_TPP5 ; !kg/s = kg/s ;
F_IN_TPP5 * X_CHCL_IN_TPP5  = F_IP1_TPP5 * X_CHCL_IP1  + F_IP2_TPP5 *
X_CHCL_IP2  + F_IP3_TPP5 * X_CHCL_IP3  + F_IP4_TPP5 * X_CHCL_IP4  +
F_IP5_TPP5 * X_CHCL_IP5  + F_IP6_TPP5 * X_CHCL_IP6  + F_IP7_TPP5 *
X_CHCL_IP7 + F_IP8_TPP5 * X_CHCL_IP8 ;
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F_IN_TPP5 * X_M_IN_TPP5     = F_IP1_TPP5 * X_M_IP1     + F_IP2_TPP5 *
X_M_IP2     + F_IP3_TPP5 * X_M_IP3     + F_IP4_TPP5 * X_M_IP4     +
F_IP5_TPP5 * X_M_IP5     + F_IP6_TPP5 * X_M_IP6     + F_IP7_TPP5 *
X_M_IP7    + F_IP8_TPP5 * X_M_IP8    ;
X_CHCL_IN_TPP5 + X_M_IN_TPP5 <= 1 ; !JUST ADD TO EASE CALCULATION IN
LINGO, DO NOT INCLUDE IN FORMULATION.;

!----;
F_IN_TPP6 = F_IP1_TPP6 + F_IP2_TPP6 + F_IP3_TPP6 + F_IP4_TPP6 +
F_IP5_TPP6 + F_IP6_TPP6 + F_IP7_TPP6 + F_IP8_TPP6 ; !kg/s = kg/s ;
F_IN_TPP6 * X_CHCL_IN_TPP6  = F_IP1_TPP6 * X_CHCL_IP1 + F_IP2_TPP6  *
X_CHCL_IP2 + F_IP3_TPP6  * X_CHCL_IP3  + F_IP4_TPP6 * X_CHCL_IP4  +
F_IP5_TPP6 * X_CHCL_IP5  + F_IP6_TPP6 * X_CHCL_IP6  + F_IP7_TPP6 *
X_CHCL_IP7 + F_IP8_TPP6 * X_CHCL_IP8 ;
F_IN_TPP6 * X_M_IN_TPP6     = F_IP1_TPP6 * X_M_IP1    + F_IP2_TPP6  *
X_M_IP2    + F_IP3_TPP6  * X_M_IP3     + F_IP4_TPP6 * X_M_IP4     +
F_IP5_TPP6 * X_M_IP5     + F_IP6_TPP6 * X_M_IP6     + F_IP7_TPP6 *
X_M_IP7    + F_IP8_TPP6 * X_M_IP8    ;
X_CHCL_IN_TPP6 + X_M_IN_TPP6 <= 1 ; !JUST ADD TO EASE CALCULATION IN
LINGO, DO NOT INCLUDE IN FORMULATION.;

!----;
F_IN_TPP7 = F_IP1_TPP7 + F_IP2_TPP7 + F_IP3_TPP7 + F_IP4_TPP7 +
F_IP5_TPP7 + F_IP6_TPP7 + F_IP7_TPP7 + F_IP8_TPP7 ; !kg/s = kg/s ;
F_IN_TPP7 * X_CHCL_IN_TPP7  = F_IP1_TPP7 * X_CHCL_IP1 + F_IP2_TPP7  *
X_CHCL_IP2 + F_IP3_TPP7  * X_CHCL_IP3  + F_IP4_TPP7 * X_CHCL_IP4  +
F_IP5_TPP7 * X_CHCL_IP5  + F_IP6_TPP7 * X_CHCL_IP6  + F_IP7_TPP7 *
X_CHCL_IP7 + F_IP8_TPP7 * X_CHCL_IP8 ;
F_IN_TPP7 * X_M_IN_TPP7     = F_IP1_TPP7 * X_M_IP1    + F_IP2_TPP7  *
X_M_IP2    + F_IP3_TPP7  * X_M_IP3     + F_IP4_TPP7 * X_M_IP4     +
F_IP5_TPP7 * X_M_IP5     + F_IP6_TPP7 * X_M_IP6     + F_IP7_TPP7 *
X_M_IP7    + F_IP8_TPP7 * X_M_IP8    ;
X_CHCL_IN_TPP7 + X_M_IN_TPP7 <= 1 ; !JUST ADD TO EASE CALCULATION IN
LINGO, DO NOT INCLUDE IN FORMULATION.;

!----;
F_IN_BLANK3 = F_IP1_BLANK3 + F_IP2_BLANK3 + F_IP3_BLANK3 +
F_IP4_BLANK3 + F_IP5_BLANK3 + F_IP6_BLANK3 + F_IP7_BLANK3 +
F_IP8_BLANK3 ; !kg/s = kg/s ;
F_IN_BLANK3 * X_CHCL_IN_BLANK3  = F_IP1_BLANK3 * X_CHCL_IP1  +
F_IP2_BLANK3 * X_CHCL_IP2  + F_IP3_BLANK3 * X_CHCL_IP3  +
F_IP4_BLANK3 * X_CHCL_IP4  + F_IP5_BLANK3 * X_CHCL_IP5  +
F_IP6_BLANK3 * X_CHCL_IP6  + F_IP7_BLANK3 * X_CHCL_IP7 + F_IP8_BLANK3
* X_CHCL_IP8 ;
F_IN_BLANK3 * X_M_IN_BLANK3     = F_IP1_BLANK3 * X_M_IP1     +
F_IP2_BLANK3 * X_M_IP2     + F_IP3_BLANK3 * X_M_IP3     +
F_IP4_BLANK3 * X_M_IP4     + F_IP5_BLANK3 * X_M_IP5     +
F_IP6_BLANK3 * X_M_IP6     + F_IP7_BLANK3 * X_M_IP7    + F_IP8_BLANK3
* X_M_IP8    ;
X_CHCL_IN_BLANK3 + X_M_IN_BLANK3 <= 1 ; !JUST ADD TO EASE CALCULATION
IN LINGO, DO NOT INCLUDE IN FORMULATION.;

F_IN_TPP1 + F_IN_TPP2 + F_IN_TPP3 + F_IN_TPP4 + F_IN_TPP5 + F_IN_TPP6
+ F_IN_TPP7 + F_IN_BLANK3 = F_IN_TPP_TOTAL ;
F_IN_TPP1 <= TOTAL_BIOMASS_AVAILABLE ;
F_IN_TPP2 <= TOTAL_BIOMASS_AVAILABLE ;
F_IN_TPP3 <= TOTAL_BIOMASS_AVAILABLE ;
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F_IN_TPP4 <= TOTAL_BIOMASS_AVAILABLE ;
F_IN_TPP5 <= TOTAL_BIOMASS_AVAILABLE ;
F_IN_TPP6 <= TOTAL_BIOMASS_AVAILABLE ;
F_IN_TPP7 <= TOTAL_BIOMASS_AVAILABLE ;
F_IN_BLANK3 <= TOTAL_BIOMASS_AVAILABLE ;
F_IN_TPP_TOTAL <= TOTAL_BIOMASS_AVAILABLE ;

(F_IN_TPP1/TOTAL_BIOMASS_AVAILABLE) <= I_TPP1 ;
(F_IN_TPP2/TOTAL_BIOMASS_AVAILABLE) <= I_TPP2 ;
(F_IN_TPP3/TOTAL_BIOMASS_AVAILABLE) <= I_TPP3 ;
(F_IN_TPP4/TOTAL_BIOMASS_AVAILABLE) <= I_TPP4 ;
(F_IN_TPP5/TOTAL_BIOMASS_AVAILABLE) <= I_TPP5 ;
(F_IN_TPP6/TOTAL_BIOMASS_AVAILABLE) <= I_TPP6 ;
(F_IN_TPP7/TOTAL_BIOMASS_AVAILABLE) <= I_TPP7 ;
(F_IN_BLANK3/TOTAL_BIOMASS_AVAILABLE) <= I_BLANK3 ;
@BIN(I_TPP1); @BIN(I_TPP2);
@BIN(I_TPP3); @BIN(I_TPP4);
@BIN(I_TPP5); @BIN(I_TPP6);
@BIN(I_TPP7); @BIN(I_BLANK3);

(0.25 * I_TPP1) <= (X_M_IN_TPP1 * I_TPP1) ;
(X_M_IN_TPP1 * I_TPP1) <= (0.65 * I_TPP1) ;
(0.25 * I_TPP2) <= (X_M_IN_TPP2 * I_TPP2) ;
(X_M_IN_TPP2 * I_TPP2) <= (0.65 * I_TPP2) ;
(0.25 * I_TPP3) <= (X_M_IN_TPP3 * I_TPP3) ;
(X_M_IN_TPP3 * I_TPP3) <= (0.65 * I_TPP3) ;
(0.25 * I_TPP4) <= (X_M_IN_TPP4 * I_TPP4) ;
(X_M_IN_TPP4 * I_TPP4) <= (0.72 * I_TPP4) ;
(0.04 * I_TPP5) <= (X_M_IN_TPP5 * I_TPP5) ;
(X_M_IN_TPP5 * I_TPP5) <= (0.07 * I_TPP5) ;
(0.04 * I_TPP6) <= (X_M_IN_TPP6 * I_TPP6) ;
(X_M_IN_TPP6 * I_TPP6) <= (0.12 * I_TPP6) ;
(0 * I_TPP7)    <= (X_M_IN_TPP7 * I_TPP7) ;
(X_M_IN_TPP7 * I_TPP7) <= (1 * I_TPP7) ;
(0 * I_BLANK3)  <= (X_M_IN_BLANK3 * I_BLANK3) ;
(X_M_IN_BLANK3 * I_BLANK3) <= (1 * I_BLANK3) ;


(25 * I_TPP1)  <= (S_3 * I_TPP1) ;
(S_3 * I_TPP1) <= (125 * I_TPP1) ;
(0.5 * I_TPP2) <= (S_3 * I_TPP2) ;
(S_3 * I_TPP2) <= (50  * I_TPP2) ;
(0 * I_TPP3)   <= (S_3 * I_TPP3) ;
(S_3 * I_TPP3) <= (100 * I_TPP3) ;
(0 * I_TPP4)   <= (S_3 * I_TPP4) ;
(S_3 * I_TPP4) <= (150 * I_TPP4) ;
(25 * I_TPP5)  <= (S_3 * I_TPP5) ;
(S_3 * I_TPP5) <= (150 * I_TPP5) ;
(25 * I_TPP6)  <= (S_3 * I_TPP6) ;
(S_3 * I_TPP6) <= (150 * I_TPP6) ;
(0 * I_TPP7)   <= (S_3 * I_TPP7) ;
(S_3 * I_TPP7) <= (150 * I_TPP7) ;
(0 * I_BLANK3) <= (S_3 * I_BLANK3) ;

 (S_3 * I_BLANK3) <= (150 * I_BLANK3) ;

F_OUTCHCL_TPP1 = F_IN_TPP1 * X_CHCL_IN_TPP1 ;
F_OUTCHCL_TPP2 = F_IN_TPP2 * X_CHCL_IN_TPP2 ;
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F_OUTCHCL_TPP3 = F_IN_TPP3 * X_CHCL_IN_TPP3 ;
F_OUTCHCL_TPP4 = F_IN_TPP4 * X_CHCL_IN_TPP4 ;
F_OUTCHCL_TPP5 = F_IN_TPP5 * X_CHCL_IN_TPP5 ;
F_OUTCHCL_TPP6 = F_IN_TPP6 * X_CHCL_IN_TPP6 ;
F_OUTCHCL_TPP7 = F_IN_TPP7 * X_CHCL_IN_TPP7 ;
F_OUTCHCL_BLANK3 = F_IN_BLANK3 * X_CHCL_IN_BLANK3 ;

F_OUTCHCL_TPP1 <= TOTAL_CHCL_AVAILABLE ;
F_OUTCHCL_TPP2 <= TOTAL_CHCL_AVAILABLE ;
F_OUTCHCL_TPP3 <= TOTAL_CHCL_AVAILABLE ;
F_OUTCHCL_TPP4 <= TOTAL_CHCL_AVAILABLE ;
F_OUTCHCL_TPP5 <= TOTAL_CHCL_AVAILABLE ;
F_OUTCHCL_TPP6 <= TOTAL_CHCL_AVAILABLE ;
F_OUTCHCL_TPP7 <= TOTAL_CHCL_AVAILABLE ;
F_OUTCHCL_BLANK3 <= TOTAL_CHCL_AVAILABLE;
F_OUTCHCL_TPP_TOTAL = F_OUTCHCL_TPP1 + F_OUTCHCL_TPP2 +
F_OUTCHCL_TPP3 + F_OUTCHCL_TPP4 + F_OUTCHCL_TPP5 + F_OUTCHCL_TPP6 +
F_OUTCHCL_TPP7 + F_OUTCHCL_BLANK3 ;
F_OUTCHCL_TPP_TOTAL <= TOTAL_CHCL_AVAILABLE ;

F_OUTM_TPP1 = F_IN_TPP1 * X_M_IN_TPP1 - F_MR_TPP1 ;
F_OUTM_TPP2 = F_IN_TPP2 * X_M_IN_TPP2 - F_MR_TPP2 ;
F_OUTM_TPP3 = F_IN_TPP3 * X_M_IN_TPP3 - F_MR_TPP3 ;
F_OUTM_TPP4 = F_IN_TPP4 * X_M_IN_TPP4 - F_MR_TPP4 ;
F_OUTM_TPP5 = F_IN_TPP5 * X_M_IN_TPP5 - F_MR_TPP5 ;
F_OUTM_TPP6 = F_IN_TPP6 * X_M_IN_TPP6 - F_MR_TPP6 ;
F_OUTM_TPP7 = F_IN_TPP7 * X_M_IN_TPP7 - F_MR_TPP7 ;
F_OUTM_BLANK3 = F_IN_BLANK3 * X_M_IN_BLANK3 - F_MR_BLANK3 ;

F_MR_TPP1 = F_IN_TPP1 * X_M_IN_TPP1 * MRR_TPP1 ;
0.56 <= MRR_TPP1 ;
MRR_TPP1 <= 0.86 ;
TR_TPP1 = 0.67 ; !kWhr/kg ;
EF_TPP1 = 0.6 ;
P_D_TPP1 * EF_TPP1 * 3600 = TR_TPP1 * F_MR_TPP1  ; !kWhr/s * 3600
s/hr = kWhr/kg * kg/s ;

F_MR_TPP2 = F_IN_TPP2 * X_M_IN_TPP2 * MRR_TPP2 ;
0.56 <= MRR_TPP2 ;
MRR_TPP2 <= 0.86 ;
TR_TPP2 = 0.67 ; !kWhr/kg ;
EF_TPP2 = 0.86 ;
P_D_TPP2 * EF_TPP2 * 3600 = TR_TPP2 * F_MR_TPP2  ; !kWhr/s * 3600
s/hr = kWhr/kg * kg/s ;

F_MR_TPp3 = F_IN_TPp3 * X_M_IN_TPP3 * MRR_TPp3 ;
0.56 <= MRR_TPP3 ;
MRR_TPP3 <= 0.86 ;
TR_TPP3 = 0.67 ; !kWhr/kg ;
EF_TPP3 = 0.87 ;
P_D_TPP3 * EF_TPp3 * 3600 = TR_TPP3 * F_MR_TPP3 ; !kWhr/s * 3600 s/hr
= kWhr/kg * kg/s ;

F_MR_TPp4 = F_IN_TPp4 * X_M_IN_TPP4 * MRR_TPP4 ;
0.64 <= MRR_TPP4 ;
MRR_TPp4 <= 0.81 ;
TR_TPp4 = 0.67 ; !kWhr/kg ;
```

```
EF_TPp4 = 0.7 ;
P_D_TPp4 * EF_TPP4 * 3600 = TR_TPP4 * F_MR_TPP4 ; !kWhr/s * 3600 s/hr
= kWhr/kg * kg/s ;

F_MR_TPp5 = F_IN_TPp5 * X_M_IN_TPP5 * MRR_TPP5 ;
MRR_TPp5 = 0.15 ;
TR_TPp5 = 0 ; !kWhr/kg ;
EF_TPp5 = 1 ;
P_D_TPp5 * EF_TPp5 * 3600  = TR_TpP5 * F_MR_TPp5 ; !kWhr/s * 3600
s/hr = kWhr/kg * kg/s ;

F_MR_TPp6 = F_IN_TpP6 * X_M_IN_TpP6 * MRR_TpP6 ;
MRR_TPp6 = 0.15 ;
TR_TPp6 = 0 ; !kWhr/kg ;
EF_TPp6 = 1 ;
P_D_TPp6 * EF_TPp6 * 3600 = TR_TpP6 * F_MR_TpP6 ; !kWhr/s * 3600 s/hr
= kWhr/kg * kg/s ;

F_MR_TPp7 = F_IN_TpP7 * X_M_IN_TpP7 * MRR_TpP7 ;
MRR_TPp7 = 0.15 ;
TR_TPp7 = 0 ; !kWhr/kg ;
EF_TPp7 = 1 ;
P_D_TPp7 * EF_TPp7 * 3600 = TR_TpP7 * F_MR_TpP7 ; !kWhr/s * 3600 s/hr
= kWhr/kg * kg/s ;

F_MR_BLANK3 = F_IN_BLANK3 * X_M_IN_BLANK3 * MRR_BLANK3 ;
MRR_BLANK3 = 0 ;
TR_BLANK3 = 0 ; !kWhr/kg ;
EF_BLANK3 = 1;
P_D_BLANK3 * EF_BLANK3 * 3600 = TR_BLANK3 * F_MR_BLANK3 ; !kWhr/s *
3600 s/hr  = kWhr/kg * kg/s ;

P_D_TPP1 + P_D_TPP2 + P_D_TPP3 + P_D_TPP4 + P_D_TPP5 + P_D_TPP6 +
P_D_TPP7 + P_D_BLANK3 = P_D_TPP_TOTAL ;

                                                F_OUTM_TPP_TOTAL =
F_OUTM_TPP1 + F_OUTM_TPP2 + F_OUTM_TPP3 + F_OUTM_TPP4 + F_OUTM_TPP5 +
F_OUTM_TPP6 + F_OUTM_TPP7 + F_OUTM_BLANK3 ;
                                                F_OUTM_TPP_TOTAL <=
TOTAL_M_AVAILABLE ;

S_IN_TPP1 = S_3 ; S_IN_TPP2 = S_3 ;
S_IN_TPP3 = S_3 ; S_IN_TPP4 = S_3 ;
S_IN_TPP5 = S_3 ; S_IN_TPP6 = S_3 ;
S_IN_TPP7 = S_3 ; S_IN_BLANK3 = S_3 ;

(S_IN_TPP1/SRR_TPP1) * I_TPP1 = S_IPP1 ;
S_IPP1 <= 10000 * I_TPP1 ;
SRR_TPP1 = 1 ;
P_SR_TPP1 = I_TPP1 * @LOG10 (SRR_TPP1) * F_IN_TPP1 ; !kW = kW/kgs-1 *
kgs-1 ;
@FREE (K_TPP1);
@FREE (P_SR_TPP1);

(S_IN_TPP2/SRR_TPP2) * I_TPP2 = S_IPP2 ;
S_IPP2 <= 10000 * I_TPP2 ;
SRR_TPP2 = 1 ;
```

```
P_SR_TPP2 = I_TPP2 * @LOG10 (SRR_TPP2) * F_IN_TPP2 ; !kW = kW/kgs-1 *
kgs-1 ;
@FREE (K_TPP2);
@FREE (P_SR_TPP2);

(S_IN_TPP3/SRR_TPP3) * I_TPP3 = S_IPP3 ;
S_IPP3 <= 10000 * I_TPP3 ;
SRR_TPP3 = 1 ;
P_SR_TPP3 = I_TPP3 * @LOG10 (SRR_TPP3) * F_IN_TPP3 ; !kW = kW/kgs-1 *
kgs-1 ;
@FREE (K_TPP3);
@FREE (P_SR_TPP3);

(S_IN_TPP4/SRR_TPP4) * I_TPP4 = S_IPP4 ;
S_IPP4 <= 10000 * I_TPP4 ;
SRR_TPP4 = 1 ;
P_SR_TPP4 = I_TPP4 * @LOG10 (SRR_TPP4) * F_IN_TPP4 ; !kW = kW/kgs-1 *
kgs-1 ;
@FREE (K_TPP4);
@FREE (P_SR_TPP4);

(S_IN_TPP5/SRR_TPP5) * I_TPP5 = S_IPP5 ;
S_IPP5 <= 10000 * I_TPP5 ;
2 <= SRR_TPP5 ;
SRR_TPP5 <= 14 ;
A_TPP5 = @LOG10(SRR_TPP5);
B_TPP5 = X_M_IN_TPP5 ;
K_TPP5 = 339.9 - 1109*A_TPP5 - 7.529*B_TPP5  + 947.4*(A_TPP5^2) +
170.5*(A_TPP5)*(B_TPP5) - 16.53*(B_TPP5^2) - 362.7*(A_TPP5^3)
      - 76.75*(A_TPP5^2)*(B_TPP5)  - 5.958*(A_TPP5)*(B_TPP5^2) +
1.836*(B_TPP5 ^3) + 56.16*(A_TPP5^4) + 3.813*(A_TPP5^3)*(B_TPP5) +
4.932*(A_TPP5^2)*(B_TPP5^2) - 0.7026*A_TPP5*(B_TPP5^3) ;
P_SR_TPP5 = I_TPP5 * K_TPP5 * @LOG10 (SRR_TPP5) * F_IN_TPP5 ; !kW =
kW/kgs-1 * kgs-1 ;
@FREE (K_TPP5);
@FREE (P_SR_TPP5);

(S_IN_TPP6/SRR_TPP6) * I_TPP6 = S_IPP6 ;
S_IPP6 <= 10000 * I_TPP6 ;
2.23 <= SRR_TPP6 ;
SRR_TPP6 <= 12.825 ;
A_TPP6 = @LOG10(SRR_TPP6);
B_TPP6 = X_M_IN_TPP6 ;
K_TPP6 = 49.02 + 10.04 *A_TPP6 - 72.54*B_TPP6  + 11.03*(A_TPP6^2) +
2.03*(A_TPP6)*(B_TPP6) + 96.17*(B_TPP6^2) +0.7976*(A_TPP6^3)
      +2.241*(A_TPP6^2)*(B_TPP6)  - 4.248*(A_TPP6)*(B_TPP6^2) -
18.67*(B_TPP6^3) + 2.451*(A_TPP6^4) + 6.563*(A_TPP6^3)*(B_TPP6) -
0.3381*(A_TPP6^2)*(B_TPP6^2) - 9.35*A_TPP6*(B_TPP6^3) -
43.85*(B_TPP6^4) ;
P_SR_TPP6 = I_TPP6 * K_TPP6 * @LOG10 (SRR_TPP6) * F_IN_TPP6 ; !kW =
kW/kgs-1 * kgs-1 ;
@FREE (K_TPP6);
@FREE (P_SR_TPP6);

(S_IN_TPP7/SRR_TPP7) * I_TPP7 = S_IPP7 ;
```

```
S_IPP7 <= 10000 * I_TPP7 ;
2.03 <= SRR_TPP7 ;
SRR_TPP7 <= 4.06 ;
A_TPP7 = @LOG10(SRR_TPP7);
K_TPP7 = 1.0633 * A_TPP7 + 0.0203 ;
P_SR_TPP7 = I_TPP7 * K_TPP7 * @LOG10 (SRR_TPP7) * F_IN_TPP7 ; !kW =
kW/kgs-1 * kgs-1 ;
@FREE (K_TPP7);
@FREE (P_SR_TPP7);

(S_IN_BLANK3/SRR_BLANK3) * I_BLANK3 = S_IPP8 ;
S_IPP8 <= 10000 * I_BLANK3 ;
SRR_BLANK3 = 1 ;
P_SR_BLANK3 = I_BLANK3 * @LOG10 (SRR_BLANK3) * F_IN_BLANK3; !kW =
kW/kgs-1 * kgs-1 ;
@FREE (K_BLANK3);
@FREE (P_SR_BLANK3);

P_SR_TPP1 + P_SR_TPP2 + P_SR_TPP3 + P_SR_TPP4 + P_SR_TPP5 + P_SR_TPP6
+ P_SR_TPP7 + P_SR_BLANK3 = P_SR_TPP_TOTAL ;

!TECHNOLOGY COST;
C_TPP1 = ((2.9*3*18^0.63)*1000)*(((F_IN_T1*3600/1000)/1)^0.6);
C_TPP2 = ((2.23*1.75*46^0.6)*1000)*(((F_IN_TPP2*3600/1000)/1)^0.6);
C_TPP3 = ((45*1^0.7)*1000)*(((F_IN_TPP3*3600/1000)/1)^0.6);
C_TPP4 = ((1.4*5^0.77)*1000)*(((F_IN_TPP4*3600/1000)/1)^0.6);
C_TPP5 = ((27.5*1*0.39)*1000)*(((F_IN_TPP5*3600/1000)/1)^0.6);
C_TPP6 = ((2.97*(F_IN_TPP6*3600/1000)^0.78)*1000);
C_TPP7 = ((7.7*1^0.57)*1000)*(((F_IN_TPP7*3600/1000)/1)^0.6);
C_BLANK3 = F_IN_BLANK3 * 0;

C_TPP_TOTAL = C_TPP1 + C_TPP2 + C_TPP3 + C_TPP4 + C_TPP5 + C_TPP6 +
C_TPP7 + C_BLANK3 ;

F_IPP1 = F_OUTCHCL_TPP1 + F_OUTM_TPP1 ; !kg/s = kg/s ;
F_IPP2 = F_OUTCHCL_TPP2 + F_OUTM_TPP2 ; !kg/s = kg/s ;
F_IPP3 = F_OUTCHCL_TPP3 + F_OUTM_TPP3 ; !kg/s = kg/s ;
F_IPP4 = F_OUTCHCL_TPP4 + F_OUTM_TPP4 ; !kg/s = kg/s ;
F_IPP5 = F_OUTCHCL_TPP5 + F_OUTM_TPP5 ; !kg/s = kg/s ;
F_IPP6 = F_OUTCHCL_TPP6 + F_OUTM_TPP6 ; !kg/s = kg/s ;
F_IPP7 = F_OUTCHCL_TPP7 + F_OUTM_TPP7 ; !kg/s = kg/s ;
F_IPP8 = F_OUTCHCL_BLANK3 + F_OUTM_BLANK3 ; !kg/s = kg/s ;

F_IPP1 <= TOTAL_BIOMASS_AVAILABLE ;
F_IPP2 <= TOTAL_BIOMASS_AVAILABLE ;
F_IPP3 <= TOTAL_BIOMASS_AVAILABLE ;
F_IPP4 <= TOTAL_BIOMASS_AVAILABLE ;
F_IPP5 <= TOTAL_BIOMASS_AVAILABLE ;
F_IPP6 <= TOTAL_BIOMASS_AVAILABLE ;
F_IPP7 <= TOTAL_BIOMASS_AVAILABLE ;
F_IPP8 <= TOTAL_BIOMASS_AVAILABLE ;
F_IPP_TOTAL = F_IPP1 + F_IPP2 + F_IPP3 + F_IPP4 + F_IPP5 + F_IPP6 +
F_IPP7 + F_IPP8 ;
F_IPP_TOTAL <= TOTAL_BIOMASS_AVAILABLE ;

F_OUTCHCL_TPP1   = F_IPP1 * X_CHCL_IPP1 ;
F_OUTM_TPP1      = F_IPP1 * X_M_IPP1    ;
```

```
X_CHCL_IPP1 + X_M_IPP1 <= 1 ; !JUST ADD TO EASE CALCULATION IN LINGO,
DO NOT INCLUDE IN FORMULATION.;

F_OUTCHCL_TPP2   = F_IPP2 * X_CHCL_IPP2 ;
F_OUTM_TPP2      = F_IPP2 * X_M_IPP2    ;
X_CHCL_IPP2 + X_M_IPP2 <= 1 ; !JUST ADD TO EASE CALCULATION IN LINGO,
DO NOT INCLUDE IN FORMULATION.;

F_OUTCHCL_TPP3   = F_IPP3 * X_CHCL_IPP3 ;
F_OUTM_TPP3      = F_IPP3 * X_M_IPP3    ;
X_CHCL_IPP3 + X_M_IPP3 <= 1 ; !JUST ADD TO EASE CALCULATION IN LINGO,
DO NOT INCLUDE IN FORMULATION.;

F_OUTCHCL_TPP4   = F_IPP4 * X_CHCL_IPP4 ;
F_OUTM_TPP4      = F_IPP4 * X_M_IPP4    ;
X_CHCL_IPP4 + X_M_IPP4 <= 1 ; !JUST ADD TO EASE CALCULATION IN LINGO,
DO NOT INCLUDE IN FORMULATION.;

F_OUTCHCL_TPP5   = F_IPP5 * X_CHCL_IPP5 ;
F_OUTM_TPP5      = F_IPP5 * X_M_IPP5    ;
X_CHCL_IPP5 + X_M_IPP5 <= 1 ; !JUST ADD TO EASE CALCULATION IN LINGO,
DO NOT INCLUDE IN FORMULATION.;

F_OUTCHCL_TPP6   = F_IPP6 * X_CHCL_IPP6 ;
F_OUTM_TPP6      = F_IPP6 * X_M_IPP6    ;
X_CHCL_IPP6 + X_M_IPP6 <= 1 ; !JUST ADD TO EASE CALCULATION IN LINGO,
DO NOT INCLUDE IN FORMULATION.;

F_OUTCHCL_TPP7   = F_IPP7 * X_CHCL_IPP7 ;
F_OUTM_TPP7      = F_IPP7 * X_M_IPP7    ;
X_CHCL_IPP7 + X_M_IPP7 <= 1 ; !JUST ADD TO EASE CALCULATION IN LINGO,
DO NOT INCLUDE IN FORMULATION.;

F_OUTCHCL_BLANK3 = F_IPP8 * X_CHCL_IPP8 ;
F_OUTM_BLANK3    = F_IPP8 * X_M_IPP8    ;
X_CHCL_IPP8 + X_M_IPP8 <= 1 ; !JUST ADD TO EASE CALCULATION IN LINGO,
DO NOT INCLUDE IN FORMULATION.;

I_TPP1 + I_TPP2 + I_TPP3 + I_TPP4 + I_TPP5 + I_TPP6 + I_TPP7 +
I_BLANK3 = I_TPP_TOTAL;

I_T_TOTAL + I_TP_TOTAL + I_TPP_TOTAL = I_TOTAL ;

P_TOTAL = (P_D_T_TOTAL + P_D_TP_TOTAL + P_D_TPP_TOTAL) +
(P_SR_T_TOTAL + P_SR_TP_TOTAL + P_SR_TPP_TOTAL);

C_TOTAL = C_T_TOTAL + C_TP_TOTAL + C_TPP_TOTAL ;

MAX = F_IPP_TOTAL -(0.00001 * I_TOTAL) ;

X_M_IPP1 <= 0.135 ;
X_M_IPP2 <= 0.135 ;
X_M_IPP3 <= 0.135 ;
X_M_IPP4 <= 0.135 ;
X_M_IPP5 <= 0.135 ;
X_M_IPP6 <= 0.135 ;
X_M_IPP7 <= 0.135 ;
```

```
X_M_IPP8 <= 0.135 ;

S_IPP1 <= 13.5 ;
S_IPP2 <= 13.5 ;
S_IPP3 <= 13.5 ;
S_IPP4 <= 13.5 ;
S_IPP5 <= 13.5 ;
S_IPP6 <= 13.5 ;
S_IPP7 <= 13.5 ;
S_IPP8 <= 13.5 ;
```

APPENDIX B1

Lingo Result

For maximising productivity

```
Global optimal solution found.
Objective value:                              5.546659
Objective bound:                              5.546659
Infeasibilities:                              0.000000
Extended solver steps:                            1013
Total solver iterations:                       1482052
Elapsed runtime seconds:                        175.71

Model Class:                                     MINLP

Total variables:                   606
Nonlinear variables:               365
Integer variables:                  24

Total constraints:                 764
Nonlinear constraints:             330

Total nonzeros:                   2589
Nonlinear nonzeros:               1182
```

Variable	Value	Reduced Cost
F_AVAILABLE_EFB	3.900000	0.000000
X_CHCL_EFB	0.5500000	0.000000
X_M_EFB	0.4500000	0.000000
S_EFB	150.0000	0.000000
F_AVAILABLE_PKS	1.200000	0.000000
X_CHCL_PKS	0.7300000	0.000000
X_M_PKS	0.2700000	0.000000
S_PKS	20.00000	0.000000
F_AVAILABLE_PMF	2.200000	0.000000
X_CHCL_PMF	0.7700000	0.000000
X_M_PMF	0.2300000	0.000000
S_PMF	30.00000	0.000000
TOTAL_BIOMASS_AVAILABLE	7.300000	0.000000
TOTAL_CHCL_AVAILABLE	4.715000	0.000000
TOTAL_M_AVAILABLE	2.585000	0.000000
F_EFB	3.900000	0.000000
F_PKS	1.200000	0.000000
F_PMF	2.200000	0.000000
S_1	150.0000	0.000000
F_EFB_T1	0.000000	0.000000
F_EFB_T2	0.000000	0.000000
F_EFB_T3	0.000000	0.000000
F_EFB_T4	0.000000	0.000000
F_EFB_T5	0.000000	0.000000
F_EFB_T6	0.000000	0.000000

F_EFB_T7	3.900000	0.000000
F_EFB_BLANK1	0.000000	0.000000
F_PKS_T1	0.000000	0.000000
F_PKS_T2	0.000000	0.000000
F_PKS_T3	0.000000	0.000000
F_PKS_T4	0.000000	0.000000
F_PKS_T5	0.000000	0.000000
F_PKS_T6	0.000000	0.4483188E-05
F_PKS_T7	1.200000	0.000000
F_PKS_BLANK1	0.000000	0.4483188E-05
F_PMF_T1	0.000000	0.000000
F_PMF_T2	0.000000	0.000000
F_PMF_T3	0.000000	0.000000
F_PMF_T4	0.000000	0.000000
F_PMF_T5	0.000000	0.000000
F_PMF_T6	0.000000	0.5479452E-05
F_PMF_T7	2.200000	0.000000
F_PMF_BLANK1	0.000000	0.5479452E-05
F_IN_T1	0.000000	0.1120797E-04
X_CHCL_IN_T1	0.000000	0.000000
X_M_IN_T1	0.000000	0.000000
F_IN_T2	0.000000	0.1120797E-04
X_CHCL_IN_T2	0.000000	0.000000
X_M_IN_T2	0.000000	0.000000
F_IN_T3	0.000000	0.1120797E-04
X_CHCL_IN_T3	0.000000	0.000000
X_M_IN_T3	0.000000	0.000000
F_IN_T4	0.000000	0.1120797E-04
X_CHCL_IN_T4	0.000000	0.000000
X_M_IN_T4	0.000000	0.000000
F_IN_T5	0.000000	0.1120797E-04
X_CHCL_IN_T5	0.000000	0.000000
X_M_IN_T5	0.000000	0.000000
F_IN_T6	0.000000	0.000000
X_CHCL_IN_T6	0.000000	0.000000
X_M_IN_T6	0.6303655	0.000000
F_IN_T7	7.300000	0.000000
X_CHCL_IN_T7	0.6458904	0.000000
X_M_IN_T7	0.3541096	0.000000
F_IN_BLANK1	0.000000	0.000000
X_CHCL_IN_BLANK1	0.000000	0.000000
X_M_IN_BLANK1	0.000000	0.000000
F_IN_T_TOTAL	7.300000	0.000000
I_T1	0.000000	0.000000
I_T2	0.000000	0.000000
I_T3	0.000000	0.000000
I_T4	0.000000	0.000000
I_T5	0.000000	0.000000
I_T6	0.000000	0.000000
I_T7	1.000000	0.000000
I_BLANK1	0.000000	0.000000
F_OUTCHCL_T1	0.000000	0.000000
F_OUTCHCL_T2	0.000000	0.000000
F_OUTCHCL_T3	0.000000	0.000000
F_OUTCHCL_T4	0.000000	0.000000
F_OUTCHCL_T5	0.000000	0.000000
F_OUTCHCL_T6	0.000000	0.000000
F_OUTCHCL_T7	4.715000	0.000000
F_OUTCHCL_BLANK1	0.000000	0.000000
F_OUTCHCL_T_TOTAL	4.715000	0.000000
F_MR_T1	0.000000	0.000000
MRR_T1	0.5600000	0.000000
TR_T1	0.6700000	0.000000
EF_T1	0.6000000	0.000000
P_D_T1	0.000000	0.000000
F_MR_T2	0.000000	0.000000
MRR_T2	0.5600000	0.000000

TR_T2	0.6700000	0.000000
EF_T2	0.8600000	0.000000
P_D_T2	0.000000	0.000000
F_MR_T3	0.000000	0.000000
MRR_T3	0.5600000	0.000000
TR_T3	0.6700000	0.000000
EF_T3	0.8700000	0.000000
P_D_T3	0.000000	0.000000
F_MR_T4	0.000000	0.000000
MRR_T4	0.8100000	0.000000
TR_T4	0.6700000	0.000000
EF_T4	0.7000000	0.000000
P_D_T4	0.000000	0.000000
F_MR_T5	0.000000	0.000000
MRR_T5	0.1500000	0.000000
TR_T5	0.000000	0.000000
EF_T5	1.000000	0.000000
P_D_T5	0.000000	0.000000
F_MR_T6	0.000000	0.000000
MRR_T6	0.1500000	0.000000
TR_T6	0.000000	0.000000
EF_T6	1.000000	0.000000
P_D_T6	0.000000	0.000000
F_MR_T7	0.3877500	0.000000
MRR_T7	0.1500000	0.000000
TR_T7	0.000000	0.000000
EF_T7	1.000000	0.000000
P_D_T7	0.000000	0.000000
F_MR_BLANK1	0.000000	0.000000
MRR_BLANK1	0.000000	0.000000
TR_BLANK1	0.000000	0.000000
EF_BLANK1	1.000000	0.000000
P_D_BLANK1	0.000000	0.000000
F_OUTM_T1	0.000000	0.000000
F_OUTM_T2	0.000000	0.000000
F_OUTM_T3	0.000000	0.000000
F_OUTM_T4	0.000000	0.000000
F_OUTM_T5	0.000000	0.000000
F_OUTM_T6	0.000000	0.000000
F_OUTM_T7	2.197250	0.000000
F_OUTM_BLANK1	0.000000	0.000000
F_OUTM_T_TOTAL	2.197250	0.000000
P_D_T_TOTAL	0.000000	0.000000
S_IN_T1	150.0000	0.000000
S_IN_T2	150.0000	0.000000
S_IN_T3	150.0000	0.000000
S_IN_T4	150.0000	0.000000
S_IN_T5	150.0000	0.000000
S_IN_T6	150.0000	0.000000
S_IN_T7	150.0000	0.000000
S_IN_BLANK1	150.0000	0.000000
SRR_T1	1.000000	0.000000
S_I1	0.000000	0.000000
P_SR_T1	0.000000	0.000000
K_T1	1.234568	0.000000
SRR_T2	1.000000	0.000000
S_I2	0.000000	0.000000
P_SR_T2	0.000000	0.000000
K_T2	1.234568	0.000000
SRR_T3	1.000000	0.000000
S_I3	0.000000	0.000000
P_SR_T3	0.000000	0.000000
K_T3	1.234568	0.000000
SRR_T4	1.000000	0.000000
S_I4	0.000000	0.000000
P_SR_T4	0.000000	0.000000
K_T4	1.234568	0.000000

SRR_T5	3.643887	0.000000
S_I5	0.000000	0.000000
A_T5	0.5615650	0.000000
B_T5	0.000000	0.000000
K_T5	-42.75439	0.000000
P_SR_T5	0.000000	0.000000
SRR_T6	2.839685	0.000000
S_I6	0.000000	0.000000
A_T6	0.4532702	0.000000
B_T6	0.6303655	0.000000
K_T6	36.30321	0.000000
P_SR_T6	0.000000	0.000000
SRR_T7	4.060000	0.000000
S_I7	36.94581	0.000000
A_T7	0.6085260	0.000000
B_T7	0.3541096	0.000000
K_T7	0.6673457	0.000000
P_SR_T7	2.964510	0.000000
SRR_BLANK1	1.000000	0.000000
S_I8	0.000000	0.000000
P_SR_BLANK1	0.000000	0.000000
K_BLANK1	1.234568	0.000000
P_SR_T_TOTAL	2.964510	0.000000
C_T1	0.000000	0.000000
C_T2	0.000000	0.000000
C_T3	0.000000	0.000000
C_T4	0.000000	0.000000
C_T5	0.000000	0.000000
C_T6	0.000000	0.000000
C_T7	54735.10	0.000000
C_BLANK1	0.000000	0.000000
C_T_TOTAL	54735.10	0.000000
F_I1	0.000000	0.000000
F_I2	0.000000	0.000000
F_I3	0.000000	0.000000
F_I4	0.000000	0.000000
F_I5	0.000000	0.000000
F_I6	0.000000	0.000000
F_I7	6.912250	0.000000
F_I8	0.000000	0.000000
F_I_TOTAL	6.912250	0.000000
X_CHCL_I1	0.000000	0.000000
X_M_I1	0.000000	0.000000
X_CHCL_I2	0.000000	0.000000
X_M_I2	0.000000	0.000000
X_CHCL_I3	0.000000	0.000000
X_M_I3	0.000000	0.000000
X_CHCL_I4	0.000000	0.000000
X_M_I4	0.000000	0.000000
X_CHCL_I5	0.000000	0.000000
X_M_I5	0.000000	0.000000
X_CHCL_I6	0.000000	0.000000
X_M_I6	0.000000	0.000000
X_CHCL_I7	0.6821223	0.000000
X_M_I7	0.3178777	0.000000
X_CHCL_I8	0.000000	0.000000
X_M_I8	0.000000	0.000000
I_T_TOTAL	1.000000	0.000000
S_2	36.94581	0.000000
F_I1_TP1	0.000000	0.000000
F_I1_TP2	0.000000	0.000000
F_I1_TP3	0.000000	0.000000
F_I1_TP4	0.000000	0.000000
F_I1_TP5	0.000000	0.000000
F_I1_TP6	0.000000	0.000000
F_I1_TP7	0.000000	0.000000
F_I1_BLANK2	0.000000	0.000000

F_I2_TP1	0.000000	0.000000
F_I2_TP2	0.000000	0.000000
F_I2_TP3	0.000000	0.000000
F_I2_TP4	0.000000	0.000000
F_I2_TP5	0.000000	0.000000
F_I2_TP6	0.000000	0.000000
F_I2_TP7	0.000000	0.000000
F_I2_BLANK2	0.000000	0.000000
F_I3_TP1	0.000000	0.000000
F_I3_TP2	0.000000	0.000000
F_I3_TP3	0.000000	0.000000
F_I3_TP4	0.000000	0.000000
F_I3_TP5	0.000000	0.000000
F_I3_TP6	0.000000	0.000000
F_I3_TP7	0.000000	0.000000
F_I3_BLANK2	0.000000	0.000000
F_I4_TP1	0.000000	0.000000
F_I4_TP2	0.000000	0.000000
F_I4_TP3	0.000000	0.000000
F_I4_TP4	0.000000	0.000000
F_I4_TP5	0.000000	0.000000
F_I4_TP6	0.000000	0.000000
F_I4_TP7	0.000000	0.000000
F_I4_BLANK2	0.000000	0.000000
F_I5_TP1	0.000000	0.000000
F_I5_TP2	0.000000	0.000000
F_I5_TP3	0.000000	0.000000
F_I5_TP4	0.000000	0.000000
F_I5_TP5	0.000000	0.000000
F_I5_TP6	0.000000	0.000000
F_I5_TP7	0.000000	0.000000
F_I5_BLANK2	0.000000	0.000000
F_I6_TP1	0.000000	0.000000
F_I6_TP2	0.000000	0.000000
F_I6_TP3	0.000000	0.000000
F_I6_TP4	0.000000	0.000000
F_I6_TP5	0.000000	0.000000
F_I6_TP6	0.000000	0.000000
F_I6_TP7	0.000000	0.000000
F_I6_BLANK2	0.000000	0.000000
F_I7_TP1	4.456728	0.000000
F_I7_TP2	0.000000	0.000000
F_I7_TP3	0.000000	0.000000
F_I7_TP4	0.000000	0.000000
F_I7_TP5	0.000000	0.000000
F_I7_TP6	0.000000	0.000000
F_I7_TP7	0.000000	0.000000
F_I7_BLANK2	2.455522	0.000000
F_I8_TP1	0.000000	0.000000
F_I8_TP2	0.000000	0.000000
F_I8_TP3	0.000000	0.000000
F_I8_TP4	0.000000	0.000000
F_I8_TP5	0.000000	0.000000
F_I8_TP6	0.000000	0.000000
F_I8_TP7	0.000000	0.000000
F_I8_BLANK2	0.000000	0.000000
F_IN_TP1	4.456728	0.000000
X_CHCL_IN_TP1	0.6821223	0.000000
X_M_IN_TP1	0.3178777	0.000000
F_IN_TP2	0.000000	0.000000
X_CHCL_IN_TP2	0.000000	0.000000
X_M_IN_TP2	0.000000	0.000000
F_IN_TP3	0.000000	0.000000
X_CHCL_IN_TP3	0.000000	0.000000
X_M_IN_TP3	0.000000	0.000000
F_IN_TP4	0.000000	0.000000
X_CHCL_IN_TP4	0.000000	0.000000

X_M_IN_TP4	0.000000	0.000000
F_IN_TP5	0.000000	0.000000
X_CHCL_IN_TP5	0.000000	0.000000
X_M_IN_TP5	0.1067240	0.000000
F_IN_TP6	0.000000	0.000000
X_CHCL_IN_TP6	0.000000	0.000000
X_M_IN_TP6	0.000000	0.000000
F_IN_TP7	0.000000	0.000000
X_CHCL_IN_TP7	0.000000	0.000000
X_M_IN_TP7	0.000000	0.000000
F_IN_BLANK2	2.455522	0.000000
X_CHCL_IN_BLANK2	0.6821223	0.000000
X_M_IN_BLANK2	0.3178777	0.000000
F_IN_TP_TOTAL	6.912250	0.000000
I_TP1	1.000000	0.1000000E-03
I_TP2	0.000000	0.000000
I_TP3	0.000000	0.000000
I_TP4	0.000000	0.000000
I_TP5	0.000000	0.000000
I_TP6	0.000000	0.000000
I_TP7	0.000000	0.000000
I_BLANK2	1.000000	0.1000000E-03
F_OUTCHCL_TP1	3.040034	0.000000
F_OUTCHCL_TP2	0.000000	0.000000
F_OUTCHCL_TP3	0.000000	0.000000
F_OUTCHCL_TP4	0.000000	0.000000
F_OUTCHCL_TP5	0.000000	0.000000
F_OUTCHCL_TP6	0.000000	0.000000
F_OUTCHCL_TP7	0.000000	0.000000
F_OUTCHCL_BLANK2	1.674966	0.000000
F_OUTCHCL_TP_TOTAL	4.715000	0.000000
F_MR_TP1	1.218357	0.000000
MRR_TP1	0.8600000	0.000000
TR_TP1	0.6700000	0.000000
EF_TP1	0.6000000	0.000000
P_D_TP1	0.3779164E-03	0.000000
F_MR_TP2	0.000000	0.000000
MRR_TP2	0.8600000	0.000000
TR_TP2	0.6700000	0.000000
EF_TP2	0.8600000	0.000000
P_D_TP2	0.000000	0.000000
F_MR_TP3	0.000000	0.000000
MRR_TP3	0.8600000	0.000000
TR_TP3	0.6700000	0.000000
EF_TP3	0.8700000	0.000000
P_D_TP3	0.000000	0.000000
F_MR_TP4	0.000000	0.000000
MRR_TP4	0.8100000	0.000000
TR_TP4	0.6700000	0.000000
EF_TP4	0.7000000	0.000000
P_D_TP4	0.000000	0.000000
F_MR_TP5	0.000000	0.000000
MRR_TP5	0.1500000	0.000000
TR_TP5	0.000000	0.000000
EF_TP5	1.000000	0.000000
P_D_TP5	0.000000	0.000000
F_MR_TP6	0.000000	0.000000
MRR_TP6	0.1500000	0.000000
TR_TP6	0.000000	0.000000
EF_TP6	1.000000	0.000000
P_D_TP6	0.000000	0.000000
F_MR_TP7	0.000000	0.000000
MRR_TP7	0.1500000	0.000000
TR_TP7	0.000000	0.000000
EF_TP7	1.000000	0.000000
P_D_TP7	0.000000	0.000000
F_MR_BLANK2	0.000000	0.000000

MRR_BLANK2	0.000000	0.000000
TR_BLANK2	0.000000	0.000000
EF_BLANK2	1.000000	0.000000
P_D_BLANK2	0.000000	0.000000
P_D_TP_TOTAL	0.3779164E-03	0.000000
F_OUTM_TP1	0.1983372	0.000000
F_OUTM_TP2	0.000000	0.000000
F_OUTM_TP3	0.000000	0.000000
F_OUTM_TP4	0.000000	0.000000
F_OUTM_TP5	0.000000	0.000000
F_OUTM_TP6	0.000000	0.000000
F_OUTM_TP7	0.000000	0.000000
F_OUTM_BLANK2	0.7805555	0.000000
F_OUTM_TP_TOTAL	0.9788927	0.000000
S_IN_TP1	36.94581	0.000000
S_IN_TP2	36.94581	0.000000
S_IN_TP3	36.94581	0.000000
S_IN_TP4	36.94581	0.000000
S_IN_TP5	36.94581	0.000000
S_IN_TP6	36.94581	0.000000
S_IN_TP7	36.94581	0.000000
S_IN_BLANK2	36.94581	0.000000
SRR_TP1	1.000000	0.000000
S_IP1	36.94581	0.000000
P_SR_TP1	0.000000	0.000000
K_TP1	1.234568	0.000000
SRR_TP2	1.000000	0.000000
S_IP2	0.000000	0.000000
P_SR_TP2	0.000000	0.000000
K_TP2	1.234568	0.000000
SRR_TP3	1.000000	0.000000
S_IP3	0.000000	0.000000
P_SR_TP3	0.000000	0.000000
K_TP3	1.234568	0.000000
SRR_TP4	1.000000	0.000000
S_IP4	0.000000	0.000000
P_SR_TP4	0.000000	0.000000
K_TP4	1.234568	0.000000
SRR_TP5	3.039886	0.000000
S_IP5	0.000000	0.000000
A_TP5	0.4828573	0.000000
B_TP5	0.1067240	0.000000
K_TP5	-6.568121	0.000000
P_SR_TP5	0.000000	0.000000
SRR_TP6	6.337137	0.000000
S_IP6	0.000000	0.000000
A_TP6	0.8018931	0.000000
B_TP6	0.000000	0.000000
K_TP6	65.58840	0.000000
P_SR_TP6	0.000000	0.000000
SRR_TP7	4.060000	0.000000
S_IP7	0.000000	0.000000
A_TP7	0.6085260	0.000000
K_TP7	0.6673457	0.000000
P_SR_TP7	0.000000	0.000000
SRR_BLANK2	1.000000	0.000000
S_IP8	36.94581	0.000000
P_SR_BLANK2	0.000000	0.000000
K_BLANK2	1.234568	0.000000
P_SR_TP_TOTAL	0.000000	0.000000
C_TP1	284139.8	0.000000
C_TP2	0.000000	0.000000
C_TP3	0.000000	0.000000
C_TP4	0.000000	0.000000
C_TP5	0.000000	0.000000
C_TP6	0.000000	0.000000
C_TP7	0.000000	0.000000

C_BLANK2	0.000000	0.000000
C_TP_TOTAL	284139.8	0.000000
F_IP1	3.238371	0.000000
F_IP2	0.000000	0.000000
F_IP3	0.000000	0.000000
F_IP4	0.000000	0.000000
F_IP5	0.000000	0.000000
F_IP6	0.000000	0.000000
F_IP7	0.000000	0.000000
F_IP8	2.455522	0.000000
F_IP_TOTAL	5.693893	0.000000
X_CHCL_IP1	0.9387540	0.000000
X_M_IP1	0.6124598E-01	0.000000
X_CHCL_IP2	0.000000	0.000000
X_M_IP2	0.000000	0.000000
X_CHCL_IP3	0.000000	0.000000
X_M_IP3	0.000000	0.000000
X_CHCL_IP4	0.000000	0.000000
X_M_IP4	0.000000	0.000000
X_CHCL_IP5	0.000000	0.000000
X_M_IP5	0.000000	0.000000
X_CHCL_IP6	0.000000	0.000000
X_M_IP6	0.000000	0.000000
X_CHCL_IP7	0.000000	0.000000
X_M_IP7	0.000000	0.000000
X_CHCL_IP8	0.6821223	0.000000
X_M_IP8	0.3178777	0.000000
I_TP_TOTAL	2.000000	0.000000
S_3	36.94581	0.000000
F_IP1_TPP1	0.000000	0.000000
F_IP1_TPP2	0.000000	0.9370494E-05
F_IP1_TPP3	0.000000	0.9370494E-05
F_IP1_TPP4	0.000000	0.000000
F_IP1_TPP5	0.000000	0.000000
F_IP1_TPP6	0.000000	0.000000
F_IP1_TPP7	3.238371	0.000000
F_IP1_BLANK3	0.000000	0.000000
F_IP2_TPP1	0.000000	0.000000
F_IP2_TPP2	0.000000	0.000000
F_IP2_TPP3	0.000000	0.000000
F_IP2_TPP4	0.000000	0.000000
F_IP2_TPP5	0.000000	0.000000
F_IP2_TPP6	0.000000	0.000000
F_IP2_TPP7	0.000000	0.000000
F_IP2_BLANK3	0.000000	0.000000
F_IP3_TPP1	0.000000	0.000000
F_IP3_TPP2	0.000000	0.000000
F_IP3_TPP3	0.000000	0.000000
F_IP3_TPP4	0.000000	0.000000
F_IP3_TPP5	0.000000	0.000000
F_IP3_TPP6	0.000000	0.000000
F_IP3_TPP7	0.000000	0.000000
F_IP3_BLANK3	0.000000	0.000000
F_IP4_TPP1	0.000000	0.000000
F_IP4_TPP2	0.000000	0.000000
F_IP4_TPP3	0.000000	0.000000
F_IP4_TPP4	0.000000	0.000000
F_IP4_TPP5	0.000000	0.000000
F_IP4_TPP6	0.000000	0.000000
F_IP4_TPP7	0.000000	0.000000
F_IP4_BLANK3	0.000000	0.000000
F_IP5_TPP1	0.000000	0.000000
F_IP5_TPP2	0.000000	0.000000
F_IP5_TPP3	0.000000	0.000000
F_IP5_TPP4	0.000000	0.000000
F_IP5_TPP5	0.000000	0.000000
F_IP5_TPP6	0.000000	0.000000

F_IP5_TPP7	0.000000	0.000000
F_IP5_BLANK3	0.000000	0.000000
F_IP6_TPP1	0.000000	0.000000
F_IP6_TPP2	0.000000	0.000000
F_IP6_TPP3	0.000000	0.000000
F_IP6_TPP4	0.000000	0.000000
F_IP6_TPP5	0.000000	0.000000
F_IP6_TPP6	0.000000	0.000000
F_IP6_TPP7	0.000000	0.000000
F_IP6_BLANK3	0.000000	0.000000
F_IP7_TPP1	0.000000	0.000000
F_IP7_TPP2	0.000000	0.000000
F_IP7_TPP3	0.000000	0.000000
F_IP7_TPP4	0.000000	0.000000
F_IP7_TPP5	0.000000	0.000000
F_IP7_TPP6	0.000000	0.000000
F_IP7_TPP7	0.000000	0.000000
F_IP7_BLANK3	0.000000	0.000000
F_IP8_TPP1	0.000000	0.000000
F_IP8_TPP2	0.000000	0.000000
F_IP8_TPP3	0.000000	0.000000
F_IP8_TPP4	0.000000	0.000000
F_IP8_TPP5	0.000000	0.000000
F_IP8_TPP6	0.000000	0.000000
F_IP8_TPP7	2.455522	0.000000
F_IP8_BLANK3	0.000000	0.000000
F_IN_TPP1	0.000000	0.2490660E-04
X_CHCL_IN_TPP1	0.000000	0.000000
X_M_IN_TPP1	0.000000	0.000000
F_IN_TPP2	0.000000	0.2490660E-04
X_CHCL_IN_TPP2	0.000000	0.000000
X_M_IN_TPP2	0.000000	0.000000
F_IN_TPP3	0.000000	0.2490660E-04
X_CHCL_IN_TPP3	0.000000	0.000000
X_M_IN_TPP3	0.000000	0.000000
F_IN_TPP4	0.000000	0.2490660E-04
X_CHCL_IN_TPP4	0.000000	0.000000
X_M_IN_TPP4	0.000000	0.000000
F_IN_TPP5	0.000000	0.2356888E-04
X_CHCL_IN_TPP5	0.000000	0.000000
X_M_IN_TPP5	0.5370963E-01	0.000000
F_IN_TPP6	0.000000	0.9027554E-05
X_CHCL_IN_TPP6	0.000000	0.000000
X_M_IN_TPP6	0.6375437	0.000000
F_IN_TPP7	5.693893	0.000000
X_CHCL_IN_TPP7	0.8280802	0.000000
X_M_IN_TPP7	0.1719198	0.000000
F_IN_BLANK3	0.000000	0.2490660E-04
X_CHCL_IN_BLANK3	0.000000	0.000000
X_M_IN_BLANK3	0.000000	0.000000
F_IN_TPP_TOTAL	5.693893	0.000000
I_TPP1	0.000000	0.000000
I_TPP2	0.000000	0.000000
I_TPP3	0.000000	0.000000
I_TPP4	0.000000	0.000000
I_TPP5	0.000000	0.000000
I_TPP6	0.000000	0.000000
I_TPP7	1.000000	0.1000000E-03
I_BLANK3	0.000000	0.000000
F_OUTCHCL_TPP1	0.000000	0.000000
F_OUTCHCL_TPP2	0.000000	0.000000
F_OUTCHCL_TPP3	0.000000	0.000000
F_OUTCHCL_TPP4	0.000000	0.000000
F_OUTCHCL_TPP5	0.000000	0.000000
F_OUTCHCL_TPP6	0.000000	0.000000
F_OUTCHCL_TPP7	4.715000	0.000000
F_OUTCHCL_BLANK3	0.000000	0.000000

F_OUTCHCL_TPP_TOTAL	4.715000	0.000000
F_OUTM_TPP1	0.000000	0.000000
F_MR_TPP1	0.000000	0.000000
F_OUTM_TPP2	0.000000	0.000000
F_MR_TPP2	0.000000	0.000000
F_OUTM_TPP3	0.000000	0.000000
F_MR_TPP3	0.000000	0.000000
F_OUTM_TPP4	0.000000	0.000000
F_MR_TPP4	0.000000	0.000000
F_OUTM_TPP5	0.000000	0.000000
F_MR_TPP5	0.000000	0.000000
F_OUTM_TPP6	0.000000	0.000000
F_MR_TPP6	0.000000	0.000000
F_OUTM_TPP7	0.8320588	0.000000
F_MR_TPP7	0.1468339	0.000000
F_OUTM_BLANK3	0.000000	0.000000
F_MR_BLANK3	0.000000	0.000000
MRR_TPP1	0.5600000	0.000000
TR_TPP1	0.6700000	0.000000
EF_TPP1	0.6000000	0.000000
P_D_TPP1	0.000000	0.000000
MRR_TPP2	0.8600000	0.000000
TR_TPP2	0.6700000	0.000000
EF_TPP2	0.8600000	0.000000
P_D_TPP2	0.000000	0.000000
MRR_TPP3	0.8600000	0.000000
TR_TPP3	0.6700000	0.000000
EF_TPP3	0.8700000	0.000000
P_D_TPP3	0.000000	0.000000
MRR_TPP4	0.8100000	0.000000
TR_TPP4	0.6700000	0.000000
EF_TPP4	0.7000000	0.000000
P_D_TPP4	0.000000	0.000000
MRR_TPP5	0.1500000	0.000000
TR_TPP5	0.000000	0.000000
EF_TPP5	1.000000	0.000000
P_D_TPP5	0.000000	0.000000
MRR_TPP6	0.1500000	0.000000
TR_TPP6	0.000000	0.000000
EF_TPP6	1.000000	0.000000
P_D_TPP6	0.000000	0.000000
MRR_TPP7	0.1500000	0.000000
TR_TPP7	0.000000	0.000000
EF_TPP7	1.000000	0.000000
P_D_TPP7	0.000000	0.000000
MRR_BLANK3	0.000000	0.000000
TR_BLANK3	0.000000	0.000000
EF_BLANK3	1.000000	0.000000
P_D_BLANK3	0.000000	0.000000
P_D_TPP_TOTAL	0.000000	0.000000
F_OUTM_TPP_TOTAL	0.8320588	0.000000
S_IN_TPP1	36.94581	0.000000
S_IN_TPP2	36.94581	0.000000
S_IN_TPP3	36.94581	0.000000
S_IN_TPP4	36.94581	0.000000
S_IN_TPP5	36.94581	0.000000
S_IN_TPP6	36.94581	0.000000
S_IN_TPP7	36.94581	0.000000
S_IN_BLANK3	36.94581	0.000000
SRR_TPP1	1.000000	0.000000
S_IPP1	0.000000	0.000000
P_SR_TPP1	0.000000	0.000000
K_TPP1	1.234568	0.000000
SRR_TPP2	1.000000	0.000000
S_IPP2	0.000000	0.000000
P_SR_TPP2	0.000000	0.000000
K_TPP2	1.234568	0.000000

SRR_TPP3	1.000000	0.000000
S_IPP3	0.000000	0.000000
P_SR_TPP3	0.000000	0.000000
K_TPP3	1.234568	0.000000
SRR_TPP4	1.000000	0.000000
S_IPP4	0.000000	0.000000
P_SR_TPP4	0.000000	0.000000
K_TPP4	1.234568	0.000000
SRR_TPP5	3.021432	0.000000
S_IPP5	0.000000	0.000000
A_TPP5	0.4802129	0.000000
B_TPP5	0.5370963E-01	0.000000
K_TPP5	-8.347260	0.000000
P_SR_TPP5	0.000000	0.000000
SRR_TPP6	5.281637	0.000000
S_IPP6	0.000000	0.000000
A_TPP6	0.7227685	0.000000
B_TPP6	0.6375437	0.000000
K_TPP6	43.95867	0.000000
P_SR_TPP6	0.000000	0.000000
SRR_TPP7	4.060000	0.000000
S_IPP7	9.099954	0.000000
A_TPP7	0.6085260	0.000000
K_TPP7	0.6673457	0.000000
P_SR_TPP7	2.312274	0.000000
SRR_BLANK3	1.000000	0.000000
S_IPP8	0.000000	0.000000
P_SR_BLANK3	0.000000	0.000000
K_BLANK3	1.234568	0.000000
P_SR_TPP_TOTAL	2.312274	0.000000
C_TPP1	0.000000	0.000000
C_TPP2	0.000000	0.000000
C_TPP3	0.000000	0.000000
C_TPP4	0.000000	0.000000
C_TPP5	0.000000	0.000000
C_TPP6	0.000000	0.000000
C_TPP7	47153.92	0.000000
C_BLANK3	0.000000	0.000000
C_TPP_TOTAL	47153.92	0.000000
F_IPP1	0.000000	0.000000
F_IPP2	0.000000	0.000000
F_IPP3	0.000000	0.000000
F_IPP4	0.000000	0.000000
F_IPP5	0.000000	0.000000
F_IPP6	0.000000	0.000000
F_IPP7	5.547059	0.000000
F_IPP8	0.000000	0.000000
F_IPP_TOTAL	5.547059	0.000000
X_CHCL_IPP1	0.000000	0.000000
X_M_IPP1	0.000000	0.000000
X_CHCL_IPP2	0.000000	0.000000
X_M_IPP2	0.1500000	0.000000
X_CHCL_IPP3	0.000000	0.000000
X_M_IPP3	0.1500000	0.000000
X_CHCL_IPP4	0.000000	0.000000
X_M_IPP4	0.1500000	0.000000
X_CHCL_IPP5	0.000000	0.000000
X_M_IPP5	0.1500000	0.000000
X_CHCL_IPP6	0.000000	0.000000
X_M_IPP6	0.1500000	0.000000
X_CHCL_IPP7	0.8500000	0.000000
X_M_IPP7	0.1500000	0.000000
X_CHCL_IPP8	0.000000	0.000000
X_M_IPP8	0.1500000	0.000000
I_TPP_TOTAL	1.000000	0.000000
I_TOTAL	4.000000	0.000000
P_TOTAL	5.277162	0.000000

C_TOTAL	386028.9	0.000000

Row	Slack or Surplus	Dual Price
1	0.000000	0.6470588
2	0.000000	4.588235
3	0.000000	0.000000
4	0.000000	0.000000
5	0.000000	0.8588235
6	0.000000	1.411765
7	0.000000	0.000000
8	0.000000	0.000000
9	0.000000	0.9058824
10	0.000000	2.588235
11	0.000000	0.000000
12	0.000000	0.000000
13	0.000000	0.1369817E-04
14	0.000000	1.176446
15	0.000000	0.000000
16	0.000000	0.000000
17	0.000000	0.4483188E-05
18	0.000000	0.5479452E-05
19	0.000000	0.000000
20	130.0000	0.000000
21	120.0000	0.000000
22	0.000000	0.000000
23	0.000000	-0.4483188E-05
24	0.000000	-0.5479452E-05
25	0.000000	0.1120797E-04
26	0.000000	0.000000
27	0.000000	-0.2490660E-04
28	1.000000	0.000000
29	0.000000	0.1120797E-04
30	0.000000	0.000000
31	0.000000	-0.2490660E-04
32	1.000000	0.000000
33	0.000000	0.1120797E-04
34	0.000000	0.000000
35	0.000000	-0.2490660E-04
36	1.000000	0.000000
37	0.000000	0.1120797E-04
38	0.000000	0.000000
39	0.000000	-0.2490660E-04
40	1.000000	0.000000
41	0.000000	0.1120797E-04
42	0.000000	0.000000
43	0.000000	-0.2490660E-04
44	1.000000	0.000000
45	0.000000	0.000000
46	0.000000	0.000000
47	0.000000	0.000000
48	0.3696345	0.000000
49	0.000000	-0.1369863E-04
50	0.000000	0.2490660E-04
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52	0.000000	0.000000
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73	0.000000	0.1000000E-03
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465	9963.054	0.000000
466	0.000000	0.000000

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552	1.000000	0.000000
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554	0.000000	0.000000
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558	0.000000	0.000000
559	0.000000	0.1000000E-03
560	0.000000	0.000000
561	36.94581	0.000000
562	36.94581	0.000000
563	36.94581	0.000000
564	36.94581	0.000000
565	36.94581	0.000000
566	36.94581	0.000000
567	0.000000	0.000000
568	0.000000	-0.2338117E-04
569	0.000000	-0.2490660E-04
570	0.000000	-0.2490660E-04
571	0.000000	-0.2490660E-04
572	0.000000	-0.2490660E-04
573	0.000000	-0.2490660E-04
574	0.000000	-0.2490660E-04
575	0.000000	-0.1698935E-04
576	0.000000	0.2490660E-04
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578	0.000000	-0.2490660E-04
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580	0.000000	0.2490660E-04
581	0.000000	-0.1160679E-04
582	0.000000	0.000000
583	1.000000	0.000000
584	0.000000	0.2490660E-04
585	0.000000	-0.1160679E-04
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587	1.000000	0.000000
588	0.000000	0.2490660E-04
589	0.000000	0.000000
590	0.000000	-0.2490660E-04
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594	0.000000	-0.2490660E-04
595	0.9462904	0.000000
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598	0.000000	-0.2490660E-04
599	0.3624563	0.000000
600	0.000000	0.2490660E-04

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616	7.300000	0.000000
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636	0.000000	0.000000
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639	0.8280802	0.000000
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646	0.000000	0.2706669E-05
647	0.000000	0.000000
648	0.000000	0.2706669E-05
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655	113.0542	0.000000
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660	0.000000	1.176471
661	0.000000	1.176471
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663	0.000000	1.176471
664	0.000000	0.2490660E-04
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666	4.715000	0.000000
667	4.715000	0.000000

668	4.715000	0.000000
669	4.715000	0.000000
670	4.715000	0.000000
671	4.715000	0.000000
672	0.000000	1.176446
673	4.715000	0.000000
674	0.000000	0.000000
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676	0.000000	1.000000
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680	0.000000	0.000000
681	0.000000	0.000000
682	0.000000	0.000000
683	0.000000	1.000000
684	0.000000	-1.000000
685	0.000000	0.000000
686	0.3000000	0.000000
687	0.000000	0.000000
688	0.000000	0.000000
689	0.000000	0.000000
690	0.000000	0.000000
691	0.3000000	0.000000
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695	0.000000	0.000000
696	0.000000	0.000000
697	0.3000000	0.000000
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727	0.000000	0.000000
728	0.000000	0.000000
729	0.000000	0.000000
730	1.752941	0.000000
731	0.000000	0.000000
732	0.000000	0.000000
733	0.000000	0.000000
734	0.000000	0.000000

735	0.000000	0.000000
736	0.000000	0.000000
737	0.000000	0.000000
738	0.000000	0.000000
739	0.000000	0.000000
740	0.000000	0.000000
741	0.000000	0.000000
742	0.000000	0.000000
743	0.000000	0.000000
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751	0.000000	0.000000
752	0.000000	0.000000
753	0.000000	0.000000
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755	0.000000	0.000000
756	0.000000	0.000000
757	1.021432	0.000000
758	10.97857	0.000000
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760	0.000000	0.000000
761	0.000000	0.000000
762	0.000000	0.000000
763	0.000000	0.000000
764	0.000000	0.000000
765	3.051637	0.000000
766	7.543363	0.000000
767	0.000000	0.000000
768	0.000000	0.000000
769	0.000000	0.000000
770	0.000000	0.000000
771	0.000000	0.000000
772	9990.900	0.000000
773	2.030000	0.000000
774	0.000000	0.000000
775	0.000000	0.000000
776	0.000000	0.000000
777	0.000000	0.000000
778	0.000000	0.000000
779	0.000000	0.000000
780	0.000000	0.000000
781	0.000000	0.000000
782	0.000000	0.000000
783	0.000000	0.000000
784	0.000000	0.000000
785	0.000000	0.000000
786	0.000000	0.000000
787	0.000000	0.000000
788	0.000000	0.000000
789	0.000000	0.000000
790	0.000000	0.000000
791	0.000000	0.000000
792	0.000000	1.000000
793	0.000000	1.176471
794	0.000000	1.176471
795	0.000000	1.176471
796	0.000000	1.176471
797	0.000000	1.176471
798	0.000000	1.176471
799	0.000000	1.000000
800	7.300000	0.000000
801	7.300000	0.000000

802	7.300000	0.000000
803	7.300000	0.000000
804	7.300000	0.000000
805	7.300000	0.000000
806	1.752941	0.000000
807	7.300000	0.000000
808	0.000000	1.000000
809	1.752941	0.000000
810	0.000000	0.000000
811	0.000000	0.000000
812	1.000000	0.000000
813	0.000000	0.000000
814	0.000000	1.176471
815	0.8500000	0.000000
816	0.000000	0.000000
817	0.000000	1.176471
818	0.8500000	0.000000
819	0.000000	0.000000
820	0.000000	1.176471
821	0.8500000	0.000000
822	0.000000	0.000000
823	0.000000	1.176471
824	0.8500000	0.000000
825	0.000000	0.000000
826	0.000000	1.176471
827	0.8500000	0.000000
828	0.000000	0.000000
829	0.000000	1.176471
830	0.000000	0.000000
831	0.000000	0.000000
832	0.000000	0.000000
833	0.8500000	0.000000
834	0.000000	0.1000000E-03
835	0.000000	0.1000000E-03
836	0.000000	0.000000
837	0.000000	0.000000
838	5.546659	1.000000
839	0.1500000	0.000000
840	0.000000	0.000000
841	0.000000	0.000000
842	0.000000	0.000000
843	0.000000	0.000000
844	0.000000	0.000000
845	0.000000	6.525952
846	0.000000	0.000000
847	15.00000	0.000000
848	15.00000	0.000000
849	15.00000	0.000000
850	15.00000	0.000000
851	15.00000	0.000000
852	15.00000	0.000000
853	5.900046	0.000000
854	15.00000	0.000000

APPENDIX B2

Lingo Result

For minimising energy requirement

```
Global optimal solution found.
Objective value:                              3.972557
Objective bound:                              3.972557
Infeasibilities:                              0.000000
Extended solver steps:                            1013
Total solver iterations:                       1482052
Elapsed runtime seconds:                        549.71

Model Class:                                     MINLP

Total variables:                    606
Nonlinear variables:                365
Integer variables:                   24

Total constraints:                  764
Nonlinear constraints:              330

Total nonzeros:                    2589
Nonlinear nonzeros:                1182
```

Variable	Value	Reduced Cost
F_AVAILABLE_EFB	3.900000	0.000000
X_CHCL_EFB	0.5500000	0.000000
X_M_EFB	0.4500000	0.000000
S_EFB	150.0000	0.000000
F_AVAILABLE_PKS	1.200000	0.000000
X_CHCL_PKS	0.7300000	0.000000
X_M_PKS	0.2700000	0.000000
S_PKS	20.00000	0.000000
F_AVAILABLE_PMF	2.200000	0.000000
X_CHCL_PMF	0.7700000	0.000000
X_M_PMF	0.2300000	0.000000
S_PMF	30.00000	0.000000
TOTAL_BIOMASS_AVAILABLE	7.300000	0.000000
TOTAL_CHCL_AVAILABLE	4.715000	0.000000
TOTAL_M_AVAILABLE	2.585000	0.000000
F_EFB	3.900000	0.000000
F_PKS	1.200000	0.000000
F_PMF	2.200000	0.000000
S_1	150.0000	0.000000
F_EFB_T1	0.000000	0.000000
F_EFB_T2	0.000000	0.000000
F_EFB_T3	0.000000	0.000000
F_EFB_T4	0.000000	0.000000
F_EFB_T5	0.000000	0.000000
F_EFB_T6	0.000000	0.000000

F_EFB_T7	3.900000	0.000000
F_EFB_BLANK1	0.000000	0.000000
F_PKS_T1	0.000000	0.000000
F_PKS_T2	0.000000	0.000000
F_PKS_T3	0.000000	0.000000
F_PKS_T4	0.000000	0.000000
F_PKS_T5	0.000000	0.000000
F_PKS_T6	0.000000	0.4483188E-05
F_PKS_T7	1.200000	0.000000
F_PKS_BLANK1	0.000000	0.4483188E-05
F_PMF_T1	0.000000	0.000000
F_PMF_T2	0.000000	0.000000
F_PMF_T3	0.000000	0.000000
F_PMF_T4	0.000000	0.000000
F_PMF_T5	0.000000	0.000000
F_PMF_T6	0.000000	0.5479452E-05
F_PMF_T7	2.200000	0.000000
F_PMF_BLANK1	0.000000	0.5479452E-05
F_IN_T1	0.000000	0.1120797E-04
X_CHCL_IN_T1	0.000000	0.000000
X_M_IN_T1	0.000000	0.000000
F_IN_T2	0.000000	0.1120797E-04
X_CHCL_IN_T2	0.000000	0.000000
X_M_IN_T2	0.000000	0.000000
F_IN_T3	0.000000	0.1120797E-04
X_CHCL_IN_T3	0.000000	0.000000
X_M_IN_T3	0.000000	0.000000
F_IN_T4	0.000000	0.1120797E-04
X_CHCL_IN_T4	0.000000	0.000000
X_M_IN_T4	0.000000	0.000000
F_IN_T5	0.000000	0.1120797E-04
X_CHCL_IN_T5	0.000000	0.000000
X_M_IN_T5	0.000000	0.000000
F_IN_T6	0.000000	0.000000
X_CHCL_IN_T6	0.000000	0.000000
X_M_IN_T6	0.6303655	0.000000
F_IN_T7	7.300000	0.000000
X_CHCL_IN_T7	0.6458904	0.000000
X_M_IN_T7	0.3541096	0.000000
F_IN_BLANK1	0.000000	0.000000
X_CHCL_IN_BLANK1	0.000000	0.000000
X_M_IN_BLANK1	0.000000	0.000000
F_IN_T_TOTAL	7.300000	0.000000
I_T1	0.000000	0.000000
I_T2	0.000000	0.000000
I_T3	0.000000	0.000000
I_T4	0.000000	0.000000
I_T5	0.000000	0.000000
I_T6	0.000000	0.000000
I_T7	1.000000	0.000000
I_BLANK1	0.000000	0.000000
F_OUTCHCL_T1	0.000000	0.000000
F_OUTCHCL_T2	0.000000	0.000000
F_OUTCHCL_T3	0.000000	0.000000
F_OUTCHCL_T4	0.000000	0.000000
F_OUTCHCL_T5	0.000000	0.000000
F_OUTCHCL_T6	0.000000	0.000000
F_OUTCHCL_T7	4.715000	0.000000
F_OUTCHCL_BLANK1	0.000000	0.000000
F_OUTCHCL_T_TOTAL	4.715000	0.000000
F_MR_T1	0.000000	0.000000
MRR_T1	0.5600000	0.000000
TR_T1	0.6700000	0.000000
EF_T1	0.6000000	0.000000
P_D_T1	0.000000	0.000000
F_MR_T2	0.000000	0.000000
MRR_T2	0.5600000	0.000000

TR_T2	0.6700000	0.000000
EF_T2	0.8600000	0.000000
P_D_T2	0.000000	0.000000
F_MR_T3	0.000000	0.000000
MRR_T3	0.5600000	0.000000
TR_T3	0.6700000	0.000000
EF_T3	0.8700000	0.000000
P_D_T3	0.000000	0.000000
F_MR_T4	0.000000	0.000000
MRR_T4	0.8100000	0.000000
TR_T4	0.6700000	0.000000
EF_T4	0.7000000	0.000000
P_D_T4	0.000000	0.000000
F_MR_T5	0.000000	0.000000
MRR_T5	0.1500000	0.000000
TR_T5	0.000000	0.000000
EF_T5	1.000000	0.000000
P_D_T5	0.000000	0.000000
F_MR_T6	0.000000	0.000000
MRR_T6	0.1500000	0.000000
TR_T6	0.000000	0.000000
EF_T6	1.000000	0.000000
P_D_T6	0.000000	0.000000
F_MR_T7	0.3877500	0.000000
MRR_T7	0.1500000	0.000000
TR_T7	0.000000	0.000000
EF_T7	1.000000	0.000000
P_D_T7	0.000000	0.000000
F_MR_BLANK1	0.000000	0.000000
MRR_BLANK1	0.000000	0.000000
TR_BLANK1	0.000000	0.000000
EF_BLANK1	1.000000	0.000000
P_D_BLANK1	0.000000	0.000000
F_OUTM_T1	0.000000	0.000000
F_OUTM_T2	0.000000	0.000000
F_OUTM_T3	0.000000	0.000000
F_OUTM_T4	0.000000	0.000000
F_OUTM_T5	0.000000	0.000000
F_OUTM_T6	0.000000	0.000000
F_OUTM_T7	2.197250	0.000000
F_OUTM_BLANK1	0.000000	0.000000
F_OUTM_T_TOTAL	2.197250	0.000000
P_D_T_TOTAL	0.000000	0.000000
S_IN_T1	150.0000	0.000000
S_IN_T2	150.0000	0.000000
S_IN_T3	150.0000	0.000000
S_IN_T4	150.0000	0.000000
S_IN_T5	150.0000	0.000000
S_IN_T6	150.0000	0.000000
S_IN_T7	150.0000	0.000000
S_IN_BLANK1	150.0000	0.000000
SRR_T1	1.000000	0.000000
S_I1	0.000000	0.000000
P_SR_T1	0.000000	0.000000
K_T1	1.234568	0.000000
SRR_T2	1.000000	0.000000
S_I2	0.000000	0.000000
P_SR_T2	0.000000	0.000000
K_T2	1.234568	0.000000
SRR_T3	1.000000	0.000000
S_I3	0.000000	0.000000
P_SR_T3	0.000000	0.000000
K_T3	1.234568	0.000000
SRR_T4	1.000000	0.000000
S_I4	0.000000	0.000000
P_SR_T4	0.000000	0.000000
K_T4	1.234568	0.000000

SRR_T5	3.643887	0.000000
S_I5	0.000000	0.000000
A_T5	0.5615650	0.000000
B_T5	0.000000	0.000000
K_T5	-42.75439	0.000000
P_SR_T5	0.000000	0.000000
SRR_T6	2.839685	0.000000
S_I6	0.000000	0.000000
A_T6	0.4532702	0.000000
B_T6	0.6303655	0.000000
K_T6	36.30321	0.000000
P_SR_T6	0.000000	0.000000
SRR_T7	4.060000	0.000000
S_I7	36.94581	0.000000
A_T7	0.6085260	0.000000
B_T7	0.3541096	0.000000
K_T7	0.6673457	0.000000
P_SR_T7	2.964510	0.000000
SRR_BLANK1	1.000000	0.000000
S_I8	0.000000	0.000000
P_SR_BLANK1	0.000000	0.000000
K_BLANK1	1.234568	0.000000
P_SR_T_TOTAL	2.964510	0.000000
C_T1	0.000000	0.000000
C_T2	0.000000	0.000000
C_T3	0.000000	0.000000
C_T4	0.000000	0.000000
C_T5	0.000000	0.000000
C_T6	0.000000	0.000000
C_T7	54735.10	0.000000
C_BLANK1	0.000000	0.000000
C_T_TOTAL	54735.10	0.000000
F_I1	0.000000	0.000000
F_I2	0.000000	0.000000
F_I3	0.000000	0.000000
F_I4	0.000000	0.000000
F_I5	0.000000	0.000000
F_I6	0.000000	0.000000
F_I7	6.912250	0.000000
F_I8	0.000000	0.000000
F_I_TOTAL	6.912250	0.000000
X_CHCL_I1	0.000000	0.000000
X_M_I1	0.000000	0.000000
X_CHCL_I2	0.000000	0.000000
X_M_I2	0.000000	0.000000
X_CHCL_I3	0.000000	0.000000
X_M_I3	0.000000	0.000000
X_CHCL_I4	0.000000	0.000000
X_M_I4	0.000000	0.000000
X_CHCL_I5	0.000000	0.000000
X_M_I5	0.000000	0.000000
X_CHCL_I6	0.000000	0.000000
X_M_I6	0.000000	0.000000
X_CHCL_I7	0.6821223	0.000000
X_M_I7	0.3178777	0.000000
X_CHCL_I8	0.000000	0.000000
X_M_I8	0.000000	0.000000
I_T_TOTAL	1.000000	0.000000
S_2	36.94581	0.000000
F_I1_TP1	0.000000	0.000000
F_I1_TP2	0.000000	0.000000
F_I1_TP3	0.000000	0.000000
F_I1_TP4	0.000000	0.000000
F_I1_TP5	0.000000	0.000000
F_I1_TP6	0.000000	0.000000
F_I1_TP7	0.000000	0.000000
F_I1_BLANK2	0.000000	0.000000

F_I2_TP1	0.000000	0.000000
F_I2_TP2	0.000000	0.000000
F_I2_TP3	0.000000	0.000000
F_I2_TP4	0.000000	0.000000
F_I2_TP5	0.000000	0.000000
F_I2_TP6	0.000000	0.000000
F_I2_TP7	0.000000	0.000000
F_I2_BLANK2	0.000000	0.000000
F_I3_TP1	0.000000	0.000000
F_I3_TP2	0.000000	0.000000
F_I3_TP3	0.000000	0.000000
F_I3_TP4	0.000000	0.000000
F_I3_TP5	0.000000	0.000000
F_I3_TP6	0.000000	0.000000
F_I3_TP7	0.000000	0.000000
F_I3_BLANK2	0.000000	0.000000
F_I4_TP1	0.000000	0.000000
F_I4_TP2	0.000000	0.000000
F_I4_TP3	0.000000	0.000000
F_I4_TP4	0.000000	0.000000
F_I4_TP5	0.000000	0.000000
F_I4_TP6	0.000000	0.000000
F_I4_TP7	0.000000	0.000000
F_I4_BLANK2	0.000000	0.000000
F_I5_TP1	0.000000	0.000000
F_I5_TP2	0.000000	0.000000
F_I5_TP3	0.000000	0.000000
F_I5_TP4	0.000000	0.000000
F_I5_TP5	0.000000	0.000000
F_I5_TP6	0.000000	0.000000
F_I5_TP7	0.000000	0.000000
F_I5_BLANK2	0.000000	0.000000
F_I6_TP1	0.000000	0.000000
F_I6_TP2	0.000000	0.000000
F_I6_TP3	0.000000	0.000000
F_I6_TP4	0.000000	0.000000
F_I6_TP5	0.000000	0.000000
F_I6_TP6	0.000000	0.000000
F_I6_TP7	0.000000	0.000000
F_I6_BLANK2	0.000000	0.000000
F_I7_TP1	4.456728	0.000000
F_I7_TP2	0.000000	0.000000
F_I7_TP3	0.000000	0.000000
F_I7_TP4	0.000000	0.000000
F_I7_TP5	0.000000	0.000000
F_I7_TP6	0.000000	0.000000
F_I7_TP7	0.000000	0.000000
F_I7_BLANK2	2.455522	0.000000
F_I8_TP1	0.000000	0.000000
F_I8_TP2	0.000000	0.000000
F_I8_TP3	0.000000	0.000000
F_I8_TP4	0.000000	0.000000
F_I8_TP5	0.000000	0.000000
F_I8_TP6	0.000000	0.000000
F_I8_TP7	0.000000	0.000000
F_I8_BLANK2	0.000000	0.000000
F_IN_TP1	4.456728	0.000000
X_CHCL_IN_TP1	0.6821223	0.000000
X_M_IN_TP1	0.3178777	0.000000
F_IN_TP2	0.000000	0.000000
X_CHCL_IN_TP2	0.000000	0.000000
X_M_IN_TP2	0.000000	0.000000
F_IN_TP3	0.000000	0.000000
X_CHCL_IN_TP3	0.000000	0.000000
X_M_IN_TP3	0.000000	0.000000
F_IN_TP4	0.000000	0.000000
X_CHCL_IN_TP4	0.000000	0.000000

X_M_IN_TP4	0.000000	0.000000
F_IN_TP5	0.000000	0.000000
X_CHCL_IN_TP5	0.000000	0.000000
X_M_IN_TP5	0.1067240	0.000000
F_IN_TP6	0.000000	0.000000
X_CHCL_IN_TP6	0.000000	0.000000
X_M_IN_TP6	0.000000	0.000000
F_IN_TP7	0.000000	0.000000
X_CHCL_IN_TP7	0.000000	0.000000
X_M_IN_TP7	0.000000	0.000000
F_IN_BLANK2	2.455522	0.000000
X_CHCL_IN_BLANK2	0.6821223	0.000000
X_M_IN_BLANK2	0.3178777	0.000000
F_IN_TP_TOTAL	6.912250	0.000000
I_TP1	1.000000	0.1000000E-03
I_TP2	0.000000	0.000000
I_TP3	0.000000	0.000000
I_TP4	0.000000	0.000000
I_TP5	0.000000	0.000000
I_TP6	0.000000	0.000000
I_TP7	0.000000	0.000000
I_BLANK2	1.000000	0.1000000E-03
F_OUTCHCL_TP1	3.040034	0.000000
F_OUTCHCL_TP2	0.000000	0.000000
F_OUTCHCL_TP3	0.000000	0.000000
F_OUTCHCL_TP4	0.000000	0.000000
F_OUTCHCL_TP5	0.000000	0.000000
F_OUTCHCL_TP6	0.000000	0.000000
F_OUTCHCL_TP7	0.000000	0.000000
F_OUTCHCL_BLANK2	1.674966	0.000000
F_OUTCHCL_TP_TOTAL	4.715000	0.000000
F_MR_TP1	1.218357	0.000000
MRR_TP1	0.8600000	0.000000
TR_TP1	0.6700000	0.000000
EF_TP1	0.6000000	0.000000
P_D_TP1	0.3779164E-03	0.000000
F_MR_TP2	0.000000	0.000000
MRR_TP2	0.8600000	0.000000
TR_TP2	0.6700000	0.000000
EF_TP2	0.8600000	0.000000
P_D_TP2	0.000000	0.000000
F_MR_TP3	0.000000	0.000000
MRR_TP3	0.8600000	0.000000
TR_TP3	0.6700000	0.000000
EF_TP3	0.8700000	0.000000
P_D_TP3	0.000000	0.000000
F_MR_TP4	0.000000	0.000000
MRR_TP4	0.8100000	0.000000
TR_TP4	0.6700000	0.000000
EF_TP4	0.7000000	0.000000
P_D_TP4	0.000000	0.000000
F_MR_TP5	0.000000	0.000000
MRR_TP5	0.1500000	0.000000
TR_TP5	0.000000	0.000000
EF_TP5	1.000000	0.000000
P_D_TP5	0.000000	0.000000
F_MR_TP6	0.000000	0.000000
MRR_TP6	0.1500000	0.000000
TR_TP6	0.000000	0.000000
EF_TP6	1.000000	0.000000
P_D_TP6	0.000000	0.000000
F_MR_TP7	0.000000	0.000000
MRR_TP7	0.1500000	0.000000
TR_TP7	0.000000	0.000000
EF_TP7	1.000000	0.000000
P_D_TP7	0.000000	0.000000
F_MR_BLANK2	0.000000	0.000000

MRR_BLANK2	0.000000	0.000000
TR_BLANK2	0.000000	0.000000
EF_BLANK2	1.000000	0.000000
P_D_BLANK2	0.000000	0.000000
P_D_TP_TOTAL	0.3779164E-03	0.000000
F_OUTM_TP1	0.1983372	0.000000
F_OUTM_TP2	0.000000	0.000000
F_OUTM_TP3	0.000000	0.000000
F_OUTM_TP4	0.000000	0.000000
F_OUTM_TP5	0.000000	0.000000
F_OUTM_TP6	0.000000	0.000000
F_OUTM_TP7	0.000000	0.000000
F_OUTM_BLANK2	0.7805555	0.000000
F_OUTM_TP_TOTAL	0.9788927	0.000000
S_IN_TP1	36.94581	0.000000
S_IN_TP2	36.94581	0.000000
S_IN_TP3	36.94581	0.000000
S_IN_TP4	36.94581	0.000000
S_IN_TP5	36.94581	0.000000
S_IN_TP6	36.94581	0.000000
S_IN_TP7	36.94581	0.000000
S_IN_BLANK2	36.94581	0.000000
SRR_TP1	1.000000	0.000000
S_IP1	36.94581	0.000000
P_SR_TP1	0.000000	0.000000
K_TP1	1.234568	0.000000
SRR_TP2	1.000000	0.000000
S_IP2	0.000000	0.000000
P_SR_TP2	0.000000	0.000000
K_TP2	1.234568	0.000000
SRR_TP3	1.000000	0.000000
S_IP3	0.000000	0.000000
P_SR_TP3	0.000000	0.000000
K_TP3	1.234568	0.000000
SRR_TP4	1.000000	0.000000
S_IP4	0.000000	0.000000
P_SR_TP4	0.000000	0.000000
K_TP4	1.234568	0.000000
SRR_TP5	3.039886	0.000000
S_IP5	0.000000	0.000000
A_TP5	0.4828573	0.000000
B_TP5	0.1067240	0.000000
K_TP5	-6.568121	0.000000
P_SR_TP5	0.000000	0.000000
SRR_TP6	6.337137	0.000000
S_IP6	0.000000	0.000000
A_TP6	0.8018931	0.000000
B_TP6	0.000000	0.000000
K_TP6	65.58840	0.000000
P_SR_TP6	0.000000	0.000000
SRR_TP7	4.060000	0.000000
S_IP7	0.000000	0.000000
A_TP7	0.6085260	0.000000
K_TP7	0.6673457	0.000000
P_SR_TP7	0.000000	0.000000
SRR_BLANK2	1.000000	0.000000
S_IP8	36.94581	0.000000
P_SR_BLANK2	0.000000	0.000000
K_BLANK2	1.234568	0.000000
P_SR_TP_TOTAL	0.000000	0.000000
C_TP1	284139.8	0.000000
C_TP2	0.000000	0.000000
C_TP3	0.000000	0.000000
C_TP4	0.000000	0.000000
C_TP5	0.000000	0.000000
C_TP6	0.000000	0.000000
C_TP7	0.000000	0.000000

C_BLANK2	0.000000	0.000000
C_TP_TOTAL	284139.8	0.000000
F_IP1	3.238371	0.000000
F_IP2	0.000000	0.000000
F_IP3	0.000000	0.000000
F_IP4	0.000000	0.000000
F_IP5	0.000000	0.000000
F_IP6	0.000000	0.000000
F_IP7	0.000000	0.000000
F_IP8	2.455522	0.000000
F_IP_TOTAL	5.693893	0.000000
X_CHCL_IP1	0.9387540	0.000000
X_M_IP1	0.6124598E-01	0.000000
X_CHCL_IP2	0.000000	0.000000
X_M_IP2	0.000000	0.000000
X_CHCL_IP3	0.000000	0.000000
X_M_IP3	0.000000	0.000000
X_CHCL_IP4	0.000000	0.000000
X_M_IP4	0.000000	0.000000
X_CHCL_IP5	0.000000	0.000000
X_M_IP5	0.000000	0.000000
X_CHCL_IP6	0.000000	0.000000
X_M_IP6	0.000000	0.000000
X_CHCL_IP7	0.000000	0.000000
X_M_IP7	0.000000	0.000000
X_CHCL_IP8	0.6821223	0.000000
X_M_IP8	0.3178777	0.000000
I_TP_TOTAL	2.000000	0.000000
S_3	36.94581	0.000000
F_IP1_TPP1	0.000000	0.000000
F_IP1_TPP2	0.000000	0.9370494E-05
F_IP1_TPP3	0.000000	0.9370494E-05
F_IP1_TPP4	0.000000	0.000000
F_IP1_TPP5	0.000000	0.000000
F_IP1_TPP6	0.000000	0.000000
F_IP1_TPP7	3.238371	0.000000
F_IP1_BLANK3	0.000000	0.000000
F_IP2_TPP1	0.000000	0.000000
F_IP2_TPP2	0.000000	0.000000
F_IP2_TPP3	0.000000	0.000000
F_IP2_TPP4	0.000000	0.000000
F_IP2_TPP5	0.000000	0.000000
F_IP2_TPP6	0.000000	0.000000
F_IP2_TPP7	0.000000	0.000000
F_IP2_BLANK3	0.000000	0.000000
F_IP3_TPP1	0.000000	0.000000
F_IP3_TPP2	0.000000	0.000000
F_IP3_TPP3	0.000000	0.000000
F_IP3_TPP4	0.000000	0.000000
F_IP3_TPP5	0.000000	0.000000
F_IP3_TPP6	0.000000	0.000000
F_IP3_TPP7	0.000000	0.000000
F_IP3_BLANK3	0.000000	0.000000
F_IP4_TPP1	0.000000	0.000000
F_IP4_TPP2	0.000000	0.000000
F_IP4_TPP3	0.000000	0.000000
F_IP4_TPP4	0.000000	0.000000
F_IP4_TPP5	0.000000	0.000000
F_IP4_TPP6	0.000000	0.000000
F_IP4_TPP7	0.000000	0.000000
F_IP4_BLANK3	0.000000	0.000000
F_IP5_TPP1	0.000000	0.000000
F_IP5_TPP2	0.000000	0.000000
F_IP5_TPP3	0.000000	0.000000
F_IP5_TPP4	0.000000	0.000000
F_IP5_TPP5	0.000000	0.000000
F_IP5_TPP6	0.000000	0.000000

F_IP5_TPP7	0.000000	0.000000
F_IP5_BLANK3	0.000000	0.000000
F_IP6_TPP1	0.000000	0.000000
F_IP6_TPP2	0.000000	0.000000
F_IP6_TPP3	0.000000	0.000000
F_IP6_TPP4	0.000000	0.000000
F_IP6_TPP5	0.000000	0.000000
F_IP6_TPP6	0.000000	0.000000
F_IP6_TPP7	0.000000	0.000000
F_IP6_BLANK3	0.000000	0.000000
F_IP7_TPP1	0.000000	0.000000
F_IP7_TPP2	0.000000	0.000000
F_IP7_TPP3	0.000000	0.000000
F_IP7_TPP4	0.000000	0.000000
F_IP7_TPP5	0.000000	0.000000
F_IP7_TPP6	0.000000	0.000000
F_IP7_TPP7	0.000000	0.000000
F_IP7_BLANK3	0.000000	0.000000
F_IP8_TPP1	0.000000	0.000000
F_IP8_TPP2	0.000000	0.000000
F_IP8_TPP3	0.000000	0.000000
F_IP8_TPP4	0.000000	0.000000
F_IP8_TPP5	0.000000	0.000000
F_IP8_TPP6	0.000000	0.000000
F_IP8_TPP7	2.455522	0.000000
F_IP8_BLANK3	0.000000	0.000000
F_IN_TPP1	0.000000	0.2490660E-04
X_CHCL_IN_TPP1	0.000000	0.000000
X_M_IN_TPP1	0.000000	0.000000
F_IN_TPP2	0.000000	0.2490660E-04
X_CHCL_IN_TPP2	0.000000	0.000000
X_M_IN_TPP2	0.000000	0.000000
F_IN_TPP3	0.000000	0.2490660E-04
X_CHCL_IN_TPP3	0.000000	0.000000
X_M_IN_TPP3	0.000000	0.000000
F_IN_TPP4	0.000000	0.2490660E-04
X_CHCL_IN_TPP4	0.000000	0.000000
X_M_IN_TPP4	0.000000	0.000000
F_IN_TPP5	0.000000	0.2356888E-04
X_CHCL_IN_TPP5	0.000000	0.000000
X_M_IN_TPP5	0.5370963E-01	0.000000
F_IN_TPP6	0.000000	0.9027554E-05
X_CHCL_IN_TPP6	0.000000	0.000000
X_M_IN_TPP6	0.6375437	0.000000
F_IN_TPP7	5.693893	0.000000
X_CHCL_IN_TPP7	0.8280802	0.000000
X_M_IN_TPP7	0.1719198	0.000000
F_IN_BLANK3	0.000000	0.2490660E-04
X_CHCL_IN_BLANK3	0.000000	0.000000
X_M_IN_BLANK3	0.000000	0.000000
F_IN_TPP_TOTAL	5.693893	0.000000
I_TPP1	0.000000	0.000000
I_TPP2	0.000000	0.000000
I_TPP3	0.000000	0.000000
I_TPP4	0.000000	0.000000
I_TPP5	0.000000	0.000000
I_TPP6	0.000000	0.000000
I_TPP7	1.000000	0.1000000E-03
I_BLANK3	0.000000	0.000000
F_OUTCHCL_TPP1	0.000000	0.000000
F_OUTCHCL_TPP2	0.000000	0.000000
F_OUTCHCL_TPP3	0.000000	0.000000
F_OUTCHCL_TPP4	0.000000	0.000000
F_OUTCHCL_TPP5	0.000000	0.000000
F_OUTCHCL_TPP6	0.000000	0.000000
F_OUTCHCL_TPP7	4.715000	0.000000
F_OUTCHCL_BLANK3	0.000000	0.000000

F_OUTCHCL_TPP_TOTAL	4.715000	0.000000
F_OUTM_TPP1	0.000000	0.000000
F_MR_TPP1	0.000000	0.000000
F_OUTM_TPP2	0.000000	0.000000
F_MR_TPP2	0.000000	0.000000
F_OUTM_TPP3	0.000000	0.000000
F_MR_TPP3	0.000000	0.000000
F_OUTM_TPP4	0.000000	0.000000
F_MR_TPP4	0.000000	0.000000
F_OUTM_TPP5	0.000000	0.000000
F_MR_TPP5	0.000000	0.000000
F_OUTM_TPP6	0.000000	0.000000
F_MR_TPP6	0.000000	0.000000
F_OUTM_TPP7	0.8320588	0.000000
F_MR_TPP7	0.1468339	0.000000
F_OUTM_BLANK3	0.000000	0.000000
F_MR_BLANK3	0.000000	0.000000
MRR_TPP1	0.5600000	0.000000
TR_TPP1	0.6700000	0.000000
EF_TPP1	0.6000000	0.000000
P_D_TPP1	0.000000	0.000000
MRR_TPP2	0.8600000	0.000000
TR_TPP2	0.6700000	0.000000
EF_TPP2	0.8600000	0.000000
P_D_TPP2	0.000000	0.000000
MRR_TPP3	0.8600000	0.000000
TR_TPP3	0.6700000	0.000000
EF_TPP3	0.8700000	0.000000
P_D_TPP3	0.000000	0.000000
MRR_TPP4	0.8100000	0.000000
TR_TPP4	0.6700000	0.000000
EF_TPP4	0.7000000	0.000000
P_D_TPP4	0.000000	0.000000
MRR_TPP5	0.1500000	0.000000
TR_TPP5	0.000000	0.000000
EF_TPP5	1.000000	0.000000
P_D_TPP5	0.000000	0.000000
MRR_TPP6	0.1500000	0.000000
TR_TPP6	0.000000	0.000000
EF_TPP6	1.000000	0.000000
P_D_TPP6	0.000000	0.000000
MRR_TPP7	0.1500000	0.000000
TR_TPP7	0.000000	0.000000
EF_TPP7	1.000000	0.000000
P_D_TPP7	0.000000	0.000000
MRR_BLANK3	0.000000	0.000000
TR_BLANK3	0.000000	0.000000
EF_BLANK3	1.000000	0.000000
P_D_BLANK3	0.000000	0.000000
P_D_TPP_TOTAL	0.000000	0.000000
F_OUTM_TPP_TOTAL	0.8320588	0.000000
S_IN_TPP1	36.94581	0.000000
S_IN_TPP2	36.94581	0.000000
S_IN_TPP3	36.94581	0.000000
S_IN_TPP4	36.94581	0.000000
S_IN_TPP5	36.94581	0.000000
S_IN_TPP6	36.94581	0.000000
S_IN_TPP7	36.94581	0.000000
S_IN_BLANK3	36.94581	0.000000
SRR_TPP1	1.000000	0.000000
S_IPP1	0.000000	0.000000
P_SR_TPP1	0.000000	0.000000
K_TPP1	1.234568	0.000000
SRR_TPP2	1.000000	0.000000
S_IPP2	0.000000	0.000000
P_SR_TPP2	0.000000	0.000000
K_TPP2	1.234568	0.000000

SRR_TPP3	1.000000	0.000000
S_IPP3	0.000000	0.000000
P_SR_TPP3	0.000000	0.000000
K_TPP3	1.234568	0.000000
SRR_TPP4	1.000000	0.000000
S_IPP4	0.000000	0.000000
P_SR_TPP4	0.000000	0.000000
K_TPP4	1.234568	0.000000
SRR_TPP5	3.021432	0.000000
S_IPP5	0.000000	0.000000
A_TPP5	0.4802129	0.000000
B_TPP5	0.5370963E-01	0.000000
K_TPP5	-8.347260	0.000000
P_SR_TPP5	0.000000	0.000000
SRR_TPP6	5.281637	0.000000
S_IPP6	0.000000	0.000000
A_TPP6	0.7227685	0.000000
B_TPP6	0.6375437	0.000000
K_TPP6	43.95867	0.000000
P_SR_TPP6	0.000000	0.000000
SRR_TPP7	4.060000	0.000000
S_IPP7	9.099954	0.000000
A_TPP7	0.6085260	0.000000
K_TPP7	0.6673457	0.000000
P_SR_TPP7	2.312274	0.000000
SRR_BLANK3	1.000000	0.000000
S_IPP8	0.000000	0.000000
P_SR_BLANK3	0.000000	0.000000
K_BLANK3	1.234568	0.000000
P_SR_TPP_TOTAL	2.312274	0.000000
C_TPP1	0.000000	0.000000
C_TPP2	0.000000	0.000000
C_TPP3	0.000000	0.000000
C_TPP4	0.000000	0.000000
C_TPP5	0.000000	0.000000
C_TPP6	0.000000	0.000000
C_TPP7	47153.92	0.000000
C_BLANK3	0.000000	0.000000
C_TPP_TOTAL	47153.92	0.000000
F_IPP1	0.000000	0.000000
F_IPP2	0.000000	0.000000
F_IPP3	0.000000	0.000000
F_IPP4	0.000000	0.000000
F_IPP5	0.000000	0.000000
F_IPP6	0.000000	0.000000
F_IPP7	5.547059	0.000000
F_IPP8	0.000000	0.000000
F_IPP_TOTAL	5.547059	0.000000
X_CHCL_IPP1	0.000000	0.000000
X_M_IPP1	0.000000	0.000000
X_CHCL_IPP2	0.000000	0.000000
X_M_IPP2	0.1500000	0.000000
X_CHCL_IPP3	0.000000	0.000000
X_M_IPP3	0.1500000	0.000000
X_CHCL_IPP4	0.000000	0.000000
X_M_IPP4	0.1500000	0.000000
X_CHCL_IPP5	0.000000	0.000000
X_M_IPP5	0.1500000	0.000000
X_CHCL_IPP6	0.000000	0.000000
X_M_IPP6	0.1500000	0.000000
X_CHCL_IPP7	0.8500000	0.000000
X_M_IPP7	0.1500000	0.000000
X_CHCL_IPP8	0.000000	0.000000
X_M_IPP8	0.1500000	0.000000
I_TPP_TOTAL	1.000000	0.000000
I_TOTAL	4.000000	0.000000
P_TOTAL	5.277162	0.000000

C_TOTAL	386028.9	0.000000

Row	Slack or Surplus	Dual Price
1	0.000000	0.6470588
2	0.000000	4.588235
3	0.000000	0.000000
4	0.000000	0.000000
5	0.000000	0.8588235
6	0.000000	1.411765
7	0.000000	0.000000
8	0.000000	0.000000
9	0.000000	0.9058824
10	0.000000	2.588235
11	0.000000	0.000000
12	0.000000	0.000000
13	0.000000	0.1369817E-04
14	0.000000	1.176446
15	0.000000	0.000000
16	0.000000	0.000000
17	0.000000	0.4483188E-05
18	0.000000	0.5479452E-05
19	0.000000	0.000000
20	130.0000	0.000000
21	120.0000	0.000000
22	0.000000	0.000000
23	0.000000	-0.4483188E-05
24	0.000000	-0.5479452E-05
25	0.000000	0.1120797E-04
26	0.000000	0.000000
27	0.000000	-0.2490660E-04
28	1.000000	0.000000
29	0.000000	0.1120797E-04
30	0.000000	0.000000
31	0.000000	-0.2490660E-04
32	1.000000	0.000000
33	0.000000	0.1120797E-04
34	0.000000	0.000000
35	0.000000	-0.2490660E-04
36	1.000000	0.000000
37	0.000000	0.1120797E-04
38	0.000000	0.000000
39	0.000000	-0.2490660E-04
40	1.000000	0.000000
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718	0.000000	0.000000
719	0.000000	0.000000
720	0.000000	0.000000
721	0.000000	0.000000
722	0.000000	0.000000
723	0.000000	-1.000000
724	0.000000	0.000000
725	0.000000	0.000000
726	0.000000	0.000000
727	0.000000	0.000000
728	0.000000	0.000000
729	0.000000	0.000000
730	1.752941	0.000000
731	0.000000	0.000000
732	0.000000	0.000000
733	0.000000	0.000000
734	0.000000	0.000000

735	0.000000	0.000000
736	0.000000	0.000000
737	0.000000	0.000000
738	0.000000	0.000000
739	0.000000	0.000000
740	0.000000	0.000000
741	0.000000	0.000000
742	0.000000	0.000000
743	0.000000	0.000000
744	0.000000	0.000000
745	0.000000	0.000000
746	0.000000	0.000000
747	0.000000	0.000000
748	0.000000	0.000000
749	0.000000	0.000000
750	0.000000	0.000000
751	0.000000	0.000000
752	0.000000	0.000000
753	0.000000	0.000000
754	0.000000	0.000000
755	0.000000	0.000000
756	0.000000	0.000000
757	1.021432	0.000000
758	10.97857	0.000000
759	0.000000	0.000000
760	0.000000	0.000000
761	0.000000	0.000000
762	0.000000	0.000000
763	0.000000	0.000000
764	0.000000	0.000000
765	3.051637	0.000000
766	7.543363	0.000000
767	0.000000	0.000000
768	0.000000	0.000000
769	0.000000	0.000000
770	0.000000	0.000000
771	0.000000	0.000000
772	9990.900	0.000000
773	2.030000	0.000000
774	0.000000	0.000000
775	0.000000	0.000000
776	0.000000	0.000000
777	0.000000	0.000000
778	0.000000	0.000000
779	0.000000	0.000000
780	0.000000	0.000000
781	0.000000	0.000000
782	0.000000	0.000000
783	0.000000	0.000000
784	0.000000	0.000000
785	0.000000	0.000000
786	0.000000	0.000000
787	0.000000	0.000000
788	0.000000	0.000000
789	0.000000	0.000000
790	0.000000	0.000000
791	0.000000	0.000000
792	0.000000	1.000000
793	0.000000	1.176471
794	0.000000	1.176471
795	0.000000	1.176471
796	0.000000	1.176471
797	0.000000	1.176471
798	0.000000	1.176471
799	0.000000	1.000000
800	7.300000	0.000000
801	7.300000	0.000000

802	7.300000	0.000000
803	7.300000	0.000000
804	7.300000	0.000000
805	7.300000	0.000000
806	1.752941	0.000000
807	7.300000	0.000000
808	0.000000	1.000000
809	1.752941	0.000000
810	0.000000	0.000000
811	0.000000	0.000000
812	1.000000	0.000000
813	0.000000	0.000000
814	0.000000	1.176471
815	0.8500000	0.000000
816	0.000000	0.000000
817	0.000000	1.176471
818	0.8500000	0.000000
819	0.000000	0.000000
820	0.000000	1.176471
821	0.8500000	0.000000
822	0.000000	0.000000
823	0.000000	1.176471
824	0.8500000	0.000000
825	0.000000	0.000000
826	0.000000	1.176471
827	0.8500000	0.000000
828	0.000000	0.000000
829	0.000000	1.176471
830	0.000000	0.000000
831	0.000000	0.000000
832	0.000000	0.000000
833	0.8500000	0.000000
834	0.000000	0.1000000E-03
835	0.000000	0.1000000E-03
836	0.000000	0.000000
837	0.000000	0.000000
838	5.546659	1.000000
839	0.1500000	0.000000
840	0.000000	0.000000
841	0.000000	0.000000
842	0.000000	0.000000
843	0.000000	0.000000
844	0.000000	0.000000
845	0.000000	6.525952
846	0.000000	0.000000
847	15.00000	0.000000
848	15.00000	0.000000
849	15.00000	0.000000
850	15.00000	0.000000
851	15.00000	0.000000
852	15.00000	0.000000
853	5.900046	0.000000
854	15.00000	0.000000

APPENDIX B3

Lingo Result

For sensitivity analysis (16.5wt% and 16.5mm)

```
Global optimal solution found.
  Objective value:                              5.646307
  Objective bound:                              5.646307
  Infeasibilities:                              0.000000
  Extended solver steps:                            1063
  Total solver iterations:                       1013878
  Elapsed runtime seconds:                        167.46

  Model Class:                                     MINLP

  Total variables:                   606
  Nonlinear variables:               365
  Integer variables:                  24

  Total constraints:                 764
  Nonlinear constraints:             330

  Total nonzeros:                   2589
  Nonlinear nonzeros:               1182
```

Variable	Value	Reduced Cost
F_AVAILABLE_EFB	3.900000	0.000000
X_CHCL_EFB	0.5500000	0.000000
X_M_EFB	0.4500000	0.000000
S_EFB	150.0000	0.000000
F_AVAILABLE_PKS	1.200000	0.000000
X_CHCL_PKS	0.7300000	0.000000
X_M_PKS	0.2700000	0.000000
S_PKS	20.00000	0.000000
F_AVAILABLE_PMF	2.200000	0.000000
X_CHCL_PMF	0.7700000	0.000000
X_M_PMF	0.2300000	0.000000
S_PMF	30.00000	0.000000
TOTAL_BIOMASS_AVAILABLE	7.300000	0.000000
TOTAL_CHCL_AVAILABLE	4.715000	0.000000
TOTAL_M_AVAILABLE	2.585000	0.000000
F_EFB	3.900000	0.000000
F_PKS	1.200000	0.000000
F_PMF	2.200000	0.000000
S_1	150.0000	0.000000
F_EFB_T1	0.000000	0.000000
F_EFB_T2	0.000000	0.000000
F_EFB_T3	0.000000	0.000000
F_EFB_T4	1.709577	0.000000
F_EFB_T5	0.000000	0.000000
F_EFB_T6	0.000000	0.000000

F_EFB_T7	0.000000	0.000000
F_EFB_BLANK1	2.190423	0.000000
F_PKS_T1	0.000000	0.000000
F_PKS_T2	0.000000	0.000000
F_PKS_T3	0.000000	0.000000
F_PKS_T4	1.200000	0.000000
F_PKS_T5	0.000000	0.000000
F_PKS_T6	0.000000	0.000000
F_PKS_T7	0.000000	0.000000
F_PKS_BLANK1	0.000000	0.000000
F_PMF_T1	0.000000	0.000000
F_PMF_T2	0.000000	0.000000
F_PMF_T3	0.000000	0.000000
F_PMF_T4	2.200000	0.000000
F_PMF_T5	0.000000	0.000000
F_PMF_T6	0.000000	0.000000
F_PMF_T7	0.000000	0.000000
F_PMF_BLANK1	0.000000	0.000000
F_IN_T1	0.000000	1.197590
X_CHCL_IN_T1	0.000000	0.000000
X_M_IN_T1	0.000000	0.000000
F_IN_T2	0.000000	1.197590
X_CHCL_IN_T2	0.000000	0.000000
X_M_IN_T2	0.000000	0.000000
F_IN_T3	0.000000	1.197590
X_CHCL_IN_T3	0.000000	0.000000
X_M_IN_T3	0.000000	0.000000
F_IN_T4	5.109577	0.000000
X_CHCL_IN_T4	0.6869976	0.000000
X_M_IN_T4	0.3130024	0.000000
F_IN_T5	0.000000	1.197590
X_CHCL_IN_T5	0.000000	0.000000
X_M_IN_T5	0.000000	0.000000
F_IN_T6	0.000000	0.6894132
X_CHCL_IN_T6	0.000000	0.000000
X_M_IN_T6	0.4243328	0.000000
F_IN_T7	0.000000	1.197590
X_CHCL_IN_T7	0.000000	0.000000
X_M_IN_T7	0.000000	0.000000
F_IN_BLANK1	2.190423	0.000000
X_CHCL_IN_BLANK1	0.5500000	0.000000
X_M_IN_BLANK1	0.4500000	0.000000
F_IN_T_TOTAL	7.300000	0.000000
I_T1	0.000000	0.000000
I_T2	0.000000	0.000000
I_T3	0.000000	0.000000
I_T4	1.000000	0.1000000E-03
I_T5	0.000000	0.000000
I_T6	0.000000	0.000000
I_T7	0.000000	0.000000
I_BLANK1	1.000000	0.1000000E-03
F_OUTCHCL_T1	0.000000	0.000000
F_OUTCHCL_T2	0.000000	0.000000
F_OUTCHCL_T3	0.000000	0.000000
F_OUTCHCL_T4	3.510267	0.000000
F_OUTCHCL_T5	0.000000	0.000000
F_OUTCHCL_T6	0.000000	0.000000
F_OUTCHCL_T7	0.000000	0.000000
F_OUTCHCL_BLANK1	1.204733	0.000000
F_OUTCHCL_T_TOTAL	4.715000	0.000000
F_MR_T1	0.000000	0.000000
MRR_T1	0.5600000	0.000000
TR_T1	0.6700000	0.000000
EF_T1	0.6000000	0.000000
P_D_T1	0.000000	0.000000
F_MR_T2	0.000000	0.000000
MRR_T2	0.5600000	0.000000

TR_T2	0.6700000	0.000000
EF_T2	0.8600000	0.000000
P_D_T2	0.000000	0.000000
F_MR_T3	0.000000	0.000000
MRR_T3	0.5600000	0.000000
TR_T3	0.6700000	0.000000
EF_T3	0.8700000	0.000000
P_D_T3	0.000000	0.000000
F_MR_T4	1.295441	0.000000
MRR_T4	0.8100000	0.000000
TR_T4	0.6700000	0.000000
EF_T4	0.7000000	0.000000
P_D_T4	0.3444227E-03	0.000000
F_MR_T5	0.000000	0.000000
MRR_T5	0.1500000	0.000000
TR_T5	0.000000	0.000000
EF_T5	1.000000	0.000000
P_D_T5	0.000000	0.000000
F_MR_T6	0.000000	0.000000
MRR_T6	0.1500000	0.000000
TR_T6	0.000000	0.000000
EF_T6	1.000000	0.000000
P_D_T6	0.000000	0.000000
F_MR_T7	0.000000	0.000000
MRR_T7	0.1500000	0.000000
TR_T7	0.000000	0.000000
EF_T7	1.000000	0.000000
P_D_T7	0.000000	0.000000
F_MR_BLANK1	0.000000	0.000000
MRR_BLANK1	0.000000	0.000000
TR_BLANK1	0.000000	0.000000
EF_BLANK1	1.000000	0.000000
P_D_BLANK1	0.000000	0.000000
F_OUTM_T1	0.000000	0.000000
F_OUTM_T2	0.000000	0.000000
F_OUTM_T3	0.000000	0.000000
F_OUTM_T4	0.3038688	0.000000
F_OUTM_T5	0.000000	0.000000
F_OUTM_T6	0.000000	0.000000
F_OUTM_T7	0.000000	0.000000
F_OUTM_BLANK1	0.9856905	0.000000
F_OUTM_T_TOTAL	1.289559	0.000000
P_D_T_TOTAL	0.3444227E-03	0.000000
S_IN_T1	150.0000	0.000000
S_IN_T2	150.0000	0.000000
S_IN_T3	150.0000	0.000000
S_IN_T4	150.0000	0.000000
S_IN_T5	150.0000	0.000000
S_IN_T6	150.0000	0.000000
S_IN_T7	150.0000	0.000000
S_IN_BLANK1	150.0000	0.000000
SRR_T1	1.000000	0.000000
S_I1	0.000000	0.000000
P_SR_T1	0.000000	0.000000
K_T1	1.234568	0.000000
SRR_T2	1.000000	0.000000
S_I2	0.000000	0.000000
P_SR_T2	0.000000	0.000000
K_T2	1.234568	0.000000
SRR_T3	1.000000	0.000000
S_I3	0.000000	0.000000
P_SR_T3	0.000000	0.000000
K_T3	1.234568	0.000000
SRR_T4	1.000000	0.000000
S_I4	150.0000	0.000000
P_SR_T4	0.000000	0.000000
K_T4	1.234568	0.000000

SRR_T5	3.117583	0.000000
S_I5	0.000000	0.000000
A_T5	0.4938180	0.000000
B_T5	0.000000	0.000000
K_T5	-17.05172	0.000000
P_SR_T5	0.000000	0.000000
SRR_T6	2.230000	0.000000
S_I6	0.000000	0.000000
A_T6	0.3483049	0.000000
B_T6	0.4243328	0.000000
K_T6	37.62229	0.000000
P_SR_T6	0.000000	0.000000
SRR_T7	2.479536	0.000000
S_I7	0.000000	0.000000
A_T7	0.3943705	0.000000
B_T7	0.000000	0.000000
K_T7	0.4396341	0.000000
P_SR_T7	0.000000	0.000000
SRR_BLANK1	1.000000	0.000000
S_I8	150.0000	0.000000
P_SR_BLANK1	0.000000	0.000000
K_BLANK1	1.234568	0.000000
P_SR_T_TOTAL	0.000000	0.000000
C_T1	0.000000	0.000000
C_T2	0.000000	0.000000
C_T3	0.000000	0.000000
C_T4	27742.61	0.000000
C_T5	0.000000	0.000000
C_T6	0.000000	0.000000
C_T7	0.000000	0.000000
C_BLANK1	0.000000	0.000000
C_T_TOTAL	27742.61	0.000000
F_I1	0.000000	0.000000
F_I2	0.000000	0.000000
F_I3	0.000000	0.000000
F_I4	3.814136	0.000000
F_I5	0.000000	0.000000
F_I6	0.000000	0.000000
F_I7	0.000000	0.000000
F_I8	2.190423	0.000000
F_I_TOTAL	6.004559	0.000000
X_CHCL_I1	0.000000	0.000000
X_M_I1	0.000000	0.000000
X_CHCL_I2	0.000000	0.000000
X_M_I2	0.000000	0.000000
X_CHCL_I3	0.000000	0.000000
X_M_I3	0.000000	0.000000
X_CHCL_I4	0.9203309	0.000000
X_M_I4	0.7966911E-01	0.000000
X_CHCL_I5	0.000000	0.000000
X_M_I5	0.000000	0.000000
X_CHCL_I6	0.000000	0.000000
X_M_I6	0.000000	0.000000
X_CHCL_I7	0.000000	0.000000
X_M_I7	0.000000	0.000000
X_CHCL_I8	0.5500000	0.000000
X_M_I8	0.4500000	0.000000
I_T_TOTAL	2.000000	0.000000
S_2	150.0000	0.000000
F_I1_TP1	0.000000	0.000000
F_I1_TP2	0.000000	0.000000
F_I1_TP3	0.000000	0.000000
F_I1_TP4	0.000000	0.000000
F_I1_TP5	0.000000	0.000000
F_I1_TP6	0.000000	0.000000
F_I1_TP7	0.000000	0.000000
F_I1_BLANK2	0.000000	0.000000

F_I2_TP1	0.000000	0.000000
F_I2_TP2	0.000000	0.000000
F_I2_TP3	0.000000	0.000000
F_I2_TP4	0.000000	0.000000
F_I2_TP5	0.000000	0.000000
F_I2_TP6	0.000000	0.000000
F_I2_TP7	0.000000	0.000000
F_I2_BLANK2	0.000000	0.000000
F_I3_TP1	0.000000	0.000000
F_I3_TP2	0.000000	0.000000
F_I3_TP3	0.000000	0.000000
F_I3_TP4	0.000000	0.000000
F_I3_TP5	0.000000	0.000000
F_I3_TP6	0.000000	0.000000
F_I3_TP7	0.000000	0.000000
F_I3_BLANK2	0.000000	0.000000
F_I4_TP1	0.000000	0.000000
F_I4_TP2	0.000000	0.000000
F_I4_TP3	0.000000	0.000000
F_I4_TP4	0.000000	0.000000
F_I4_TP5	0.000000	0.000000
F_I4_TP6	0.000000	0.000000
F_I4_TP7	3.814136	0.000000
F_I4_BLANK2	0.000000	0.000000
F_I5_TP1	0.000000	0.000000
F_I5_TP2	0.000000	0.000000
F_I5_TP3	0.000000	0.000000
F_I5_TP4	0.000000	0.000000
F_I5_TP5	0.000000	0.000000
F_I5_TP6	0.000000	0.000000
F_I5_TP7	0.000000	0.000000
F_I5_BLANK2	0.000000	0.000000
F_I6_TP1	0.000000	0.000000
F_I6_TP2	0.000000	0.000000
F_I6_TP3	0.000000	0.000000
F_I6_TP4	0.000000	0.000000
F_I6_TP5	0.000000	0.000000
F_I6_TP6	0.000000	0.000000
F_I6_TP7	0.000000	0.000000
F_I6_BLANK2	0.000000	0.000000
F_I7_TP1	0.000000	0.000000
F_I7_TP2	0.000000	0.000000
F_I7_TP3	0.000000	0.000000
F_I7_TP4	0.000000	0.000000
F_I7_TP5	0.000000	0.000000
F_I7_TP6	0.000000	0.000000
F_I7_TP7	0.000000	0.000000
F_I7_BLANK2	0.000000	0.000000
F_I8_TP1	0.000000	0.000000
F_I8_TP2	0.000000	0.000000
F_I8_TP3	0.000000	0.000000
F_I8_TP4	0.000000	0.000000
F_I8_TP5	0.000000	0.000000
F_I8_TP6	0.000000	0.000000
F_I8_TP7	2.190423	0.000000
F_I8_BLANK2	0.000000	0.000000
F_IN_TP1	0.000000	0.000000
X_CHCL_IN_TP1	0.000000	0.000000
X_M_IN_TP1	0.000000	0.000000
F_IN_TP2	0.000000	0.000000
X_CHCL_IN_TP2	0.000000	0.000000
X_M_IN_TP2	0.000000	0.000000
F_IN_TP3	0.000000	0.000000
X_CHCL_IN_TP3	0.000000	0.000000
X_M_IN_TP3	0.000000	0.000000
F_IN_TP4	0.000000	0.000000
X_CHCL_IN_TP4	0.000000	0.000000

X_M_IN_TP4	0.000000	0.000000
F_IN_TP5	0.000000	0.8019871
X_CHCL_IN_TP5	0.6696676	0.000000
X_M_IN_TP5	0.3303324	0.000000
F_IN_TP6	0.000000	0.000000
X_CHCL_IN_TP6	0.9203319	0.000000
X_M_IN_TP6	0.7966808E-01	0.000000
F_IN_TP7	6.004559	0.000000
X_CHCL_IN_TP7	0.7852366	0.000000
X_M_IN_TP7	0.2147634	0.000000
F_IN_BLANK2	0.000000	0.000000
X_CHCL_IN_BLANK2	0.000000	0.000000
X_M_IN_BLANK2	0.000000	0.000000
F_IN_TP_TOTAL	6.004559	0.000000
I_TP1	0.000000	0.000000
I_TP2	0.000000	0.000000
I_TP3	0.000000	0.000000
I_TP4	0.000000	0.000000
I_TP5	0.000000	0.000000
I_TP6	0.000000	0.000000
I_TP7	1.000000	0.1000000E-03
I_BLANK2	0.000000	0.000000
F_OUTCHCL_TP1	0.000000	0.000000
F_OUTCHCL_TP2	0.000000	0.000000
F_OUTCHCL_TP3	0.000000	0.000000
F_OUTCHCL_TP4	0.000000	0.000000
F_OUTCHCL_TP5	0.000000	0.000000
F_OUTCHCL_TP6	0.000000	0.000000
F_OUTCHCL_TP7	4.715000	0.000000
F_OUTCHCL_BLANK2	0.000000	0.000000
F_OUTCHCL_TP_TOTAL	4.715000	0.000000
F_MR_TP1	0.000000	0.000000
MRR_TP1	0.8600000	0.000000
TR_TP1	0.6700000	0.000000
EF_TP1	0.6000000	0.000000
P_D_TP1	0.000000	0.000000
F_MR_TP2	0.000000	0.000000
MRR_TP2	0.8600000	0.000000
TR_TP2	0.6700000	0.000000
EF_TP2	0.8600000	0.000000
P_D_TP2	0.000000	0.000000
F_MR_TP3	0.000000	0.000000
MRR_TP3	0.8600000	0.000000
TR_TP3	0.6700000	0.000000
EF_TP3	0.8700000	0.000000
P_D_TP3	0.000000	0.000000
F_MR_TP4	0.000000	0.000000
MRR_TP4	0.8100000	0.000000
TR_TP4	0.6700000	0.000000
EF_TP4	0.7000000	0.000000
P_D_TP4	0.000000	0.000000
F_MR_TP5	0.000000	0.000000
MRR_TP5	0.1500000	0.000000
TR_TP5	0.000000	0.000000
EF_TP5	1.000000	0.000000
P_D_TP5	0.000000	0.000000
F_MR_TP6	0.000000	0.000000
MRR_TP6	0.1500000	0.000000
TR_TP6	0.000000	0.000000
EF_TP6	1.000000	0.000000
P_D_TP6	0.000000	0.000000
F_MR_TP7	0.1934339	0.000000
MRR_TP7	0.1500000	0.000000
TR_TP7	0.000000	0.000000
EF_TP7	1.000000	0.000000
P_D_TP7	0.000000	0.000000
F_MR_BLANK2	0.000000	0.000000

MRR_BLANK2	0.000000	0.000000
TR_BLANK2	0.000000	0.000000
EF_BLANK2	1.000000	0.000000
P_D_BLANK2	0.000000	0.000000
P_D_TP_TOTAL	0.000000	0.000000
F_OUTM_TP1	0.000000	0.000000
F_OUTM_TP2	0.000000	0.000000
F_OUTM_TP3	0.000000	0.000000
F_OUTM_TP4	0.000000	0.000000
F_OUTM_TP5	0.000000	0.000000
F_OUTM_TP6	0.000000	0.000000
F_OUTM_TP7	1.096125	0.000000
F_OUTM_BLANK2	0.000000	0.000000
F_OUTM_TP_TOTAL	1.096125	0.000000
S_IN_TP1	150.0000	0.000000
S_IN_TP2	150.0000	0.000000
S_IN_TP3	150.0000	0.000000
S_IN_TP4	150.0000	0.000000
S_IN_TP5	150.0000	0.000000
S_IN_TP6	150.0000	0.000000
S_IN_TP7	150.0000	0.000000
S_IN_BLANK2	150.0000	0.000000
SRR_TP1	1.000000	0.000000
S_IP1	0.000000	0.000000
P_SR_TP1	0.000000	0.000000
K_TP1	1.234568	0.000000
SRR_TP2	1.000000	0.000000
S_IP2	0.000000	0.000000
P_SR_TP2	0.000000	0.000000
K_TP2	1.234568	0.000000
SRR_TP3	1.000000	0.000000
S_IP3	0.000000	0.000000
P_SR_TP3	0.000000	0.000000
K_TP3	1.234568	0.000000
SRR_TP4	1.000000	0.000000
S_IP4	0.000000	0.000000
P_SR_TP4	0.000000	0.000000
K_TP4	1.234568	0.000000
SRR_TP5	2.000000	0.000000
S_IP5	0.000000	0.000000
A_TP5	0.3010300	0.000000
B_TP5	0.3303324	0.000000
K_TP5	92.78950	0.000000
P_SR_TP5	0.000000	0.000000
SRR_TP6	12.82500	0.000000
S_IP6	0.000000	0.000000
A_TP6	1.108057	0.000000
B_TP6	0.7966808E-01	0.000000
K_TP6	74.16186	0.000000
P_SR_TP6	0.000000	0.000000
SRR_TP7	4.060000	0.000000
S_IP7	36.94581	0.000000
A_TP7	0.6085260	0.000000
K_TP7	0.6673457	0.000000
P_SR_TP7	2.438435	0.000000
SRR_BLANK2	1.000000	0.000000
S_IP8	0.000000	0.000000
P_SR_BLANK2	0.000000	0.000000
K_BLANK2	1.234568	0.000000
P_SR_TP_TOTAL	2.438435	0.000000
C_TP1	0.000000	0.000000
C_TP2	0.000000	0.000000
C_TP3	0.000000	0.000000
C_TP4	0.000000	0.000000
C_TP5	0.000000	0.000000
C_TP6	0.000000	0.000000
C_TP7	48681.16	0.000000

C_BLANK2	0.000000	0.000000
C_TP_TOTAL	48681.16	0.000000
F_IP1	0.000000	0.000000
F_IP2	0.000000	0.000000
F_IP3	0.000000	0.000000
F_IP4	0.000000	0.000000
F_IP5	0.000000	0.000000
F_IP6	0.000000	0.000000
F_IP7	5.811125	0.000000
F_IP8	0.000000	0.000000
F_IP_TOTAL	5.811125	0.000000
X_CHCL_IP1	0.000000	0.000000
X_M_IP1	0.000000	0.000000
X_CHCL_IP2	0.000000	0.000000
X_M_IP2	0.000000	0.000000
X_CHCL_IP3	0.000000	0.000000
X_M_IP3	0.000000	0.000000
X_CHCL_IP4	0.000000	0.000000
X_M_IP4	0.000000	0.000000
X_CHCL_IP5	0.000000	0.000000
X_M_IP5	0.000000	0.000000
X_CHCL_IP6	0.9314631	0.000000
X_M_IP6	0.6853690E-01	0.000000
X_CHCL_IP7	0.8113747	0.000000
X_M_IP7	0.1886253	0.000000
X_CHCL_IP8	0.000000	0.000000
X_M_IP8	0.000000	0.000000
I_TP_TOTAL	1.000000	0.000000
S_3	36.94581	0.000000
F_IP1_TPP1	0.000000	0.000000
F_IP1_TPP2	0.000000	0.000000
F_IP1_TPP3	0.000000	0.000000
F_IP1_TPP4	0.000000	0.000000
F_IP1_TPP5	0.000000	0.000000
F_IP1_TPP6	0.000000	0.000000
F_IP1_TPP7	0.000000	0.000000
F_IP1_BLANK3	0.000000	0.000000
F_IP2_TPP1	0.000000	0.000000
F_IP2_TPP2	0.000000	0.000000
F_IP2_TPP3	0.000000	0.000000
F_IP2_TPP4	0.000000	0.000000
F_IP2_TPP5	0.000000	0.000000
F_IP2_TPP6	0.000000	0.000000
F_IP2_TPP7	0.000000	0.000000
F_IP2_BLANK3	0.000000	0.000000
F_IP3_TPP1	0.000000	0.000000
F_IP3_TPP2	0.000000	0.000000
F_IP3_TPP3	0.000000	0.000000
F_IP3_TPP4	0.000000	0.000000
F_IP3_TPP5	0.000000	0.000000
F_IP3_TPP6	0.000000	0.000000
F_IP3_TPP7	0.000000	0.000000
F_IP3_BLANK3	0.000000	0.000000
F_IP4_TPP1	0.000000	0.000000
F_IP4_TPP2	0.000000	0.000000
F_IP4_TPP3	0.000000	0.000000
F_IP4_TPP4	0.000000	0.000000
F_IP4_TPP5	0.000000	0.000000
F_IP4_TPP6	0.000000	0.000000
F_IP4_TPP7	0.000000	0.000000
F_IP4_BLANK3	0.000000	0.000000
F_IP5_TPP1	0.000000	0.000000
F_IP5_TPP2	0.000000	0.000000
F_IP5_TPP3	0.000000	0.000000
F_IP5_TPP4	0.000000	0.000000
F_IP5_TPP5	0.000000	0.000000
F_IP5_TPP6	0.000000	0.000000

F_IP5_TPP7	0.000000	0.000000
F_IP5_BLANK3	0.000000	0.000000
F_IP6_TPP1	0.000000	0.000000
F_IP6_TPP2	0.000000	0.000000
F_IP6_TPP3	0.000000	0.000000
F_IP6_TPP4	0.000000	0.000000
F_IP6_TPP5	0.000000	0.000000
F_IP6_TPP6	0.000000	0.000000
F_IP6_TPP7	0.000000	0.000000
F_IP6_BLANK3	0.000000	0.000000
F_IP7_TPP1	0.000000	0.000000
F_IP7_TPP2	0.000000	0.000000
F_IP7_TPP3	0.000000	0.000000
F_IP7_TPP4	0.000000	0.000000
F_IP7_TPP5	0.000000	0.000000
F_IP7_TPP6	0.000000	0.000000
F_IP7_TPP7	5.811125	0.000000
F_IP7_BLANK3	0.000000	0.000000
F_IP8_TPP1	0.000000	0.000000
F_IP8_TPP2	0.000000	0.000000
F_IP8_TPP3	0.000000	0.000000
F_IP8_TPP4	0.000000	0.000000
F_IP8_TPP5	0.000000	0.000000
F_IP8_TPP6	0.000000	0.000000
F_IP8_TPP7	0.000000	0.000000
F_IP8_BLANK3	0.000000	0.000000
F_IN_TPP1	0.000000	0.000000
X_CHCL_IN_TPP1	0.000000	0.000000
X_M_IN_TPP1	0.000000	0.000000
F_IN_TPP2	0.000000	0.000000
X_CHCL_IN_TPP2	0.000000	0.000000
X_M_IN_TPP2	0.000000	0.000000
F_IN_TPP3	0.000000	0.000000
X_CHCL_IN_TPP3	0.000000	0.000000
X_M_IN_TPP3	0.000000	0.000000
F_IN_TPP4	0.000000	0.000000
X_CHCL_IN_TPP4	0.000000	0.000000
X_M_IN_TPP4	0.000000	0.000000
F_IN_TPP5	0.000000	0.000000
X_CHCL_IN_TPP5	0.000000	0.000000
X_M_IN_TPP5	0.5056544	0.000000
F_IN_TPP6	0.000000	0.000000
X_CHCL_IN_TPP6	0.000000	0.000000
X_M_IN_TPP6	0.4918120E-01	0.000000
F_IN_TPP7	5.811125	0.000000
X_CHCL_IN_TPP7	0.8113747	0.000000
X_M_IN_TPP7	0.1886253	0.000000
F_IN_BLANK3	0.000000	0.000000
X_CHCL_IN_BLANK3	0.000000	0.000000
X_M_IN_BLANK3	0.000000	0.000000
F_IN_TPP_TOTAL	5.811125	0.000000
I_TPP1	0.000000	0.000000
I_TPP2	0.000000	0.000000
I_TPP3	0.000000	0.000000
I_TPP4	0.000000	0.000000
I_TPP5	0.000000	0.000000
I_TPP6	0.000000	0.000000
I_TPP7	1.000000	0.1000000E-03
I_BLANK3	0.000000	0.000000
F_OUTCHCL_TPP1	0.000000	0.000000
F_OUTCHCL_TPP2	0.000000	0.000000
F_OUTCHCL_TPP3	0.000000	0.000000
F_OUTCHCL_TPP4	0.000000	0.000000
F_OUTCHCL_TPP5	0.000000	0.000000
F_OUTCHCL_TPP6	0.000000	0.000000
F_OUTCHCL_TPP7	4.715000	0.000000
F_OUTCHCL_BLANK3	0.000000	0.000000

F_OUTCHCL_TPP_TOTAL	4.715000	0.000000
F_OUTM_TPP1	0.000000	0.000000
F_MR_TPP1	0.000000	0.000000
F_OUTM_TPP2	0.000000	0.000000
F_MR_TPP2	0.000000	0.000000
F_OUTM_TPP3	0.000000	0.000000
F_MR_TPP3	0.000000	0.000000
F_OUTM_TPP4	0.000000	0.000000
F_MR_TPP4	0.000000	0.000000
F_OUTM_TPP5	0.000000	0.000000
F_MR_TPP5	0.000000	0.000000
F_OUTM_TPP6	0.000000	0.000000
F_MR_TPP6	0.000000	0.000000
F_OUTM_TPP7	0.9317066	0.000000
F_MR_TPP7	0.1644188	0.000000
F_OUTM_BLANK3	0.000000	0.000000
F_MR_BLANK3	0.000000	0.000000
MRR_TPP1	0.5600000	0.000000
TR_TPP1	0.6700000	0.000000
EF_TPP1	0.6000000	0.000000
P_D_TPP1	0.000000	0.000000
MRR_TPP2	0.8600000	0.000000
TR_TPP2	0.6700000	0.000000
EF_TPP2	0.8600000	0.000000
P_D_TPP2	0.000000	0.000000
MRR_TPP3	0.5600000	0.000000
TR_TPP3	0.6700000	0.000000
EF_TPP3	0.8700000	0.000000
P_D_TPP3	0.000000	0.000000
MRR_TPP4	0.8100000	0.000000
TR_TPP4	0.6700000	0.000000
EF_TPP4	0.7000000	0.000000
P_D_TPP4	0.000000	0.000000
MRR_TPP5	0.1500000	0.000000
TR_TPP5	0.000000	0.000000
EF_TPP5	1.000000	0.000000
P_D_TPP5	0.000000	0.000000
MRR_TPP6	0.1500000	0.000000
TR_TPP6	0.000000	0.000000
EF_TPP6	1.000000	0.000000
P_D_TPP6	0.000000	0.000000
MRR_TPP7	0.1500000	0.000000
TR_TPP7	0.000000	0.000000
EF_TPP7	1.000000	0.000000
P_D_TPP7	0.000000	0.000000
MRR_BLANK3	0.000000	0.000000
TR_BLANK3	0.000000	0.000000
EF_BLANK3	1.000000	0.000000
P_D_BLANK3	0.000000	0.000000
P_D_TPP_TOTAL	0.000000	0.000000
F_OUTM_TPP_TOTAL	0.9317066	0.000000
S_IN_TPP1	36.94581	0.000000
S_IN_TPP2	36.94581	0.000000
S_IN_TPP3	36.94581	0.000000
S_IN_TPP4	36.94581	0.000000
S_IN_TPP5	36.94581	0.000000
S_IN_TPP6	36.94581	0.000000
S_IN_TPP7	36.94581	0.000000
S_IN_BLANK3	36.94581	0.000000
SRR_TPP1	1.000000	0.000000
S_IPP1	0.000000	0.000000
P_SR_TPP1	0.000000	0.000000
K_TPP1	1.234568	0.000000
SRR_TPP2	1.000000	0.000000
S_IPP2	0.000000	0.000000
P_SR_TPP2	0.000000	0.000000
K_TPP2	1.234568	0.000000

SRR_TPP3	1.000000	0.000000
S_IPP3	0.000000	0.000000
P_SR_TPP3	0.000000	0.000000
K_TPP3	1.234568	0.000000
SRR_TPP4	1.000000	0.000000
S_IPP4	0.000000	0.000000
P_SR_TPP4	0.000000	0.000000
K_TPP4	1.234568	0.000000
SRR_TPP5	3.289145	0.000000
S_IPP5	0.000000	0.000000
A_TPP5	0.5170830	0.000000
B_TPP5	0.5056544	0.000000
K_TPP5	-0.1882349	0.000000
P_SR_TPP5	0.000000	0.000000
SRR_TPP6	2.702957	0.000000
S_IPP6	0.000000	0.000000
A_TPP6	0.4318391	0.000000
B_TPP6	0.4918120E-01	0.000000
K_TPP6	52.30919	0.000000
P_SR_TPP6	0.000000	0.000000
SRR_TPP7	2.797281	0.000000
S_IPP7	13.20776	0.000000
A_TPP7	0.4467361	0.000000
K_TPP7	0.4953144	0.000000
P_SR_TPP7	1.285856	0.000000
SRR_BLANK3	1.000000	0.000000
S_IPP8	0.000000	0.000000
P_SR_BLANK3	0.000000	0.000000
K_BLANK3	1.234568	0.000000
P_SR_TPP_TOTAL	1.285856	0.000000
C_TPP1	0.000000	0.000000
C_TPP2	0.000000	0.000000
C_TPP3	0.000000	0.000000
C_TPP4	0.000000	0.000000
C_TPP5	0.000000	0.000000
C_TPP6	0.000000	0.000000
C_TPP7	47734.06	0.000000
C_BLANK3	0.000000	0.000000
C_TPP_TOTAL	47734.06	0.000000
F_IPP1	0.000000	0.000000
F_IPP2	0.000000	0.000000
F_IPP3	0.000000	0.000000
F_IPP4	0.000000	0.000000
F_IPP5	0.000000	0.000000
F_IPP6	0.000000	0.000000
F_IPP7	5.646707	0.000000
F_IPP8	0.000000	0.000000
F_IPP_TOTAL	5.646707	0.000000
X_CHCL_IPP1	0.000000	0.000000
X_M_IPP1	0.000000	0.000000
X_CHCL_IPP2	0.000000	0.000000
X_M_IPP2	0.1650000	0.000000
X_CHCL_IPP3	1.000000	0.000000
X_M_IPP3	0.000000	0.000000
X_CHCL_IPP4	0.000000	0.000000
X_M_IPP4	0.1650000	0.000000
X_CHCL_IPP5	0.000000	0.000000
X_M_IPP5	0.1650000	0.000000
X_CHCL_IPP6	0.000000	0.000000
X_M_IPP6	0.1650000	0.000000
X_CHCL_IPP7	0.8350000	0.000000
X_M_IPP7	0.1650000	0.000000
X_CHCL_IPP8	0.000000	0.000000
X_M_IPP8	0.1650000	0.000000
I_TPP_TOTAL	1.000000	0.000000
I_TOTAL	4.000000	0.000000
P_TOTAL	3.972557	0.000000

C_TOTAL	124157.8	0.000000

Row	Slack or Surplus	Dual Price
1	0.000000	0.6586826
2	0.000000	2.623287
3	0.000000	-2.047372
4	0.000000	0.000000
5	0.000000	0.8742515
6	0.000000	0.1786133E-04
7	0.000000	-1.437108
8	0.000000	0.000000
9	0.000000	0.9221557
10	0.000000	0.3274578E-04
11	0.000000	-2.634698
12	0.000000	0.000000
13	0.000000	0.000000
14	0.000000	0.1488445E-04
15	0.000000	0.000000
16	0.000000	0.6586744
17	0.000000	0.8742406
18	0.000000	0.9221442
19	0.000000	0.000000
20	130.0000	0.000000
21	120.0000	0.000000
22	0.000000	-0.6586744
23	0.000000	-0.8742406
24	0.000000	-0.9221442
25	0.000000	1.197590
26	0.000000	0.000000
27	0.000000	-1.197590
28	1.000000	0.000000
29	0.000000	1.197590
30	0.000000	0.000000
31	0.000000	-1.197590
32	1.000000	0.000000
33	0.000000	1.197590
34	0.000000	0.000000
35	0.000000	-1.197590
36	1.000000	0.000000
37	0.000000	1.197590
38	0.000000	0.000000
39	0.000000	-1.197590
40	0.000000	6.119177
41	0.000000	1.197590
42	0.000000	0.000000
43	0.000000	-1.197590
44	1.000000	0.000000
45	0.000000	1.197590
46	0.000000	0.000000
47	0.000000	-1.197590
48	0.5756672	0.000000
49	0.000000	1.197590
50	0.000000	0.000000
51	0.000000	-1.197590
52	1.000000	0.000000
53	0.000000	0.000000
54	0.000000	1.197590
55	0.000000	0.000000
56	0.000000	0.000000
57	0.000000	0.000000
58	7.300000	0.000000
59	7.300000	0.000000
60	7.300000	0.000000
61	2.190423	0.000000
62	7.300000	0.000000
63	7.300000	0.000000
64	7.300000	0.000000

65	5.109577	0.000000
66	0.000000	0.000000
67	0.000000	0.000000
68	0.000000	0.000000
69	0.000000	0.000000
70	0.3000580	0.000000
71	0.000000	0.000000
72	0.000000	0.000000
73	0.000000	0.000000
74	0.6999420	0.000000
75	0.000000	0.000000
76	0.000000	0.000000
77	0.000000	0.000000
78	0.000000	0.000000
79	0.000000	0.000000
80	0.000000	0.000000
81	0.6300235E-01	0.000000
82	0.4069976	0.000000
83	0.000000	0.000000
84	0.000000	0.000000
85	0.000000	0.000000
86	0.000000	0.000000
87	0.000000	0.000000
88	0.000000	0.000000
89	0.4500000	0.000000
90	0.5500000	0.000000
91	0.000000	0.8000000E-06
92	0.000000	0.000000
93	0.000000	0.6688963E-06
94	0.000000	0.000000
95	0.000000	0.6666667E-06
96	0.000000	0.000000
97	150.0000	0.000000
98	0.000000	0.000000
99	0.000000	0.8000000E-06
100	0.000000	0.000000
101	0.000000	0.8000000E-06
102	0.000000	0.000000
103	0.000000	0.6666667E-06
104	0.000000	0.000000
105	150.0000	0.000000
106	0.000000	0.000000
107	0.000000	0.000000
108	0.000000	0.000000
109	0.000000	0.000000
110	0.000000	1.197590
111	0.000000	0.000000
112	0.000000	0.000000
113	0.000000	0.000000
114	0.000000	1.197590
115	4.715000	0.000000
116	4.715000	0.000000
117	4.715000	0.000000
118	1.204733	0.000000
119	4.715000	0.000000
120	4.715000	0.000000
121	4.715000	0.000000
122	3.510267	0.000000
123	0.000000	0.000000
124	0.000000	0.000000
125	0.000000	0.000000
126	0.000000	0.000000
127	0.3000000	0.000000
128	0.000000	0.000000
129	0.000000	0.000000
130	0.000000	0.000000
131	0.000000	0.000000

132	0.000000	0.000000
133	0.3000000	0.000000
134	0.000000	0.000000
135	0.000000	0.000000
136	0.000000	0.000000
137	0.000000	0.000000
138	0.000000	0.000000
139	0.3000000	0.000000
140	0.000000	0.000000
141	0.000000	0.000000
142	0.000000	0.000000
143	0.000000	0.000000
144	0.1700000	0.000000
145	0.000000	0.000000
146	0.000000	0.000000
147	0.000000	0.000000
148	0.000000	0.000000
149	0.000000	0.000000
150	0.000000	0.000000
151	0.000000	0.000000
152	0.000000	0.000000
153	0.000000	0.000000
154	0.000000	0.000000
155	0.000000	0.000000
156	0.000000	0.000000
157	0.000000	0.000000
158	0.000000	0.000000
159	0.000000	0.000000
160	0.000000	0.000000
161	0.000000	0.000000
162	0.000000	0.000000
163	0.000000	0.000000
164	0.000000	0.000000
165	0.000000	0.000000
166	0.000000	0.000000
167	0.000000	0.000000
168	0.000000	0.000000
169	0.000000	0.000000
170	0.000000	0.000000
171	0.000000	0.000000
172	0.000000	0.000000
173	0.000000	0.000000
174	0.000000	0.000000
175	0.000000	0.000000
176	0.000000	0.000000
177	0.000000	0.000000
178	1.295441	0.000000
179	0.000000	0.000000
180	0.000000	0.000000
181	0.000000	0.000000
182	0.000000	0.000000
183	0.000000	0.000000
184	0.000000	0.000000
185	0.000000	0.000000
186	0.000000	0.000000
187	0.000000	0.000000
188	0.000000	0.000000
189	0.000000	0.000000
190	0.000000	0.000000
191	0.000000	0.000000
192	0.000000	0.000000
193	0.000000	0.000000
194	0.000000	0.000000
195	0.000000	0.000000
196	0.000000	0.000000
197	0.000000	0.000000
198	0.000000	0.000000

199	0.000000	0.000000
200	0.000000	0.000000
201	9850.000	0.000000
202	0.000000	0.000000
203	0.000000	0.000000
204	0.000000	0.000000
205	0.000000	0.000000
206	1.117583	0.000000
207	10.88242	0.000000
208	0.000000	0.000000
209	0.000000	0.000000
210	0.000000	0.000000
211	0.000000	0.000000
212	0.000000	0.000000
213	0.000000	0.000000
214	0.000000	0.000000
215	10.59500	0.000000
216	0.000000	0.000000
217	0.000000	0.000000
218	0.000000	0.000000
219	0.000000	0.000000
220	0.000000	0.000000
221	0.000000	0.000000
222	0.4495363	0.000000
223	1.580464	0.000000
224	0.000000	0.000000
225	0.000000	0.000000
226	0.000000	0.000000
227	0.000000	0.000000
228	0.000000	0.000000
229	9850.000	0.000000
230	0.000000	0.000000
231	0.000000	0.000000
232	0.000000	0.000000
233	0.000000	0.000000
234	0.000000	0.000000
235	0.000000	0.000000
236	0.000000	0.000000
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693	0.000000	0.000000
694	0.000000	0.000000
695	0.000000	0.000000
696	0.000000	0.000000
697	0.000000	0.000000
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699	0.000000	0.000000
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773	0.7672808	0.000000
774	1.262719	0.000000
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847	16.50000	0.000000
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849	16.50000	0.000000
850	16.50000	0.000000
851	16.50000	0.000000
852	16.50000	0.000000
853	3.292240	0.000000
854	16.50000	0.000000

APPENDIX B4

Lingo Result

For sensitivity analysis (13.5wt% and 13.5mm)

```
Global optimal solution found.
Objective value:                              5.450567
Objective bound:                              5.450590
Infeasibilities:                              0.000000
Extended solver steps:                             347
Total solver iterations:                        987517
Elapsed runtime seconds:                         70.82

Model Class:                                     MINLP

Total variables:                   606
Nonlinear variables:               365
Integer variables:                  24

Total constraints:                 764
Nonlinear constraints:             330

Total nonzeros:                   2589
Nonlinear nonzeros:               1182
```

Variable	Value
F_AVAILABLE_EFB	3.900000
X_CHCL_EFB	0.5500000
X_M_EFB	0.4500000
S_EFB	150.0000
F_AVAILABLE_PKS	1.200000
X_CHCL_PKS	0.7300000
X_M_PKS	0.2700000
S_PKS	20.00000
F_AVAILABLE_PMF	2.200000
X_CHCL_PMF	0.7700000
X_M_PMF	0.2300000
S_PMF	30.00000
TOTAL_BIOMASS_AVAILABLE	7.300000
TOTAL_CHCL_AVAILABLE	4.715000
TOTAL_M_AVAILABLE	2.585000
F_EFB	3.900000
F_PKS	1.200000
F_PMF	2.200000
S_1	150.0000
F_EFB_T1	0.000000
F_EFB_T2	0.000000
F_EFB_T3	0.000000
F_EFB_T4	0.000000
F_EFB_T5	0.000000

F_EFB_T6	0.000000
F_EFB_T7	3.900000
F_EFB_BLANK1	0.000000
F_PKS_T1	0.000000
F_PKS_T2	0.000000
F_PKS_T3	0.000000
F_PKS_T4	0.000000
F_PKS_T5	0.000000
F_PKS_T6	0.000000
F_PKS_T7	1.200000
F_PKS_BLANK1	0.000000
F_PMF_T1	0.000000
F_PMF_T2	0.000000
F_PMF_T3	0.000000
F_PMF_T4	0.000000
F_PMF_T5	0.000000
F_PMF_T6	0.000000
F_PMF_T7	2.200000
F_PMF_BLANK1	0.000000
F_IN_T1	0.000000
X_CHCL_IN_T1	0.000000
X_M_IN_T1	0.000000
F_IN_T2	0.000000
X_CHCL_IN_T2	0.000000
X_M_IN_T2	0.000000
F_IN_T3	0.000000
X_CHCL_IN_T3	0.000000
X_M_IN_T3	0.000000
F_IN_T4	0.000000
X_CHCL_IN_T4	0.000000
X_M_IN_T4	0.000000
F_IN_T5	0.000000
X_CHCL_IN_T5	0.000000
X_M_IN_T5	0.000000
F_IN_T6	0.000000
X_CHCL_IN_T6	0.000000
X_M_IN_T6	0.4576017
F_IN_T7	7.300000
X_CHCL_IN_T7	0.6458904
X_M_IN_T7	0.3541096
F_IN_BLANK1	0.000000
X_CHCL_IN_BLANK1	0.000000
X_M_IN_BLANK1	0.000000
F_IN_T_TOTAL	7.300000
I_T1	0.000000
I_T2	0.000000
I_T3	0.000000
I_T4	0.000000
I_T5	0.000000
I_T6	0.000000
I_T7	1.000000
I_BLANK1	0.000000
F_OUTCHCL_T1	0.000000
F_OUTCHCL_T2	0.000000
F_OUTCHCL_T3	0.000000
F_OUTCHCL_T4	0.000000
F_OUTCHCL_T5	0.000000
F_OUTCHCL_T6	0.000000
F_OUTCHCL_T7	4.715000
F_OUTCHCL_BLANK1	0.000000
F_OUTCHCL_T_TOTAL	4.715000
F_MR_T1	0.000000
MRR_T1	0.5600000
TR_T1	0.6700000
EF_T1	0.6000000
P_D_T1	0.000000
F_MR_T2	0.000000

MRR_T2	0.5600000
TR_T2	0.6700000
EF_T2	0.8600000
P_D_T2	0.000000
F_MR_T3	0.000000
MRR_T3	0.5600000
TR_T3	0.6700000
EF_T3	0.8700000
P_D_T3	0.000000
F_MR_T4	0.000000
MRR_T4	0.8100000
TR_T4	0.6700000
EF_T4	0.7000000
P_D_T4	0.000000
F_MR_T5	0.000000
MRR_T5	0.1500000
TR_T5	0.000000
EF_T5	1.000000
P_D_T5	0.000000
F_MR_T6	0.000000
MRR_T6	0.1500000
TR_T6	0.000000
EF_T6	1.000000
P_D_T6	0.000000
F_MR_T7	0.3877500
MRR_T7	0.1500000
TR_T7	0.000000
EF_T7	1.000000
P_D_T7	0.000000
F_MR_BLANK1	0.000000
MRR_BLANK1	0.000000
TR_BLANK1	0.000000
EF_BLANK1	1.000000
P_D_BLANK1	0.000000
F_OUTM_T1	0.000000
F_OUTM_T2	0.000000
F_OUTM_T3	0.000000
F_OUTM_T4	0.000000
F_OUTM_T5	0.000000
F_OUTM_T6	0.000000
F_OUTM_T7	2.197250
F_OUTM_BLANK1	0.000000
F_OUTM_T_TOTAL	2.197250
P_D_T_TOTAL	0.000000
S_IN_T1	150.0000
S_IN_T2	150.0000
S_IN_T3	150.0000
S_IN_T4	150.0000
S_IN_T5	150.0000
S_IN_T6	150.0000
S_IN_T7	150.0000
S_IN_BLANK1	150.0000
SRR_T1	1.000000
S_I1	0.000000
P_SR_T1	0.000000
K_T1	1.234568
SRR_T2	1.000000
S_I2	0.000000
P_SR_T2	0.000000
K_T2	1.234568
SRR_T3	1.000000
S_I3	0.000000
P_SR_T3	0.000000
K_T3	1.234568
SRR_T4	1.000000
S_I4	0.000000
P_SR_T4	0.000000

K_T4	1.234568
SRR_T5	3.348521
S_I5	0.000000
A_T5	0.5248531
B_T5	0.000000
K_T5	-29.35919
P_SR_T5	0.000000
SRR_T6	2.230000
S_I6	0.000000
A_T6	0.3483049
B_T6	0.4576017
K_T6	37.10104
P_SR_T6	0.000000
SRR_T7	4.060000
S_I7	36.94581
A_T7	0.6085260
B_T7	0.3541096
K_T7	0.6673457
P_SR_T7	2.964510
SRR_BLANK1	1.000000
S_I8	0.000000
P_SR_BLANK1	0.000000
K_BLANK1	1.234568
P_SR_T_TOTAL	2.964510
C_T1	0.000000
C_T2	0.000000
C_T3	0.000000
C_T4	0.000000
C_T5	0.000000
C_T6	0.000000
C_T7	54735.10
C_BLANK1	0.000000
C_T_TOTAL	54735.10
F_I1	0.000000
F_I2	0.000000
F_I3	0.000000
F_I4	0.000000
F_I5	0.000000
F_I6	0.000000
F_I7	6.912250
F_I8	0.000000
F_I_TOTAL	6.912250
X_CHCL_I1	0.000000
X_M_I1	0.000000
X_CHCL_I2	0.000000
X_M_I2	0.000000
X_CHCL_I3	0.000000
X_M_I3	0.000000
X_CHCL_I4	0.000000
X_M_I4	0.000000
X_CHCL_I5	0.000000
X_M_I5	0.000000
X_CHCL_I6	0.000000
X_M_I6	0.000000
X_CHCL_I7	0.6821223
X_M_I7	0.3178777
X_CHCL_I8	0.000000
X_M_I8	0.000000
I_T_TOTAL	1.000000
S_2	36.94581
F_I1_TP1	0.000000
F_I1_TP2	0.000000
F_I1_TP3	0.000000
F_I1_TP4	0.000000
F_I1_TP5	0.000000
F_I1_TP6	0.000000
F_I1_TP7	0.000000

F_I1_BLANK2	0.000000
F_I2_TP1	0.000000
F_I2_TP2	0.000000
F_I2_TP3	0.000000
F_I2_TP4	0.000000
F_I2_TP5	0.000000
F_I2_TP6	0.000000
F_I2_TP7	0.000000
F_I2_BLANK2	0.000000
F_I3_TP1	0.000000
F_I3_TP2	0.000000
F_I3_TP3	0.000000
F_I3_TP4	0.000000
F_I3_TP5	0.000000
F_I3_TP6	0.000000
F_I3_TP7	0.000000
F_I3_BLANK2	0.000000
F_I4_TP1	0.000000
F_I4_TP2	0.000000
F_I4_TP3	0.000000
F_I4_TP4	0.000000
F_I4_TP5	0.000000
F_I4_TP6	0.000000
F_I4_TP7	0.000000
F_I4_BLANK2	0.000000
F_I5_TP1	0.000000
F_I5_TP2	0.000000
F_I5_TP3	0.000000
F_I5_TP4	0.000000
F_I5_TP5	0.000000
F_I5_TP6	0.000000
F_I5_TP7	0.000000
F_I5_BLANK2	0.000000
F_I6_TP1	0.000000
F_I6_TP2	0.000000
F_I6_TP3	0.000000
F_I6_TP4	0.000000
F_I6_TP5	0.000000
F_I6_TP6	0.000000
F_I6_TP7	0.000000
F_I6_BLANK2	0.000000
F_I7_TP1	6.912250
F_I7_TP2	0.000000
F_I7_TP3	0.000000
F_I7_TP4	0.000000
F_I7_TP5	0.000000
F_I7_TP6	0.000000
F_I7_TP7	0.000000
F_I7_BLANK2	0.000000
F_I8_TP1	0.000000
F_I8_TP2	0.000000
F_I8_TP3	0.000000
F_I8_TP4	0.000000
F_I8_TP5	0.000000
F_I8_TP6	0.000000
F_I8_TP7	0.000000
F_I8_BLANK2	0.000000
F_IN_TP1	6.912250
X_CHCL_IN_TP1	0.6821223
X_M_IN_TP1	0.3178777
F_IN_TP2	0.000000
X_CHCL_IN_TP2	0.000000
X_M_IN_TP2	0.000000
F_IN_TP3	0.000000
X_CHCL_IN_TP3	0.000000
X_M_IN_TP3	0.000000
F_IN_TP4	0.000000

X_CHCL_IN_TP4	0.000000
X_M_IN_TP4	0.000000
F_IN_TP5	0.000000
X_CHCL_IN_TP5	0.000000
X_M_IN_TP5	0.9997118
F_IN_TP6	0.000000
X_CHCL_IN_TP6	0.000000
X_M_IN_TP6	0.7031250
F_IN_TP7	0.000000
X_CHCL_IN_TP7	0.000000
X_M_IN_TP7	0.000000
F_IN_BLANK2	0.000000
X_CHCL_IN_BLANK2	0.6821226
X_M_IN_BLANK2	0.3178774
F_IN_TP_TOTAL	6.912250
I_TP1	1.000000
I_TP2	0.000000
I_TP3	0.000000
I_TP4	0.000000
I_TP5	0.000000
I_TP6	0.000000
I_TP7	0.000000
I_BLANK2	0.000000
F_OUTCHCL_TP1	4.715000
F_OUTCHCL_TP2	0.000000
F_OUTCHCL_TP3	0.000000
F_OUTCHCL_TP4	0.000000
F_OUTCHCL_TP5	0.000000
F_OUTCHCL_TP6	0.000000
F_OUTCHCL_TP7	0.000000
F_OUTCHCL_BLANK2	0.000000
F_OUTCHCL_TP_TOTAL	4.715000
F_MR_TP1	1.331524
MRR_TP1	0.6059957
TR_TP1	0.6700000
EF_TP1	0.6000000
P_D_TP1	0.4130190E-03
F_MR_TP2	0.000000
MRR_TP2	0.8600000
TR_TP2	0.6700000
EF_TP2	0.8600000
P_D_TP2	0.000000
F_MR_TP3	0.000000
MRR_TP3	0.5600000
TR_TP3	0.6700000
EF_TP3	0.8700000
P_D_TP3	0.000000
F_MR_TP4	0.000000
MRR_TP4	0.6400000
TR_TP4	0.6700000
EF_TP4	0.7000000
P_D_TP4	0.000000
F_MR_TP5	0.000000
MRR_TP5	0.1500000
TR_TP5	0.000000
EF_TP5	1.000000
P_D_TP5	0.000000
F_MR_TP6	0.000000
MRR_TP6	0.1500000
TR_TP6	0.000000
EF_TP6	1.000000
P_D_TP6	0.000000
F_MR_TP7	0.000000
MRR_TP7	0.1500000
TR_TP7	0.000000
EF_TP7	1.000000
P_D_TP7	0.000000

F_MR_BLANK2	0.000000
MRR_BLANK2	0.000000
TR_BLANK2	0.000000
EF_BLANK2	1.000000
P_D_BLANK2	0.000000
P_D_TP_TOTAL	0.4130190E-03
F_OUTM_TP1	0.8657259
F_OUTM_TP2	0.000000
F_OUTM_TP3	0.000000
F_OUTM_TP4	0.000000
F_OUTM_TP5	0.000000
F_OUTM_TP6	0.000000
F_OUTM_TP7	0.000000
F_OUTM_BLANK2	0.000000
F_OUTM_TP_TOTAL	0.8657259
S_IN_TP1	36.94581
S_IN_TP2	36.94581
S_IN_TP3	36.94581
S_IN_TP4	36.94581
S_IN_TP5	36.94581
S_IN_TP6	36.94581
S_IN_TP7	36.94581
S_IN_BLANK2	36.94581
SRR_TP1	1.000000
S_IP1	36.94581
P_SR_TP1	0.000000
K_TP1	1.234568
SRR_TP2	1.000000
S_IP2	0.000000
P_SR_TP2	0.000000
K_TP2	1.234568
SRR_TP3	1.000000
S_IP3	0.000000
P_SR_TP3	0.000000
K_TP3	1.234568
SRR_TP4	1.000000
S_IP4	0.000000
P_SR_TP4	0.000000
K_TP4	1.234568
SRR_TP5	2.002698
S_IP5	0.000000
A_TP5	0.3016155
B_TP5	0.9997118
K_TP5	102.8709
P_SR_TP5	0.000000
SRR_TP6	3.019381
S_IP6	0.000000
A_TP6	0.4799179
B_TP6	0.7031250
K_TP6	34.70970
P_SR_TP6	0.000000
SRR_TP7	3.726903
S_IP7	0.000000
A_TP7	0.5713481
K_TP7	0.6278144
P_SR_TP7	0.000000
SRR_BLANK2	1.000000
S_IP8	0.000000
P_SR_BLANK2	0.000000
K_BLANK2	1.234568
P_SR_TP_TOTAL	0.000000
C_TP1	369738.0
C_TP2	0.000000
C_TP3	0.000000
C_TP4	0.000000
C_TP5	0.000000
C_TP6	0.000000

C_TP7	0.000000
C_BLANK2	0.000000
C_TP_TOTAL	369738.0
F_IP1	5.580726
F_IP2	0.000000
F_IP3	0.000000
F_IP4	0.000000
F_IP5	0.000000
F_IP6	0.000000
F_IP7	0.000000
F_IP8	0.000000
F_IP_TOTAL	5.580726
X_CHCL_IP1	0.8448722
X_M_IP1	0.1551278
X_CHCL_IP2	0.000000
X_M_IP2	0.000000
X_CHCL_IP3	0.000000
X_M_IP3	0.000000
X_CHCL_IP4	0.000000
X_M_IP4	0.000000
X_CHCL_IP5	0.000000
X_M_IP5	0.000000
X_CHCL_IP6	1.000000
X_M_IP6	0.000000
X_CHCL_IP7	0.000000
X_M_IP7	0.000000
X_CHCL_IP8	0.6821226
X_M_IP8	0.3178774
I_TP_TOTAL	1.000000
S_3	36.94581
F_IP1_TPP1	0.000000
F_IP1_TPP2	0.000000
F_IP1_TPP3	0.000000
F_IP1_TPP4	0.000000
F_IP1_TPP5	0.000000
F_IP1_TPP6	0.000000
F_IP1_TPP7	5.580726
F_IP1_BLANK3	0.000000
F_IP2_TPP1	0.000000
F_IP2_TPP2	0.000000
F_IP2_TPP3	0.000000
F_IP2_TPP4	0.000000
F_IP2_TPP5	0.000000
F_IP2_TPP6	0.000000
F_IP2_TPP7	0.000000
F_IP2_BLANK3	0.000000
F_IP3_TPP1	0.000000
F_IP3_TPP2	0.000000
F_IP3_TPP3	0.000000
F_IP3_TPP4	0.000000
F_IP3_TPP5	0.000000
F_IP3_TPP6	0.000000
F_IP3_TPP7	0.000000
F_IP3_BLANK3	0.000000
F_IP4_TPP1	0.000000
F_IP4_TPP2	0.000000
F_IP4_TPP3	0.000000
F_IP4_TPP4	0.000000
F_IP4_TPP5	0.000000
F_IP4_TPP6	0.000000
F_IP4_TPP7	0.000000
F_IP4_BLANK3	0.000000
F_IP5_TPP1	0.000000
F_IP5_TPP2	0.000000
F_IP5_TPP3	0.000000
F_IP5_TPP4	0.000000
F_IP5_TPP5	0.000000

F_IP5_TPP6	0.000000
F_IP5_TPP7	0.000000
F_IP5_BLANK3	0.000000
F_IP6_TPP1	0.000000
F_IP6_TPP2	0.000000
F_IP6_TPP3	0.000000
F_IP6_TPP4	0.000000
F_IP6_TPP5	0.000000
F_IP6_TPP6	0.000000
F_IP6_TPP7	0.000000
F_IP6_BLANK3	0.000000
F_IP7_TPP1	0.000000
F_IP7_TPP2	0.000000
F_IP7_TPP3	0.000000
F_IP7_TPP4	0.000000
F_IP7_TPP5	0.000000
F_IP7_TPP6	0.000000
F_IP7_TPP7	0.000000
F_IP7_BLANK3	0.000000
F_IP8_TPP1	0.000000
F_IP8_TPP2	0.000000
F_IP8_TPP3	0.000000
F_IP8_TPP4	0.000000
F_IP8_TPP5	0.000000
F_IP8_TPP6	0.000000
F_IP8_TPP7	0.000000
F_IP8_BLANK3	0.000000
F_IN_TPP1	0.000000
X_CHCL_IN_TPP1	0.000000
X_M_IN_TPP1	0.000000
F_IN_TPP2	0.000000
X_CHCL_IN_TPP2	0.000000
X_M_IN_TPP2	0.000000
F_IN_TPP3	0.000000
X_CHCL_IN_TPP3	0.000000
X_M_IN_TPP3	0.000000
F_IN_TPP4	0.000000
X_CHCL_IN_TPP4	0.000000
X_M_IN_TPP4	0.000000
F_IN_TPP5	0.000000
X_CHCL_IN_TPP5	0.000000
X_M_IN_TPP5	0.000000
F_IN_TPP6	0.000000
X_CHCL_IN_TPP6	0.000000
X_M_IN_TPP6	0.3530308E-01
F_IN_TPP7	5.580726
X_CHCL_IN_TPP7	0.8448722
X_M_IN_TPP7	0.1551278
F_IN_BLANK3	0.000000
X_CHCL_IN_BLANK3	0.000000
X_M_IN_BLANK3	0.000000
F_IN_TPP_TOTAL	5.580726
I_TPP1	0.000000
I_TPP2	0.000000
I_TPP3	0.000000
I_TPP4	0.000000
I_TPP5	0.000000
I_TPP6	0.000000
I_TPP7	1.000000
I_BLANK3	0.000000
F_OUTCHCL_TPP1	0.000000
F_OUTCHCL_TPP2	0.000000
F_OUTCHCL_TPP3	0.000000
F_OUTCHCL_TPP4	0.000000
F_OUTCHCL_TPP5	0.000000
F_OUTCHCL_TPP6	0.000000
F_OUTCHCL_TPP7	4.715000

F_OUTCHCL_BLANK3	0.000000
F_OUTCHCL_TPP_TOTAL	4.715000
F_OUTM_TPP1	0.000000
F_MR_TPP1	0.000000
F_OUTM_TPP2	0.000000
F_MR_TPP2	0.000000
F_OUTM_TPP3	0.000000
F_MR_TPP3	0.000000
F_OUTM_TPP4	0.000000
F_MR_TPP4	0.000000
F_OUTM_TPP5	0.000000
F_MR_TPP5	0.000000
F_OUTM_TPP6	0.000000
F_MR_TPP6	0.000000
F_OUTM_TPP7	0.7358671
F_MR_TPP7	0.1298589
F_OUTM_BLANK3	0.000000
F_MR_BLANK3	0.000000
MRR_TPP1	0.5600000
TR_TPP1	0.6700000
EF_TPP1	0.6000000
P_D_TPP1	0.000000
MRR_TPP2	0.8600000
TR_TPP2	0.6700000
EF_TPP2	0.8600000
P_D_TPP2	0.000000
MRR_TPP3	0.8600000
TR_TPP3	0.6700000
EF_TPP3	0.8700000
P_D_TPP3	0.000000
MRR_TPP4	0.8100000
TR_TPP4	0.6700000
EF_TPP4	0.7000000
P_D_TPP4	0.000000
MRR_TPP5	0.1500000
TR_TPP5	0.000000
EF_TPP5	1.000000
P_D_TPP5	0.000000
MRR_TPP6	0.1500000
TR_TPP6	0.000000
EF_TPP6	1.000000
P_D_TPP6	0.000000
MRR_TPP7	0.1500000
TR_TPP7	0.000000
EF_TPP7	1.000000
P_D_TPP7	0.000000
MRR_BLANK3	0.000000
TR_BLANK3	0.000000
EF_BLANK3	1.000000
P_D_BLANK3	0.000000
P_D_TPP_TOTAL	0.000000
F_OUTM_TPP_TOTAL	0.7358671
S_IN_TPP1	36.94581
S_IN_TPP2	36.94581
S_IN_TPP3	36.94581
S_IN_TPP4	36.94581
S_IN_TPP5	36.94581
S_IN_TPP6	36.94581
S_IN_TPP7	36.94581
S_IN_BLANK3	36.94581
SRR_TPP1	1.000000
S_IPP1	0.000000
P_SR_TPP1	0.000000
K_TPP1	1.234568
SRR_TPP2	1.000000
S_IPP2	0.000000
P_SR_TPP2	0.000000

K_TPP2	1.234568
SRR_TPP3	1.000000
S_IPP3	0.000000
P_SR_TPP3	0.000000
K_TPP3	1.234568
SRR_TPP4	1.000000
S_IPP4	0.000000
P_SR_TPP4	0.000000
K_TPP4	1.234568
SRR_TPP5	9.042284
S_IPP5	0.000000
A_TPP5	0.9562781
B_TPP5	0.000000
K_TPP5	-124.4576
P_SR_TPP5	0.000000
SRR_TPP6	4.075918
S_IPP6	0.000000
A_TPP6	0.6102254
B_TPP6	0.3530308E-01
K_TPP6	57.45535
P_SR_TPP6	0.000000
SRR_TPP7	2.736727
S_IPP7	13.50000
A_TPP7	0.4372315
K_TPP7	0.4852082
P_SR_TPP7	1.183941
SRR_BLANK3	1.000000
S_IPP8	0.000000
P_SR_BLANK3	0.000000
K_BLANK3	1.234568
P_SR_TPP_TOTAL	1.183941
C_TPP1	0.000000
C_TPP2	0.000000
C_TPP3	0.000000
C_TPP4	0.000000
C_TPP5	0.000000
C_TPP6	0.000000
C_TPP7	46589.35
C_BLANK3	0.000000
C_TPP_TOTAL	46589.35
F_IPP1	0.000000
F_IPP2	0.000000
F_IPP3	0.000000
F_IPP4	0.000000
F_IPP5	0.000000
F_IPP6	0.000000
F_IPP7	5.450867
F_IPP8	0.000000
F_IPP_TOTAL	5.450867
X_CHCL_IPP1	0.000000
X_M_IPP1	0.000000
X_CHCL_IPP2	0.000000
X_M_IPP2	0.1350000
X_CHCL_IPP3	0.000000
X_M_IPP3	0.1350000
X_CHCL_IPP4	0.000000
X_M_IPP4	0.1350000
X_CHCL_IPP5	0.000000
X_M_IPP5	0.1350000
X_CHCL_IPP6	0.000000
X_M_IPP6	0.1350000
X_CHCL_IPP7	0.8650000
X_M_IPP7	0.1350000
X_CHCL_IPP8	0.000000
X_M_IPP8	0.1350000
I_TPP_TOTAL	1.000000
I_TOTAL	3.000000

P_TOTAL	4.148864
C_TOTAL	471062.5

Row	Slack or Surplus
1	0.000000
2	0.000000
3	0.000000
4	0.000000
5	0.000000
6	0.000000
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