CHALMERS

Analysis of Biofuel production

Bachelor Thesis

SEEX15-20-2, Advanced Biofuels

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Preface

This bachelor thesis was carried out in the project ”Advanced Biofuels” at Chalmers University of Technology. Consultation was received from the two supervisors, Paraskevi Karka and Ivar Petersson, as well as the examiner Stavros Papadokonstantakis at the department of Energy Technology. The duration of the project was 2020.01.20 − 2020.05.27.

Abstract

The world is slowly transitioning from fossil fuel use into renewable fuel use, but the technology is still in low TRL(Technology Readiness Level) and has not yet reached its full potential in commercial areas. The objective of this thesis is to provide information regarding the production processes of advanced biofuels, analyze the transparency of available data and provide a standardized way of presenting, compiling and evaluating already existing data.

The processes examined in this project are thermochemical processes such as methanol-, DME-, FT diesel- and ethanol via gasification in addition to the biochemical process of ethanol to jetfuel via fermentation and hydrocarbons via pyrolysis.

Available literature for each process has been studied and reviewed to check for consistency of mass and energy balances, conversion rate of biomass to advanced biofuel and carbon balances. All of the information is then compiled in tables and presented in such a way that is easy to understand and compare. Any inconsistencies in the data have been noted so that the reader can accurately judge the usefulness of the process and the study.

The aim is that this project will assist in making it easier to make decisions regarding technological constraints and investments into advanced biofuel production and increase the interest in the improvement and implementation of these processes.

List of Abbreviations

DME - Dimethyl ether

FT diesel - Fischer Tropsch diesel

Study - General name for all literary articles

TRL - Techonology Readiness Level

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1 Introduction

In this chapter a general introduction is presented regarding the description of this project. The introduction contains information regarding the purpose of this thesis and the reason for it being performed. The structure of the report and the results that it seeks to produce was presented in addition to the limitations placed upon the work and the final results.

1.1 Aim

The aim of this project is to examine biofuel production from lignocellulosic biomass by investigating the mass, energy and carbon balances of the processes. This analysis aims to present the available information and identify the degree of available data in order to make it more accessible for stakeholders and other interested parties, without them having to read and examine each study. The thesis will then help interested parties understand which studies could be of interest to them.

1.2 Background

In today's society the use of fossil fuels is becoming an issue that is more relevant than ever. To prevent further escalation in fossil fuels use it is becoming increasingly relevant to develop and implement renewable fuels production in society at large. The continued use of fossil fuels will further damage the environment and lead to the release of greenhouse gases and by extension an increase in global warming[9]. Therefore this is perhaps one of the most relevant fields in which to research and develop in today's society. In this bachelor's thesis the focus is liquid advanced fuels for use in the transportation sector.

The subject examined in this bachelor thesis is of high importance and further research is needed in order to change society's dependence on fossil fuels. Due to the process of producing biofuels being relatively young there is a lack of existing data and the available data has quite a large amount of uncertainties which will make it hard to implement a scale up of biofuel production.

In this thesis studies regarding production of various liquid advanced biofuels have been assembled into a database. The studies have been written by experts within the field as scientific articles or simulations reports they seek to analyze different processes and present processes for fuel production.

These studies were gathered by the Institution of Energy Technology at Chalmers University of Technology in the framework of a larger EU-project. They are mainly from the Pacific Northwest National Laboratory, the National Energy Research Laboratory and VTT but there are also various other studies from other sources.

1.3 Contribution

For the task at hand to be accomplished with as much efficiency and quality as possible the problem needed to be clearly defined and divided into manageable pieces. For this to be achieved the task was first divided into two major parts of work. Specifically the task itself and also the literature review and data extraction.

The main task of the project is to gather and compile data regarding different processes for producing biofuels and evaluate the quality of the information as well as the different processes elucidated in the literature studies. Some of these biofuels can be created using different process paths and a comparison, supported by calculations, was made between these paths.

A unit analysis of the data was performed, after which all the relevant data was converted to SI-units in order to make the results easy to grasp and because this report is made for the European market.

All of the data is checked for inaccuracies to help increase the reliability of the final report and its use of information. If the data is inaccurate, an analysis is made to find out the cause of the inaccuracy. This analysis will give a better understanding of the process and the errors it might contain.

The comparison shows the variation of conversion rate, energy requirements and environmental impact. Readers should be able to judge what kind of process that best suit them, with a basis in which aspect they consider most important, without needing to make significant research on each process and study. This report presents a conclusion regarding which studies are appropriate for which purposes and provide a summary of what information can be found in the studies.

1.4 Delimitations

This report is a part of a large scale EU-project and the studies as well as the processes to be researched were already given.What the results entail and what conclusions to be drawn from them is what needs to be specified.

The boundaries of this report includes the production of biofuels and the process path for production of said fuels. Many of the studies written describe processes that do not exist or that have only been tried in a pilot scale or in simulations. This does not measure up to the vast amount of information available regarding process for production of fossil fuels. The amount of data that can be found for the production of biofuels is limited and access to real data extracted from a biofuel production facility is difficult to find.

Only the efficiency as well as the balances of the processes are compared. The environmental impact of constructing the plants and transporting various materials is ignored due to time limitations. The cost of production will also not be examined individually but is possible to extract from other results.

2 Theoretical Background

In this section a description regarding the different processes will be presented. The three processes that are evaluated in this project are gasification, fermentation and pyrolysis. These are categorized as two different kinds of processes, thermochemical and biochemical.

2.1 Thermochemical Processes

A thermochemical process is a process where the conversion from biomass to biofuel is achieved using thermal and chemical energy, which cause changes in the material, making it possible to produce things such as biofuels and power. Basically it means that a process uses heat and chemicals to convert an intermediate product into a final one[8]. The thermochemical processes of relevance in this thesis are gasification and pyrolysis.

2.1.1 Gasification

Gasification can be done either directly or indirectly and the two different methods are quite different, they are therefore explained separately.

The directly heated gasifier is an oxygen-fired pressurized fluidized bed reactor. The biomass that is entering the gasifier is burned with a sub−stoichiometric flow of oxygen for the endothermic gasification reaction to occur. The directly heated gasifier is exactly what it seems. A gasifier that gets its heat from the exothermic reaction taking place in the gasification chamber e.g some form of combustion heats the gasifier[1].

In the case of the indirectly heated gasifier the heat used for gasification is not directly added by combustion but rather delivered to the process by a recirculating flow of some material, e.g sand, which provides the needed energy for gasification to occur.The sand is heated in a separate combustor[1].

2.1.2 Pyrolysis

Pyrolysis is a process were a substance is heated to a high temperature in the abscence of oxygen so it can decay without combustion happening. All the volatile substances departs as gas and the product will come out as liquid in this case. The difference between gasification and pyrolysis is the presence of vapour and oxygen.[9]

2.2 Biochemical Processes

A biochemical process is a metabolic process which produces chemical changes in organic compounds with help from enzymes. Literature describes biochemical processes as the extraction of energy from carbohydrates in the absence of oxygen. Biochemical processes happen continuously in nature in animals, humans and the rest of the environment. The biochemical process in focus for this thesis is fermentation.[9]

2.2.1 Fermentation

Fermentation is a process were incomplete oxidation occurs with organic compounds in the absence of oxygen, which makes fermentation an anaeorbic process. Energy is released since fermentation is an exothermic reaction[10].

2.3 Literature Review

In the process of analyzing different biofuels and their methods of production a plethora of studies have been examined. A study from the Pacific Northwest National Laboratory (PNNL) (Zhu, et al., 2011) was used to investigate production of methanol, DME and FT diesel via gasification. The study from the National Renewable Energy Laboratory (NREL) (Swanson, et al., 2010) was used for analysis of FT diesel via gasification. The study from VTT (Hannula, et al,. 2013) contained synthesis of DME and methanol via gasification. Another study from the National Renewable Energy Laboratory (NREL) (Humbird, et al., 2011) was used to fermentation of ethanol to jetfuel. The study from the National Renewable Energy Laboratory (NREL) (Dutta, et al., 2015) where used for examination of hydrocarbons via pyrolysis. The other study that was also used for examination of hydrocarbons via pyrolysis was from the Pacific Northwest National Laboratory (PNNL) (Jones, et al., 2009). The study from the National Renewable Energy Laboratory (NREL) (Dutta, et al., 2011) was used for examination of ethanol via indirect gasification.

The PNNL study[1] contained extensive flow sheets for each process, the sheets were divided into gasification, steam reforming in addition to fuel synthesis. The fuel synthesis was different for each process. The FT synthesis was divided into FT process in addition to hydrocracking and hydrotreating, the methanol fuel syntheis consisting only of the methanol synthesis. The DME fuel synthesis consisted of half of the methanol synthesis, up until raw methanol had been produced, and thereafter DME synthesis. The unit for mass flow was

$\frac{lbM}{h}$ and the unit for energy was $\frac{MMBtu}{h}$. In the PNNL study[1] there was also a flow sheet for the steam cycle of each process but this was of use in the analysis performed.

In the case of the NREL study[2] the process was presented in seven flow sheets and one flow sheet over the process an aggregated form. The mass flows were given in $\frac{ton}{d}$ and there was also information for pressure and temperature of each flow.

The VTT study[3] did not have any flow sheet containing information on mass or energy flows. It contained a summary of their process with regards to five different cases, case one being an already tested pilot, case two being a modification and is currently tested whereas case three through five are target cases that needs further research. Any mass flows were given in $\frac{kg}{h}$ and any energy flows were given in MW.

The NREL study[4] was used for investigating ethanol to jetfuel via fermentation. It contained an overview of how the whole process was disposed as well as smaller individual flow sheets that contained useful information. The mass flows were given in $\frac{kg}{h}$ and the energy flows where given in $\frac{Gcal}{hr}$.

The NREL study[5] used for the investigation of hyrdocarbons via pyrolysis was an extensive report, divided into eight different areas for the sake of simplicity. These areas had their own separate flow sheets. The unit for mass flow was $\frac{lb}{h}$ and the unit for energy was $\frac{MMBtu}{h}$.

The PNNL study[6] which was also used for investigating hydrocarbons via pyrolysis, contained larger overview flow sheets and six smaller extensive flow sheets. The unit for mass flow was $\frac{lb}{h}$ and the unit for energy was $\frac{MMBtu}{h}$.

The NREL study [7] was used for evaluating Ethanol via indirect gasification. The report was very comprehensive with detailed flow sheets. The flow sheets were divided into several different areas in order to facilitate the understanding. However some of the areas were not always in the right order which made the calculations more difficult. The unit for mass flow was $\frac{lb}{h}$ and the unit for energy was $\frac{MMBtu}{h}$.

3 Methodological Framework

In order to be able to compare the results from the different studies the data in the reports first needed to be processed and summarized. This was done for each one of the different studies using methods appropriate for each individual case. The mass balance describes the amount of given inflows compared with the amount of given outflows. This should close upwards 100 percent meaning the inflow and outflow should be equal, since the measurements were taken at fully developed flow. The same applies for the energy balance which describes the total energy input compared with the total energy output. Lastly the comparison takes into account the carbon balance, which describes the total amount of carbon put in to the process compared with the amount of fuel going out of the process, and conversion rate which is the ratio of fuel produced and feedstock introduced.

In order to perform the balances swiftly and correctly an excel table was made. In the table mass-, energy- and carbon balances are performed and presented in the same way for each process. An example of the structure is presented in Table 1.

Table 1: Example of Table used for balances

Biomass to Methanol through Direct Gasification								
PHYSICAL PROPERTIES AND DATA CONVERSION								
INPUT								
	Flow Number	Name	Unit	Amount	Flow Amount	Energy Unit	Energy content	Details
	A		kg/h			kW		
OUTPUT								
	B		kg/h			kW		
ENERGY STREAM INPUT								
	Flow Number	Name	Unit	Amount	Flow amount	Energy Unit	Energy content	Details
	C					kW		
ENERGY STREAM OUTPUT								
	D					kW		
Calculations								
Mass Balance								
In			kg/h					
Out			kg/h					
Closure			kg/h					
Energy Balance								
Flow input			kW					
Flow output			kW					
Energy stream input			kW					
Energy stream output			kW					
Consumption			kW					
Closure								
Methanol Conversion								
In			kg/h					
Out			kg/h					
Conversion rate								
Carbon Balance								
Product			kg/h					
Byproducts			kg/h					
Biomass			kg/h					
Input fuels			kg/h					
Carbon efficiency								

The appropriate flows and flow numbers are inserted in the respective slots in the table and results are presented in calculations. The way to use the table differs slightly from report to report but the basis is that data for relevant flows going in or out of the system boundary is extracted and written in the table. In the physical properties and data conversion part of the table the numbers and information necessary for processing data in to SI-units, $\frac{kg}{h}$ and kW is inserted. After that the input and output parts, with flows going in and out of the process, are registered, see flow A and B. In the energy stream part of the table, flows that only change the energy of the system are considered e.g. heat exchangers and air coolers, see flow C and D. Finally the calculations present the final balances and energy consumption. The carbon balance used has been taken from the PNNL study[1].

$$\text{Carbon Efficiency} = \frac{\mathrm{C}_{fuel}+C_{byproduct}}{\mathrm{C}_{biomass}+C_{otherinputfuels}} \tag{1}$$

Where C_{fuel} and $C_{byproduct}$ is the carbon fracture of outlet streams while $C_{biomass}$ and $C_{otherinputfuels}$ is the carbon fracture of inlet streams. The outlet streams only include any fuel that will be sold and not any fuel that is used to power the process. This balance is used to show how well the process converts biomass carbon into the desired fuel carbon.

4 Results and Discussion

The results from the different studies are presented as tables with all the balances presented. Depending on the study the mass flow will either be presented in $\frac{kg}{h}$ or in $\frac{ton}{d}$. All balances are presented in complete form in the appendix. The carbon balance for all cases is calculated using equation (1).

4.1 Methanol via Gasification

The process for producing methanol from biomass was discussed in two separate studies, the PNNL- and VTT study[1,3]. Direct gasification to methanol was examined in both studies while indirect gasification was only examined in the PNNL study[1].

4.1.1 Direct Gasification

The balances calculated from the PNNL study[1] for methanol through direct gasification are presented in Table 2.

Table 2: Balances Methanol - Direct gasification from PNNL study[1]

Mass Balance		
In	898831,73	kg/h
Out	897817,79	kg/h
Closure	0,00113	
Energy Balance		
Flow input	−1544995,99	kW
Flow output	−1778939,41	kW
Energy stream input	−10456492,67	kW
Energy stream output	−10192994,23	kW
Consumption	19930,00	kW
Closure	0,00080	
Methanol Conversion		
In	83333,00	kg/h
Out	38577,14	kg/h
Conversion rate	0,46	
Carbon Balance		
Product	1204030,61	mol carbon/h
Byproducts	0	mol carbon/h
Biomass	3513874,83	mol carbon/h
Input fuels	0	mol carbon/h
Carbon efficiency	0,343	mol useful carbon atoms/mol input carbon atoms

As by Table 2 the balances all close within one percent but there were still some problems in performing the mass balance. This was because of a natural gas flow for which the flow amount was not available. The flow amount for this was calculated by comparing the total output with the four input streams and subtracting. There was also some energy loss across the tar reformer which was not explained but the sum of unexplained energy losses is the consumption given in the text.

The results calculated from the VTT study[3] are presented in Table 3.

Table 3: Balances Methanol - Direct gasification from VTT study[3]

Cases	1	2	3	4	5
Mass Balance - Cannot be done					
Energy Balance - Cannot be done					
Methanol Conversion					
In	20.5	20.5	20.5	20.5	20.5
Out	9.2	9.2	10	8.7	8.7
Conversion rate	0.449	0.449	0.488	0.424	0.424
Methanol Conversion					
Product (mol/h)	287.117	287.117	312.083	271.513	271.513
Byproducts (mol/h)	0	0	0	0	0
Biomass (mol/h)	876.375	876.375	876.375	876.375	876.375
Input fuels (mol/h)	0	0	0	0	0
Carbon efficiency	0.328	0.328	0.356	0.310	0.310

The results given were not enough to recreate a mass or energy balance. Biomass flow in, fuel flow out as well as biomass properties are presented which are needed to calculate conversion rate and carbon balance.

4.1.2 Indirect gasification

The production of methanol via indirect gasification was only described in the PNNL study[1] and the balances constructed from its flow sheets are presented in Table 4.

Table 4: Balances Methanol - Indirect gasification from PNNL study[1]

Mass Balance					
In	424165,86	kg/h			
Out	420624,82	kg/h			
Closure	0,00835				
Energy Balance					
Flow input	−519266,59	kW			
Flow output	−638178,03	kW			
Energy stream inp	−10159291,97	kW			
Energy stream out	−10044799,91	kW			
Consumption	4419,38	kW			
Closure	−0,00083				
Methanol Conversion					
In	83333,33	kg/h			
Out	36507,73	kg/h			
Conversion rate	0,44	Methanol/Biomass			
Carbon Balance					
Product	1139442,12	mol carbon/h			
Byproducts	0	mol carbon/h			
Biomass	3513888,86	mol carbon/h			
Input fuels	0	mol carbon/h			
Carbon efficiency	0,324	mol useful carbon atoms/mol input carbon atom			

The flow sheets for indirect gasification were very inconsistent. There was data missing for the entire vent stream from the dryer in the indirect gasification flow sheet. In order to perform the balances without them being affected by the missing flow data the system boundaries were moved to exclude the dryer. Despite the inconsistencies the balances close to a high degree and the result was satisfactory.

4.1.3 Discussion

The process of producing methanol via gasification was examined in the PNNL and VTT studies[1,3] and the results obtained were vastly different. From the VTT study[3] the only balance that was possible to make was the carbon balance but with the information from the PNNL study[1] all balances could be performed. It should however be noted that the PNNL study[1] is based on simulations while the VTT study[3] is based on a pilot plant, hence the process from the PNNL study[1] has not yet been performed physically. There are also some inconsistencies with the flows in the PNNL study[1] and therefore the results are not entirely trustworthy.

4.2 Fischer Tropsch Diesel via Gasification

The process of producing FT diesel was presented in the PNNL and the NREL studies[1,2]. In the PNNL study[1] the production of FT diesel is performed using both direct as well as indirect gasification and in the NREL study[2] it is produced using high- and low temperature methods of direct gasification.

4.2.1 Direct gasification

The balances calculated from the PNNL study[1] for direct gasification of biomass for production of FT diesel are presented in Table 5. The balances close to a high degree due to the consistency of the flow sheets regarding this process.

Table 5: Balances FT diesel - Direct gasification from PNNL study[1]

Mass Balance				
In	908756	kg/h		
Out	904540	kg/h		
Closure	0,00464			
Energy Balance				
Flow input	−1540582	kW		
Flow output	−1793753	kW		
Energy stream in	−10173382	kW		
Energy stream ou	−9919913	kW		
Consumption	16710	kW		
Closure	0,00140			
Fuel Conversion				
In	83333	kg/h		
Out	13261	kg/h		
Conversion rate	0,159			
Carbon Balance				
Product	718809,24	mol carbon/h		
Byproducts	218027	mol carbon/h		
Biomass	3513888,75	mol carbon/h		
Input fuels	0	mol carbon/h		
Carbon efficienc	0,267	mol useful carbon atoms/mol input carbon atoms		

The second study examining the production of FT was the NREL study[2]. The mass balance was initially performed using only the combined flow sheet but due to some inconsistencies the more detailed ones had to be analyzed as well. It was not possible to perform energy balances since only temperature and pressure was available, it would have required additional simulations or extensive chemical data which was not present.

The mass balance performed for the high temperature flow sheets closes to a high degree, see Table 6. The more detailed flow sheets were required when performing mass balance for the fuel synthesis because of a missing water flow.

Table 6: Balances FT diesel - High Temperature Process from NREL study[2]

Mass Balance					
In	22757.30	ton/d			
Out	22692.50	ton/d			
Closure	0.00285				
Energy Balance - Not possible to calculate					
Fuel Conversion					
In	2000.00	ton/d			
Out	379.00	ton/d			
Conversion rate	0.190				
Carbon Balance					
Product	18825.607	kmol carbon/d			
Byproducts	7896.377	kmol carbon/d			
Biomass	78734.388	kmol carbon/d			
Input fuels	0	kmol carbon/d			
Carbon efficiency	0.339	mol useful carbon atoms/mol input carbon atoms			

The mass balance closes to high degree and the small difference between inflow and outflow is negligible.

For the low temperature case the mass balance outflow is one percent larger than the inflow, see Table 7, which is not possible. However the balance still closes within one percent which means it is consistent enough to use.

Table 7: Balances FT diesel - Low Temperature Process from NREL study[2]

Mass Balance						
In	24984.40	ton/d				
Out	25333.10	ton/d				
Closure	0.01					
Energy Balance - Not possible						
Fuel Conversion						
In	2000.00	ton/d				
Out	293.00	ton/d				
Conversion rate	0.147					
Carbon Balance						
Product	14541.99	kmol carbon/d				
Byproducts	6099.77	kmol carbon/d				
Biomass	78734.39	kmol carbon/d				
Input fuels	0	kmol carbon/d				
Carbon efficienc	0.26	mol useful carbon atoms/mol input carbon atoms				

4.2.2 Indirect gasification

The performed balances for indirect gasification of FT diesel from the PNNL study[1] close to a high degree and the flow sheets for this process are almost completely free from inconsistencies, see Table 8.

Table 8: Balances FT diesel - Indirect gasification from PNNL study[1]

Mass Balance					
In	698232,51	kg/h			
Out	698027,47	kg/h			
Closure	0,00029				
Energy Balance					
Flow input	−893283,22	kW			
Flow output	−1101412,00	kW			
Energy stream in	−11354631,55	kW			
Energy stream ou	−11119275,34	kW			
Power consumpti	24600,00	kW			
Closure	0,00021				
Fuel Conversion					
In	83333	kg/h			
Out	11517	kg/h			
Conversion rate	0,138				
Carbon Balance					
Product	629803,19	mol carbon/h			
Byproducts	183884	mol carbon/h			
Biomass	3513888,86	mol carbon/h			
Input fuels	0	mol carbon/h			
Carbon efficiency	0,232	mol useful carbon atoms/mol input carbon atoms			

One thing that was missing from the flow sheets was a single large water stream from the steam reforming, which would have had a large impact on the mass- and energy balances. However this flow was replaced with a water stream that goes in to the gasification flow sheet.

4.2.3 Discussion

In the case of FT diesel for both studies, i.e. the NREL and PNNL[1,2], the balances close and the process is presented clearly in flow sheets. Both studies were made using simulations and are great tools for examining the process, their results are detailed enough to be of great help in recreating them in real life. In the NREL study[2] the data available is not enough to calculate energy balances but they could potentially be extracted by using the temperatures and pressures of the flows. The data in the NREL study[3] is presented in $\frac{ton}{d}$ without any decimal points. This could be the cause of the difference between outflow and inflow since the difference is small enough to be caused by rounding.

4.3 Dimethyl Ether via Gasification

The production of DME is examined in the PNNL study[1] and also the VTT study[3]. In the PNNL study[1] the production of DME is done both through direct and indirect gasification.

As mentioned in the theoretical background the outflow from the steam reforming goes halfway through the methanol synthesis before it goes in to the DME synthesis. Because of this a mass- and energy balance was performed for the flows between the steam cycle and the DME synthesis. These flows were found in the methanol synthesis and might differ slightly from the values from the DME process.

4.3.1 Direct gasification

The balances from the PNNL study[1] for DME via direct gasification are displayed in Table 9.

Table 9: Balances DME - Direct gasification from PNNL study[1]

Mass Balance					
In	870216,69	kg/h			
Out	870009,82	kg/h			
Closure	0,00024				
Energy Balance					
Flow input	−1565747,06	kW			
Flow output	−1753202,76	kW			
Energy stream inp	−9537032,01	kW			
Energy stream out	−9329448,60	kW			
Consumption	19930,00	kW			
Closure	0,00002				
DME Conversion					
In	83333,00	kg/h			
Out	24621,18	kg/h			
Conversion rate	0,295	kg DME/kg Biomass			
Carbon Balance					
Product	1068859,434	mol carbon/h			
Byproducts	0	mol carbon/h			
Biomass	3513874,833	mol carbon/h			
Input fuels	0	mol carbon/h			
Carbon efficiency	0,304	mol useful carbon atoms/mol input carbon atoms			

The balances for direct DME production close to a high degree and the remaining errors in the mass- and energy balance could have been caused by lacking accuracy or because of some small streams that were neglected in the balances. They, although small, could also have been caused by the insecurity of the flow analysis between steam reforming and DME synthesis.

The balances from the VTT study[3] for DME via direct gasification are displayed in Table 10.

Table 10: Balances DME - Direct gasification from VTT study[3]

Cases	1	2	3	4	5
Mass Balance - Cannot be done					
Energy Balance - Cannot be done					
DME Conversion					
In	20.5	20.5	20.5	20.5	20.5
Out	6.9	6.9	7.6	6.4	6.4
Conversion rate	0.337	0.337	0.371	0.312	0.312
DME Conversion					
Product (mol/h)	300.000	300.000	330.435	278.261	278.261
Byproducts (mol/h)	0	0	0	0	0
Biomass (mol/h)	876.375	876.375	876.375	876.375	876.375
Input fuels (mol/h)	0	0	0	0	0
Carbon efficiency	0.342	0.342	0.377	0.318	0.318

Data given in the VTT study[3] is not enough to complete any mass and energy balances. The flow amount for the biomass input as well as DME output and biomass properties were given which makes calculations of both conversion rate and carbon balance possible.

4.3.2 Indirect gasification

The balances for the indirect gasification into DME production process from the PNNL study[1] are not as accurate as for the direct gasification, see Table 11.

Table 11: Balances DME - Indirect gasification from PNNL study[1]

Mass Balance		
In	724636,556	kg/h
Out	719976,333	kg/h
Closure	0,00643	
Energy Balance		
Flow input	−1066282,613	kW
Flow output	−1167768,157	kW
Energy stream input	−12423874,69	kW
Energy stream output	−12158478,29	kW
Consumption	28840	kW
Closure	0,01	
DME Conversion		
In	83333,333	kg/h
Out	26294,099	kg/h
Conversion rate	0,316	kg DME/kg Biomass
Carbon Balance		
Product	1141484,636	mol carbon/h
Byproducts	0	mol carbon/h
Biomass	3513888,857	mol carbon/h
Input fuels	0	mol carbon/h
Carbon efficiency	0,325	mol useful carbon atoms/mol input carbon atoms

The reason for the inaccuracy in this case is most likely that the outflow of raw methanol from the methanol synthesis is not the same as the inflow of raw methanol in to the DME synthesis, which it should be. The difference between these flows is quite large which means that the inaccuracy is as well .

4.3.3 Discussion

The process of producing DME via gasification is examined in the same studies as the process of producing methanol via gasification, the PNNL and the VTT studies [1,3]. The data in the PNNL study[1] is very extensive and can therefore be used for those interested in the process of producing DME using gasification. The VTT study[3] does not contain the same amount of data, it is as such more appropriate if someone wants to read about the process and not actually recreate it.

4.4 Ethanol via Gasification

The process of producing ethanol via gasification are examined in the NREL study[7].

4.4.1 Balances

The mass, energy and carbon balances calculated from the NREL study[7] for indirect gasification of biomass to Ethanol are presented in Table 12.

Table 12: Balances Ethanol - Indirect gasification from NREL study[7]

Flow Balance		
Flow stream input	5135460,665	kg/h
Flow stream output	5138755,557	kg/h
Closure	0,000642	
Energy Balance		
Flow input	4728731,015	kW
Flow output	4706694,374	kW
Energy stream input	987883,331	kW
Energy stream output	768490,96	kW
Consumption	49572	kW
Closure	0,0505	
Biomass Conversion		
In	119047,488	kg/h
Out	23126,388	kg/h
Conversion rate	0,194	
Carbon Balance		
Product	261735,867	mol carbon/h
Byproducts	0	mol carbon/h
Biomass	5049358,067	mol carbon/h
Input fuels	0	mol carbon/h
Carbon efficiency	0,0518	mol useful carbon atoms/mol input carbon atoms

As can be seen in Table 12 the mass balance almost closes completely. However the energy balance does not close. Since the system boundaries need to be the same throughout the report, some flow sheets were not taken into consideration. The flow sheets that have not been evaluated are Steam System and Power Generation, Cooling Water and Other Utilities, Sulfuric Recovery and Materials Storage because it did not make any difference for either balance. This because the streams in those flow sheets mainly contained transport of heat and an insignificant amount of solids. The mass balance was very consistent and the flow sheets that have been evaluated did not have many large differences in input and output flows. However the energy balance is a bit more complicated because it does not have all of the values needed, and therefore some flows are missing and others have an approximate value. The conversion of biomass to ethanol is pretty low in comparison tho other processes.

4.4.2 Discussion

The process of producing Ethanol via gasification did not have too many inconsistencies, on the contrary it turned out to get a very low conversion rate which is not desirable. The NREL study[7] was pretty consistent with the flow sheets and given values. It is very extensive and can show the bigger picture for those interested in producing ethanol via gasification. Miss calculations and rounding errors, together with some unclear streams, may be the reason to some deviations together with the approximate values for some energy flows.

4.5 Ethanol to Jetfuel via Fermentation

The study used for examination of the production of ethanol to jetfuel was the NREL[4].

4.5.1 Balances

The mass, energy and carbon balances calculated from the NREL study[4] are presented in Table 15.

Table 13: Balances Ethanol to Jetfuel via Fermentation from NREL study[4]

Flow Balance		
Flow stream input	3882146	kg/h
Flow stream output	3882481	kg/h
Closure	0.0000863	
Energy Balance		
Flow input	-1192656.5	kW
Flow output	-1144159.4	kW
Energy stream input	-268363.413	kW
Energy stream output	-243997.4	kW
Consumption	64411	kW
Closure	0.00605	
Ethanol Conversion		
In	104167	kg/h
Out	21808	kg/h
Conversion rate	0.209	
Carbon Balance		
Product	9475.633	mol carbon/h
Byproducts	0	mol carbon/h
Biomass	32260	mol carbon/h
Input fuels	0	mol carbon/h
Carbon efficiency	0.294	mol useful carbon atoms/mol input carbon atoms

As presented from Table 15 both of the balances close to a high degree. To be able to perform the energy and mass balances and also be within the system boundaries a couple of flow sheets were excluded from the calculations. The mass balance was consistent and well presented which made it easy to examine. The process part that had a noticeable difference was the Ammonia Addition which had 411 $\frac{kg}{h}$ more inflow and the Cellulase Seed Fermentation which had 711 $\frac{kg}{h}$ more outflow. It was more of a struggle performing the energy balance as the individual flow sheets were a bit inconsistent. Even though some of the values were not compatible within the individual flow sheets the overall balance closed to a high degree which was satisfactory.

4.5.2 Discussion

A reason for the incompatible values between the flow sheets could be because of miscalculations, rounding errors and inconsistencies respecting decimals. The inconsistencies concerning the energy flow sheets could be explained by the usage of electricity as well as inadequacy concerning the information for some of the heat exchanges. In general the report where rather easy to understand due to it is well explained flow sheets.

4.6 Hydrocarbons via Pyrolysis

The reports used for examination regarding the production of hydrocarbons via pyrolysis were the NREL study[5] and the PNNL study[6].

4.6.1 Balances

The mass, energy and carbon balances calculated from the NREL study[5] are presented in Table 14.

Table 14: Balances Hydrocarbons via Pyrolysis from NREL study[5]

Flow Balance					
Flow stream input	1216090.666	kg/h			
Flow stream output	1216102.913	kg/h			
Closure	0.0000101				
Energy Balance					
Flow input	-1552684.86	kW			
Flow output	-1762816.05	kW			
Energy stream input	-221560.92	kW			
Energy stream output	-309481.92	kW			
Consumption	-48000	kW			
Closure	0.137				
Hydrocarbons Conversion					
In	183718	kg/h			
Out	43711	kg/h			
Conversion rate	0.238				
Carbon Balance					
Product	18555.320	mol carbon/h			
Byproducts		mol carbon/h			
Biomass	47166.253	mol carbon/h			
Input fuels		mol carbon/h			
Carbon efficiency	0.365	mol useful carbon atoms/mol input carbon atoms			

From Table 14 presenting the balances some delimitations were made to be able to stay within the system boundaries. These delimitations were to exclude a couple of flow sheets from the calculations. This because the study had to stay within the system boundaries. The mass balance closed to a high degree unlike the energy balance which had a lot of inconsistencies and closed only to 13,7 percent.

The mass, energy and carbon balances calculated from the PNNL study[6] are presented in Table 15.

Table 15: Balances Hydrocarbons via Pyrolysis from PNNL study[6]

Flow Balance		
Flow stream input	649578.268	kg/h
Flow stream output	651398.216	kg/h
Closure	0.0028	
Energy Balance		
Flow input	-1098726.050	kW
Flow output	-1186561.040	kW
Energy stream input	-21386154.058	kW
Energy stream output	-21171578.461	kW
Consumption	25.589	kW
Closure	0.0056	
Hydrocarbons Conversion		
In	183718	kg/h
Out	30355.377	kg/h
Conversion rate	0.165	
Carbon Balance		
Product	14671.765	mol carbon/h
Byproducts		mol carbon/h
Biomass	70277.199	mol carbon/h
Input fuels		mol carbon/h
Carbon efficiency	0.547	mol useful carbon atoms/mol input carbon atoms

The mass balance was consistent, well presented and the values agrees well which is evident with the closure. Both the mass and energy balance close to a satisfying degree.

4.6.2 Discussion

The inconsistent values in a few of the processes could be due to some errors concerning the streams. Some of the streams didn't have any values and to compensate this some corresponding streams where used instead. Another reason could be that the energy balance had no value for quench water in flow sheet Pyrolysis unit. Another contributing factor could be an error in the flow sheet Hydrocracking and Product Separation were stream 302 and stream 531 should add up to stream 601 since they go into each other, but the streams does not correlate with the numbers.

5 Conclusions

Methanol via Gasification The production of methanol via gasification is presented in a detailed manner in the PNNL study[1]. This is the most comprehensive study of the two and should be read by anyone interested, e.g. process designers or environmental scientists. Due to inconsistencies in several flow sheets, e.g. the missing energy stream and vent stream from dryer for indirect gasification, PNNL study[1], the information is not exact and needs to be complemented. Both studies gives very similar results which helps in strengthen the accuracy of both conversion rate and carbon balance. This process seems to be more developed than other pathways due to the high conversion rate and carbon balance percentage which signifies that the research in the area is well done.

FT Diesel via Gasification For FT Diesel via gasification there are two well performed studies to choose from, both of them has extensive flow sheets which supplies detailed information and good closure for all balances. They treat different cases and give a broad view of how different process paths yield different results. While the NREL study[2] is easier to work with, the PNNL study[1] includes more information and allows for mass,energy and carbon balances to be calculated, note that the energy balance for NREL takes a lot of work to calculate and even if done the results obtained may not be correct.

DME via Gasification The process of creating DME via gasification has been researched in the PNNL study[1] as well as the VTT study[3]. The VTT study[3] is lacking in information and neither mass- nor energy balances could be done due to a severe lack of information regarding streams. The information in the other study, the PNNL study [1], contains a lot more information which in turn made it possible to make all different calculations.

Ethanol via Gasification Indirect gasification of biomass to produce Ethanol has one well made study[7], which was used. The report was detailed and described all of the parts of the process clearly. The study has a lot of flow sheets which made the calculation very time consuming and in some cases hard to follow. The results of the calculations were mixed, some balances had a good closure and others did not which needs to be taken into consideration of stakeholders.

Ethanol to Jetfuel via Fermentation As for the production of Ethanol to Jetfuel via fermentation the NREL study[4] was used. This report was well detailed and described the different processes well with individual flow sheets. There where many flow sheets which made it time consuming to understand and examine all of them. There was not any overview that could be used instead of the individual flow sheets. The overview that were presented in the report could only be used for a better understanding of how the different processes were connected to each other. This report is well suited for those who intend to do calculations for a mass balance but for the energy balances the process is more complex and inconsistent between the individual flow sheets.

Hydrocarbons via Pyrolysis The production of hydrocarbons, in this case diesel and gasoline, are presented in two different reports, the PNNL[6] and the NREL[5]. The PNNL study was easy to work with since it didn't have that many individual flow sheets as the NREL study[5]. The difficulties regarding the energy balance for the NREL study[5] made it not suited for these kind of calculations.

Final Conclusion To summarize all of the results and weigh the conversions and carbon efficiency against each other can one see that the Methanol via Indirect gacification has the highest conversion rate with 46,0 percent unlike the FT Diesel via indirect gasification that only has a conversion rate on 13,8 percent.

Table 16: All Balances for all Processes

Study	Process	Mass Balance	Energy Balance	Conversion Rate	Carbon Balance
Methanol via Direct Gasification	PNNL study[1]	0.00113	0.0008	0.46	0.343
	VTT study[3]	-	-	0.449	0.328
Methanol via Indirect Gasification	PNNL study[1]	0.00835	-0.00083	0.44	0.324
FT via Direct Gasification	PNNL study[1]	0.00464	0.001403	0.159	0.267
	NREL study[3] High Temperature Case	0.00285	-	0.190	0.339
	NREL study[3] Low Temperature Case	0.01	-	0.147	0.26
FT via Indirect Gasification	PNNL study[1]	0.00029	0.00021	0.138	0.232
DME via Direct Gasification	PNNL study[1]	0.00024	0.00002	0.295	0.304
	VTT study[3]	-	-	0.337	0.342
DME via Indirect Gasification	PNNL study[1]	0.00643	0.01	0.316	0.325
Ethanol via Indirect Gasification	NREL study[7]	0.0028	0.0056	0.165	0.547
Ethanol to Jetfuel via Fermentation	NREL study[4]	0.000863	0.00605	0.209	0.294
Hydrocarbons via Pyrolysis	NREL study[5]	0.00001	0.137	0.238	0.365
	PNNL study[6]	0.0028	0.0056	0.165	0.547

In the presentation of the results extracted from a process it is simple to see which balances close to a high degree and how efficient the production of the biofuel is. The studies with balances presented that close to a high degree can therefore immediately be regarded as studies worth examining. This is because these studies contain all the information needed to perform a balance that closes to a hundred percent and hence it is reasonable to assume that the process and data given is entirely correct and can be used for further investigation.

Bibliography

1. Y. Zhu, S.A Tjokro Rahardjo, C. Valkenburg, L.J. Snowden-Swan, M.A. Machinal. Techno-economic Analysis for the Thermochemical Conversion of Biomass to Liquid Fuels. Washington: Pacific Northwest National Laboratory; 2011 [06-2011]

2. R.M. Swanson, J.A. Satrio, R.C. Brown, A. Platon, D.D. Hsu. Techno-Economic Analysis of Biofuels Production Based on Gasification. Colorado: National Renewable Energy Laboratory; 2010[11-2010].

3. I. Hannula, E. Kurkela. Liquid transportation fuels via large-scale fluidised- bed gasification of lignocellulosic biomass. Kuopio: VTT Technical Research Centre of Finland; 2013.

4. D. Humbird, R. Davis, L. Tao, C. Kinchin, D. Hsu, and A. Aden. P. Schoen, J. Lukas, B. Olthof, M. Worley, D. Sexton, and D. Dudgeon. Process Design and Economics for Biochemical Conversion of Lignocellulosic Biomass to Ethanol. Colorado and Georgia: National Renewable Energy Laboratory; 2011 [05-2011]

5. A. Dutta, A. Sahir, E.T. David Humbird, L.J. Snowden-Swan, P. Meyer J. Ross, et al. Process Design and Economics for the Conversion of Lignocellulosic Biomass to Hydrocarbon Fuels. Colorado: National Renewable Energy Laboratory; 2015[03-2015]

6. S.B. Jones, J.E. Holladay, C. Valkenburg, D.J. Stevens, C.W. Walton, C. Kinchin, et al. Production of Gasoline and Diesel from Biomass via Fast Pyrolysis, Hydrotreating and Hydrocracking: A Design Case. Washington: Pacific Northwest National Laboratory; 2009 [0.2-2009]

7. A. Dutta, M. Talmadge, J. Hensley, M. Worley, D. Dudgeon, D. Barton, et al. Process Design and Economics for Conversion of Lignocellulosic Biomass to Ethanol. Colorado: National Renewable Energy Laboratory; 2011[05-2011]

8. C.A Hill, J. Dewulf, H.V. Langenhove, J.H. Clark, F.E Deswerte, W. Soetart, et al. Thermochemical Processing of Biomass Conversion into Fuels, Chemicals and Power. Iowa: Wiley; 2011.

9. D. Archer. Global warming: Understanding the forecast. Massachusetts: Blackwell publishing; 2007. 10. H.C. Vogel. Fermentation and Biochemical Engineering Handbook - Principles, Process Design, and Equipment (3rd Edition). Massachusetts: Elsevier; 2014

A Calculations

A.1 Balances for Methanol via Direct Gasification from PNNL study[1]

Biomass to Methanol through Direct Gasification

PHYSICAL PROPERTIES AND DATA CONVERSION

lb/h to kg/h	**Molar mass**	**g/mol**	**Carbon % in biomass**
0,453592	Nitrogen	28,0134	0,506
	Hydrogen	2,01568	**Mol carbon atoms in 1kg biomass**
MMBtu/h to kW	Carbon Monoxide	28,01	42,16666667
293,07107	Carbon Dioxide	44,01	**Carbon % in methanol**
	Methane	16,04	0,374531835
lbmol to mol	Ethylene	28,05	**Mol carbon atoms in 1kg methanol**
453,59	Ethane	30,07	31,21098627
	Ammonia	17,03	
g to kg	Hydrogen Chloride	36,46	
0,001	Methanol	32,04	
	Water	18,01528	
	Ethanol	46,07	
	Dimethyl Ether	46,07	
	Calcium Oxide	56,0774	
	Hydrogen Sulfide	34,1	
	Benzene	78,11	
	Naphthalene	128,1705	
	Nitric Oxide	30,01	
	Oxygen	31,998	
	Argon	39,948	
	Sulfur Dioxide	64,066	
	Hybrid Poplar	145	

INPUT

	Flow Number	Name	Unit	Amount	Flow Amount	Energy Unit	Energy content	Details
Gasification								
	200,00	Dry Wood Chips	kg/h	83333	166667,2928	kW	-511379,71	
		Water	kg/h	83334,2928		kW		
	100,00	Oxygen	kg/h	20933,9384	92267,63686	kW	-7628,35	
		Nitrogen	kg/h	68322,6537		kW		
		Argon	kg/h	1165,25819		kW		
		Carbon Dioxide	kg/h	45,4925319		kW		
		Water	kg/h	1800,29398		kW		
	1931,00	Water	kg/h	18939,3832	18939,38319	kW	-69337,68	
	201,00	Nitrogen	kg/h	50,3181285	3186,673898	kW	-4418,63	
		Argon	kg/h	9,2466428		kW		
		Hydrogen	kg/h	229,868625		kW		
		Carbon Monoxide	kg/h	1485,61235		kW		
		Carbon Dioxide	kg/h	706,528625		kW		
		Methane	kg/h	471,094038		kW		
		Ethylene	kg/h	0,00254464		kW		
		Ethane	kg/h	0,00681973		kW		
		Water	kg/h	3,1656588		kW		
		Methanol	kg/h	224,205315		kW		
		Ethanol	kg/h	4,51999759		kW		
		Dimethyl Ether	kg/h	2,10515283		kW		
	202,00	Oxygen	kg/h	8804,63455	37802,14608	kW	-102,09	
		Nitrogen	kg/h	28997,5115		kW		
	234,00	Carbon Dioxide	kg/h	2732,0093	2732,009298	kW	-6682,31	
	310,00	Oxygen	kg/h	12191,7662	52344,61621	kW	-141,37	
		Nitrogen	kg/h	40152,85		kW		
	343,00	Argon	kg/h	0,001812	77702,98056	kW	-340226,21	
		Hydrogen	kg/h	0,02166873		kW		
		Carbon Monoxide	kg/h	0,06479579		kW		
		Carbon Dioxide	kg/h	440,712022		kW		
		Methane	kg/h	0,02400943		kW		
		Water	kg/h	77262,1359		kW		
		Methanol	kg/h	0,02034623		kW		
	Total		kg/h	451642,739		kW	-939916,35	
Steam Reforming								
	435,00	Nitrogen	kg/h	380,274173	112755,9842	kW	-186914,867	
		Argon	kg/h	69,8870794		kW		
		Hydrogen	kg/h	3798,05521		kW		
		Carbon Monoxide	kg/h	37425,6008		kW		
		Carbon Dioxide	kg/h	61559,4266		kW		
		Methane	kg/h	7737,99059		kW		
		Ethylene	kg/h	234,832093		kW		
		Ethane	kg/h	87,9799167		kW		
		Water	kg/h	273,322033		kW		
		Benzene	kg/h	1111,81553		kW		

	Naphthalene	kg/h	76,7987882		kW	
	Methanol	kg/h	0,0014533		kW	
732,00	Water	kg/h	58089,9044	58089,90438	kW	-205958,6252
1931,00	Water	kg/h	31797,155	31797,15503	kW	-116410,7597
1605,00	Nitrogen	kg/h	329,957316	21023,00926	kW	-28978,8674
	Argon	kg/h	60,6368126		kW	
	Hydrogen	kg/h	1507,22639		kW	
	Carbon Monoxide	kg/h	9743,13638		kW	
	Carbon Dioxide	kg/h	4633,96404		kW	
	Methane	kg/h	3089,37068		kW	
	Ethylene	kg/h	0,0190848		kW	
	Ethane	kg/h	0,04091835		kW	
	Water	kg/h	20,7598249		kW	
	Methanol	kg/h	1470,20863		kW	
	Ethanol	kg/h	29,6359712		kW	
	Dimethyl Ether	kg/h	138,053223		kW	
490,00	Oxygen	kg/h	37173,6952	159603,0132	kW	-431,0489298
	Nitrogen	kg/h	122429,318		kW	
Total		kg/h	383269,066		kW	-538694,1682
Methanol Synthesis						
471,00	Nitrogen	kg/h	380,274173	61559,49433	kW	-63783,98767
	Argon	kg/h	69,8834554		kW	
	Hydrogen	kg/h	6916,53524		kW	
	Carbon Monoxide	kg/h	45610,0453		kW	
	Carbon Dioxide	kg/h	7022,94779		kW	
	Methane	kg/h	1559,72579		kW	
	Ethylene	kg/h	0,02162944		kW	
	Ethane	kg/h	0,04637413		kW	
	Methanol	kg/h	0,01453302		kW	
Natural Gas	Methane	kg/h	1976,79789	2360,430475	kW	-2601,483452
	Methanol	kg/h	383,632584		kW	
Total		kg/h	63919,9248		kW	-66385,47113
			OUTPUT			
Gasification						
111,00	Oxygen	kg/h	18,0031319	71244,21291	kW	-8305,341053
	Nitrogen	kg/h	68285,0803		kW	
	Argon	kg/h	1095,34212		kW	
	Carbon Dioxide	kg/h	45,4925319		kW	
	Water	kg/h	1800,2948		kW	
309,00	Water	kg/h	4163,99106	6413,986218	kW	-32897,22761
	Calcium Oxide	kg/h	2249,99516		kW	
210,00	Oxygen	kg/h	5427,85283	168730,1468	kW	-324400,3674
	Nitrogen	kg/h	69014,3501		kW	
	Argon	kg/h	9,2466428		kW	
	Hydrogen	kg/h	4,78696015		kW	
	Carbon Monoxide	kg/h	446,816488		kW	
	Carbon Dioxide	kg/h	14384,1241		kW	
	Water	kg/h	79004,5475		kW	
	Sulfur Dioxide	kg/h	2,78973091		kW	
	Nitric Oxide	kg/h	435,632386		kW	
1702,00	Nitrogen	kg/h	0,05717969	91593,43168	kW	-400159,239
	Argon	kg/h	0,03080402		kW	
	Hydrogen	kg/h	1,08965355		kW	
	Carbon Monoxide	kg/h	11,3824596		kW	
	Carbon Dioxide	kg/h	432,190032		kW	
	Methane	kg/h	2,99317509		kW	
	Ethylene	kg/h	1,23160571		kW	
	Ethane	kg/h	0,39418014		kW	
	Water	kg/h	90920,5154		kW	
	Hydrogen Sulfide	kg/h	0,25675916		kW	
	Ammonia	kg/h	161,190787		kW	
	Hydrogen Chloride	kg/h	8,40455641		kW	
	Benzene	kg/h	40,9746966		kW	
	Naphthalene	kg/h	12,7029033		kW	
	Methanol	kg/h	0,01743963		kW	
428,00	Carbon Dioxide	kg/h	1,66087966	222,3128766	kW	-973,6114016
	Methane	kg/h	0,00072756		kW	
	Water	kg/h	220,639227		kW	
	Hydrogen Sulfide	kg/h	0,00154674		kW	
	Ammonia	kg/h	0,00695217		kW	
	Benzene	kg/h	0,00354299		kW	
434,00	Hydrogen Sulfide	kg/h	15,6437476	30,09577225	kW	-8,535987985

		Ammonia	kg/h	14,4520247		kW		
	435,00	Nitrogen	kg/h	380,274173	112756,0258	kW	-186914,867	
		Argon	kg/h	69,8870794		kW		
		Hydrogen	kg/h	3798,05521		kW		
		Carbon Monoxide	kg/h	37425,6008		kW		
		Carbon Dioxide	kg/h	61559,4665		kW		
		Methane	kg/h	7737,99059		kW		
		Ethylene	kg/h	234,832093		kW		
		Ethane	kg/h	87,9799167		kW		
		Water	kg/h	273,323667		kW		
		Benzene	kg/h	1111,81553		kW		
		Naphthalene	kg/h	76,7987882		kW		
		Methanol	kg/h	0,0014533		kW		
	Total		kg/h	450990,212		kW	-953659,1894	
Steam Reforming								
	1748,00	Argon	kg/h	0,001812	77443,72418	kW	-339083,228	
		Hydrogen	kg/h	0,0215773		kW		
		Carbon Monoxide	kg/h	0,06479579		kW		
		Carbon Dioxide	kg/h	439,03118		kW		
		Methane	kg/h	0,02400943		kW		
		Water	kg/h	77004,5605		kW		
		Methanol	kg/h	0,02034623		kW		
	453,00	Carbon Dioxide	kg/h	63206,4323	63640,94308	kW	-158870,8963	
		Water	kg/h	434,510777		kW		
	499,00	Oxygen	kg/h	4757,07215	180627,8643	kW	-148214,8322	
		Nitrogen	kg/h	122750,299		kW		
		Argon	kg/h	60,6368126		kW		
		Hydrogen	kg/h	0,00064		kW		
		Carbon Monoxide	kg/h	0,00762303		kW		
		Carbon Dioxide	kg/h	30759,1519		kW		
		Water	kg/h	22281,4739		kW		
		Nitric Oxide	kg/h	19,2218383		kW		
	471,00	Nitrogen	kg/h	380,274173	61559,13345	kW	-63781,05696	
		Argon	kg/h	69,8834554		kW		
		Hydrogen	kg/h	6916,51147		kW		
		Carbon Monoxide	kg/h	45609,7531		kW		
		Carbon Dioxide	kg/h	7022,93781		kW		
		Methane	kg/h	1559,70396		kW		
		Ethylene	kg/h	0,02162944		kW		
		Ethane	kg/h	0,04637413		kW		
		Methanol	kg/h	0,0014533		kW		
	Total		kg/h	383271,665		kW	-709950,0135	
Methanol Synthesis								
	630,00	Nitrogen	kg/h	380,274173	24226,156	kW	-33392,51772	
		Argon	kg/h	69,8834554		kW		
		Hydrogen	kg/h	1737,2093		kW		
		Carbon Monoxide	kg/h	11227,3664		kW		
		Carbon Dioxide	kg/h	5339,5145		kW		
		Methane	kg/h	3560,2479		kW		
		Ethylene	kg/h	0,02162944		kW		
		Ethane	kg/h	0,04637413		kW		
		Water	kg/h	23,9246666		kW		
		Methanol	kg/h	1694,41103		kW		
		Ethanol	kg/h	34,1538791		kW		
		Dimethyl Ether	kg/h	159,102661		kW		
	610,00	Water	kg/h	0,3856972	38577,77109	kW	-78724,75082	
		Methanol	kg/h	38577,1409		kW		
		Ethanol	kg/h	0,24449363		kW		
	625,00	Water	kg/h	741,764357	751,9820032	kW	-3212,93814	
		Methanol	kg/h	6,45411578		kW		
		Ethanol	kg/h	3,76353012		kW		
	Total		kg/h	63555,9091		kW	-115330,2067	

ENERGY STREAM INPUT

	Flow Number	Name	Unit	Amount	Flow amount	Energy Unit	Energy content	Details
Gasification								
	1935,00					kW	-293035,90	
	1830,00					kW	-5194684,72	
	1844,00					kW	-1083190,67	
	1941,00					kW	-3008,08	
	331,00					kW	-227273,68	Tar reformer
	Total					kW	-6801193,06	
Steam Reforming								

	1947,00	kW	-375834,3402	
	1944,00	kW	-431429,9221	
	1949,00	kW	-664890,3365	
	448,00	kW	-562432,6904	
	449,00	kW	-566330,5357	
	Total	kW	-2600917,825	
Methanol Synthesis				
	784,00	kW	-222649,0226	
	503,00	kW	-228826,9607	
	519,00	kW	-298844,5701	
	520,00	kW	-304061,2351	
	Total	kW	-1054381,789	
ENERGY STREAM OUTPUT				
Gasification				
	1938,00	kW	-249746,37	
	1831,00	kW	-5179445,02	
	1845,00	kW	-1080787,49	
	1942,00	kW	-3223,78	
	330,00	kW	-241505,22	Tar reformer
	Total	kW	-6754707,88	
Steam Reforming				
	1948,00	kW	-358836,2181	
	1945,00	kW	-411911,3889	
	703,00	kW	-566652,9138	
	447,00	kW	-536788,9718	
	448,00	kW	-562432,6904	
	Total	kW	-2436622,183	
Methanol Synthesis				
	502,00	kW	-233765,2083	
	1954,00	kW	-188852,0668	
	518,00	kW	-280202,3193	
	519,00	kW	-298844,5701	
	Total	kW	-1001664,164	

Calculations

Mass Balance		
In	898831,73	kg/h
Out	897817,79	kg/h
Closure	0,00113	
Energy Balance		
Flow input	-1544995,99	kW
Flow output	-1778939,41	kW
Energy stream in	-10456492,67	kW
Energy stream ou	-10192994,23	kW
Consumption	19930,00	kW
Closure	0,00080	
Methanol Conversion		
In	83333,00	kg/h
Out	38577,14	kg/h
Conversion rate	0,46	
Carbon Balance		
Product	1204030,61	mol carbon/h
Byproducts	0	mol carbon/h
Biomass	3513874,83	mol carbon/h
Input fuels	0	mol carbon/h
Carbon efficiency	0,343	mol usefull carbon atoms/mol input carbon atoms

A.2 Balances for Methanol via Gasification from VTT study[3]

Biomass to Methanol through Gasification (VTT)

Data necessary for calculations

Carbon % in biomass
51,3
Mol Carbon in 1kg biomass
42,75
Carbon % in methanol
37,45
Mol Carbon in 1kg methanol
31,20833333

FLOW INPUT

	Case				
	1	**2**	**3**	**4**	**5**
Biomass to dryer (kg/s)	34,9	34,9	34,9	34,9	34,9
Biomass to gasifier (kg/s)	20,5	20,5	20,5	20,5	20,5
Biomass to dryer (MW)	300	300	300	300	300
Biomass to gasifier (MW)	335	335	335	335	335

FLOW OUTPUT

	Case				
	1	**2**	**3**	**4**	**5**
Product output	9,2	9,2	10	8,7	8,7
Product energy output	183	183	200	172	172

ENERGY STREAMS

	Case				
	1	**2**	**3**	**4**	**5**
On-site consumption (MW)	-29,8	-29,8	-28,9	-21,1	-27,5
Oxygen production	-9,3	-9,3	-8,1	-8	-8
Oxygen compression	-1,9	-1,9	-1,7	-3,1	-3,1
Drying and feeding	-2	-2	-2	-2	-2
Gasifier RC compression	0	0	0	0,1	0,1
Syngas scrubbing	-0,2	-0,2	-0,1	-0,2	-0,2
Syngas compression	-13,1	-13,1	-13,9	-4,9	-4,9
Acid gas removal	-0,8	-0,8	-0,7	-0,7	-0,7
Synthesis	-0,5	-0,5	-0,5	-0,6	-0,6
Product upgrading	0	0	0	0	0
CO2 compression	0	0	0	0	-6,1
Power island	-0,6	-0,6	-0,5	-0,7	-0,7
Miscellaneous	-1,4	-1,4	-1,4	-1	-1,3
Gross production	32,5	24,8	20,4	25,9	25,9

Calculations

Cases	1	2	3	4	5
Mass Balance - Cannot be done					
Energy Balance - Cannot be done					
Methanol Conversion					
In	20,5	20,5	20,5	20,5	20,5
Out	9,2	9,2	10	8,7	8,7
Conversion rate	0,449	0,449	0,488	0,424	0,424
Methanol Conversion					
Product (mol/h)	287,117	287,117	312,083	271,513	271,513
Byproducts (mol/h)	0	0	0	0	0
Biomass (mol/h)	876,375	876,375	876,375	876,375	876,375
Input fuels (mol/h)	0	0	0	0	0
Carbon efficiency	0,328	0,328	0,356	0,310	0,310

A.3 Balances for Methanol via Indirect Gasification from PNNL study[1]

Biomass to Methanol through Indirect Gasification

PHYSICAL PROPERTIES AND DATA CONVERSION

	Molar mass	g/mol	
lb/h to kg/h	**Molar mass**	**g/mol**	**Carbon % in biomass**
0,453592	Nitrogen	28,0134	0,506
	Hydrogen	2,01568	**Mol carbon atoms in 1kg biomass**
MMBtu/h to kW	Carbon Monoxide	28,01	42,16666667
293,07107	Carbon Dioxide	44,01	**Carbon % in methanol**
	Methane	16,04	0,374531835
lbmol to mol	Ethylene	28,05	**Mol carbon in methanol**
453,59	Ethane	30,07	31,21098627
	Ammonia	17,03	
g to kg	Hydrogen Chloride	36,46	
0,001	Methanol	32,04	
	Water	18,01528	
	Ethanol	46,07	
	Dimethyl Ether	46,07	

FLOW INPUT

	Flow Number	Name	Unit	Amount	Flow amount	Energy Unit	Energy content	Details
Gasification								
	220	Dry Wood Chips	kg/h	83333,33	94696,71935	kW	-188570,7186	
		Water	kg/h	11363,39		kW		
	300	Water	kg/h	33166,67	33166,66518	kW	-121425,2057	
	110	Air	kg/h	45504,35	200561,5995	kW	-11833,33059	
		Hydrogen	kg/h	148512,4		kW		
		Argon	kg/h	2532,858		kW		
		Water	kg/h	3913,138		kW		
		Carbon Dioxide	kg/h	98,88306		kW		
	343	Water	kg/h	44836,21	45026,01672	kW	-197266,1372	
		Nitrogen	kg/h	0,000227		kW		
		Hydrogen	kg/h	0,01329		kW		
		Carbon Monoxide	kg/h	0,039417		kW		
		Methane	kg/h	0,029483		kW		
		Ammonia	kg/h	0,667778		kW		
		Hydrogen Chloride	kg/h	0,025673		kW		
		Methanol	kg/h	0,02336		kW		
		Carbon Dioxide	kg/h	189,0091		kW		
	Total		kg/h	373451		kW	-519095,3921	
Methanol Synthesis								
	471	Nitrogen	kg/h	375,4622	50714,86422	kW	-171,2	
		Hydrogen	kg/h	5796,897		kW		
		Carbon Monoxide	kg/h	37855,36		kW		
		Carbon Dioxide	kg/h	4066,55		kW		
		Methane	kg/h	2604,31		kW		
		Ethylene	kg/h	0,059799		kW		
		Ethane	kg/h	0,15549		kW		
		Ammonia	kg/h	7,66902		kW		
		Hydrogen Chloride	kg/h	8,397941		kW		
		Methanol	kg/h	0,001453		kW		
	Total		kg/h	50714,86		kW	-171,2	

FLOW OUTPUT

	Flow Number	Name	Unit	Amount	Flow amount	Energy Unit	Energy content	Details
Gasification								
	370	Oxygen	kg/h	4508,417	215972,7552	kW	-101484,6501	
		Nitrogen	kg/h	148502,8		kW		
		Argon	kg/h	2532,858		kW		
		Hydrogen	kg/h	0,000318		kW		
		Carbon Dioxide	kg/h	46961,38		kW		
		Water	kg/h	13446,68		kW		
		Nitric Oxide	kg/h	20,57611		kW		
	354	Carbon	kg/h	0,000544	2590,215434	kW	-8514,300726	
		Water	kg/h	340,194		kW		
		Calcium Oxide	kg/h	2250,021		kW		
	1702	Nitrogen	kg/h	0,002631	72390,92293	kW	-316340,913	
		Hydrogen	kg/h	0,030844		kW		
		Carbon Monoxide	kg/h	0,481034		kW		
		Carbon Dioxide	kg/h	331,0357		kW		
		Methane	kg/h	0,100652		kW		
		Acetylene	kg/h	0,002722		kW		
		Ethylene	kg/h	0,097341		kW		
		Ethane	kg/h	0,000499		kW		
		Water	kg/h	71915,65		kW		
		Hydrogen Sulfide	kg/h	0,386324		kW		
		Ammonia	kg/h	143,128		kW		
		Hydrogen Chloride	kg/h	0,001814		kW		
		Benzene	kg/h	0,002268		kW		
		Naphthalene	kg/h	0,00068		kW		
		Methanol	kg/h	0,001633		kW		

	1749	Nitrogen	kg/h	4,54E-05	4277,372651	kW	-18483,40624	
		Hydrogen	kg/h	0,003992		kW		
		Carbon Monoxide	kg/h	0,025719		kW		
		Carbon Dioxide	kg/h	2,654738		kW		
		Methane	kg/h	0,02023		kW		
		Acetylene	kg/h	0,00635		kW		
		Ethylene	kg/h	0,017236		kW		
		Ethane	kg/h	0,000227		kW		
		Water	kg/h	4274,49		kW		
		Hydrogen Sulfide	kg/h	0,014606		kW		
		Ammonia	kg/h	0,114351		kW		
		Hydrogen Chloride	kg/h	0,002404		kW		
		Benzene	kg/h	0,012338		kW		
		Naphthalene	kg/h	0,008664		kW		
		Methanol	kg/h	0,002223		kW		
	428	Hydrogen	kg/h	0,000771	3259,392454	kW	-14288,38695	
		Carbon Monoxide	kg/h	0,005171		kW		
		Carbon Dioxide	kg/h	8,485527		kW		
		Methane	kg/h	0,007348		kW		
		Acetylene	kg/h	0,004264		kW		
		Ethylene	kg/h	0,005625		kW		
		Ethane	kg/h	4,54E-05		kW		
		Water	kg/h	3250,526		kW		
		Hydrogen Sulfide	kg/h	0,01955		kW		
		Ammonia	kg/h	0,320055		kW		
		Hydrogen Chloride	kg/h	0,002903		kW		
		Benzene	kg/h	0,003357		kW		
		Naphthalene	kg/h	0,000998		kW		
		Methanol	kg/h	0,011294		kW		
	434	Hydrogen Sulfide	kg/h	16,93123	16,93122858	kW	-1,118652274	
	435	Nitrogen	kg/h	354,6801	71403,69832	kW	-83173,56967	
		Hydrogen	kg/h	2886,161		kW		
		Carbon Monoxide	kg/h	43706,7		kW		
		Carbon Dioxide	kg/h	16319,46		kW		
		Methane	kg/h	5774,535		kW		
		Acetylene	kg/h	155,5113		kW		
		Ethylene	kg/h	1786,52		kW		
		Ethane	kg/h	25,70479		kW		
		Water	kg/h	221,4265		kW		
		Ammonia	kg/h	34,10009		kW		
		Hydrogen Chloride	kg/h	8,423385		kW		
		Benzene	kg/h	86,97645		kW		
		Naphthalene	kg/h	43,48686		kW		
		Methanol	kg/h	0,008119		kW		
	Total		kg/h	369911,3		kW	-542286,3453	
Methanol Synthesis								
	630	Nitrogen	kg/h	375,6846	13452,57247	kW	-18166,30335	
		Hydrogen	kg/h	910,7202		kW		
		Carbon Monoxide	kg/h	5514,003		kW		
		Carbon Dioxide	kg/h	2381,869		kW		
		Methane	kg/h	2604,427		kW		
		Ethylene	kg/h	0,059799		kW		
		Ethane	kg/h	0,15549		kW		
		Water	kg/h	23,23499		kW		
		Ammonia	kg/h	7,669793		kW		
		Hydrogen Chloride	kg/h	8,397941		kW		
		Methanol	kg/h	1426,361		kW		
		Ethanol	kg/h	41,87319		kW		
		Dimethyl Ether	kg/h	158,1163		kW		
	625	Water	kg/h	745,6099	752,946154	kW	-3223,78177	
		Methanol	kg/h	4,67818		kW		
		Ethanol	kg/h	2,658085		kW		
	610	Water	kg/h	0,075995	36508,01677	kW	-74501,5967	
		Methanol	kg/h	36507,73		kW		
		Ethanol	kg/h	0,215238		kW		
	Total		kg/h	50713,54		kW	-95891,68182	
ENERGY STREAM INPUT								
	Flow Number	**Name**	**Unit**	**Amount**	**Flow amount**	**Energy Unit**	**Energy content**	**Details**
Gasification								
	1931					kW	-14598,74921	
	1935					kW	-250080,4747	
	1830					kW	-8682816,591	
	1844					kW	0	
	1941					kW	-1406,770443	
	Total					kW	-8948902,585	
Methanol Synthesis								
	503					kW	-282259,6782	

	519	kW	-364961,4035
	520	kW	-357957,0049
	784	kW	-205211,2939
	Total	kW	-1210389,381
ENERGY STREAM OUTPUT			
Gasification			
	1932	kW	-12440,86692
	1938	kW	-213118,3514
	1831	kW	-8657319,408
	1845	kW	0
	1942	kW	-1465,35535
	Total	kW	-8884343,981
Methanol Synthesis			
	502	kW	-288976,8672
	1954	kW	-174145,7605
	519	kW	-357957,0049
	518	kW	-339376,2991
	Total	kW	-1160455,932

Calculations		
Mass Balance		
In	424165,86	kg/h
Out	420624,82	kg/h
Closure	0,00835	
Energy Balance		
Flow input	-519266,59	kW
Flow output	-638178,03	kW
Energy stream inpu	-10159291,97	kW
Energy stream outp	-10044799,91	kW
Consumption	4419,38	kW
Methanol Conversion		
In	83333,33	kg/h
Out	36507,73	kg/h
Conversion rate	0,44	Methanol/Biomass
Carbon Balance		
Product	1139442,12	mol carbon/h
Byproducts	0	mol carbon/h
Biomass	3513888,86	mol carbon/h
Input fuels	0	mol carbon/h
Carbon efficiency	0,324	mol usefull carbon atoms/mol input carbon atoms

A.4 Balances for FT diesel via Direct Gasification from PNNL study[1]

Biomass to Fischer Tropsch through Direct Gasification

lb/h to kg/h			Name	g/mol	Conversion		Carbon % in biomass	
0,45			Water	18,01528	8,17		0,51	
			Methanol	32,04	14,53		**Mol carbon in 1kg biomass**	
MMBtu/h to kW			Hydrogen	2,01568	0,91		42,17	
293,07			Carbon Monoxide	28,01	12,70		**Mol carbon in 1kg Pentane**	
			Carbon Dioxide	44,01	19,96		69,17	
lbmol to mol			Methane	16,04	7,28		**Mol carbon in 1kg Hexane**	
453,59			Oxygen	31,998	14,51		70,00	
			Calcium Oxide	56,0774	25,44		**Mol carbon in 1kg Octane**	
g to kg			Nitrogen	28,0134	12,70		70,00	
0,00			Argon	39,948	18,13		**Mol carbon in 1kg Nonane**	
			Ethane	30,07	13,64		70,00	
			Propane		20,00		**Mol carbon in 1kg Decane**	
			N-Butane		26,36		70,83	
			Pentane	72,15	32,73		**Mol carbon in 1kg Dodecane**	
			Hexane	86,18	39,09		70,83	
			Octane	114,23	51,81		**Mol carbon in 1kg Tridecane**	
			Nonane	128,20	58,15		70,83	
			Decane	142,29	64,54		**Mol carbon in 1kg Tetradecane**	
			Dodecane	170,33	77,26		70,83	
			Tridecane	184,37	83,63		**Mol carbon in 1kg Hexadecane**	
			Tetradecane	198,39	89,99		70,83	
			Hexadecane	226,41	102,70		**Mol carbon in 1kg Heptadecane**	
			Heptadecane	240,48	109,08		70,83	
			Octadecane	254,50	115,44		**Mol carbon in 1kg Octadecane**	
			Eicosane	282,55	128,16		70,83	
			Docosane	310,60	140,89			
			Tetracosane	338,65	153,61			
			Hexacosane	366,71	166,34			
			Octacosane	394,77	179,06			
			Dotriacontane	450,88	204,51			
			Hexatriacontane	507,00	229,97			
			Naphthalene	128,17	58,14			
			Ammonia	17,03	7,73			
			Sulfur Dioxide	64,07	29,06			
			Nitric Oxide	46,01	20,87			
			Benzene	78,11	35,43			
			Napthalene	128,17	58,14			
			Ethylene	28,05	12,72			
			Ethane	30,07	13,64			
			Acetylene	26,04	11,81			

INPUT

	Flow Number	Name	Unit	Amount	Flow Amount	Energy Unit	Energy content	Details
Gasification								
	200	Dry Wood Chips	kg/h	83333,33	166669,46	kW	-511379,71	
		Water	kg/h	83336,13		kW		
	100	Oxygen	kg/h	20935,25	91025,55	kW	-7628,35	
		Nitrogen	kg/h	68289,97		kW		
		Water	kg/h	1800,33		kW		
		Argon	kg/h	1166,18		kW		
	1931	Water	kg/h	18939,80	18939,80	kW	-69337,68	
	201	Hydrogen	kg/h	228,08	1713,17	kW	-4418,63	
		Carbon Monoxide	kg/h	1485,09		kW		
	202	Oxygen	kg/h	8805,18	37788,83	kW	-102,09	
		Nitrogen	kg/h	28983,64		kW		
	234	Carbon Dioxide	kg/h	2732,02	2732,02	kW	-6682,31	
	310	Oxygen	kg/h	12192,53	52326,17	kW	-141,37	
		Nitrogen	kg/h	40133,64		kW		
	343	Water	kg/h	77263,72	77263,72	kW	-340226,21	
	Total		kg/h	449624,90		kW	-939916,35	
Steam Reforming								
	435	Nitrogen	kg/h	380,09	112183,75	kW	-185818,78	
		Argon	kg/h	69,94		kW		
		Hydrogen	kg/h	3768,50		kW		
		Carbon Monoxide	kg/h	37403,20		kW		
		Carbon Dioxide	kg/h	61122,01		kW		
		Methane	kg/h	7737,95		kW		
		Ethylene	kg/h	234,82		kW		
		Ethane	kg/h	87,97		kW		
		Water	kg/h	243,04		kW		
		Ammonia	kg/h	13,52		kW		
		Benzene	kg/h	1099,17		kW		
		Naphthalene	kg/h	23,53		kW		
	731	Water	kg/h	89889,04	89889,04	kW	-318685,48	
	490	Nitrogen	kg/h	112982,29	147291,59	kW	-399,69	
		Oxygen	kg/h	34309,30		kW		
	1012	Hydrogen	kg/h	1496,75	20321,53	kW	-15778,07	
		Carbon Monoxide	kg/h	15799,62		kW		

	Carbon Dioxide	kg/h	598,88		kW	
	Methane	kg/h	1618,28		kW	
	Ethane	kg/h	137,75		kW	
	Propane	kg/h	201,97		kW	
	N-Butane	kg/h	468,28		kW	
Total		kg/h	369685,91		kW	-520682,02
FT Process						
461	Nitrogen	kg/h	384,82	54975,16	kW	-52011,32
	Argon	kg/h	69,94		kW	
	Hydrogen	kg/h	6859,50		kW	
	Carbon Monoxide	kg/h	45403,84		kW	
	Carbon Dioxide	kg/h	703,42		kW	
	Methane	kg/h	1545,83		kW	
	Ethylene	kg/h	0,02		kW	
	Ethane	kg/h	0,05		kW	
	Ammonia	kg/h	7,75		kW	
Total		kg/h	54975,16		kW	-52011,32
Hydrocracking & Hydrotreating						
600	Nitrogen	kg/h	0,56	14281,97	kW	-7080,60
	Argon	kg/h	0,17		kW	
	Hydrogen	kg/h	1,40		kW	
	Carbon Monoxide	kg/h	19,93		kW	
	Carbon Dioxide	kg/h	10,70		kW	
	Methane	kg/h	8,84		kW	
	Ethane	kg/h	3,45		kW	
	Propane	kg/h	14,84		kW	
	Water	kg/h	2,48		kW	
	Butane	kg/h	54,01		kW	
	Pentane	kg/h	156,20		kW	
	Hexane	kg/h	338,75		kW	
	Octane	kg/h	760,22		kW	
	Nonane	kg/h	872,31		kW	
	Decane	kg/h	970,98		kW	
	Dodecane	kg/h	422,83		kW	
	Tridecane	kg/h	457,68		kW	
	Tetradecane	kg/h	492,48		kW	
	Hexadecane	kg/h	562,04		kW	
	Heptadecane	kg/h	746,22		kW	
	Octadecane	kg/h	789,73		kW	
	Eicosane	kg/h	876,76		kW	
	Docosane	kg/h	771,04		kW	
	Tetracosane	kg/h	840,67		kW	
	Hexacosane	kg/h	910,32		kW	
	Octacosane	kg/h	1224,99		kW	
	Dotriacontane	kg/h	1399,11		kW	
	Hexatriacontane	kg/h	1573,25		kW	
540	Nitrogen	kg/h	381,02	20188,22	kW	-20892,16
	Hydrogen	kg/h	1986,19		kW	
	Carbon Monoxide	kg/h	13601,05		kW	
	Carbon Dioxide	kg/h	802,50		kW	
	Methane	kg/h	2184,14		kW	
	Ethane	kg/h	182,77		kW	
	Propane	kg/h	258,04		kW	
	Butane	kg/h	305,81		kW	
	Pentane	kg/h	291,27		kW	
	Hexane	kg/h	195,45		kW	
Total		kg/h	34470,19		kW	-27972,75
OUTPUT						
Gasification						
111,00	Oxygen	kg/h	18,0042572	71212,45961	kW	-8305,341053
	Nitrogen	kg/h	68252,4167		kW	
	Argon	kg/h	1096,21146		kW	
	Carbon Dioxide	kg/h	45,4927325		kW	
	Water	kg/h	1800,33449		kW	
309,00	Water	kg/h	4164,08286	6414,078019	kW	-32897,22761
	Calcium Oxide	kg/h	2249,99516		kW	
210,00	Oxygen	kg/h	5428,19209	168931,2786	kW	-324400,3674
	Nitrogen	kg/h	68981,3376		kW	
	Argon	kg/h	9,25398156		kW	
	Hydrogen	kg/h	4,74974327		kW	
	Carbon Monoxide	kg/h	446,658937		kW	
	Carbon Dioxide	kg/h	14384,1876		kW	
	Water	kg/h	79006,2893		kW	
	Sulfur Dioxide	kg/h	2,78973091		kW	
	Nitric Oxide	kg/h	667,819657		kW	
1702,00	Nitrogen	kg/h	0,05715234	91586,77372	kW	-400159,239
	Argon	kg/h	0,03082847		kW	

	Hydrogen	kg/h	1,08118189	kW	
	Carbon Monoxide	kg/h	11,378446	kW	
	Carbon Dioxide	kg/h	432,191938	kW	
	Methane	kg/h	2,99318829	kW	
	Ethylene	kg/h	1,23160571	kW	
	Ethane	kg/h	0,39418014	kW	
	Water	kg/h	90922,52	kW	
	Ammonia	kg/h	161,200252	kW	
	Benzene	kg/h	40,9746966	kW	
	Naphthalene	kg/h	12,7029033	kW	
	Methanol	kg/h	0,01743971	kW	
428,00	Carbon Dioxide	kg/h	1,66088698	222,3162019 kW	-973,6114016
	Methane	kg/h	0,00072756	kW	
	Water	kg/h	220,644092	kW	
	Ammonia	kg/h	0,00695258	kW	
	Benzene	kg/h	0,00354299	kW	
434,00	Ammonia	kg/h	14,4528733	14,45287329 kW	-8,535987985
435,00	Nitrogen	kg/h	380,092272	112713,4859 kW	-186914,867
	Argon	kg/h	69,9425465	kW	
	Hydrogen	kg/h	3768,5267	kW	
	Carbon Monoxide	kg/h	37412,4042	kW	
	Carbon Dioxide	kg/h	61559,7379	kW	
	Methane	kg/h	7738,02471	kW	
	Ethylene	kg/h	234,832093	kW	
	Ethane	kg/h	87,9799167	kW	
	Water	kg/h	273,329693	kW	
	Benzene	kg/h	1111,81553	kW	
	Naphthalene	kg/h	76,7987882	kW	
	Methanol	kg/h	0,00145331	kW	
Total		kg/h	451094,845	kW	-953659,1894
Steam Reforming					
499	Nitrogen	kg/h	113270,97	162639,21 kW	-130513,34
	Oxygen	kg/h	3918,74	kW	
	Carbon Dioxide	kg/h	25836,43	kW	
	Water	kg/h	19613,06	kW	
1751	Water	kg/h	77029,89	77029,89 kW	-338057,48
453	Carbon Dioxide	kg/h	69638,92	70050,55 kW	-174767,07
	Water	kg/h	411,63	kW	
461	Nitrogen	kg/h	384,82	54975,16 kW	-52011,32
	Argon	kg/h	69,94	kW	
	Hydrogen	kg/h	6859,50	kW	
	Carbon Monoxide	kg/h	45403,84	kW	
	Carbon Dioxide	kg/h	703,42	kW	
	Methane	kg/h	1545,83	kW	
	Ethylene	kg/h	0,02	kW	
	Ethane	kg/h	0,05	kW	
	Ammonia	kg/h	7,75	kW	
Total		kg/h	364694,81	kW	-695349,21
FT Process					
531	Water	kg/h	20342,96	20342,96 kW	-89158,08
470	Hydrogen	kg/h	90,72	90,72 kW	13,70
540	Nitrogen	kg/h	384,26	20301,28 kW	-20892,16
	Argon	kg/h	69,77	kW	
	Hydrogen	kg/h	1986,20	kW	
	Carbon Monoxide	kg/h	13601,22	kW	
	Carbon Dioxide	kg/h	801,98	kW	
	Methane	kg/h	2184,04	kW	
	Ethylene	kg/h	0,02	kW	
	Ethane	kg/h	183,21	kW	
	Propane	kg/h	258,85	kW	
	Water	kg/h	14,55	kW	
	Butane	kg/h	306,69	kW	
	Pentane	kg/h	291,57	kW	
	Hexane	kg/h	196,09	kW	
	Octane	kg/h	19,59	kW	
	Nonane	kg/h	2,87	kW	
	Decane	kg/h	0,39	kW	
600	Nitrogen	kg/h	0,56	14281,97 kW	-7080,60
	Argon	kg/h	0,17	kW	
	Hydrogen	kg/h	1,40	kW	
	Carbon Monoxide	kg/h	19,93	kW	
	Carbon Dioxide	kg/h	10,70	kW	
	Methane	kg/h	8,84	kW	
	Ethane	kg/h	3,45	kW	
	Propane	kg/h	14,84	kW	
	Water	kg/h	2,48	kW	
	Butane	kg/h	54,01	kW	

	Pentane	kg/h	156,20		kW		
	Hexane	kg/h	338,75		kW		
	Octane	kg/h	760,22		kW		
	Nonane	kg/h	872,31		kW		
	Decane	kg/h	970,98		kW		
	Dodecane	kg/h	422,83		kW		
	Tridecane	kg/h	457,68		kW		
	Tetradecane	kg/h	492,48		kW		
	Hexadecane	kg/h	562,04		kW		
	Heptadecane	kg/h	746,22		kW		
	Octadecane	kg/h	789,73		kW		
	Eicosane	kg/h	876,76		kW		
	Docosane	kg/h	771,04		kW		
	Tetracosane	kg/h	840,67		kW		
	Hexacosane	kg/h	910,32		kW		
	Octacosane	kg/h	1224,99		kW		
	Dotriacontane	kg/h	1399,11		kW		
	Hexatriacontane	kg/h	1573,25		kW		
Total		kg/h	55016,93		kW	-117117,14	
Hydrocracking & Hydrotreating							
661	Pentane	kg/h	134,18		kW	-1755,32	
	Hexane	kg/h	445,63		kW		
	Octane	kg/h	1295,34		kW		
	Nonane	kg/h	1006,00		kW		
	Decane	kg/h	232,35		kW		
671	Decane	kg/h	1891,06		kW	-4814,86	
	Dodecane	kg/h	826,68		kW		
	Tridecane	kg/h	1329,69		kW		
	Tetradecane	kg/h	1664,77		kW		
	Hexadecane	kg/h	1232,37		kW		
	Heptadecane	kg/h	1090,79		kW		
	Octadecane	kg/h	2112,53		kW		
540	Nitrogen	kg/h	381,02		kW	-20892,16	
	Hydrogen	kg/h	1986,19		kW		
	Carbon Monoxide	kg/h	13601,05		kW		
	Carbon Dioxide	kg/h	802,50		kW		
	Methane	kg/h	2184,14		kW		
	Ethane	kg/h	182,77		kW		
	Propane	kg/h	258,04		kW		
	Butane	kg/h	305,81		kW		
	Pentane	kg/h	291,27		kW		
	Hexane	kg/h	195,45		kW		
631	Hydrogen	kg/h	33,11		kW	-4,92	
656	Butane	kg/h	250,45		kW	-160,44	
Total		kg/h	33733,17		kW	-27627,70	
ENERGY STREAM INPUT							
Flow Number	**Name**	**Unit**	**Amount**	**Flow amount**	**Energy Unit**	**Energy content**	**Details**
Gasification							
1935,00					kW	-293035,90	
1830,00					kW	-5194684,72	
1844,00					kW	-1083190,67	
1941,00					kW	-3008,08	
331,00					kW	-227273,68	Tar reformer
Total					kW	-6801193,06	
Steam Reforming							
1943,00					kW	-495671,10	
7703,00					kW	-642118,71	
1947,00					kW	-319271,62	
448,00					kW	-561436,25	Air cooler
449,00					kW	-565275,48	CWS
Total					kW	-2583773,17	
FT Process							
785					kW	-338966,00	
519					kW	-96660,70	
1850					kW	-304940,45	
1961					kW	-4720,20	
524					kW	-21737,37	
Total					kW	-767024,73	
Hydrocracking & Hydrotreating							
604					kW	-83,51	
617					kW	-5260,33	
618					kW	-7546,29	
619					kW	-8500,82	
Total					kW	-21390,95	
ENERGY STREAM OUTPUT							
Gasification							
1938,00					kW	-249746,37	

	1831,00	kW	-5179445,02	
	1845,00	kW	-1080787,49	
	1942,00	kW	-3223,78	
	330,00	kW	-241505,22	Tar reformer
	Total	kW	-6754707,88	
Steam Reforming				
	1948,00	kW	-304852,53	
	1944,00	kW	-473251,16	
	703,00	kW	-547280,92	
	447,00	kW	-535587,38	Air cooler
	448,00	kW	-561436,25	CWR
	Total	kW	-2422408,24	
FT Process				
	1958	kW	-288241,26	
	1851	kW	-304061,24	
	518	kW	-102736,06	
	523	kW	-20953,41	
	1962	kW	-5414,78	
	Total	kW	-721406,75	
Hydrocracking & Hydrotreating				
	603	kW	-81,40	
	617	kW	-5260,33	
	618	kW	-7546,29	
	619	kW	-8501,70	
	Total	kW	-21389,72	

Calculations		
Mass Balance		
In	908756	kg/h
Out	904540	kg/h
Closure	0,00464	
Energy Balance		
Flow input	-1540582	kW
Flow output	-1793753	kW
Energy stream in	-10173382	kW
Energy stream ou	-9919913	kW
Consumption	16710	kW
Closure	0,001403	
Fuel Conversion		
In	83333	kg/h
Out	13261	kg/h
Conversion rate	0,159	
Carbon Balance		
Product	718809,24	mol carbon/h
Byproducts	218027	mol carbon/h
Biomass	3513888,75	mol carbon/h
Input fuels	0	mol carbon/h
Carbon efficiency	0,267	mol usefull carbon atoms/mol input carbon atoms

A.5 Balances for FT diesel via Gasification High Temperature from NREL study[2]

Biomass to Fischer Tropsch, High Temperature				
Necessary data for calculations				
Carbon % in biomass				
0,4728				
Carbon % in diesel				
0,848388521				
Carbon % in Gasoline				
0,8408892				
INPUT				
	Flow Number	**Name**	**Unit**	**Flow Amount**
Preprocessing (A100)				
	PL00BMAS	Biomass	ton/d	2667,00
	Total		ton/d	2667,00
Gasification (A200)				
	PL09AIR	Air	ton/d	238,00
	PL90OX	Oxygen	ton/d	735,00
	PL42CO2	Carbon Dioxide	ton/d	180,00
	PL47SGAS	Syngas	ton/d	29,00
	PL98STM	Steam	ton/d	960,00
	PL08BMAS	Biomass	ton/d	2222,00
	Total		ton/d	4364,00
Syngas Cleaning (A300)				
	PL21SGAS	Syngas	ton/d	3825,00
	PL90STM	Steam	ton/d	550,00
	PL48SGAS	Syngas	ton/d	2130,00
	PL80WAT	Water	ton/d	50,00
	Total		ton/d	6555,00
Fuel Synthesis (A400)				
	PL34SGAS	Syngas	ton/d	3377,00
	Total		ton/d	3377,00
Hydroprocessing (A500)				
	PL50FT	Raw FT	ton/d	427,00
	PL90HYD	Hydrogen	ton/d	4,30
	Total		ton/d	431,30
Power Generation (A600)				
	PL49SGAS	Syngas	ton/d	144,00
	PL65FGAS	Fuel Gas	ton/d	53,00
	PL99AIR	Air	ton/d	2242,00
	Total		ton/d	2439,00
Air Separation Unit (A700)				
	PL89AIR	Air	ton/d	2924,00
	Total		ton/d	2924,00
OUTPUT				
Preprocessing (A100)				
	PL92WAT	Water	ton/d	444,00
	PL08BMAS	Biomass	ton/d	2222,00

	Total		ton/d	2666,00
Gasification (A200)				
	PL21SGAS	Syngas	ton/d	3825,00
	PL52FLUE	Flue Gas	ton/d	267,00
	PL17SLAG	Slag	ton/d	114,00
	Total		ton/d	4206,00
Syngas Cleaning (A300)				
	PL34SGAS	Syngas	ton/d	3377,00
	PL81WAT	Water	ton/d	1501,00
	PL83SUL	Sulfur	ton/d	7,20
	PL42CO2	Carbon Dioxide	ton/d	180,00
	PL43CO2	Carbon Dioxide	ton/d	1585,00
	Total		ton/d	6650,20
Fuel Synthesis (A400)				
	PL90HYD	Hydrogen	ton/d	4,30
	PL47SGAS	Syngas	ton/d	29,00
	PL48SGAS	Syngas	ton/d	2130,00
	PL49SGAS	Syngas	ton/d	144,00
	PL50FT	Fischer Tropsch	ton/d	427,00
	FS60WAT	Water	ton/d	641,00
	Total		ton/d	3375,30
Hydroprocessing (A500)				
	PL81DIES	Diesel	ton/d	266,00
	PL71GASO	Gasoline	ton/d	113,00
	PL65FGAS	Fuel Gas	ton/d	53,00
	Total		ton/d	432,00
Power Generation (A600)				
	PL88FLUE	Flue Gas	ton/d	2439,00
	Total		ton/d	2439,00
Air Separation Unit (A700)				
	PL90OX	Oxygen	ton/d	735,00
	PL92NTGN	Nitrogen	ton/d	2189,00
	Total			2924,00

Calculations

Mass Balance		
In	22757,30	ton/d
Out	22692,50	ton/d
Closure	0,00285	
Energy Balance - Not possible to calculate		
Fuel Conversion		
In	2000,00	ton/d
Out	379,00	ton/d
Conversion rate	0,190	
Carbon Balance		
Product	18825,60706	kmol carbon/d
Byproducts	7896,376685	kmol carbon/d

Biomass	78734,38801	kmol carbon/d
Input fuels	0	kmol carbon/d
Carbon efficiency	0,339394062	mol usefull carbon atoms/mol input carbon atoms

A.6 Balances for FT diesel via Gasification Low Temperature from NREL study[2]

Biomass to Fischer Tropsch, Low Temperature				
Carbon % in biomass				
0,4728				
Carbon % in diesel				
0,848388521				
Carbon % in Gasoline				
0,8408892				
INPUT				
	Flow Number	**Name**	**Unit**	**Amount**
Preprocessing (A100)				
	PL00BMAS	Biomass	Ton/hr	2667,00
	PL81STM	Gasification	Ton/hr	4000,00
	Total		Ton/hr	6667,00
Gasification (A200)				
	PL07BMAS		Ton/day	2016,00
	PL09Air		Ton/day	1375,00
	PL98STM		Ton/day	352
	PL90OX		Ton/day	562
	PL43CO2		Ton/day	180
	Total		Ton/day	4485
Syngas Cleaning (A300)				
	PL21SGAS		Ton/day	2930,00
	PL55SGAS		Ton/day	2080,00
	PL80WAT		Ton/day	500,00
	Total		Ton/day	5510,00
Fuel Synthesis (A400)				
	PL34SGAS		Ton/day	2716,00
	PL90STM		Ton/day	1000,00
	Total		Ton/day	3716,00
Hydroprocessing (A500)				
	PL56FT		Ton/day	331,00
	PL90HYD		Ton/day	3,40
	Total		Ton/day	334,40
Power Generation (A600)				
	PL56SGAS		Ton/day	169,00
	PL65FGAS		Ton/day	41,00
	PL99Air		Ton/day	1749,00
	Total		Ton/day	1959,00
Air Separation Unit (A700)				
	PL89Air		Ton/day	2313,00
	Total		Ton/day	2313,00
OUTPUT				
Preprocessing (A100)				
	PL84STM		Ton/day	4000,00
	PL92WAT		Ton/day	2222,00

	PL08BMAS	Ton/day	444,00
	Total	Ton/day	6666,00
Gasification (A200)			
	PL52FLUE	Ton/day	1471,00
	PL46CO2	Ton/day	171,00
	PL60ASH	Ton/day	119,00
	PL21SGAS	Ton/day	2930,00
	Total	Ton/day	4691,00
Syngas Cleaning (A300)			
	PL43CO2	Ton/day	180,00
	PL81WAT	Ton/day	1380,00
	PL83SUL	Ton/day	0,70
	PL34Sgas	Ton/day	2716,00
	PL41CO2	Ton/day	1387,00
	Total	Ton/day	5663,70
Fuel Synthesis (A400)			
	PL56FT	Ton/day	331,00
	PL90HYD	Ton/day	3,40
	PL55SGAS	Ton/day	2080,00
	PL56SGAS	Ton/day	169,00
	FS60WAT	Ton/day	1132,00
	Total	Ton/day	3715,40
Hydroprocessing (A500)			
	PL71GASO	Ton/day	87,00
	PL81DIES	Ton/day	206,00
	PL65FGAS	Ton/day	41,00
	Total	Ton/day	334,00
Power Generation (A600)			
	PL86FLUE	Ton/day	1958,00
	Total	Ton/day	1958,00
Air Separation Unit (A700)			
	PL90OX	Ton/day	561,00
	PL92NTGN	Ton/day	1744,00
	Total	Ton/day	2305,00

Calculations		
Mass Balance		
In	24984,40	ton/d
Out	25333,10	ton/d
Closure	0,01	
Energy Balance - Not possible		
Fuel Conversion		
In	2000,00	ton/d
Out	293,00	ton/d
Conversion rate	0,147	
Carbon Balance		
Product	14541,99	kmol carbon/d

Byproducts	6099,77	kmol carbon/d
Biomass	78734,39	kmol carbon/d
Input fuels	0	kmol carbon/d
Carbon efficiency	0,26	mol usefull carbon atoms/mol input carbon atoms

A.7 Balances for FT diesel via Indirect Gasification from PNNL study[1]

Biomass to Fischer Tropsch through Direct Gasification								
Necessary data for calculations								
lb/h to kg/h		Water	18,02	8,17		**Carbon % in biomass**		
0,45		Methanol		14,53		0,51		
		Hydrogen		0,91		**Mol carbon in 1kg biomass**		
MMBtu/h to kW		Carbon Monoxide		12,70		42,17		
293,07		Carbon Dioxide		19,96		**Mol carbon in 1kg Pentane**		
		Methane		7,28		69,17		
lbmol to mol		Oxygen		14,51		**Mol carbon in 1kg Hexane**		
453,59		Calcium Oxide		25,44		70,00		
		Nitrogen		12,70		**Mol carbon in 1kg Octane**		
g to kg		Argon		18,13		70,00		
0,00		Ethane		13,64		**Mol carbon in 1kg Nonane**		
		Propane		20,00		70,00		
		Butane		26,36		**Mol carbon in 1kg Decane**		
		Pentane	72,15	32,73		70,83		
		Hexane	86,18	39,09		**Mol carbon in 1kg Dodecane**		
		Octane	114,23	51,81		70,83		
		Nonane	128,20	58,15		**Mol carbon in 1kg Tridecane**		
		Decane	142,29	64,54		70,83		
		Dodecane	170,33	77,26		**Mol carbon in 1kg Tetradecane**		
		Tridecane	184,37	83,63		70,83		
		Tetradecane	198,39	89,99		**Mol carbon in 1kg Hexadecane**		
		Hexadecane	226,41	102,70		70,83		
		Heptadecane	240,48	109,08		**Mol carbon in 1kg Heptadecane**		
		Ethylene	28,05	12,72		70,83		
		Benzene	78,11	35,43		**Mol carbon in 1kg Octadecane**		
		Octadecane	254,50	115,44		70,83		
		Eicosane	282,55	128,16				
		Docosane	310,60	140,89				
		Tetracosane	338,65	153,61				
		Hexacosane	366,71	166,34				
		Octacosane	394,77	179,06				
		Dotriacontane	450,88	204,51				
		Hexatriacontane	507,00	229,97				
		Naphthalene	128,17	58,14				
		Ammonia	17,03	7,73				
		Acetylene	26,04	11,81				
		Water	18,00	8,16				
INPUT								
	Flow Number	**Name**	**Unit**	**Amount**	**Flow Amount**	**Energy Unit**	**Energy content**	**Details**
Gasification								
	220	Dry Wood Chips	kg/h	83333,33		kW	-188570,72	
		Water	kg/h	11363,39		kW		
	300	Water	kg/h	33166,67		kW	-121425,21	
	110	Air	kg/h	45504,35		kW	-11833,33059	
		Hydrogen	kg/h	148512,37		kW		
		Argon	kg/h	2532,86		kW		
		Water	kg/h	3913,14		kW		
	343	Water	kg/h	44836,21		kW	-197266,1372	
		Carbon Dioxide	kg/h	189,01		kW		
	Total		kg/h	373351,32		kW	-519095,39	
Steam Reforming								
	435	Nitrogen	kg/h	354,50		kW	-82766,20	
		Hydrogen	kg/h	2863,53		kW		
		Carbon Monoxide	kg/h	43691,07		kW		
		Carbon Dioxide	kg/h	16175,21		kW		
		Methane	kg/h	5773,46		kW		
		Acetylene	kg/h	155,53		kW		
		Ethylene	kg/h	1786,29		kW		
		Ethane	kg/h	25,70		kW		
		Water	kg/h	207,53		kW		
		Ammonia	kg/h	44,82		kW		
		Benzene	kg/h	86,99		kW		
		Naphthalene	kg/h	43,49		kW		
	731	Water	kg/h	59601,51		kW	-211500,60	
	490	Nitrogen	kg/h	81595,76		kW	784,26	
		Oxygen	kg/h	24788,51		kW		
	1012	Hydrogen	kg/h	939,57		kW	-10965,55	
		Carbon Monoxide	kg/h	6500,66		kW		
		Carbon Dioxide	kg/h	281,47		kW		
		Propane	kg/h	130,02		kW		

	Methane	kg/h	1891,66		kW	
	Ethane	kg/h	88,66		kW	
	Pentane	kg/H	153,81		kW	
	N-Butane	kg/h	308,44		kW	
Total		kg/h	247488,21		kW	-304448,09
FT Process						
461	Nitrogen	kg/h	384,31		kW	-44948,31
	Hydrogen	kg/h	5674,09		kW	
	Carbon Monoxide	kg/h	37871,57		kW	
	Carbon Dioxide	kg/h	402,40		kW	
	Methane	kg/h	2760,05		kW	
	Ethylene	kg/h	0,07		kW	
	Ethane	kg/h	0,18		kW	
	Ammonia	kg/h	8,53		kW	
Total		kg/h	47101,20		kW	-44948,31
Hydrocracking & Hydrotreating						
600	Nitrogen	kg/h	0,54	12017,28	kW	-5905,09
	Hydrogen	kg/h	1,08		kW	
	Carbon Monoxide	kg/h	15,93		kW	
	Carbon Dioxide	kg/h	6,22		kW	
	Methane	kg/h	12,74		kW	
	Ethylene	kg/h	0,00		kW	
	Ethane	kg/h	2,76		kW	
	Propane	kg/h	11,83		kW	
	Water	kg/h	2,06		kW	
	Ammonia	kg/h	0,29		kW	
	Butane	kg/h	43,17		kW	
	Pentane	kg/h	125,87		kW	
	Hexane	kg/h	276,56		kW	
	Octane	kg/h	632,75		kW	
	Nonane	kg/h	727,37		kW	
	Decane	kg/h	809,86		kW	
	Dodecane	kg/h	352,68		kW	
	Tridecane	kg/h	381,76		kW	
	Tetradecane	kg/h	410,78		kW	
	Hexadecane	kg/h	586,00		kW	
	Heptadecane	kg/h	622,42		kW	
	Octadecane	kg/h	658,70		kW	
	Eicosane	kg/h	731,30		kW	
	Docosane	kg/h	643,13		kW	
	Tetracosane	kg/h	701,21		kW	
	Hexacosane	kg/h	759,31		kW	
	Octacosane	kg/h	1021,76		kW	
	Dotriacontane	kg/h	1166,98		kW	
	Hexatriacontane	kg/h	1312,23		kW	
479	Hydrogen	kg/h	85,28	85,28	kW	27,00
540	Nitrogen	kg/h	383,75	18189,23	kW	-18913,34
	Hydrogen	kg/h	1599,75		kW	
	Carbon monoxide	kg/h	11345,49		kW	
	Carbon Dioxide	kg/h	487,30		kW	
	Methane	kg/h	3287,03		kW	
	Ethylene	kg/h	0,07		kW	
	Ethane	kg/h	153,08		kW	
	Propane	kg/h	216,45		kW	
	Water	kg/h	12,55		kW	
	Ammonia	kg/h	8,25		kW	
	Butane	kg/h	257,68		kW	
	Pentane	kg/h	247,62		kW	
	Hexane	kg/h	169,55		kW	
	Octane	kg/h	17,69		kW	
	Nonane	kg/h	2,63		kW	
	Decane	kg/h	0,36		kW	
Total		kg/h	30291,79		kW	-24791,43
OUTPUT						
Gasification						
370	Oxygen	kg/h	4508,41736	215972,7552	kW	-101484,6501
	Nitrogen	kg/h	148502,846		kW	
	Argon	kg/h	2532,85773		kW	
	Hydrogen	kg/h	0,00031751		kW	
	Carbon Dioxide	kg/h	46961,3777		kW	
	Water	kg/h	13446,6804		kW	

	Nitric Oxide	kg/h	20,5761125		kW	
354	Carbon	kg/h	0,00054431	2590,215434	kW	-8514,300726
	Water	kg/h	340,194		kW	
	Calcium Oxide	kg/h	2250,02089		kW	
1702	Nitrogen	kg/h	0,00263083	72390,92293	kW	-316340,913
	Hydrogen	kg/h	0,03084426		kW	
	Carbon Monoxide	kg/h	0,48103432		kW	
	Carbon Dioxide	kg/h	331,03566		kW	
	Methane	kg/h	0,10065206		kW	
	Acetylene	kg/h	0,00272155		kW	
	Ethylene	kg/h	0,09734084		kW	
	Ethane	kg/h	0,00049895		kW	
	Water	kg/h	71915,6508		kW	
	Hydrogen Sulfide	kg/h	0,38632431		kW	
	Ammonia	kg/h	143,128007		kW	
	Hydrogen Chloride	kg/h	0,00181437		kW	
	Benzene	kg/h	0,00226796		kW	
	Naphthalene	kg/h	0,00068039		kW	
	Methanol	kg/h	0,00163293		kW	
1749	Nitrogen	kg/h	4,5359E-05	4277,372651	kW	-18483,40624
	Hydrogen	kg/h	0,00399161		kW	
	Carbon Monoxide	kg/h	0,02571867		kW	
	Carbon Dioxide	kg/h	2,6547379		kW	
	Methane	kg/h	0,0202302		kW	
	Acetylene	kg/h	0,00635029		kW	
	Ethylene	kg/h	0,0172365		kW	
	Ethane	kg/h	0,0002268		kW	
	Water	kg/h	4274,48953		kW	
	Hydrogen Sulfide	kg/h	0,01460566		kW	
	Ammonia	kg/h	0,11435054		kW	
	Hydrogen Chloride	kg/h	0,00240404		kW	
	Benzene	kg/h	0,0123377		kW	
	Naphthalene	kg/h	0,00866361		kW	
	Methanol	kg/h	0,0022226		kW	
428	Hydrogen	kg/h	0,00077111	3259,392454	kW	-14288,38695
	Carbon Monoxide	kg/h	0,00517095		kW	
	Carbon Dioxide	kg/h	8,48552698		kW	
	Methane	kg/h	0,00734819		kW	
	Acetylene	kg/h	0,00426376		kW	
	Ethylene	kg/h	0,00562454		kW	
	Ethane	kg/h	4,5359E-05		kW	
	Water	kg/h	3250,52555		kW	
	Hydrogen Sulfide	kg/h	0,01954982		kW	
	Ammonia	kg/h	0,32005452		kW	
	Hydrogen Chloride	kg/h	0,00290299		kW	
	Benzene	kg/h	0,00335658		kW	
	Naphthalene	kg/h	0,0009979		kW	
	Methanol	kg/h	0,01129444		kW	
434	Hydrogen Sulfide	kg/h	16,9312286	16,93122858	kW	-1,118652274
435	Nitrogen	kg/h	354,680141	71403,69832	kW	-83173,56967
	Hydrogen	kg/h	2886,16099		kW	
	Carbon Monoxide	kg/h	43706,7008		kW	
	Carbon Dioxide	kg/h	16319,4645		kW	
	Methane	kg/h	5774,5346		kW	
	Acetylene	kg/h	155,511296		kW	
	Ethylene	kg/h	1786,51972		kW	
	Ethane	kg/h	25,7047865		kW	
	Water	kg/h	221,426514		kW	
	Ammonia	kg/h	34,100094		kW	
	Hydrogen Chloride	kg/h	8,42338488		kW	
	Benzene	kg/h	86,9764474		kW	
	Naphthalene	kg/h	43,4868629		kW	
	Methanol	kg/h	0,0081193		kW	
Total		kg/h	369911,288		kW	-542286,3453
Steam Reforming						
499	Nitrogen	kg/h	81819,29	117052,22	kW	-92672,00
	Oxygen	kg/h	3096,02		kW	
	Carbon Dioxide	kg/h	18142,00		kW	
	Water	kg/h	13994,91		kW	
1751	Water	kg/h	44836,01	44836,01	kW	-197266,14
453	Carbon Dioxide	kg/h	39837,33	40151,13	kW	-100329,95

		Water	kg/h	313,79		kW	
	461	Nitrogen	kg/h	384,31	47101,19	kW	-44948,31
		Hydrogen	kg/h	5674,09		kW	
		Carbon Monoxide	kg/h	37871,57		kW	
		Carbon Dioxide	kg/h	402,40		kW	
		Methane	kg/h	2760,05		kW	
		Ethylene	kg/h	0,07		kW	
		Ethane	kg/h	0,18		kW	
		Ammonia	kg/h	8,53		kW	
	Total		kg/h	249140,55		kW	-435216,40
FT Process							
	531	Water	kg/h	16967,78	16967,78	kW	-74366,78
	470	Hydrogen	kg/h	1883,66	1883,66	kW	11,64
	540	Nitrogen	kg/h	383,75	18189,23	kW	-18913,34
		Hydrogen	kg/h	1599,75		kW	
		Carbon monoxide	kg/h	11345,49		kW	
		Carbon Dioxide	kg/h	487,30		kW	
		Methane	kg/h	3287,03		kW	
		Ethylene	kg/h	0,07		kW	
		Ethane	kg/h	153,08		kW	
		Propane	kg/h	216,45		kW	
		Water	kg/h	12,55		kW	
		Ammonia	kg/h	8,25		kW	
		Butane	kg/h	257,68		kW	
		Pentane	kg/h	247,62		kW	
		Hexane	kg/h	169,55		kW	
		Octane	kg/h	17,69		kW	
		Nonane	kg/h	2,63		kW	
		Decane	kg/h	0,36		kW	
	600	Nitrogen	kg/h	0,54	12017,28	kW	-5905,09
		Hydrogen	kg/h	1,08		kW	
		Carbon Monoxide	kg/h	15,93		kW	
		Carbon Dioxide	kg/h	6,22		kW	
		Methane	kg/h	12,74		kW	
		Ethylene	kg/h	0,00		kW	
		Ethane	kg/h	2,76		kW	
		Propane	kg/h	11,83		kW	
		Water	kg/h	2,06		kW	
		Ammonia	kg/h	0,29		kW	
		Butane	kg/h	43,17		kW	
		Pentane	kg/h	125,87		kW	
		Hexane	kg/h	276,56		kW	
		Octane	kg/h	632,75		kW	
		Nonane	kg/h	727,37		kW	
		Decane	kg/h	809,86		kW	
		Dodecane	kg/h	352,68		kW	
		Tridecane	kg/h	381,76		kW	
		Tetradecane	kg/h	410,78		kW	
		Hexadecane	kg/h	586,00		kW	
		Heptadecane	kg/h	622,42		kW	
		Octadecane	kg/h	658,70		kW	
		Eicosane	kg/h	731,30		kW	
		Docosane	kg/h	643,13		kW	
		Tetracosane	kg/h	701,21		kW	
		Hexacosane	kg/h	759,31		kW	
		Octacosane	kg/h	1021,76		kW	
		Dotriacontane	kg/h	1166,98		kW	
		Hexatriacontane	kg/h	1312,23		kW	
	Total		kg/h	49057,96		kW	-99173,58
Hydrocracking & Hydrotreating							
	661	Pentane	kg/h	108,00	2625,81	kW	-1477,52
		Hexane	kg/h	370,30		kW	
		Octane	kg/h	1098,45		kW	
		Nonane	kg/h	848,99		kW	
		Decane	kg/h	200,08		kW	
	671	Decane	kg/h	1632,90	8891,34	kW	-4203,52
		Dodecane	kg/h	703,07		kW	
		Tridecane	kg/h	1145,71		kW	
		Tetradecane	kg/h	1439,80		kW	
		Hexadecane	kg/h	1057,78		kW	
		Heptadecane	kg/h	938,08		kW	

	Flow Number	Name	Unit	Amount	Flow amount	Energy Unit	Energy content	Details
		Octadecane	kg/h	1974,00		kW		
	540	Nitrogen	kg/h	383,56	18146,88	kW	-18913,34	
		Hydrogen	kg/h	1599,73		kW		
		Carbon Monoxide	kg/h	11345,42		kW		
		Carbon Dioxide	kg/h	487,09		kW		
		Methane	kg/h	3287,12		kW		
		Ethane	kg/h	152,76		kW		
		Propane	kg/h	216,04		kW		
		Butane	kg/h	258,35		kW		
		Pentane	kg/h	248,72		kW		
		Hexane	kg/h	168,09		kW		
	631	Hydrogen	kg/h	34,84	34,84	kW	-4,40	
	656	Butane	kg/h	218,81	218,81	kW	-136,91	
	Total		kg/h	29917,68		kW	-24735,68	
ENERGY STREAM INPUT								
	Flow Number	**Name**	**Unit**	**Amount**	**Flow amount**	**Energy Unit**	**Energy content**	**Details**
Gasification								
	1931					kW	-14598,75	
	1935					kW	-250080,47	
	1830					kW	-8682816,59	
	1844					kW	0,00	
	1941					kW	-1406,77	Tar reformer
	Total					kW	-8948902,59	
Steam Reforming								
	1948					kW	-415721,31	
	1943					kW	-191621,59	
	7703					kW	-441892,56	
	448					kW	-334306,17	Air cooler
	449					kW	-336855,89	CWS
	Total					kW	-1720397,52	
FT Process								
	785					kW	-282201,06	
	1850					kW	-259707,86	
	519					kW	-98337,07	
	524					kW	-19647,19	
	1961					kW	-3880,55	
	Total					kW	-663773,74	
Hydrocracking & Hydrotreating								
	604					kW	-72,38	
	618					kW	-6573,29	
	619					kW	-7361,07	
	630					kW	-7550,98	
	Total					kW	-21557,71	
ENERGY STREAM OUTPUT								
Gasification								
	1932					kW	-12440,87	
	1938					kW	-213118,35	
	1831					kW	-8657319,41	
	1845					kW	0,00	
	1942					kW	-1465,36	Tar reformer
	Total					kW	-8884343,98	
Steam Reforming								
	1949					kW	-396935,46	
	1944					kW	-182964,27	
	703					kW	-376537,71	
	447					kW	-316135,76	Air cooler
	448					kW	-334306,17	CWR
	Total					kW	-1606879,37	
FT Process								
	1958					kW	-239960,73	
	1851					kW	-258937,08	
	518					kW	-87217,95	
	523					kW	-18913,05	
	1962					kW	-4448,82	
	Total					kW	-609477,63	
Hydrocracking & Hydrotreating								
	603					kW	-70,44	
	617					kW	-4554,03	
	618					kW	-6573,29	
	619					kW	-7376,60	
	Total					kW	-18574,36	

Calculations		
Mass Balance		
In	698232,51	kg/h
Out	698027,47	kg/h
Closure	0,00029	
Energy Balance		
Flow input	-893283,22	kW
Flow output	-1101412,00	kW
Energy stream in	-11354631,55	kW
Energy stream ou	-11119275,34	kW
Power consumptic	24600,00	kW
Closure	0,00021	
Fuel Conversion		
In	83333	kg/h
Out	11517	kg/h
Conversion rate	0,138	
Carbon Balance		
Product	629803,19	mol carbon/h
Byproducts	183884	mol carbon/h
Biomass	3513888,86	mol carbon/h
Input fuels	0	mol carbon/h
Carbon efficiency	0,232	mol usefull carbon atoms/mol input carbon atoms

A.8 Balances for DME via Direct Gasification from PNNL study[1]

Biomass to Methanol through Direct Gasification

PHYSICAL PROPERTIES AND DATA CONVERSION

	Molar mass	g/mol	Conversion	
lb/h to kg/h				**Carbon % in biomass**
0,45	Nitrogen	28,01	12,71	0,506
	Hydrogen	2,02	0,91	**Mol carbon atoms in 1kg biomass**
MMBtu/h to kW	Carbon Monoxide	28,01	12,71	42,16666667
293,07	Carbon Dioxide	44,01	19,96	**Carbon % in DME**
	Methane	16,04	7,28	0,520946386
lbmol to mol	Ethylene	28,05	12,72	**Carbon % in DME**
453,59	Ethane	30,07	13,64	43,41219883
	Ammonia	17,03	7,72	
g to kg	Hydrogen Chloride	36,46	16,54	
0,00	Methanol	32,04	14,53	
	Water	18,02	8,17	
	Ethanol	46,07	20,90	
	Dimethyl Ether	46,07	20,90	
	Calcium Oxide	56,08	25,44	
	Hydrogen Sulfide	34,10	15,47	
	Benzene	78,11	35,43	
	Naphthalene	128,17	58,14	
	Nitric Oxide	30,01	13,61	
	Oxygen	32,00	14,51	
	Argon	39,95	18,12	
	Sulfur Dioxide	64,07	29,06	
	Hybrid Poplar	145,00	65,77	

INPUT

	Flow Number	Name	Unit	Amount	Flow Amount	Energy Unit	Energy content	Details
Gasification								
	200,00	Dry Wood Chips	kg/h	83333,00	166667,29	kW	-511379,71	
		Water	kg/h	83334,29		kW		
	100,00	Oxygen	kg/h	20933,94	92267,64	kW	-7628,35	
		Nitrogen	kg/h	68322,65		kW		
		Argon	kg/h	1165,26		kW		
		Carbon Dioxide	kg/h	45,49		kW		
		Water	kg/h	1800,29		kW		
	1931,00	Water	kg/h	18939,38	18939,38	kW	-69337,68	
	201,00	Nitrogen	kg/h	50,32	3186,67	kW	-4418,63	
		Argon	kg/h	9,25		kW		
		Hydrogen	kg/h	229,87		kW		
		Carbon Monoxide	kg/h	1485,61		kW		
		Carbon Dioxide	kg/h	706,53		kW		
		Methane	kg/h	471,09		kW		
		Ethylene	kg/h	0,00		kW		
		Ethane	kg/h	0,01		kW		
		Water	kg/h	3,17		kW		
		Methanol	kg/h	224,21		kW		
		Ethanol	kg/h	4,52		kW		
		Dimethyl Ether	kg/h	2,11		kW		
	202,00	Oxygen	kg/h	8804,63	37802,15	kW	-102,09	
		Nitrogen	kg/h	28997,51		kW		
	234,00	Carbon Dioxide	kg/h	2732,01	2732,01	kW	-6682,31	
	310,00	Oxygen	kg/h	12191,77	52344,62	kW	-141,37	
		Nitrogen	kg/h	40152,85		kW		
	343,00	Argon	kg/h	0,00	77702,98	kW	-340226,21	
		Hydrogen	kg/h	0,02		kW		
		Carbon Monoxide	kg/h	0,06		kW		
		Carbon Dioxide	kg/h	440,71		kW		
		Methane	kg/h	0,02		kW		
		Water	kg/h	77262,14		kW		
		Methanol	kg/h	0,02		kW		
	Total		kg/h	451642,74		kW	-939916,35	
Steam Reforming								
	732,00	Water	kg/h	61779,01	61779,01	kW	-219038,39	
	1943,00	Water	kg/h	28123,02	28123,02	kW	-102958,80	
	490,00	Oxygen	kg/h	35714,04	153335,92	kW	-414,11	
		Nitrogen	kg/h	117621,88		kW		
	1605,00	Nitrogen	kg/h	329,57	23207,26	kW	-32906,02	
		Hydrogen	kg/h	1738,49		kW		
		Carbon Monoxide	kg/h	11162,30		kW		
		Carbon Dioxide	kg/h	4823,85		kW		
		MEthane	kg/h	1351,57		kW		
		Water	kg/h	47,02		kW		
		Methanol	kg/h	3437,20		kW		

	Ethanol	kg/h	30,39		kW	
	Dimethyl Ether	kg/h	286,86		kW	
435,00	Nitrogen	kg/h	380,27	112755,40	kW	-186914,87
	Argon	kg/h	69,89		kW	
	Hydrogen	kg/h	3798,05		kW	
	Carbon Monoxide	kg/h	37425,58		kW	
	Carbon Dioxide	kg/h	61558,89		kW	
	Methane	kg/h	7737,98		kW	
	Ethylane	kg/h	234,83		kW	
	Ethane	kg/h	87,98		kW	
	Water	kg/h	273,32		kW	
	Benzene	kg/h	1111,80		kW	
	Naphthalene	kg/h	76,80		kW	
	Methanol	kg/h	0,00		kW	
Total		kg/h	379200,60		kW	-542232,18
Syngas to Raw Methanol						
471,00	Nitrogen	kg/h	380,27		kW	-63783,99
	Argon	kg/h	69,88		kW	
	Hydrogen	kg/h	6916,88		kW	
	Carbon Monoxide	kg/h	45099,35		kW	
	Carbon Dioxide	kg/h	7023,36		kW	
	Methane	kg/h	1559,38		kW	
Total		kg/h	61049,12		kW	-63783,99
DME Synthesis						
528,00	Hydrogen	kg/h	3,12	78746,70	kW	-83598,52
	Carbon Monoxide	kg/h	58,76		kW	
	Carbon Dioxide	kg/h	838,50		kW	
	Methane	kg/h	26,29		kW	
	Water	kg/h	667,06		kW	
	Methanol	kg/h	37662,72		kW	
	Ethanol	kg/h	34,77		kW	
	Dimethyl Ether	kg/h	82,13		kW	
Total		kg/h	39373,35		kW	-83598,52
			OUTPUT			
Gasification						
111,00	Oxygen	kg/h	18,00	71244,21	kW	-8305,34
	Nitrogen	kg/h	68285,08		kW	
	Argon	kg/h	1095,34		kW	
	Carbon Dioxide	kg/h	45,49		kW	
	Water	kg/h	1800,29		kW	
309,00	Water	kg/h	4163,99	6413,99	kW	-32897,23
	Calcium Oxide	kg/h	2250,00		kW	
210,00	Oxygen	kg/h	5427,85	168730,15	kW	-324400,37
	Nitrogen	kg/h	69014,35		kW	
	Argon	kg/h	9,25		kW	
	Hydrogen	kg/h	4,79		kW	
	Carbon Monoxide	kg/h	446,82		kW	
	Carbon Dioxide	kg/h	14384,12		kW	
	Water	kg/h	79004,55		kW	
	Sulfur Dioxide	kg/h	2,79		kW	
	Nitric Oxide	kg/h	435,63		kW	
1702,00	Nitrogen	kg/h	0,06	91593,43	kW	-400159,24
	Argon	kg/h	0,03		kW	
	Hydrogen	kg/h	1,09		kW	
	Carbon Monoxide	kg/h	11,38		kW	
	Carbon Dioxide	kg/h	432,19		kW	
	Methane	kg/h	2,99		kW	
	Ethylene	kg/h	1,23		kW	
	Ethane	kg/h	0,39		kW	
	Water	kg/h	90920,52		kW	
	Hydrogen Sulfide	kg/h	0,26		kW	
	Ammonia	kg/h	161,19		kW	
	Hydrogen Chloride	kg/h	8,40		kW	
	Benzene	kg/h	40,97		kW	
	Naphthalene	kg/h	12,70		kW	
	Methanol	kg/h	0,02		kW	
428,00	Carbon Dioxide	kg/h	1,66	222,31	kW	-973,61
	Methane	kg/h	0,00		kW	
	Water	kg/h	220,64		kW	
	Hydrogen Sulfide	kg/h	0,00		kW	
	Ammonia	kg/h	0,01		kW	
	Benzene	kg/h	0,00		kW	
434,00	Hydrogen Sulfide	kg/h	15,64	30,10	kW	-8,54

		Ammonia	kg/h	14,45		kW		
	435,00	Nitrogen	kg/h	380,27	112756,03	kW	-186914,87	
		Argon	kg/h	69,89		kW		
		Hydrogen	kg/h	3798,06		kW		
		Carbon Monoxide	kg/h	37425,60		kW		
		Carbon Dioxide	kg/h	61559,47		kW		
		Methane	kg/h	7737,99		kW		
		Ethylene	kg/h	234,83		kW		
		Ethane	kg/h	87,98		kW		
		Water	kg/h	273,32		kW		
		Benzene	kg/h	1111,82		kW		
		Naphthalene	kg/h	76,80		kW		
		Methanol	kg/h	0,00		kW		
	Total		kg/h	450990,21		kW	-953659,19	
Steam Reforming								
	499,00	Oxygen	kg/h	4653,05		kW	-154653,60	
		Nitrogen	kg/h	117942,76		kW		
		Argon	kg/h	60,57		kW		
		Carbon Dioxide	kg/h	31099,15		kW		
		Water	kg/h	22674,72		kW		
		Nitric Oxide	kg/h	18,63		kW		
	1748,00	Carbon Dioxide	kg/h	439,12		kW	-339141,84	
		Water	kg/h	77017,09		kW		
	453,00	Carbon Dioxide	kg/h	63210,23		kW	-158879,69	
		Water	kg/h	434,52		kW		
	471,00	Nitrogen	kg/h	380,27		kW	-63781,06	
		Argon	kg/h	69,88		kW		
		Hydrogen	kg/h	6916,88		kW		
		Carbon Monoxide	kg/h	45099,35		kW		
		Carbon Dioxide	kg/h	7023,36		kW		
		Methane	kg/h	1559,38		kW		
	Total		kg/h	378598,96		kW	-716456,19	
Syngas to Raw Methanol								
	540,00	Nitrogen	kg/h	378,52		kW	-25835,09	
		Argon	kg/h	68,69		kW		
		Hydrogen	kg/h	1729,59		kW		
		Carbon Monoxide	kg/h	11127,33		kW		
		Carbon Dioxide	kg/h	4379,25		kW		
		Methane	kg/h	1521,06		kW		
		Methanol	kg/h	512,96		kW		
		Dimethyl Ether	kg/h	64,93		kW		
	527,00	Hydrogen	kg/h	4,36		kW	-119,30	
		Carbon Monoxide	kg/h	39,76		kW		
		Carbon Dioxide	kg/h	24,81		kW		
		Methane	kg/h	7,24		kW		
		Methanol	kg/h	2,81		kW		
	528,00	Hydrogen	kg/h	3,20		kW	-88659,86	
		Carbon Monoxide	kg/h	60,61		kW		
		Carbon Dioxide	kg/h	935,58		kW		
		Methane	kg/h	31,19		kW		
		Water	kg/h	763,38		kW		
		Methanol	kg/h	39762,22		kW		
		Ethanol	kg/h	37,90		kW		
		Dimethyl Ether	kg/h	720,72		kW		
	Total		kg/h	62176,09		kW	-114614,25	
DME Synthesis Process								
	601,00	Hydrogen	kg/h	3,12		kW	-2920,13	
		Carbon Monoxide	kg/h	58,76		kW		
		Carbon Dioxide	kg/h	838,50		kW		
		Methane	kg/h	26,29		kW		
		Methanol	kg/h	376,63		kW		
		Dimethyl Ether	kg/h	1126,97		kW		
	820,00	Water	kg/h	51,73		kW	-6374,88	
		Methanol	kg/h	3003,60		kW		
		Ethanol	kg/h	34,74		kW		
	809,00	Methanol	kg/h	36,27		kW	-29904,97	
		Dimethyl Ether	kg/h	24621,18		kW		
	816,00	Water	kg/h	10242,87		kW	-43887,39	
	Total		kg/h	40420,65		kW	-83087,38	

ENERGY STREAM INPUT

	Flow Number	Name	Unit	Amount	Flow amount	Energy Unit	Energy content	Details
Gasification								
	1935,00					kW	-293035,90	

	1830,00	kW	-5194684,72	
	1844,00	kW	-1083190,67	
	1941,00	kW	-3008,08	
	331,00	kW	-227273,68	Tar reformer
	Total	kW	-6801193,06	
Steam Reforming				
	1947,00	kW	-355876,20	
	1944,00	kW	-443152,76	
	1949,00	kW	-655072,46	
	448,00	kW	-562491,30	Air cooler
	449,00	kW	-566389,15	CWS
	Total	kW	-2582981,88	
DME Synthesis Process				
	804,00	kW	-69651,27	
	808,00	kW	-83205,81	
	Total	kW	-152857,08	
ENERGY STREAM OUTPUT				
Gasification				
	1938,00	kW	-249746,37	
	1831,00	kW	-5179445,02	
	1845,00	kW	-1080787,49	
	1942,00	kW	-3223,78	
	330,00	kW	-241505,22	Tar reformer
	Total	kW	-6754707,88	
Steam Reforming				
	1948,00	kW	-339757,29	
	1945,00	kW	-423106,70	
	703,00	kW	-558329,70	
	447,00	kW	-535909,76	Air cooler
	448,00	kW	-562491,30	CWR
	Total	kW	-2419594,75	
DME Synthesis Process				
	807,00	kW	-80541,79	
	803,00	kW	-74604,17	
	Total	kW	-155145,96	
Calculations				
Mass Balance				
In	870216,69	kg/h		
Out	870009,82	kg/h		
Closure	0,00024			
Energy Balance				
Flow input	-1565747,06	kW		
Flow output	-1753202,76	kW		
Energy stream inpu	-9537032,01	kW		
Energy stream outp	-9329448,60	kW		
Consumption	19930,00	kW		
Closure	0,00002			
DME Conversion				
In	83333,00	kg/h		
Out	24621,18	kg/h		
Conversion rate	0,295	kg DME/kg Biomass		
Carbon Balance				
Product	1068859,434	mol carbon/h		
Byproducts	0	mol carbon/h		
Biomass	3513874,833	mol carbon/h		
Input fuels	0	mol carbon/h		
Carbon efficiency	0,304	mol usefull carbon atoms/mol input carbon atoms		

A.9 Balances for DME via Gasification from VTT study[3]

Biomass to DME through Gasification (VTT)

Data necessary for calculations

Carbon % in biomass
51,3
Mol Carbon in 1kg biomass
42,75
Carbon % in DME
52,1739
Mol Carbon in 1kg DME
43,47825

FLOW INPUT

	Case				
	1	**2**	**3**	**4**	**5**
Biomass to dryer (kg/s)	34,9	34,9	34,9	34,9	34,9
Biomass to gasifier (kg/s)	20,5	20,5	20,5	20,5	20,5
Biomass to dryer (MW)	300	300	300	300	300
Biomass to gasifier (MW)	335	335	335	335	335

FLOW OUTPUT

	Case				
	1	**2**	**3**	**4**	**5**
Product output (kg/s)	6,9	6,9	7,6	6,4	6,4
Product energy output (MW)	26	26	26	26,1	26,1

ENERGY STREAMS

	Case				
	1	**2**	**3**	**4**	**5**
On-site consumption (MW)	**-29**	**-29**	**-28**	**-20,2**	**-27**
Oxygen production	-9,3	-9,3	-8,1	-8	-8
Oxygen compression	-1,9	-1,9	-1,7	-3,1	-3,1
Drying and feeding	-2	-2	-2	-2	-2
Gasifier RC compression	0	0	0	0,1	0,1
Syngas scrubbing	-0,2	-0,2	-0,1	-0,2	-0,2
Syngas compression	-12,1	-12,1	-12,8	-4	-4
Acid gas removal	-0,8	-0,8	-0,8	-0,8	-0,8
Synthesis	-0,4	-0,4	-0,5	-0,4	-0,4
Product upgrading	0	0	0	0	0
CO2 compression	0	0	0	0	0
Power island	-0,7	-0,7	-0,6	-0,7	-0,7
Miscellaneous	-1,5	-1,5	-1,4	-1,1	-1,1
Gross production	**36,4**	**26,9**	**22,2**	**27,9**	**27,9**

Calculations

Cases	**1**	**2**	**3**	**4**	**5**
Mass Balance - Cannot be done					
Energy Balance - Cannot be done					
DME Conversion					
In	20,5	20,5	20,5	20,5	20,5
Out	6,9	6,9	7,6	6,4	6,4
Conversion rate	0,337	0,337	0,371	0,312	0,312
DME Conversion					
Product (mol/h)	300,000	300,000	330,435	278,261	278,261
Byproducts (mol/h)	0	0	0	0	0
Biomass (mol/h)	876,375	876,375	876,375	876,375	876,375
Input fuels (mol/h)	0	0	0	0	0
Carbon efficiency	0,342	0,342	0,377	0,318	0,318

A.10 Balances for DME via Indirect Gasification from PNNL study[1]

Biomass to Fischer Tropsch through Direct Gasification								
lb/h to kg/h			**Name**	**g/mol**	**Conversion**		**Carbon % in biomass**	
0,45			Water	18,01528	8,17		0,51	
			Methanol	32,04	14,53		**Mol carbon in 1kg biomass**	
MMBtu/h to kW			Hydrogen	2,01568	0,91		42,17	
293,07			Carbon Monoxide	28,01	12,70		**Mol carbon in 1kg Pentane**	
			Carbon Dioxide	44,01	19,96		69,17	
lbmol to mol			Methane	16,04	7,28		**Mol carbon in 1kg Hexane**	
453,59			Oxygen	31,998	14,51		70,00	
			Calcium Oxide	56,0774	25,44		**Mol carbon in 1kg Octane**	
g to kg			Nitrogen	28,0134	12,70		70,00	
0,00			Argon	39,948	18,13		**Mol carbon in 1kg Nonane**	
			Ethane	30,07	13,64		70,00	
			Propane		20,00		**Mol carbon in 1kg Decane**	
			N-Butane		26,36		70,83	
			Pentane	72,15	32,73		**Mol carbon in 1kg Dodecane**	
			Hexane	86,18	39,09		70,83	
			Octane	114,23	51,81		**Mol carbon in 1kg Tridecane**	
			Nonane	128,20	58,15		70,83	
			Decane	142,29	64,54		**Mol carbon in 1kg Tetradecane**	
			Dodecane	170,33	77,26		70,83	
			Tridecane	184,37	83,63		**Mol carbon in 1kg Hexadecane**	
			Tetradecane	198,39	89,99		70,83	
			Hexadecane	226,41	102,70		**Mol carbon in 1kg Heptadecane**	
			Heptadecane	240,48	109,08		70,83	
			Octadecane	254,50	115,44		**Mol carbon in 1kg Octadecane**	
			Eicosane	282,55	128,16		70,83	
			Docosane	310,60	140,89			
			Tetracosane	338,65	153,61			
			Hexacosane	366,71	166,34			
			Octacosane	394,77	179,06			
			Dotriacontane	450,88	204,51			
			Hexatriacontane	507,00	229,97			
			Naphthalene	128,17	58,14			
			Ammonia	17,03	7,73			
			Sulfur Dioxide	64,07	29,06			
			Nitric Oxide	46,01	20,87			
			Benzene	78,11	35,43			
			Napthalene	128,17	58,14			
			Ethylene	28,05	12,72			
			Ethane	30,07	13,64			
			Acetylene	26,04	11,81			
INPUT								
	Flow Number	**Name**	**Unit**	**Amount**	**Flow Amount**	**Energy Unit**	**Energy content**	**Details**
Gasification								
	200	Dry Wood Chips	kg/h	83333,33	166669,46	kW	-511379,71	
		Water	kg/h	83336,13		kW		
	100	Oxygen	kg/h	20935,25	91025,55	kW	-7628,35	
		Nitrogen	kg/h	68289,97		kW		
		Water	kg/h	1800,33		kW		
		Argon	kg/h	1166,18		kW		
	1931	Water	kg/h	18939,80	18939,80	kW	-69337,68	
	201	Hydrogen	kg/h	228,08	1713,17	kW	-4418,63	
		Carbon Monoxide	kg/h	1485,09		kW		
	202	Oxygen	kg/h	8805,18	37788,83	kW	-102,09	
		Nitrogen	kg/h	28983,64		kW		
	234	Carbon Dioxide	kg/h	2732,02	2732,02	kW	-6682,31	
	310	Oxygen	kg/h	12192,53	52326,17	kW	-141,37	
		Nitrogen	kg/h	40133,64		kW		
	343	Water	kg/h	77263,72	77263,72	kW	-340226,21	
	Total		kg/h	449624,90		kW	-939916,35	
Steam Reforming								
	435	Nitrogen	kg/h	380,09	112183,75	kW	-185818,78	
		Argon	kg/h	69,94		kW		
		Hydrogen	kg/h	3768,50		kW		
		Carbon Monoxide	kg/h	37403,20		kW		
		Carbon Dioxide	kg/h	61122,01		kW		
		Methane	kg/h	7737,95		kW		
		Ethylene	kg/h	234,82		kW		
		Ethane	kg/h	87,97		kW		
		Water	kg/h	243,04		kW		
		Ammonia	kg/h	13,52		kW		
		Benzene	kg/h	1099,17		kW		
		Naphthalene	kg/h	23,53		kW		
	731	Water	kg/h	89889,04	89889,04	kW	-318685,48	
	490	Nitrogen	kg/h	112982,29	147291,59	kW	-399,69	
		Oxygen	kg/h	34309,30		kW		
	1012	Hydrogen	kg/h	1496,75	20321,53	kW	-15778,07	
		Carbon Monoxide	kg/h	15799,62		kW		

	Carbon Dioxide	kg/h	598,88		kW	
	Methane	kg/h	1618,28		kW	
	Ethane	kg/h	137,75		kW	
	Propane	kg/h	201,97		kW	
	N-Butane	kg/h	468,28		kW	
Total		kg/h	369685,91		kW	-520682,02
FT Process						
461	Nitrogen	kg/h	384,82	54975,16	kW	-52011,32
	Argon	kg/h	69,94		kW	
	Hydrogen	kg/h	6859,50		kW	
	Carbon Monoxide	kg/h	45403,84		kW	
	Carbon Dioxide	kg/h	703,42		kW	
	Methane	kg/h	1545,83		kW	
	Ethylene	kg/h	0,02		kW	
	Ethane	kg/h	0,05		kW	
	Ammonia	kg/h	7,75		kW	
Total		kg/h	54975,16		kW	-52011,32
Hydrocracking & Hydrotreating						
600	Nitrogen	kg/h	0,56	14281,97	kW	-7080,60
	Argon	kg/h	0,17		kW	
	Hydrogen	kg/h	1,40		kW	
	Carbon Monoxide	kg/h	19,93		kW	
	Carbon Dioxide	kg/h	10,70		kW	
	Methane	kg/h	8,84		kW	
	Ethane	kg/h	3,45		kW	
	Propane	kg/h	14,84		kW	
	Water	kg/h	2,48		kW	
	Butane	kg/h	54,01		kW	
	Pentane	kg/h	156,20		kW	
	Hexane	kg/h	338,75		kW	
	Octane	kg/h	760,22		kW	
	Nonane	kg/h	872,31		kW	
	Decane	kg/h	970,98		kW	
	Dodecane	kg/h	422,83		kW	
	Tridecane	kg/h	457,68		kW	
	Tetradecane	kg/h	492,48		kW	
	Hexadecane	kg/h	562,04		kW	
	Heptadecane	kg/h	746,22		kW	
	Octadecane	kg/h	789,73		kW	
	Eicosane	kg/h	876,76		kW	
	Docosane	kg/h	771,04		kW	
	Tetracosane	kg/h	840,67		kW	
	Hexacosane	kg/h	910,32		kW	
	Octacosane	kg/h	1224,99		kW	
	Dotriacontane	kg/h	1399,11		kW	
	Hexatriacontane	kg/h	1573,25		kW	
540	Nitrogen	kg/h	381,02	20188,22	kW	-20892,16
	Hydrogen	kg/h	1986,19		kW	
	Carbon Monoxide	kg/h	13601,05		kW	
	Carbon Dioxide	kg/h	802,50		kW	
	Methane	kg/h	2184,14		kW	
	Ethane	kg/h	182,77		kW	
	Propane	kg/h	258,04		kW	
	Butane	kg/h	305,81		kW	
	Pentane	kg/h	291,27		kW	
	Hexane	kg/h	195,45		kW	
Total		kg/h	34470,19		kW	-27972,75
OUTPUT						
Gasification						
111,00	Oxygen	kg/h	18,0042572	71212,45961	kW	-8305,341053
	Nitrogen	kg/h	68252,4167		kW	
	Argon	kg/h	1096,21146		kW	
	Carbon Dioxide	kg/h	45,4927325		kW	
	Water	kg/h	1800,33449		kW	
309,00	Water	kg/h	4164,08286	6414,078019	kW	-32897,22761
	Calcium Oxide	kg/h	2249,99516		kW	
210,00	Oxygen	kg/h	5428,19209	168931,2786	kW	-324400,3674
	Nitrogen	kg/h	68981,3376		kW	
	Argon	kg/h	9,25398156		kW	
	Hydrogen	kg/h	4,74974327		kW	
	Carbon Monoxide	kg/h	446,658937		kW	
	Carbon Dioxide	kg/h	14384,1876		kW	
	Water	kg/h	79006,2893		kW	
	Sulfur Dioxide	kg/h	2,78973091		kW	
	Nitric Oxide	kg/h	667,819657		kW	
1702,00	Nitrogen	kg/h	0,05715234	91586,77372	kW	-400159,239
	Argon	kg/h	0,03082847		kW	

		Hydrogen	kg/h	1,08118189	kW	
		Carbon Monoxide	kg/h	11,378446	kW	
		Carbon Dioxide	kg/h	432,191938	kW	
		Methane	kg/h	2,99318829	kW	
		Ethylene	kg/h	1,23160571	kW	
		Ethane	kg/h	0,39418014	kW	
		Water	kg/h	90922,52	kW	
		Ammonia	kg/h	161,200252	kW	
		Benzene	kg/h	40,9746966	kW	
		Naphthalene	kg/h	12,7029033	kW	
		Methanol	kg/h	0,01743971	kW	
	428,00	Carbon Dioxide	kg/h	1,66088698	222,3162019 kW	-973,6114016
		Methane	kg/h	0,00072756	kW	
		Water	kg/h	220,644092	kW	
		Ammonia	kg/h	0,00695258	kW	
		Benzene	kg/h	0,00354299	kW	
	434,00	Ammonia	kg/h	14,4528733	14,45287329 kW	-8,535987985
	435,00	Nitrogen	kg/h	380,092272	112713,4859 kW	-186914,867
		Argon	kg/h	69,9425465	kW	
		Hydrogen	kg/h	3768,5267	kW	
		Carbon Monoxide	kg/h	37412,4042	kW	
		Carbon Dioxide	kg/h	61559,7379	kW	
		Methane	kg/h	7738,02471	kW	
		Ethylene	kg/h	234,832093	kW	
		Ethane	kg/h	87,9799167	kW	
		Water	kg/h	273,329693	kW	
		Benzene	kg/h	1111,81553	kW	
		Naphthalene	kg/h	76,7987882	kW	
		Methanol	kg/h	0,00145331	kW	
	Total		kg/h	451094,845	kW	-953659,1894
Steam Reforming						
	499	Nitrogen	kg/h	113270,97	162639,21 kW	-130513,34
		Oxygen	kg/h	3918,74	kW	
		Carbon Dioxide	kg/h	25836,43	kW	
		Water	kg/h	19613,06	kW	
	1751	Water	kg/h	77029,89	77029,89 kW	-338057,48
	453	Carbon Dioxide	kg/h	69638,92	70050,55 kW	-174767,07
		Water	kg/h	411,63	kW	
	461	Nitrogen	kg/h	384,82	54975,16 kW	-52011,32
		Argon	kg/h	69,94	kW	
		Hydrogen	kg/h	6859,50	kW	
		Carbon Monoxide	kg/h	45403,84	kW	
		Carbon Dioxide	kg/h	703,42	kW	
		Methane	kg/h	1545,83	kW	
		Ethylene	kg/h	0,02	kW	
		Ethane	kg/h	0,05	kW	
		Ammonia	kg/h	7,75	kW	
	Total		kg/h	364694,81	kW	-695349,21
FT Process						
	531	Water	kg/h	20342,96	20342,96 kW	-89158,08
	470	Hydrogen	kg/h	90,72	90,72 kW	13,70
	540	Nitrogen	kg/h	384,26	20301,28 kW	-20892,16
		Argon	kg/h	69,77	kW	
		Hydrogen	kg/h	1986,20	kW	
		Carbon Monoxide	kg/h	13601,22	kW	
		Carbon Dioxide	kg/h	801,98	kW	
		Methane	kg/h	2184,04	kW	
		Ethylene	kg/h	0,02	kW	
		Ethane	kg/h	183,21	kW	
		Propane	kg/h	258,85	kW	
		Water	kg/h	14,55	kW	
		Butane	kg/h	306,69	kW	
		Pentane	kg/h	291,57	kW	
		Hexane	kg/h	196,09	kW	
		Octane	kg/h	19,59	kW	
		Nonane	kg/h	2,87	kW	
		Decane	kg/h	0,39	kW	
	600	Nitrogen	kg/h	0,56	14281,97 kW	-7080,60
		Argon	kg/h	0,17	kW	
		Hydrogen	kg/h	1,40	kW	
		Carbon Monoxide	kg/h	19,93	kW	
		Carbon Dioxide	kg/h	10,70	kW	
		Methane	kg/h	8,84	kW	
		Ethane	kg/h	3,45	kW	
		Propane	kg/h	14,84	kW	
		Water	kg/h	2,48	kW	
		Butane	kg/h	54,01	kW	

	Pentane	kg/h	156,20		kW		
	Hexane	kg/h	338,75		kW		
	Octane	kg/h	760,22		kW		
	Nonane	kg/h	872,31		kW		
	Decane	kg/h	970,98		kW		
	Dodecane	kg/h	422,83		kW		
	Tridecane	kg/h	457,68		kW		
	Tetradecane	kg/h	492,48		kW		
	Hexadecane	kg/h	562,04		kW		
	Heptadecane	kg/h	746,22		kW		
	Octadecane	kg/h	789,73		kW		
	Eicosane	kg/h	876,76		kW		
	Docosane	kg/h	771,04		kW		
	Tetracosane	kg/h	840,67		kW		
	Hexacosane	kg/h	910,32		kW		
	Octacosane	kg/h	1224,99		kW		
	Dotriacontane	kg/h	1399,11		kW		
	Hexatriacontane	kg/h	1573,25		kW		
Total		kg/h	55016,93		kW	-117117,14	
Hydrocracking & Hydrotreating							
661	Pentane	kg/h	134,18		kW	-1755,32	
	Hexane	kg/h	445,63		kW		
	Octane	kg/h	1295,34		kW		
	Nonane	kg/h	1006,00		kW		
	Decane	kg/h	232,35		kW		
671	Decane	kg/h	1891,06		kW	-4814,86	
	Dodecane	kg/h	826,68		kW		
	Tridecane	kg/h	1329,69		kW		
	Tetradecane	kg/h	1664,77		kW		
	Hexadecane	kg/h	1232,37		kW		
	Heptadecane	kg/h	1090,79		kW		
	Octadecane	kg/h	2112,53		kW		
540	Nitrogen	kg/h	381,02		kW	-20892,16	
	Hydrogen	kg/h	1986,19		kW		
	Carbon Monoxide	kg/h	13601,05		kW		
	Carbon Dioxide	kg/h	802,50		kW		
	Methane	kg/h	2184,14		kW		
	Ethane	kg/h	182,77		kW		
	Propane	kg/h	258,04		kW		
	Butane	kg/h	305,81		kW		
	Pentane	kg/h	291,27		kW		
	Hexane	kg/h	195,45		kW		
631	Hydrogen	kg/h	33,11		kW	-4,92	
656	Butane	kg/h	250,45		kW	-160,44	
Total		kg/h	33733,17		kW	-27627,70	
ENERGY STREAM INPUT							
Flow Number	**Name**	**Unit**	**Amount**	**Flow amount**	**Energy Unit**	**Energy content**	**Details**
Gasification							
1935,00					kW	-293035,90	
1830,00					kW	-5194684,72	
1844,00					kW	-1083190,67	
1941,00					kW	-3008,08	
331,00					kW	-227273,68	Tar reformer
Total					kW	-6801193,06	
Steam Reforming							
1943,00					kW	-495671,10	
7703,00					kW	-642118,71	
1947,00					kW	-319271,62	
448,00					kW	-561436,25	Air cooler
449,00					kW	-565275,48	CWS
Total					kW	-2583773,17	
FT Process							
785					kW	-338966,00	
519					kW	-96660,70	
1850					kW	-304940,45	
1961					kW	-4720,20	
524					kW	-21737,37	
Total					kW	-767024,73	
Hydrocracking & Hydrotreating							
604					kW	-83,51	
617					kW	-5260,33	
618					kW	-7546,29	
619					kW	-8500,82	
Total					kW	-21390,95	
ENERGY STREAM OUTPUT							
Gasification							
1938,00					kW	-249746,37	

	1831,00	kW	-5179445,02	
	1845,00	kW	-1080787,49	
	1942,00	kW	-3223,78	
	330,00	kW	-241505,22	Tar reformer
	Total	kW	-6754707,88	
Steam Reforming				
	1948,00	kW	-304852,53	
	1944,00	kW	-473251,16	
	703,00	kW	-547280,92	
	447,00	kW	-535587,38	Air cooler
	448,00	kW	-561436,25	CWR
	Total	kW	-2422408,24	
FT Process				
	1958	kW	-288241,26	
	1851	kW	-304061,24	
	518	kW	-102736,06	
	523	kW	-20953,41	
	1962	kW	-5414,78	
	Total	kW	-721406,75	
Hydrocracking & Hydrotreating				
	603	kW	-81,40	
	617	kW	-5260,33	
	618	kW	-7546,29	
	619	kW	-8501,70	
	Total	kW	-21389,72	

Calculations

Mass Balance		
In	908756	kg/h
Out	904540	kg/h
Closure	0,00464	
Energy Balance		
Flow input	-1540582	kW
Flow output	-1793753	kW
Energy stream in	-10173382	kW
Energy stream ou	-9919913	kW
Consumption	16710	kW
Closure	0,001403	
Fuel Conversion		
In	83333	kg/h
Out	13261	kg/h
Conversion rate	0,159	
Carbon Balance		
Product	718809,24	mol carbon/h
Byproducts	218027	mol carbon/h
Biomass	3513888,75	mol carbon/h
Input fuels	0	mol carbon/h
Carbon efficiency	0,267	mol usefull carbon atoms/mol input carbon atoms

A.11 Balances for Ethanol via Indirect Gasification from NREL study[7]

Biomass to Ethanol through Indirect Gasification

PHYSICAL PROPETRIES AND DATA CONVERSION

MMBtu/hr to kW	1	MMBtu/hr	293,0711	kW	**Carbon % in biomass**
lb/hr to kg/h	1	lb/hr	0,453592	kg/h	0,5094
					Mol carbon atoms in 1kg biomass
Molarmass	**g/mol**				42,41465445
Carbon	12,01				**Carbon % in ethanol**
Ethanol	46,069				0,521391825
					Mol carbon in 1kg ethanol
					11,31762846

FLOW INPUT

	Flow number	Name	Unit	Amount	Flow Amount	Energy Unit	Energy content	Details
Feed handling and drying								
	101	Biomass	kg/h		119047,488	kW	285128,844	
	107	Flue Gas	kg/h		398581,723	kW	349047,644	
	Total		kg/h		517629,211	kW	634176,488	OK!
Gasification pt.1								
	105	Dried Biomass	kg/h		92592,189	kW	162068,302	
	208		kg/h		216656,404	kW	15620,688	
	200	LP Steam	kg/h		30182,919	kW	108055,304	
	513L-G1	Water/Methanol	kg/h		7197,144	kW	17467,036	
	221	Olivine	kg/h		244,032	kW	0	
	220	MgO	kg/h		3,175	kW	0	In-Out
	Total		kg/h		346875,863	kW	303211,33	2137,118
Gasification pt.2								
	287	Char Combustor Flue Gas	kg/h		234397,295	kW	156968,865	
	334	Catalyst Regen Flue Gas	kg/h		164184,428	kW	192078,779	
	218	Brine	kg/h		110,223	kW	498,221	In-Out
	Total		kg/h		398691,946	kW	349545,865	-146,535
Tar Reforming, Quench and Clean Up pt.1								
	329B		kg/h		115066,765	kW	8293,911	OK!
	225F	Gasifier Exhaust	kg/h		4118,615	kW	7385,391	
	514-MV	Condensed Methanol	kg/h		1495,946	kW	3370,317	
	430-1	CO2 Rich Gas	kg/h		27054,948	kW	59815,805	
	385F	Unreacted Syngas	kg/h		16447,7	kW	27226,302	In-Out
	Total		kg/h		164183,974	kW	106091,726	9788,573
Tar Reforming, Quench and Clean Up pt.2								
	513	Off-Gases	kg/h		15237,516	kW	35051,3	
	393	Steam	kg/h		124,284	kW	439,607	
	385T		kg/h		49343,552	kW	81708,214	In-Out
	Total		kg/h		64705,352	kW	117199,121	21745,873
Tar Reforming								
	225A	Gasifier Effluent	kg/h		107368,402	kW	192694,228	
	386A	Steam & Recycle	kg/h		64705,352	kW	95453,248	
	330A-2	Pre-Heated Air	kg/h		115066,765	kW	1142,977	
	328	Combustor Fuel	kg/h		49117,663	kW	95160,176	
	326	Make-up Catalyst	kg/h		5,443	kW	0	In-Out
	Total		kg/h		336263,625	kW	384450,629	2285,954
Syngas Scrubber								
	300	From Syngas Cooling	kg/h		172074,208	kW	318861,32	
	415SCRUB		kg/h		686,738	kW	2989,325	In-Out
	Total		kg/h		172760,946	kW	321850,645	322,374
Syngas Compression								
	313	Syngas	kg/h		159351,406	kW	263119,207	In-Out
	Total		kg/h		159351,406	kW	263119,207	-3519,852
Mixed Alcohol Synthesis								
	H2S-RECY	Methanol & H2S Recycle	kg/h		3514,884	kW	7356,084	
	466	Compressed Syngas	kg/h		143031,165	kW	195302,561	
	483	Syngas Recycle	kg/h		317862,759	kW	507745,629	
	515	Methanol Recycle	kg/h		20396,218	kW	41704,013	
	472-GB	Effluent From Cooling	kg/h		488887,354	kW	838095,339	
	482-1		kg/h		363779,423	kW	582097,76	
	428		kg/h		23956,915	kW	50759,909	In-Out
	Total		kg/h		1361428,718	kW	2223061,295	-10609,17
Depg Acid Gas Removal								
	474		kg/h		415185,458	kW	6945,784	In-Out
	Total		kg/h		415185,458	kW	6945,784	-58,614
Amine Acid Gas Enrichment								
	CO2-H2S		kg/h		27448,666	kW	674,063	
	H2O-MKUP	Water	kg/h		387,368	kW	29,307	In-Out
	Total		kg/h		27836,034	kW	703,37	58,614
Methanol/H2S Absorption								
	H2S-RCH2		kg/h		781,085	kW	29,307	
	COLDMEOH		kg/h		3234,111	kW	58,614	In-Out
	Total		kg/h		4015,196	kW	87,921	0
Mixed Alcohol Synthesis								
	430		kg/h		27054,948	kW	644,756	
	470		kg/h		488887,354	kW	7531,926	
	471		kg/h		488887,354	kW	7619,848	In-Out
	Total		kg/h		1004829,656	kW	15796,53	29,307
Alcohol Purification pt.1								
	503		kg/h		73701,896	kW	1523,97	
	FLUSH		kg/h		4448,83	kW	87,921	In-Out
	Total		kg/h		78150,726	kW	1611,891	175,843
Alcohol Purification pt.2								
	507	Crude Alcohol	kg/h		55716,52	kW	879,213	In-Out
	Total		kg/h		55716,52	kW	879,213	-146,534
Storage								
	592C	Ethanol Product	kg/h		23133,192	kW	0	
	590C	Mixed Alcohol Product	kg/h		2924,761	kW	0	
	Total		kg/h		26057,953	kW	0	

FLOW OUTPUT

	Flow number	Name	Unit	Amount	Flow Amount	Energy Unit	Energy content	Details
Feed handling and drying								
	105	Dried Biomass	kg/h		92592,189	kW	162068,302	
	110	Flue Gas	kg/h		425036,569	kW	472108,187	
	Total		kg/h		517628,758	kW	634176,489	OK!

Gasification pt.1								
	225A	Syngas	kg/h		107368,402	kW	192694,223	
	225F	Syngas	kg/h		4118,615	kW	7358,391	
	212	Flue Gas	kg/h		235388,393	kW	101021,598	
	Total		kg/h		346875,41	kW	301074,212	
Gasification pt.2								
	107	Flue Gas	kg/h		398581,723	kW	349047,644	
	219		kg/h		1101,321	kW	644,756	
	Total		kg/h		399683,044	kW	349692,4	
Tar Reforming, Quench and Clean Up pt.1								
	330A-2	Pre-Heated Air	kg/h		115066,765	kW	1142,977	
	328	Combustor Fuel	kg/h		49117,663	kW	95160,176	
	Total		kg/h		164184,428	kW	96303,153	
Tar Reforming, Quench and Clean Up pt.2								
	386A	Steam & Recycle	kg/h		64705,352	kW	95453,248	
	Total		kg/h		64705,352	kW	95453,248	
Tar Reforming								
	329		kg/h		5,443	kW	0	
	330	To Syngas Cooling	kg/h		172074,208	kW	229503,955	
	332	Flue Gas	kg/h		164184,428	kW	152660,72	
	Total		kg/h		336264,079	kW	382164,675	
Syngas Scrubber								
	313	To Syngas Compression	kg/h		159351,406	kW	263119,207	
	302B	Water To Treatment	kg/h		13409,087	kW	58409,064	
	Total		kg/h		172760,493	kW	321528,271	
Syngas Compression								
	415L	Condensate	kg/h		16320,24	kW	71333,498	
	466	Compressed Syngas	kg/h		143031,165	kW	195302,561	
	Total		kg/h		159351,405	kW	266636,059	
Mixed Alcohol Synthesis								
	471	Effluent To Cooling	kg/h		488887,354	kW	762307,16	
	478		kg/h		321945,087	kW	515131,02	
	385F		kg/h		16447,7	kW	27226,302	
	385T		kg/h		49343,552	kW	81708,214	
	474		kg/h		415185,458	kW	693464,766	
	503	Molecular Sieve Feed	kg/h		73701,896	kW	153833,005	
	Total		kg/h		1365511,047	kW	2233670,467	
Depg Acid Gas Removal								
	CO2-H2S		kg/h		27448,666	kW	674,063	
	482-1	Syngas	kg/h		363779,423	kW	5832,114	
	428		kg/h		23956,915	kW	498,221	
	Total		kg/h		415185,004	kW	7004,398	
Amine Acid Gas Enrichment								
	H2S-RCH2	Acid Gas	kg/h		781,085	kW	29,307	
	430		kg/h		27054,948	kW	644,756	
	Total		kg/h		27836,033	kW	674,063	
Methanol/H2S Absorption								
	H2S-RECY		kg/h		3514,884	kW	87,921	
	CO2-H2S1		kg/h		500,312	kW	0	
	Total		kg/h		4015,196	kW	87,921	
Mixed Alcohol Synthesis								
	485		kg/h		488887,354	kW	6857,863	
	430-1		kg/h		27054,948	kW	586,142	
	472-GB		kg/h		488887,354	kW	8323,218	
	Total		kg/h		1004829,656	kW	15767,223	
Alcohol Purification pt.1								
	507	Crude Alcohol	kg/h		55716,52	kW	879,213	
	513L	Water/Methanol	kg/h		7197,144	kW	205,15	
	513	To Tar Reformer	kg/h		15237,516	kW	351,685	
	Total		kg/h		78151,18	kW	1436,048	
Alcohol Purification pt.2								
	514-MV		kg/h		1495,946	kW	29,307	
	FLUSH		kg/h		4448,83	kW	87,921	
	590C	Higher Alcohols	kg/h		2924,761	kW	58,614	
	592C	Ethanol Fuel	kg/h		23133,192	kW	380,992	
	COLDMEOH		kg/h		3317,572	kW	58,614	
	515		kg/h		20396,218	kW	410,299	
	Total		kg/h		55716,519	kW	1025,747	
Storage								
	592C	Ethanol Product	kg/h		23133,192	kW		
	590C	Mixed Alcohol Product	kg/h		2924,761	kW		
	Total		kg/h		26057,953	kW		

ENERGY INPUT

	Flow number	Name	Unit	Amount	Flow Amount	Energy Unit	Energy content	Details
Feed handling and drying								
	102		kg/h		119047,488	kW	285128,844	
	107		kg/h		398581,723	kW	349047,644	
	Total		kg/h		517629,211	kW	634176,488	OK!
Gasification pt.1								
	209A		kg/h		216656,404	kW	9173,124	In-Out
	Total		kg/h		216656,404	kW	9173,124	4278,837
Gasification pt.2								
	219		kg/h		1101,321	kW	644,756	In-Out
	Total		kg/h		1101,321	kW	644,756	527,528
Tar Reforming, Quench and Clean Up pt.1								
	QH305					kW	463,052	OK!
	QH306					kW	773,708	
	QH307					kW	1732,05	
	QH308					kW	1562,068	
	QH309					kW	3736,656	
	QH311					kW	2661,085	In-Out
	Total					kW	10928,619	10928,619
Tar Reforming, Quench and Clean Up pt.2								
	513		kg/h		15237,516	kW	35051,3	OK!
	386		kg/h		64705,352	kW	115909,608	In-Out
	Total		kg/h		79942,868	kW	150960,908	21745,873
Syngas Scrubber								

	QCM301		kg/h			kW	2907,265	In-Out
	Total		kg/h			kW	2907,265	2907,265
Syngas Compression								
	QAH410A		kg/h			kW	7672,601	
	QAH410B		kg/h			kW	1866,863	
	QAH410C		kg/h			kW	2948,295	
	QAH410D		kg/h			kW	1913,754	
	QAH410E		kg/h			kW	1758,426	
	QCH411A		kg/h			kW	2326,984	
	QCH411B		kg/h			kW	1239,691	
	QCH411C		kg/h			kW	1260,206	
	QCH411D		kg/h			kW	937,827	
	QCH411E		kg/h			kW	937,827	
	Total		kg/h			kW	22862,474	
Mixed Alcohol Synthesis								
	QCH414		kg/h			kW	6051,918	
	QH418		kg/h			kW	2845,72	
	QH419		kg/h			kW	1116,601	
	QH420		kg/h			kW	7347,292	
	QH421		kg/h			kW	1236,136	
	QH422		kg/h			kW	3214,99	
	QH423		kg/h			kW	4777,058	
	Total		kg/h			kW	26589,715	
Depg Acid Gas Removal and Amine Acid Gas Enrichment								
	QCM401		kg/h			kW	23296,214	
	Total		kg/h			kW	23296,214	
Methanol/H2S Absorption								
	H2S-RCH2		kg/h		781,085	kW	29,307	
	COLDMEOH		kg/h		3234,111	kW	58,614	
	Total		kg/h		4015,196	kW	87,921	
Mixed Alcohol Synthesis								
	QH401		kg/h			kW	37425,176	
	QH402		kg/h			kW	21555,377	
	QH415		kg/h			kW	5732,47	
	QH417		kg/h			kW	1567,93	
	QH427		kg/h			kW	5984,511	In-Out
	Total		kg/h			kW	72265,464	72265,464
Alcohol Purification pt.1								
	Total		kg/h			kW	0	
Alcohol Purification pt.2								
	QRH504		kg/h			kW	9495,503	
	QH502		kg/h			kW	222,734	
	QCH591		kg/h			kW	14,654	
	QRH505		kg/h			kW	22730,592	
	QH501		kg/h			kW	1409,672	
	QCH593		kg/h			kW	117,228	
	Total		kg/h			kW	33990,383	

ENERGY OUTPUT

	Flow number	Name	Unit	Amount	Flow Amount	Energy Unit	Energy content	Details
Feed handling and drying								
	103		kg/h		92592,189	kW	162068,302	
	110		kg/h		425036,569	kW	472108,187	
	Total		kg/h		517628,758	kW	634176,489	OK!
Gasification pt.1								
	209B		kg/h		216656,404	kW	4894,287	
	Total		kg/h		216656,404	kW	4894,287	
Gasification pt.2								
	216		kg/h		991,099	kW	117,228	
	Total		kg/h		991,099	kW	117,228	
Tar Reforming, Quench and Clean Up pt.1								
	Total					kW	0	
Tar Reforming, Quench and Clean Up pt.2								
	373		kg/h		15237,516	kW	33761,787	
	386A		kg/h		64705,352	kW	95453,248	
	Total		kg/h		79942,868	kW	129215,035	
Syngas Scrubber								
	Total		kg/h			kW	0	
Syngas Compression								
	Total		kg/h			kW	0	
Mixed Alcohol Synthesis								
	Total		kg/h			kW	0	
Depg Acid Gas Removal and Amine Acid Gas Enrichment								
	Total		kg/h			kW	0	
Methanol/H2S Absorption								
	H2S-RECY		kg/h		3514,884	kW	87,921	
	CO2-H2S1		kg/h		500,312	kW	0	
	Total		kg/h		4015,196	kW	87,921	
Mixed Alcohol Synthesis								
	Total		kg/h			kW	0	
Alcohol Purification pt.1								
	QAS513		kg/h			kW	0	
	Total		kg/h			kW	0	
Alcohol Purification pt.2								
	Total		kg/h			kW	0	

CALCULATIONS

Flow Balance		
Flow stream input	5135460,665	kg/h
Flow stream output	5138755,557	kg/h
Closure	0,000642	
Energy Balance		
Flow input	4728731,015	kW
Flow output	4706694,374	kW
Energy stream input	987883,331	kW
Energy stream output	768490,96	kW
Consumption	49572	kW
Closure	0,050467	

Biomass Conversion		
In	119047,488	kg/h
Out	23126,388	kg/h
Conversion rate	0,1943	
Carbon Balance		
Product	261735,867	mol carbon/h
Byproducts	0	mol carbon/h
Biomass	5049358,067	mol carbon/h
Input fuels	0	mol carbon/h
Carbon efficiency	0,05184	mol useful carbon atoms/mol input carbon atoms

A.12 Balances for Ethanol to Jetfuel via Fermentation from NREL study[4]

Biomass to Ethanol to Jetfuel through Fermentation								
PHYSICAL PROPERTIES AND DATA CONVERSION								
Gcal/hr to kw	1	**Gcal/hr**		**1163** Kw	**Carbon % in biomass**			
					0,371634011			
					Mol carbon atoms in 1kg biomass			
					0,309695009			
					Carbon % in ethanol			
					0,521403143			
					Mol carbon in 1kg ethanol			
					0,434502619			
INPUT								
	Flow Number	**Name**	**Unit**	**Amount**	**Flow Amount**	**Energy Unit**	**Energy content**	**Details**
Corn Stover Feed Handling								
	101			kg/h	104167	kW	-367042,8	
		Total		kg/h	104167	kW	-367042,8	
Pretreatment								
	105			kg/h	104167	kW	-367042,8	
	516			kg/h	36821	kW	19654,7	
	212			kg/h	140850	kW	83968,6	
	215			kg/h	3490	kW	-465,2	
	216			kg/h	24534	kW	-3140,1	
	710			kg/h	1981	kW	1395,6	
		Total		kg/h	311843	kW	-265629,2	
Ammonia addition								
	250			kg/h	15932	kW	-1977,1	
	222			kg/h	292060	kW	-267490	
	251			kg/h	3850	kW	2209,7	
	274			kg/h	150310	kW	100366,9	
	273			kg/h	1051	kW	-5117,2	
		Total		kg/h	463203	kW	-172007,7	
Seed Production								
	310			kg/h	26	kW	0	
	309			kg/h	211	kW	-465,2	
	303			kg/h	44339	kW	-14770,1	
		Total		kg/h	44576	kW	-15235,3	
Saccharification & Fermentation								
	422			kg/h	13836	kW	4186,8	
	301			kg/h	429554	kW	-171193,6	
	304			kg/h	42607	kW	-14653,8	
	312			kg/h	116	kW	0	
	311			kg/h	948	kW	-1977,1	
	551			kg/h	27197	kW	14653,8	
		Total		kg/h	514258	kW	-168983,9	
Cellulase Seed Fermentation								
	450			kg/h	32583	kW	0	
	406			kg/h	6	kW	0	
	404			kg/h	8	kW	0	
	403			kg/h	79	kW	-116,3	
		Total		kg/h	32676	kW	-116,3	
Cellulase Product Fermentation								
	453			kg/h	31031	kW	0	
	409			kg/h	770	kW	232,6	
	441			kg/h	109	kW	-581,5	
	443			kg/h	157	kW	-348,9	
	440			kg/h	67	kW	-232,6	
	446			kg/h	13	kW	-116,3	
	400			kg/h	11419	kW	7675,8	
	401			kg/h	2845	kW	-9187,7	
		Total		kg/h	46411	kW	-2558,6	
Beer Destillation								
	501			kg/h	450740	kW	-128511,5	
		Total		kg/h	450740	kW	-128511,5	
Rectification Destilation								
	521			kg/h	7405	kW	-38727,9	
	510			kg/h	58629	kW	-159679,9	
	305			kg/h	1969	kW	-232,6	
	317			kg/h	19180	kW	-2442,3	
	524			kg/h	26836	kW	17910,2	
	509			kg/h	610	kW	-465,2	
		Total		kg/h	114629	kW	-183637,7	
Ethanol Dehydration								
	511			kg/h	29213	kW	-195151,4	
		Total		kg/h	29213	kW	-195151,4	
Lignin Separation								
	559			kg/h	12105	kW	-232,6	
	508			kg/h	391501	kW	4419,4	
		Total		kg/h	403606	kW	4186,8	
Anaerobic Digestion								
	640			kg/h	21	kW	0	
	601			kg/h	411178	kW	149212,9	

		Total	kg/h		411199	kW	149212,9	
Aerobic Digestion								
	611		kg/h		360712	kW	218411,4	
	612		kg/h		28626	kW	10350,7	
	632		kg/h		4504	kW	3837,9	
	630		kg/h		223602	kW	0	
		Total	kg/h		617444	kW	232600	
Particulate Removal/FGD								
	802		kg/h		318399	kW	-76409,1	
		Total	kg/h		318399	kW	-76409,1	
Boiler Feed Water Preparations								
	218		kg/h		19782	kW	-3372,7	
		Total	kg/h		19782	kW	-3372,7	

OUTPUT

	Flow Number	Name	Unit	Amount	Flow Amount	Energy Unit	Energy content	Details
Corn Stover Feed Handling								
	105		kg/h		104167	kW	-367042,8	
		Total	kg/h		104167	kW	-367042,8	
Pretreatment								
	218		kg/h		19782	kW	-3372,7	
	222		kg/h		292060	kW	-267490	
		Total	kg/h		311842	kW	-270862,7	
Ammonia addition								
	301		kg/h		429554	kW	-171193,6	
	260		kg/h		33248	kW	17212,4	
		Total	kg/h		462802	kW	-153981,2	
Seed Production								
	304		kg/h		42607	kW	-14653,8	
	305		kg/h		1969	kW	-232,6	
		Tota.	kg/h		44576	kW	-14886,4	
Saccharification & Fermentation								
	501		kg/h		450740	kW	-128511,5	
	303		kg/h		44339	kW	-14770,1	
	317		kg/h		19180	kW	-2442,3	
		Total	kg/h		514259	kW	-145723,9	
Cellulase Seed Fermentation								
	453		kg/h		31031	kW	0	
	409		kg/h		770	kW	232,6	
	435		kg/h		1586	kW	0	
		Total	kg/h		33387	kW	232,6	
Cellulase Product Fermentation								
	403		kg/h		790	kW	-116,3	
	422		kg/h		13836	kW	4186,8	
	423		kg/h		31801	kW	0	
		Total	kg/h		46427	kW	4070,5	
Beer Destillation								
	508		kg/h		391501	kW	4419,4	
	509		kg/h		610	kW	-465,2	
	510		kg/h		58629	kW	-159679,9	
		Total	kg/h		450740	kW	-155725,7	
Rectification Destilation								
	511		kg/h		29213	kW	-195151,4	
	551		kg/h		27197	kW	14653,8	
	516		kg/h		36826	kW	19654,7	
	550		kg/h		21398	kW	-116,3	
		Total	kg/h		114634	kW	-160959,2	
Ethanol Dehydration								
	515		kg/h		21808	kW	-161540,7	Our product
	521		kg/h		7405	kW	-38727,9	
		Total	kg/h		29213	kW	-200268,6	
Lignin Separation								
	560		kg/h		12044	kW	-116,3	
	571		kg/h		36538	kW	-113159,9	
	535		kg/h		355024	kW	117230,4	
		Total	kg/h		403606	kW	3954,2	
Anaerobic Digestion								
	612		kg/h		28626	kW	10350,7	
	615		kg/h		21860	kW	-76176,5	
	611		kg/h		360712	kW	218411,4	
		Total	kg/h		411198	kW	152585,6	
Aerobic Digestion								
	623		kg/h		9758	kW	-6047,6	
	640		kg/h		21	kW	0	
	626		kg/h		376324	kW	253650,3	
	627		kg/h		9929	kW	9536,6	
	622		kg/h		221417	kW	-1279,3	
		Total	kg/h		617449	kW	255860	
Particulate Removal/FGD								
	803		kg/h		318399	kW	-91644,4	
		Total	kg/h		318399	kW	-91644,4	

	Flow Number	Name	Unit	Amount	Flow Amount	Energy Unit	Energy content	Details
Boiler feed water preparation								
	250		kg/h		15932	kW	-1977,1	
	251		kg/h		3850	kW	2209,7	
		Total	kg/h		19782	kW	232,6	
ENERGY STREAM INPUT								
	Flow Number	**Name**	**Unit**	**Amount**	**Flow Amount**	**Energy Unit**	**Energy content**	**Details**
Ammonia addition								
	211					kW	94086,7	
	255					kW	5931,3	
		Total				kW	100018	
Saccharification and Fermentation								
	302					kW	-158749,5	
	H-310					kW	6915,198	
	H-300					kW	5136,971	
		Total				kW	-146697,331	
Beer destillation								
	H-504					kW	537,306	
	H-501					kW	-38404,586	
		Total				kW	-37867,28	
Rectification Distillation								
	H-502					kW	-6575,602	
		Total				kW	-6575,602	
Ethanol dehydration								
	511a					kW	-195500,3	
	517					kW	-38495,3	
	515					kW	-161540,7	
		Total				kW	-395536,3	
Anaerobic digestion								
	903					kW	101413,6	
		Total				kW	101413,6	
Particulate Removal FGD								
	850					kW	2442,3	
	851					kW	348,9	
	806					kW	-30703,2	
		Total				kW	-27912	
Boiler Feed Water Preparations								
	815a					kW	0	
	811					kW	23492,6	
	816a					kW	66174,7	
	896					kW	37913,8	
	821					kW	2791,2	
	823					kW	14421,2	
		Total				kW	144793,5	
ENERGY STREAM OUTPUT								
	Flow Number	**Name**	**Unit**	**Amount**	**Flow Amount**	**Energy Unit**	**Energy content**	**Details**
Ammonia addition								
	212					kW	83968,6	
	252					kW	-2442,3	
		Total				kW	81526,3	
Saccharification and Fermentation								
	301					kW	-171193,6	
	H-310					kW	0	entet in input
	H-300	Total				kW	-171193,6	
Ethanol dehydration								
	511					kW	-195151,4	
	512					kW	-38727,9	
	514					kW	0	
	519					kW	-156423,5	
		Total				kW	-390302,8	
Anaerobic digestion								
	904					kW	93970,4	
		Total				kW	93970,4	
Particulate Removal FGD								
	809					kW	116,3	
		Total				kW	116,3	
Boiler Feed Water Preparations								
	250					kW	-1977,1	
	251					kW	2209,7	
	821					kW	2791,2	
	813a					kW	138862,2	
		Total				kW	141886	
Calculations								
Flow Balance								
Flow stream input	3882146	kg/h						
Flow stream output	3882481	kg/h						
Closure	8,62925E-05							
Energy Balance								
Flow input	-1192656,5	kW						
Flow output	-1144159,4	kW						
Energy stream input	-268363,4	kW						

Energy stream output	-243997,4	kW
Consumption	64411	kW
Closure	0,00605	
Ethanol Conversion		
In	104167	kg/h
Out	21808	kg/h
Conversion rate	0,20935613	
Carbon Balance		
Product	9475,63	mol carbon/h
Byproducts	0	mol carbon/h
Biomass	32260	mol carbon/h
Input fuels	0	mol carbon/h
Carbon efficiency	0,294	mol useful carbon atoms/mol input carbon atoms

A.13 Balances for Hydrocarbons via Pyrolysis from PNNL study[6]

PYROLYSIS - HYDROCARBONS

PHYSICAL PROPERTIES AND DATA CONVERSION

lb/h to kg/h		1 lb	0,45359 kg/h	**Carbon % in biomass**		
				50,6	tabel 5.1	
MMBtu/h to kW		1 MMBtu/h	293,07 kW	**Mol carbon atoms in 1kg biomass**		
				42,16666667		
kg/stone	6,35029			**Carbon % in Hydrocarbons**		
				58		tabell 5.2
kWh/gallon		2,5		**Mol carbon in 1kg hydrocarbons**		
				48,33333333		
Gallon/st		65				

INPUT

	Flow Number	Name	Unit	Amount	Flow Amount	Energy Unit	Energy content	Details
Pyrolysis Unit								
	100	Feedstock	kg/h		166665,2952	kW	-510821,01	
	120		kg/h		158756,5	kW	-432,336864	
		Total	kg/h		325421,7952	kW	-511253,3469	
Pyrolysis Oil Stabilization								
	200		kg/h		68767,69128	kW	-169798,8966	
	250		kg/h		2948,335	kW	-266,6819772	
		Total	kg/h		71716,02628	kW	-170065,5786	
Hydrocracking and Product Separation								
	532		kg/h		498,949	kW	-27,1001829	
	227		kg/h		31522,24159	kW	-8794,44456	
		Total	kg/h		32021,19059	kW	-8821,544743	
Hydrogen Generation by Steam Reforming								
	500	Natural Gas	kg/h		7799,960855	kW	-10228,72914	
	526		kg/h		93,04822791	kW	2,90754747	
	601		kg/h		7177,671663	kW	-11468,12217	
	615		kg/h		23428,59481	kW	-54469,9902	
	706		kg/h		77594,28053	kW	-332136,231	
	610		kg/h		104325,7	kW	-285,4150116	
		Total	kg/h		220419,2561	kW	-408585,58	

OUTPUT

	Flow Number	Name	Unit	Amount	Flow Amount	Energy Unit	Energy content	Details
Pyrolysis Unit								
	150		kg/h		68781,02683	kW	-167413,3068	
	161		kg/h		4354,119272	kW	-10935,32091	
	105		kg/h		254331,5417	kW	-388288,443	
		Total	kg/h		327466,6878	kW	-566637,0707	
Pyrolysis Oil Stabilization								
	270		kg/h		7466,218405	kW	-13216,28472	
	227		kg/h		31522,24159	kW	-8794,44456	
	230		kg/h		32729,25365	kW	-142982,9916	
		Total	kg/h		71717,71364	kW	-164993,7209	
Hydrocracking and Product Separation								
	531		kg/h		0,445017149	kW	-0,1817034	
	302		kg/h		1572,374271	kW	-1226,703099	
	526		kg/h		93,04822791	kW	-5,0085663	
	544	Gasoline	kg/h		12952,37585	kW	-6403,5795	
	547	Diesel	kg/h		17403,00093	kW	-4551,3771	
		Total	kg/h		32021,24429	kW	-12186,84997	
Hydrogen Generation by Steam Reforming								
	520		kg/h		3456,450147	kW	557,213991	
	754		kg/h		37451,61089	kW	-157152,9261	
	514		kg/h		23054,65068	kW	-100587,4854	
	630		kg/h		132801,2637	kW	-131090,211	
	615		kg/h		23428,59481	kW	-54469,9902	
		Total	kg/h		220192,5703	kW	-442743,3987	

ENERGY STREAM INPUT

	Flow Number	Name	Unit	Amount	Flow Amount	Energy Unit	Energy content	Details
Pyrolysis Unit								
	1810					kW	-20054780,1	
		Total				kW	-20054780,1	
Pyrolysis Oil Stabilization								
	736					kW	-6584,69676	
	1820					kW	-680127,549	
		Total				kW	-686712,2458	
Hydrocracking and Product Separation								
	510					kW	1669,883553	
	1850					kW	-37952,565	
	735					kW	-8470,60221	
		Total				kW	-44753,28366	
Hydrogen Generation by Steam Reforming								
	721					kW	-401828,277	
	730					kW	-198080,1516	
		Total				kW	-599908,4286	

ENERGY STREAM OUTPUT

	Flow Number	Name	Unit	Amount	Flow Amount	Energy Unit	Energy content	Details

Pyrolysis Unit			
1811		kW	-20010526,53
	Total	kW	-20010526,53
Pyrolysis Oil Stabilization			
1821		kW	-678632,892
	Total	kW	-678632,892
Hydrocracking and Product Separation			
510		kW	1669,883553
737		kW	-9710,87445
1851		kW	-37867,5747
	Total	kW	-45908,5656
Hydrogen Generation by Steam Reforming			
725		kW	-385855,962
735		kW	-8470,60221
736		kW	-6584,69676
733		kW	-35599,2129
	Total	kW	-436510,4739

Calculations

Flow Balance		
Flow stream input	649578,268	kg/h
Flow stream output	651398,216	kg/h
Closure	0,0028	
Energy Balance		
Flow input	-1098726,050	kW
Flow output	-1186561,040	kW
Energy stream input	-21386154,058	kW
Energy stream output	-21171578,461	kW
Consumption	25,589	kW
Closure	0,0056	
Hydrocarbons Conversion		
In	183718	kg/h
Out	30355,377	kg/h
Conversion rate	0,165	
Carbon Balance		
Product	1467176,544	mol carbon/h
Byproducts		mol carbon/h
Biomass	7027719,949	mol carbon/h
Input fuels		mol carbon/h
Carbon efficiency	0,547	mol useful carbon atoms/mol input carbon atoms

A.14 Balances for Hydrocarbons via Pyrolysis from NREL study[5]

PYROLYSIS - HYDROCARBONS

PHYSICAL PROPERTIES AND DATA CONVERSION

lb/h to kg/h	1	lbmol	0,45359	kg/h	**Carbon % in biomass**		
					0,5094		
MMBtu/h to kW	1	MMBtu/h	293,07	kW	**Mol carbon atoms in 1kg biomass**		
					0,4245		
					Carbon % in hydrocarbons		
					0,87	Gasoline	
					Mol carbon in 1kg hydrocarbons		
					0,725		

INPUT

	Flow Number	Name	Unit	Amount	Flow Amount	Energy Unit	Energy content	Details
Area 100: Feed Handling and Drying								
	101		kg/h		92591,78029	kW	-166756,83	
		Total	kg/h		92591,78029	kW	-166756,83	
Area 200: In-situ Pyrolysis								
	105		kg/h		92591,78029	kW	-162067,71	
	346		kg/h		71529,78223	kW	-83524,95	
	223		kg/h		197488,5501	kW	-14360,43	
	210		kg/h		1882,85209	kW	-6740,61	
		Total	kg/h		363492,9647	kW	-266693,7	
Area 300: Condensation Stage 1								
	300		kg/h		149290,5303	kW	-199873,74	
	332		kg/h		39339,8607	kW	-21394,11	
		Total	kg/h		188630,391	kW	-221267,85	
Area 300: Condensation Stage 2								
	317		kg/h		179764,5209	kW	-287501,67	
	320A		kg/h		8858,15911	kW	-2930,7	
	335A		kg/h		8,16462	kW	0	
		Total	kg/h		188630,8446	kW	-290432,37	
Area 300: Water Gas Shift								
	813		kg/h		13406,30604	kW	-48942,69	
	343		kg/h		21933,79804	kW	-26669,37	
		Total	kg/h		35340,10408	kW	-75612,06	
Area 300: PSA								
	374		kg/h		35340,10408	kW	-84990,3	
		Total	kg/h		35340,10408	kW	-84990,3	
Area 400: Hydrotreating								
	337		kg/h		23610,72027	kW	-11136,66	
	435		kg/h		1662,40735	kW	-293,07	
		Total	kg/h		25273,12762	kW	-11429,73	
Area 400: Product Separation								
	429		kg/h		20421,98257	kW	-7033,68	
	480		kg/h		3659,56412	kW	-1172,28	
		Total	kg/h		24081,54669	kW	-8205,96	
Area 400: Hydrocracking								
	460		kg/h		4006,56047	kW	-293,07	
	485		kg/h		484,43412	kW	0	
		Total			4490,99459	kW	-293,07	
Area 400: Reformer								
	823		kg/h		18808,56294	kW	-67992,24	
	502		kg/h		24,49386	kW	0	
	428		kg/h		394,6233	kW	-293,07	
	478		kg/h		186,87908	kW	-293,07	
	345		kg/h		906,27282	kW	-1172,28	
	389		kg/h		23950,45918	kW	-45425,85	
	452		kg/h		248,11373	kW	-4982,19	
	589		kg/h		40030,67827	kW	-92023,98	
	542		kg/h		70914,2606	kW	-4982,19	
		Total	kg/h		155464,3438	kW	-217164,87	
Area 500: Water Gas Shift								
	540		kg/h		46866,27957	kW	-87921	
		Total	kg/h		46866,27957	kW	-87921	
Area 500: PSA								
	481		kg/h		608,71778	kW	-293,07	
	431		kg/h		2416,27393	kW	-1758,42	
	574		kg/h		46866,27957	kW	-118400,28	
		Total	kg/h		49891,27128	kW	-120451,77	
Area 500: Hydrogen Distribution								
	590		kg/h		3519,40481	kW	-879,21	
	390		kg/h		2477,50858	kW	-586,14	
		Total	kg/h		5996,91339	kW	-1465,35	

OUTPUT

	Flow Number	Name	Unit	Amount	Flow Amount	Energy Unit	Energy content	Details
Area 100: Feed Handling and Drying								
	105		kg/h		92591,78029	kW	-162067,71	
		Total	kg/h		92591,78029	kW	-162067,71	

Area 200: In-situ Pyrolysis								
	300		kg/h		149290,5303	kW	-199873,74	
	235		kg/h		921,69488	kW	-879,21	
	239		kg/h		213442,6712	kW	-146828,07	
		Total	kg/h		363654,8963	kW	-347581,02	
Area 300: Condensation Stage 1								
	317		kg/h		179764,5209	kW	-287501,67	
	320A		kg/h		8858,15911	kW	-2930,7	
	335A		kg/h		8,16462	kW	0	
		Total	kg/h		188630,8446	kW	-290432,37	
Area 300: Condensation Stage 2								
	321		kg/h		90610,49917	kW	-111659,67	
	332		kg/h		39339,8607	kW	-21394,11	
	337		kg/h		23610,72027	kW	-11136,66	
	334		kg/h		35050,26007	kW	-150344,91	
	335		kg/h		19,50437	kW	0	
		Total	kg/h		188630,8446	kW	-294535,35	
Area 300: Water Gas Shift								
	374		kg/h		35340,10408	kW	-84990,3	
		Total	kg/h		35340,10408	kW	-84990,3	
Area 300: PSA								
	389		kg/h		23950,45918	kW	-45425,85	
	390		kg/h		2477,50858	kW	-586,14	
	377		kg/h		8912,13632	kW	-39271,38	
		Total	kg/h		35340,10408	kW	-85283,37	
Area 400: Hydrotreating								
	431		kg/h		2416,27393	kW	-1758,42	
	428		kg/h		394,6233	kW	-293,07	
	429		kg/h		20421,98257	kW	-7033,68	
	424		kg/h		2130,05864	kW	-9378,24	Mostly Water
	430		kg/h		0	kW		missing info
	411		kg/h		0	kW		missing info
		Total	kg/h		25362,93844	kW	-18463,41	
Area 400: Product Separation								
hydroprpurgh	452		kg/h		248,11373	kW	-293,07	
gasoline product	453		kg/h		14454,09894	kW	-5861,4	
diesel product	456		kg/h		5372,77355	kW	-2344,56	
heavy key	460		kg/h		4006,56047	kW	-293,07	
		Total	kg/h		24081,54669	kW	-8792,1	
Area 400: Hydrocracking								
	481		kg/h		608,71778	kW	-293,07	
	478		kg/h		186,87908	kW	-293,07	
	479		kg/h		3659,56412	kW	-2051,49	
vatten	474		kg/h		36,2872	kW	-293,07	
		Total	kg/h		4491,44818	kW	-2930,7	
Area 400: Reformer								
	549		kg/h		108597,6106	kW	-139501,32	
	540		kg/h		46866,27957	kW	-87921	
		Total	kg/h		155463,8902	kW	-227422,32	
Area 500: Water Gas Shift								
	574		kg/h		46866,27957	kW	-118400,28	
		Total	kg/h		46866,27957	kW	-118400,28	
Area 500: PSA								
	589		kg/h		40030,67827	kW	-92023,98	
	590		kg/h		3519,40481	kW	-879,21	
	576		kg/h		6341,1882	kW	-27841,65	
		Total	kg/h		49891,27128	kW	-120744,84	
Area 500: Distribution								
	590		kg/h		3519,40481	kW	-879,21	
	435		kg/h		1753,12535	kW	-293,07	
	485		kg/h		484,43412	kW	0	
		Total	kg/h		5756,96428	kW	-1172,28	

ENERGY STREAM INPUT

	Flow Number	Name	Unit	Amount	Flow Amount	Energy Unit	Energy content	Details
Area 100: Feed Handling and Drying								
	107					kW	-289846,23	
		Total				kW	-289846,23	
Area 200: In-situ Pyrolysis								
	QA-K202					kW	12602,01	
	Q-H210					kW	-1465,35	
	Q-H209					kW	-9964,38	
	Q-H201					kW	-22273,32	
	Q-H208					kW	36047,61	
	Q-ST202A					kW	-75905,13	
		Total				kW	-60958,56	
Area 300: Condensation Stage 1								
	QA-H313					kW	21687,18	
	QX-H315					kW	1465,35	
	QC-H314					kW	3516,84	

	Flow Number	Name	Unit	Amount	Flow Amount	Energy Unit	Energy content	Details
	Q-H318					kW	586,14	
	Q-H312					kW	12308,94	
	QCH-H316					kW	2930,7	
	Q-H310					kW	26669,37	
	QA-H320					kW	0	
		Total				kW	69164,52	
Area 300: Condensation Stage 2								
	QCH-H326					kW	3809,91	
		Total				kW	3809,91	
Area 300: Water Gas Shift								
	Q-H367					kW	-293,07	
	Q-H366					kW	-2637,63	
	QC-H374					kW	879,21	
	Q-H369					kW	-879,21	
	QA-H373					kW	3516,84	
	Q-H372					kW	8792,1	
		Total				kW	9378,24	
Area 400: Hydrotreating								
	QA-H413					kW	879,21	
	QA-H412					kW	1758,42	
	QC-H413					kW	586,14	
	QF-H411					kW	-879,21	
	Q-H412					kW	5861,4	
	QX-H410					kW	-7912,89	
		Total				kW	293,07	
Area 400: Product Separation								
	Q-H450					kW	-3516,84	
	Q-H452					kW	-879,21	
	QR-H451					kW	-879,21	
	Q-H456					kW	586,14	
	QC-H459					kW	0	
	QCN-D450					kW	4102,98	
	QRB-D450					kW	-2051,49	
	QC-H451					kW	879,21	
	QC-H454					kW	293,07	
	QC-H457					kW	0	
		Total				kW	-1465,35	
Area 400: Hydrocracking								
	QA-K462					kW	586,14	
	Q-H462					kW	2344,56	
	QX-460					kW	-293,07	
		Total				kW	2637,63	
Area 500: Reformer								
	QF-H548					kW	879,21	
	H-H456					kW	38392,17	
	Q-H525					kW	-1172,28	
	Q-H530					kW	-12308,94	
	Q-H545					kW	-4982,19	
	Q-H547					kW	-2344,56	
		Total				kW	18463,41	
Area 500: Water Gas Shift								
	Q-H565					kW	14360,43	
	Q-H566					kW	5861,4	
	Q-H567					kW	5861,4	
	QC-H568					kW	879,21	
		Total				kW	26962,44	
ENERGY STREAM OUTPUT								
	Flow Number	**Name**	**Unit**	**Amount**	**Flow Amount**	**Energy Unit**	**Energy content**	**Details**
Area 100: Feed Handling and Drying								
	108					kW	-309481,92	
		Total				kW	-309481,92	

Calculations

Flow Balance		
Flow stream input	1216090,666	kg/h
Flow stream output	1216102,913	kg/h
Closure	0,0000101	
Energy Balance		
Flow input	-1552684,86	kW
Flow output	-1762816,05	kW
Energy stream input	-221560,92	kW
Energy stream outpu	-309481,92	kW
Consumption	-48000	kW
Closure	0,137	
Hydrocarbons Conversion		
In	183718	kg/h
Out	43711	kg/h
Conversion rate	0,238	
Carbon Balance		
Product	18555,320	mol carbon/h

Byproducts		mol carbon/h
Biomass	47166,253	mol carbon/h
Input fuels		mol carbon/h
Carbon efficiency	0,365	mol useful carbon atoms/mol input carbon atoms