CPD NR 3309
Appendices

Process Systems Engineering
DelftChemTech - Faculty of Applied Sciences
Delft University of Technology

Basis of Design:
Design of a life-cycle chain from biomass acquisition and transport to the production of Synthesis Gas for Shell Middle Distillate Products through large-scale gasification of biomass in the Rotterdam Harbour area

Authors	***(Study nr.)***	***Telephone***
M.E. Djatmiko	1059300	06-24578184
W. Hensen	1046624	06-10067854
E.M. Herben	9328149	06-21828025
A. Kurniawan	9489256	06-22923838
B.J. Vreugdenhil	1113712	015-2140201

Keywords
Syngas, sustainability tool, gasification, biomass, wood, life cycle, Biomass to Liquid (BTL).

Assignment issued	: April 19th 2004
Report issued	: July 30th 2004
Appraisal	: August 6th 2004

Appendices

Table of Content

Appendix 2.1 Impact Category Selection Table

The impact categories that were evaluated are in bold.

The impact categories that were evaluated qualitatively are in bold and italics.

Some impact categories are evaluated qualitatively, because it is difficult and time consuming to find data about other countries (land of origin of the feedstock).

~~The impact categories that were not evaluated are strikethrough.~~

B group impact categories, which are study specific, were not all evaluated.

C group impact categories, which are optional, were not evaluated.

Table A.2.1.1: Impact Category Selection Table

Impact Category Selection Table	
	Explanation
Efficiency impact categories	
Material intensity	Material usage is important for people, planet and profit.
Renewables contribution to material input	As well as the renewables.
Energy intensity	Energy usage is important for people, planet and profit.
Renewables contribution to energy input	As well as the renewables.
Water usage	The water usage for the growing of biomass contributes to unsustainability.
Triple P impact categories	
People	
Abiotic depletion	A category indicator calculated with GaBi.
~~Acute toxicity~~	EHS indicator: In this phase no difference between cases.
~~Biotic depletion~~	C category indicator not evaluated.
~~Capital investment~~	When economic margin is negative, nothing can be said about the capital investment
~~Chronic Toxicity~~	EHS indicator: In this phase no difference between cases.
Direct local jobs	Biomass is imported from another country, so creating local jobs is important.
Fatal occupational and commuting accidents	Idem as direct local jobs.
~~Fire/Explosion~~	EHS indicator: In this phase no difference between cases.
Forced Labour, Child Labour, Discrimination and Unskilled workers	Idem as direct local jobs.
Freedom of association	Idem as direct local jobs.
Human toxicity	A category indicator calculated with GaBi.
Investment in employee training	Idem as direct local jobs.
~~Investment in R&D~~	Difficult to determine in this phase of design.
~~Irritation~~	EHS indicator: In this phase no difference between cases.
Land comptetion	The land usage for growing biomass contributes to sustainability of the supply chain.
~~Mobility~~	EHS indicator: In this phase no difference between cases.
Non-fatal Occupational and commuting accidents	Idem as direct local jobs.
~~Reaction/Decomposition I, II~~	EHS indicator: In this phase no difference between cases.
~~Wages and salaries~~	In this phase no difference between cases and difficult to determine.

Planet	
~~Accumulation~~	EHS indicator: In this phase no difference between cases.
Acidification	A category indicator calculated with GaBi.
~~Air Mediated effects~~	EHS indicator: In this phase no difference between cases.
Climate change	A category indicator calculated with GaBi.
~~Degradation~~	EHS indicator: In this phase no difference between cases.
~~Desiccation~~	C category indicator not evaluated.
Eutrophication	A category indicator calculated with GaBi.
Freshwater aquatic ecotoxicity	A category indicator calculated with GaBi.
~~Freshwater sediment ecotoxicity~~	B category indicator not evaluated.
~~Impacts of ionising radiation~~	B category indicator not evaluated.
Loss of biodiversity	B category indicator, but evaluated because the process works on biomass.
Loss of life support function	B category indicator, but evaluated because the process works on biomass.
~~Malodourous air~~	B category indicator not evaluated.
~~Malodourous water~~	C category indicator not evaluated.
Marine aquatic ecotoxicity	A category indicator calculated with GaBi.
~~Marine sediment ecotoxicity~~	B category indicator not evaluated.
~~Noise~~	C category indicator not evaluated.
Photo-oxidant formation	A category indicator calculated with GaBi.
~~Solid Waste~~	EHS indicator: In this phase no difference between cases.
Stratospheric ozone depletion	A category indicator calculated with GaBi.
Terrestial ecotoxicity	A category indicator calculated with GaBi.
~~Waste heat~~	B category indicator not evaluated.
~~Water mediated effects~~	EHS indicator: In this phase no difference between cases.
Profit	
~~Decommissioning Costs~~	Not evaluated, because in this phase of the design no differences between cases.
Economic Margin	Important indicator.
Emission costs	Evaluated because it is assumed in this phase that H2S, NH3, HCl and ash are emitted to the environment.
Feedstock costs	Depended which biomass/feedstock is used.
~~Income from by-product sales~~	Assumed that all by-products are waste in this phase of the design.
Income from main product sales	Evaluated, but for all cases the same, because syngas is the main product.
~~Labour costs~~	In this phase no difference between cases and difficult to determine.
~~Maximum allowable capital investment~~	Depends on economic margin and gives the same ranking, so it will count twice.
~~Training costs~~	In this phase no difference between cases and difficult to determine.
Supply Chain Evaluation impact categories	
Legislational Compliance	For transportation and handling of each biomass not the same legislation applies.
Maturity of Technology	Biomass gasification is not a proven technology, some biomass gasification is more investigated than others.
Robustness of supply chain	This indicator shows to what extent the supply chain will react on changes and assumptions.
Social political acceptance	New designed processes should be accepted by the society to avoid future problems.

Appendix 2.2 Brainstorm session and quick selection of feedstock

In Table A.2.2.1 the results are shown of the brainstorm session about all the different kinds of feedstock/biomass that were available for the process. A quick selection is done to reduce the number of different supply chains that needs further investigation with the CPD-SAT tool.

Table A.2.2.1: Results brainstorm session and quick selection

Biomass	**Quick selection**
Manure	OK
Algae	Growth of algae is too slow.
Corn waste	= Agricultural waste
Agricultural waste	OK
Waste wood	= **Wood residues** (from forestry)
Organic household waste	Not available in large quantities and composition is not uniform.
Wood waste	Contains a lot of unwanted metals when impregnated.
Trees	= **Fresh wood**
Slaughter waste	Too expensive to transport and to store, because of legislation.
Dry manure	= Manure (with pre-treatment).
Energy crops	OK
Sewer/river slurry	Contains a lot of unwanted halogens and metals.
Coco industrial waste	Not available in large quantities.
Sugarcane	= Agricultural waste
Coconut/palm waste	Not available in large quantities.
Flower waste	= Agricultural waste
Wine/cork waste	Not available in large quantities.
Wood pellets	= Forest residues (with pre-treatment).
Crop pellets	= Agricultural waste (with pre-treatment).
Dry algae	= Algae (with pre-treatment).

The conclusion that can be drawn is that:

- Wood residues
- Energy crops
- Fresh wood
- Agricultural waste
- Manure

will be further investigated with the CPD-SAT tool.

Appendix 2.3 Feedstock Alternatives

Wood residues

Wood waste comes from different sectors, mainly from forestry and industrial sawmills. This waste cannot been used anymore for production of wood materials and can therefore be burned or converted. Forestry residues consist of the tops and branches of trees that are left after harvesting when the round wood has been removed for lumber or producing pulp and paper. They are available in large amount in e.g. Sweden, the Baltic States, Canada and Russia. ([1] [2]). Spruce trees make out the major part of the residues, come available during the whole year, since they can be harvested anytime of the year [1].

Energy crops

Energy crops cultivation in The Netherlands and Europe is small-scale and therefore inefficient and relatively expensive to be used as biomass source.
Other alternative is South America like Brazil. Examination of the land availability has been done by the Brazilian utility responsible for electricity in northeast Brazil (Companhia Hidroeletrica do Sao Francisco-CHESF). The examination is based on their experience in Eucalyptus plantation. That the biomass energy production potential of the region is so large is surprising because a large part of the region is considered semi-arid. Furthermore, roughly half the area identified by CHESF as suitable for plantations is characterized as having soil that is being degraded to some extent by wind erosion, water erosion, or chemical deterioration. A smaller percentage of area has also been characterized as susceptible to desertification, based on physical characteristics (soils, water resources, etc.), social conditions (e.g., land ownership structure), economic criteria (e.g., present use of land), and other indicators [3]. These facts have made Brazil as first candidate as biomass source (utilizing energy crops).

Fresh wood

Large wood producers close to the Netherlands are e.g. Scandinavia. These countries have sites with dedicated energy crops, but current production levels are still limited. Agricultural plots are scattered all over the countries, cultivation and harvest are still rather inefficient due to the small scale, and prices are relatively high. Eastern European Countries and FSU states have much lower land and labour costs, and therefore a larger potential bio energy production against lower costs. Moreover, it can be expected that large agricultural areas come available when entry to the European Union can lead to increased competition and improvements in agricultural productivity and efficiency.
There is plentiful experience with short rotation forestry for the pulp and paper industry. For moderate climates a typical crop is probably willow or poplar.
Because of competing applications (e.g. paper, furniture, construction) only part of the available wood is effectively usable for applications like this syngas production.

Agricultural waste

Of all agricultural residues, only primary residues; wheat straw, will be considered, because they are available in large amount in e.g. Europe (France, Germany, UK, Italy), Russia and China ([4] [5]). According to Bowyer [6], it is assumed that 1 ton of wheat can generate 1 ton of gross straw. Wheat straw comes available 1- to 3-months period each year [6], which is sufficient for the required quantity, but storage will be a concern. Agricultural residues are nowadays used for this soil conservation on the farmland and for other agricultural uses (cattle food) [6]. Therefore it is likely that more structured collecting system of wheat straw is needed.

Manure

The biomass amount in the Netherlands is not large enough to be a source in the syngas production. There for the manure has to come from a large supplier or from several countries. The information found on the internet on manure amounts in the EU is small. However it clear that in the EU enough cow manure must exist. The US produces 200 Mton/a of dry cow manure [7]. This is better manure than depicted in the table because it hardly contains water.

For transporting the biomass Panamax (63.000 tonne) and Capesize (110.000 tonne) ships are used. Panamax ships are used for transport from Europe and Baltic States. Capesize ships come from the USA and Brazil [1].

References:

[1] C.N. Hamelinck, R.A.A. Suurs, A.P.C. Faaij, *International bioenergy transport costs and energy*, Universiteit van Utrecht, Copernicus Institute, Augustus 2003

[2] http://www.unece.org/trade/timber/mis/tb-6/tb-56-6.pdf, Table 9, read: April 28th 2004

[3] http://www.undp.org/seed/energy/policy/ch_9.htm, E.D. Larson, R.H. Williams, Energy as an instrument for socio-economic development, part III, chapter 9, Biomass plantation energy systems and sustainable development.

[4] http://www.globaltechnoscan.com/27thSep-2ndOct/agricultural_straw.htm, Table 1, *Worldwide availability of wheat and rice straw residues* (as in 1999), read: April 29, 2004.

[5] http://apps.fao.org/faostat/form?collection=Production.Crops.Primary&Domain=Production&servlet=1&hasbulk=0&version=ext&language=EN, FAOSTAT database, Agriculture - Crops Primary, read: May 2, 2004.

[6] J. L. Bowyer, V. E. Stockmann, *Agricultural Residues - An Exciting Bio-Based Raw Material for the Global Panels Industry*, Forest Products Journal, Vol. 51, No. 1, pp.10-21, January 2001.

[7] http://bioproducts-bioenergy.gov/pdfs/bcota/abstracts/2/z219.pdf, Manufacturing and Technology Conversion International, Inc., Steam reforming of animal waste, read: 1 May, 2004

Appendix 2.4 Graphical representation of all assessment scores

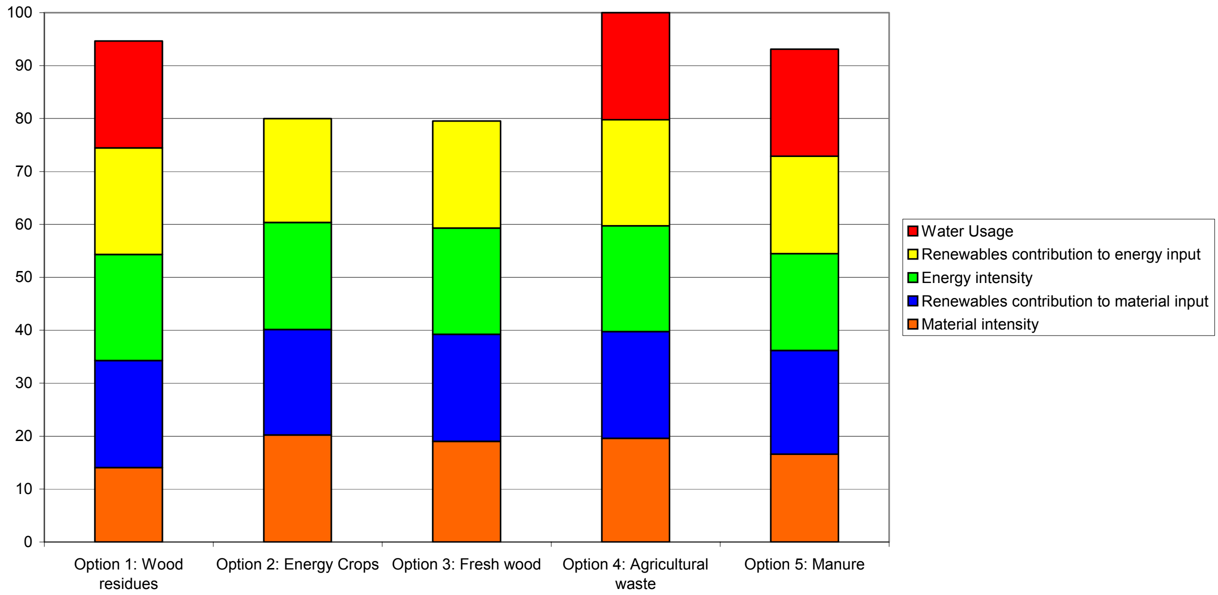


Figure A.2.4.1: Efficiency Assessment Score

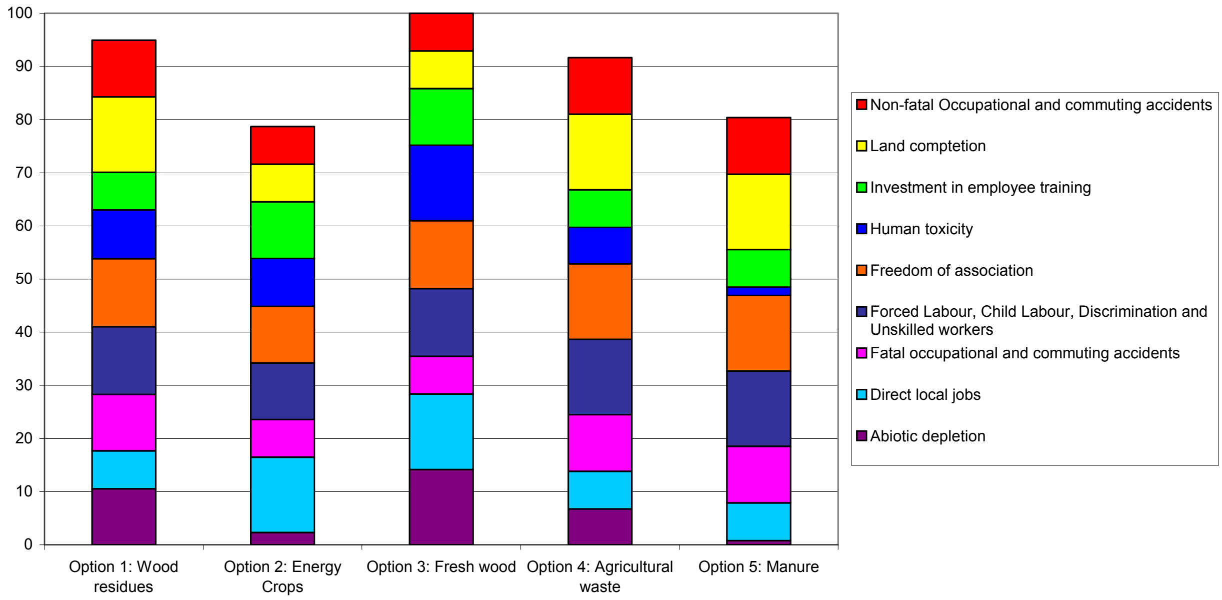
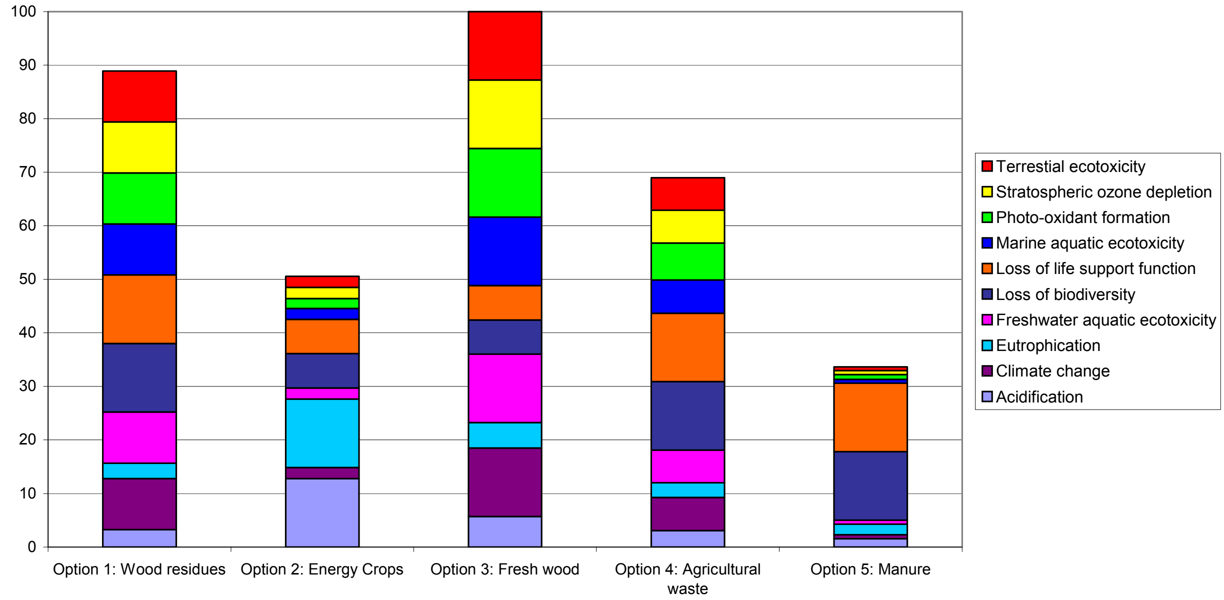


Figure A.2.4.2: People Score



FigureA. 2.4.3: Planet Score

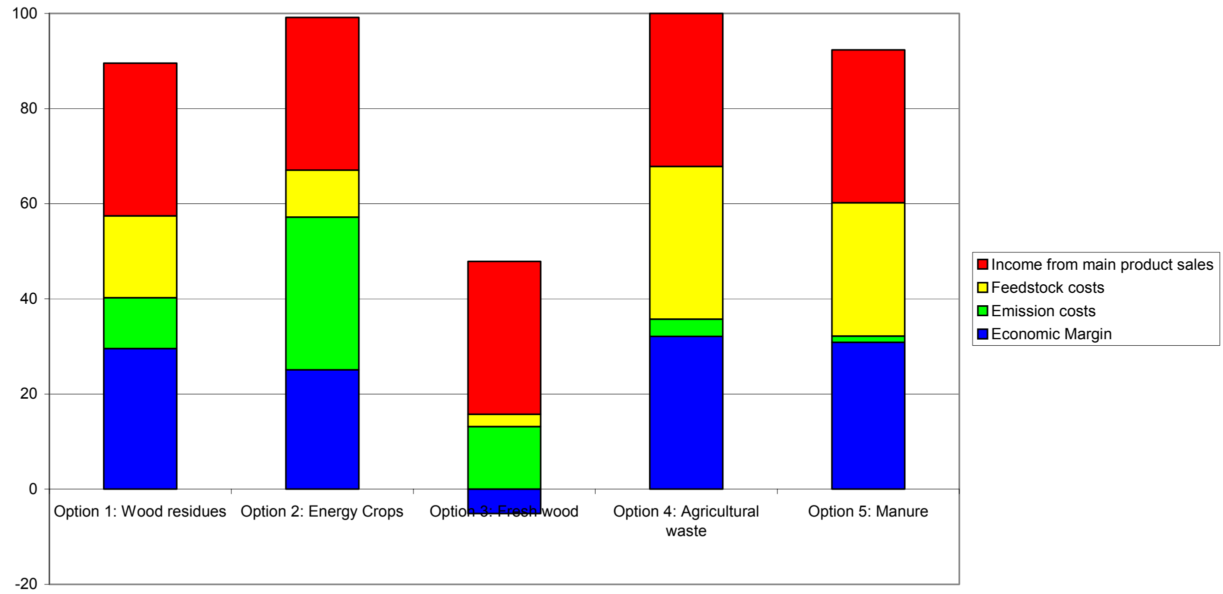


Figure A.2.4.4: Profit Score

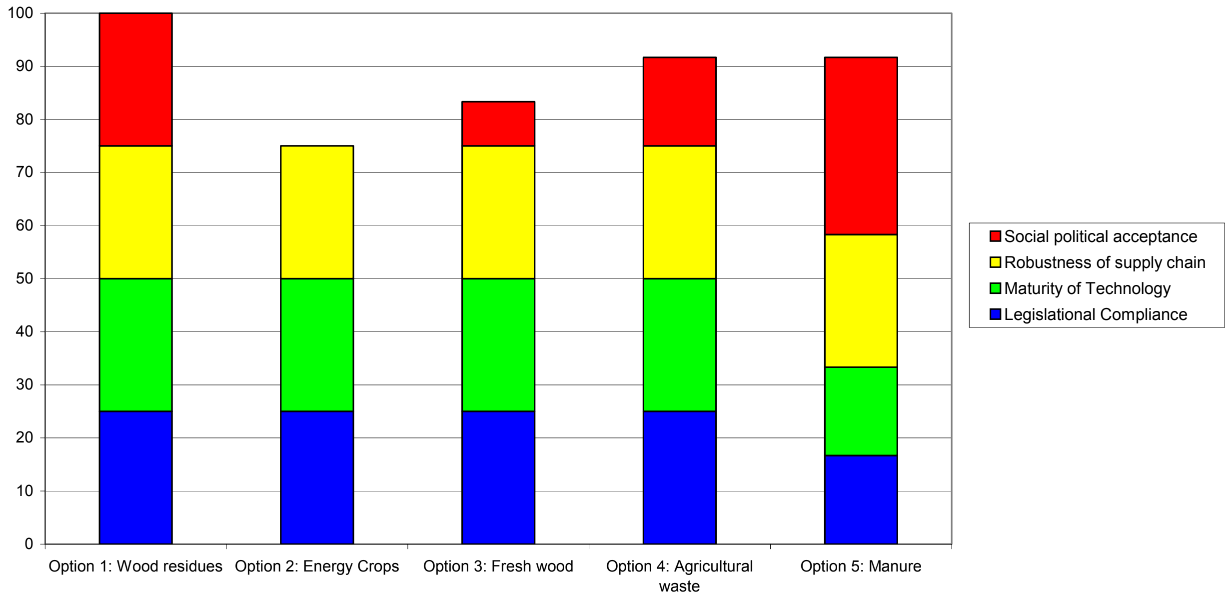


Figure A.2.4.5: Supply Chain Evaluation Score

Appendix 2.5.1 Values of impact category and assessment scores

Table A.2.5.1.1: Impact Category and Assessment Scores for Efficiency

Impact Category and Assessment Scores Table																						
	Functional Unit 8000 MW syngas		*Option 1: Wood residues* from Baltic States and Scandinavia				*Option 2: Energy Crops* from Brazil				*Option 3: Fresh wood* from Baltic States				*Option 4: Agricultural waste* from West Europe				*Option 5: Manure* from United States of America			
Efficiency Assessment																						
Efficiency Assessment Score				***aggr.***	***norm.***			***aggr.***	***norm.***			***aggr.***	***norm.***			***aggr.***	***norm.***			***aggr.***	***norm.***	
Total score				***468***	***95***			***396***	***80***			***394***	***80***			***494***	***100***			***459***	***93***	
	UIR	Best IR	Ind. result	Score	Score	Reas. #	Ind. result	Score	Score	Reas. #	Ind. result	Score	Score	Reas. #	Ind. result	Score	Score	Reas. #	Ind. result	Score	Score	Reas. #
Material intensity	**[kg material / kg main product]**	**3.2**	4.6	70	14	I	3.2	100	20	I	3.4	94	19	I	3.3	97	20	I	3.9	82	17	I
Renewables contribution to material input	%	**72.4**	72.0	99	20	II	71.7	99	20	II	72.4	100	20	II	71.4	99	20	II	69.2	96	19	II
Energy intensity	**[MJ primary energy / MJ main product]**	**1.540**	1.551	99	20	III	1.540	100	20	III	1.548	99	20	III	1.557	99	20	III	1.698	91	18	III
Renewables contribution to energy input	%	**99.4**	99.2	100	20	IV	96.5	97	20	IV	99.4	100	20	IV	98.8	99	20	IV	90.6	91	18	IV
Water Usage	-			100	20	A		0	0	A		0	0	A		100	20	A		100	20	A

Table A.2.5.1.2: Impact category and Assessment Scores for People

	Functional Unit 8000 MW syngas		*Option 1: Wood residues* from Baltic States and Scandinavia				*Option 2: Energy Crops* from Brazil				*Option 3: Fresh wood* from Baltic States				*Option 4: Agricultural waste* from West Europe				*Option 5: Manure* from United States of America			
Triple P Assessment																						
People																						
People Score				***aggr.***	***norm.***			***aggr.***	***norm.***			***aggr.***	***norm.***			***aggr.***	***norm.***			***aggr.***	***norm.***	
Total score				***669***	***95***			***555***	***79***			***705***	***100***			***646***	***92***			***567***	***80***	
	UIR	Best IR	Ind. result	Score	Score	Reas. #	Ind. result	Score	Score	Reas .#	Ind. result	Score	Score	Reas .#	Ind. result	Score	Score	Reas. #	Ind. result	Score	Score	Reas. #
Abiotic depletion	**[kg Sb-Equiv./year]**	**1.1E+6**	1.5E+6	74	11	GaBi	7.0E+6	16	2	GaBi	1.1E+6	100	14	GaBi	2.4E+6	48	7	GaBi	2.0E+7	6	1	GaBi
Direct local jobs	-			50	7	B		100	14	B		100	14	B		50	7	B		50	7	B
Fatal occupational and commuting accidents	-			75	11	C		50	7	C		50	7	C		75	11	C		75	11	C
Forced Labour, Child Labour, Discrimination and Unskilled workers	-			90	13	D		75	11	D		90	13	D		100	14	D		100	14	D
Freedom of association	-			90	13	E		75	11	E		90	13	E		100	14	E		100	14	E
Human toxicity	**[kg DCB-Equiv./year]**	**2.8E+7**	4.3E+7	65	9	GaBi	4.4E+7	64	9	GaBi	2.8E+7	100	14	GaBi	5.7E+7	49	7	GaBi	2.5E+8	11	2	GaBi
Investment in employee training	-			50	7	F		75	11	F		75	11	F		50	7	F		50	7	F
Land competition	-			100	14	G		50	7	G		50	7	G		100	14	G		100	14	G
Non-fatal Occupational and commuting accidents	-			75	11	H		50	7	H		50	7	H		75	11	H		75	11	H

Table A.2.5.1.3: Impact category and Assessment Score for Planet

	Functional Unit		Option 1: Wood residues				Option 2: Energy Crops				Option 3: Fresh wood				Option 4: Agricultural waste				Option 5: Manure			
	8000 MW syngas		from Baltic States and Scandinavia				from Brazil				from Baltic States				from West Europe				from United States of America			
Planet																						
Planet Score				*aggr.*	*norm.*			*aggr.*	*norm.*			*aggr.*	*norm.*			*aggr.*	*norm.*			*aggr.*	*norm.*	
Total score				*695*	*89*			*395*	*51*			*782*	*100*			*539*	*69*			*263*	*34*	
	UIR	Best IR	Ind. result	Score	Score	Reas. #	Ind. result	Score	Score	Reas. #	Ind. result	Score	Score	Reas. #	Ind. result	Score	Score	Reas. #	Ind. result	Score	Score	Reas. #
Acidification	[kg SO2-Equiv./year]	**1.1E+8**	4.3E+8	25	3	GaBi	1.1E+8	100	13	GaBi	2.4E+8	45	6	GaBi	4.6E+8	24	3	GaBi	9.0E+8	12	2	GaBi
Climate change	[kg CO2-Equiv./year]	**1.8E+8**	2.4E+8	74	10	GaBi	1.1E+9	16	2	GaBi	1.8E+8	100	13	GaBi	3.7E+8	48	6	GaBi	3.1E+9	6	1	GaBi
Eutrophication	[kg Phosphate-Equiv./year]	**1.5E+7**	6.7E+7	23	3	GaBi	1.5E+7	100	13	GaBi	4.1E+7	37	5	GaBi	7.0E+7	22	3	GaBi	9.7E+7	16	2	GaBi
Freshwater aquatic ecotoxicity	[kg DCB-Equiv./year]	**1.9E+5**	2.6E+5	74	10	GaBi	1.2E+6	16	2	GaBi	1.9E+5	100	13	GaBi	4.0E+5	48	6	GaBi	3.4E+6	6	1	GaBi
Loss of biodiversity	-			100	13	I		50	6	I		50	6	I		100	13	I		100	13	I
Loss of life support function	-			100	13	J		50	6	J		50	6	J		100	13	J		100	13	J
Marine aquatic ecotoxicity	[kg DCB-Equiv./year]	**1.4E+9**	1.9E+9	74	10	GaBi	9.0E+9	16	2	GaBi	1.4E+9	100	13	GaBi	3.0E+9	48	6	GaBi	2.5E+10	6	1	GaBi
Photo-oxidant formation	[kg Ethene-Equiv./year]	**3.6E+5**	4.8E+5	74	10	GaBi	2.5E+6	14	2	GaBi	3.6E+5	100	13	GaBi	6.6E+5	54	7	GaBi	5.1E+6	7	1	GaBi
Stratospheric ozone depletion	[kg R11-Equiv./year]	**6.1E+1**	8.2E+1	74	10	GaBi	3.8E+2	16	2	GaBi	6.1E+1	100	13	GaBi	1.3E+2	48	6	GaBi	1.1E+3	6	1	GaBi
Terrestial ecotoxicity	[kg DCB-Equiv./year]	**3.0E+4**	4.0E+4	74	10	GaBi	1.8E+5	16	2	GaBi	3.0E+4	100	13	GaBi	6.2E+4	48	6	GaBi	5.2E+5	6	1	GaBi

Table A.2.5.1.4: Impact Category and Assessment score for Profit and Supply Chain Evaluation

	Functional Unit 8000 MW syngas		*Option 1: Wood residues* from Baltic States and Scandinavia				*Option 2: Energy Crops* from Brazil				*Option 3: Fresh wood* from Baltic States				*Option 4: Agricultural waste* from West Europe				*Option 5: Manure* from United States of America			
Profit																						
Profit Score				***aggr.***	***norm.***			***aggr.***	***norm.***			***aggr.***	***norm.***			***aggr.***	***norm.***			***aggr.***	***norm.***	
Total score				***279***	***90***			***309***	***99***			***133***	***43***			***311***	***100***			***287***	***92***	
	UIR	Best IR	Ind. result	Score	Score	Reas. #	Ind. result	Score	Score	Reas .#	Ind. result	Score	Score	Reas. #	Ind. result	Score	Score	Reas. #	Ind. result	Score	Score	Reas. #
Economic Margin	**[M€/year]**	**1114**	1025	92	30	V	869	78	25	V	-178	-16	-5	V	1114	100	32	V	1070	96	31	V
Emission costs	**[M€/year]**	**2**	5	33	11	VI	2	100	32	VI	4	41	13	VI	15	11	4	VI	42	4	1	VI
Feedstock costs	**[M€/year]**	**114**	212	53	17	VII	371	31	10	VII	1416	8	3	VII	114	100	32	VII	130	87	28	VII
Income from main product sales	**[M€/year]**	**1242**	1242	100	32	VIII	1242	100	32	VIII	1242	100	32	VIII	1242	100	32	VIII	1242	100	32	VIII
Supply Chain Evaluation																						
Supply Chain Evaluation Score				***aggr.***	***norm.***			***aggr.***	***norm.***			***aggr.***	***norm.***			***aggr.***	***norm.***			***aggr.***	***norm.***	
Total score				***300***	***100***			***225***	***75***			***250***	***83***			***275***	***92***			***275***	***92***	
	UIR	Best IR	Ind. result	Score	Score	Reas. #	Ind. result	Score	Score	Reas .#	Ind. result	Score	Score	Reas. #	Ind. result	Score	Score	Reas. #	Ind. result	Score	Score	Reas. #
Legislational Compliance	-			75	25	K		75	25	K		75	25	K		75	25	K		50	17	K
Maturity of Technology	-			75	25	L		75	25	L		75	25	L		75	25	L		50	17	L
Robustness of supply chain	-			75	25	M		75	25	M		75	25	M		75	25	M		75	25	M
Social political acceptance	-			75	25	N		0	0	N		25	8	N		50	17	N		100	33	N

Appendix 2.5.2 Reasoning Inventory Table

Table A.2.5.2.1: Reasoning Inventory Table for qualitative scores

Impact category	Reasoning #	Reasoning for qualitative scores
Water Usage	A	For waste biomass there is no water usage (100). For biomass products there is water needed to let it grow (0).
Direct local jobs	B	For waste biomass less local people are needed than for the production of biomass products (maintenance of land and crops).
Fatal occupational and commuting accidents	C	For waste biomass, only collection and transport is needed (75), for woody products, also more dangerous foresting is needed (50).
Forced Labour, Child Labour, Discrimination and Unskilled workers	D	In West Europe and USA there is no forced labour, in the Baltic States there is little forced labour, and in Brazil, there is more forced labour.
Freedom of association	E	Idem as for forced labour.
Investment in employee training	F	For waste biomass, less investment is needed than for biomass products, since production is more extensive.
Land competition	G	For waste biomass, there is no land competition, for biomass products, there is more land competition.
Non-fatal Occupational and commuting accidents	H	Idem as for fatal accidents.
Loss of biodiversity	I	For waste biomass, there is no loss of biodiversity because it is waste, for biomass products, there is more a monoculture.
Loss of life support function	J	Idem as for loss of biodiversity.
Legislational Compliance	K	The transport and storage of manure is not always allowed; the combustion of biomass is not always allowed.
Maturity of Technology	L	The handling and gasification of manure seems more difficult than that of wood or agricultural waste.
Robustness of supply chain	M	The robustness depends on a lot of factors, so it is difficult to distinguish between options.
Social political acceptance	N	Ranking determined through questionnaire among friends and family (see Appendix I).

Table A.2.5.2.2: Reasoning Inventory Table for quantitative scores

Impact category	Reasoning #	Reasoning for quantitative scores
Material intensity	I	kg mass in over life-cycle / kg main product out = (kg biomass input + kg diesel input for transport) / kg syngas out Data # used: 1, 2, 9 and 10
Renewables contribution to material input	II	(kg mass renewable in / kg mass in over life cycle) * 100% = kg biomass input / (kg biomass input + kg diesel input for transport) * 100% Data # used: 1, 2 and 9
Energy intensity	III	MJ primary energy in / MJ of main product out Data # used: 1, 2 and 9
Renewables contribution to energy input	IV	(MJ renewable energy in over life-cycle / MJ of main product out) * 100 % Data # used: 1, 2 and 9
Economic Margin	V	Syngas price per ton * output syngas - Emission costs per ton * total emissions - Feedstock costs per ton * input biomass Data # used: 9, 10, 15, 16, 17 and 18
Emission costs	VI	Emission costs per ton * total emissions Data # used: 15 and 17
Feedstock costs	VII	Feedstock costs per ton * input biomass Data # used: 9 and 16
Income from main product sales	VIII	Syngas price per ton * output syngas Data # used: 10 and 18

Appendix 2.5.3 Data Inventory Table

Table A.2.5.3.1: Data Inventory Table

Data Inventory Table																	
			Option 1: Wood residues			*Option 2: Energy Crops*			*Option 3: Fresh wood*			*Option 4: Agricultural waste*			*Option 5: Manure*		
Data label	Data #	Unit	Value	QI	Source #	Value	QI	Source #	Value	QI	Source #	Value	QI	Source #	Value	QI	Source #
Distance from harbour	1	km	100	1	6	400	1	6	100	1	6	300	1	6	2500	1	6
Distance from Rotterdam	2	km	1100	1	6	1100	1	6	1100	1	6	1300	1	6	7200	1	6
Water content	3	wt%	29.6	4	1	9.3	4	2	15	4	3	9.7	4	4	13.9	4	5
Ash content	4	wt%	0.8	4	1	0.5	4	2	1.1	4	3	5.3	4	4	13.7	4	5
N content	5	wt%	0.49	4	1	0.13	4	2	0.4	4	3	0.72	4	4	0.83	4	5
S content	6	wt%	0.07	4	1	0.03	4	2	0.01	4	3	0.08	4	4	0.25	4	5
Cl content	7	wt%	0.07	4	1	0.05	4	2	0.084	4	3	0.199	4	4	0.999	4	5
LHV biomass input	8	MJ/kg	11.098	4	1	16.058	4	2	14.936	4	3	15.573	4	4	13.606	4	5
Input biomass	9	Mton/year	31.9	1	7	22.1	1	7	23.7	1	7	22.7	1	7	26	1	7
Output syngas	10	Mton/year	9.63	1	13	9.63	1	13	9.63	1	13	9.63	1	13	9.63	1	13
Emissions NH3	11	kg/year	1.90E+8	1	8	3.48E+7	1	8	1.16E+8	1	8	1.99E+8	1	8	2.63E+8	1	8
Emissions H2S	12	kg/year	2.38E+7	1	8	7.02E+6	1	8	2.53E+6	1	8	1.93E+7	1	8	6.92E+7	1	8
Emissions HCl	13	kg/year	2.30E+7	1	8	1.13E+7	1	8	2.05E+7	1	8	4.65E+7	1	8	2.68E+8	1	8
Emissions Ash	14	kg/year	2.55E+8	1	9	1.11E+8	1	9	2.61E+8	1	9	1.20E+9	1	9	3.56E+9	1	9
Total emissions	15	kg/year	4.92E+8	1	10	1.64E+8	1	10	3.99E+8	1	10	1.47E+9	1	10	4.16E+9	1	10
Feedstock costs per ton	16	€/ton	6.6588	4	11	16.8	4	12	59.744	4	11	5.0	1	15	5.0	1	15
Emission costs per ton	17	€/ton	10.0	1	14	10.0	1	14	10.0	1	14	10.0	1	14	10.0	1	14
Syngas price per ton	18	€/ton	129	3	16	129	3	16	129	3	16	129	3	16	129	3	16

Appendix 2.5.3 List of sources

Table A.2.5.3.1: List of references

Source #	Reference
1	Phyllis, database for biomass and waste, http://www.ecn.nl/phyllis, Energy research Centre of the Netherlands (1995 forest residue)
2	Phyllis, database for biomass and waste, http://www.ecn.nl/phyllis, Energy research Centre of the Netherlands (699 eucalyptus)
3	Phyllis, database for biomass and waste, http://www.ecn.nl/phyllis, Energy research Centre of the Netherlands (1930 poplar wood)
4	Phyllis, database for biomass and waste, http://www.ecn.nl/phyllis, Energy research Centre of the Netherlands (1903)
5	Phyllis, database for biomass and waste, http://www.ecn.nl/phyllis, Energy research Centre of the Netherlands (1882)
6	Estimated with world map
7	Known: 8000 MW syngas output and LHV biomass input. Assumed: overall 65 % energy (LHV) efficiency from: H.P.A. Calis e.a., *Preliminary techno-economic analysis of large-scale synthesis gas manufacturing from imported biomass*, Paper presented at "Pyrolysis and Gasification of Biomass and Waste", 30 Sept - 1 Oct 2002, Strasbourg, France
8	Estimated with GaBi and data # 5,6 and 7
9	Estimated with data # 4
10	Estimated: sum of data # 10-13
11	Wood residues: 0.6 €/GJ and Fresh wood: 4 €/GJ H.P.A. Calis e.a., *Preliminary techno-economic analysis of large-scale synthesis gas manufacturing from imported biomass*, Paper presented at "Pyrolysis and Gasification of Biomass and Waste", 30 Sept - 1 Oct 2002, Strasbourg, France
12	price eucalyptus
13	Estimated with 8000 MW and LHV = 23.9 MJ/kg syngas
14	C.N. Hamelinck, R.A.A. Suurs, A.P.C. Faaij, *International bioenergy transport costs and energy balance*, Universiteit Utrecht Copernicus Institute, August 2003
15	No source
16	SMDS data from J.W. Coppelmans, paper*: The Shell Middle Distillate Synthesis, Plant at Bintulu*, Shell MDS (Malaysia) SDN BHD

Appendix 2.6 Questionnaire feedstock selection (in Dutch)

Het proces waar deze vragen over gaan is biomassa vergassing. In dit proces wordt biomassa omgezet in synthese gas, een ideaal mengsel voor het SMDS proces van Shell. Zij maken namelijk met synthesegas brandstoffen zoals diesel. Het voordeel van het gebruik van biomassa is dat de fossiele brandstoffen worden overgeslagen. Hierdoor wordt de bijdrage aan het broeikas effect nihil en dat noemen we duurzaamheid.
De opties voor biomassa zijn zeer divers en tijdens ons overleg zijn wij tot de volgende opties gekomen. De onderstaande biomassa heeft de potentie om de concurrentie met de fossiele brandstoffen aan te gaan. Onze vraag luid: Welke biomassa optie zou u kiezen met daarbij een redenatie waarom? Ook zouden wij graag willen weten waarom de andere biomassa opties volgens u niet geschikt zijn?

- Mest (afkomstig van de veehouderij)
- Houtafval afkomstig van de houtverwerkings industrie.
- Hout afkomstig van bos aanplant.
- Landbouw afval.
- Landbouw gewassen.

The results of this survey is summarized in Table A.2.6.1.

Table A.2.6.1: Results Questionnaire

Person	Option 1: Wood residues	Option 2: Energy crops	Option 3: Fresh wood	Option 4: Agricultural waste	Option 5: Manure
1	0	0	0	0	-
2	0	0	0	0	0
3	+	0	-	+	+
4	0	-	0	-	+
5	-	-	-	-	+
6	+	-	-	+	+
7	-	-	-	0	+
8	+	-	+	0	0
9	+	-	-	-	+
Total	+2	-6	-4	-1	+5
Ranking	75	0	25	50	100

Appendix 2.7 Complete list of indicators in SUSDAT

Table A.2.7.1: List of indicators in SUSDAT with its desired intention

PPP	Indicator	Unit	Desired High (1) or Low (0)
People	Skilled labour jobs created	[Manhour / functional unit]	1
People	Unskilled labour jobs created	[Manhour / functional unit]	1
People	Health issues	[health issues / functional unit]	0
People	Total Fatalities (employees and neighbours)	[fatalities / functional unit]	0
People	Room for SOCIALEX	[Margin for social investments M€/ functional unit]	1
People	Ease of Operation	Qualitative	1
People	Harmful impurities in product	Qualitative	0
People	New Technology	[€ / functional unit]	1
People	Capital created	[M€ / functional unit]	1
People	Land use: Competitive	[Land Use / functional unit]	0
People	Sustainability feedstock	[biomass use / functional unit]	0
Planet	Abiotic Depletion	[kg Sb-Equiv. / functional unit]	0
Planet	Acidification Potential	[kg SO2-Equiv. / functional unit]	0
Planet	Eutrophication Potential	[kg Phosphate-Equiv. / functional unit]	0
Planet	Freshwater Aquatic Ecotoxicity Pot.	[kg DCB-Equiv. / functional unit]	0
Planet	Global Warming Potential	[kg CO2-Equiv. / functional unit]	0
Planet	Human Toxicity Potential	[kg DCB-Equiv. / functional unit]	0
Planet	Marine Aquatic Ecotoxicity Pot.	[kg DCB-Equiv. / functional unit]	0
Planet	Ozone Layer Depletion Potential	[kg R11-Equiv. / functional unit]	0
Planet	Photochem. Ozone Creation Potential	[kg Ethene-Equiv. / functional unit]	0
Planet	Radioactive Radiation	DALY	0
Planet	Terrestric Ecotoxicity Potential	[kg DCB-Equiv. / functional unit]	0
Planet	Land use: Loss of Biodiversity	[Max. Contribution to extinction of species i / functional unit]	0
Profit	Capital expenditure	[M€] / Functional unit	0
Profit	Operational expenditure	[M€] / Functional unit	0
Profit	Net Present Value	[M€] / Functional unit	1
Profit	Return on Investment	[%]	1
Profit	Research & Development Expenditure	[€] / Functional unit	0
Profit	Externalities Best case scenario	[€] / Functional unit	1
Profit	Externalities Worst case scenario	[-€] / Functional unit	0
Profit	Margin Best Case Scenario	[€] / Functional unit	1
Profit	Margin Worst Case Scenario	[€] / Functional unit	1

Appendix 2.8 Stakeholders questionnaire and results

As mentioned in above, a questionnaire among stakeholders is performed. The goal is to investigate what the stakeholders consider as important (key) indicators when a chemical plant is built in the Rotterdam Harbour area. The survey is carried out on people who come from different group of society and have different backgrounds.
Two main questions are enquired to the stakeholders:

1. What are the important indicators to design a chemical plant? The goal of this question is to get new ideas on indicators from the stakeholders, who have different points of view than a chemical engineer.
2. Choose the most important indicator for each factor (People, Planet, Profit) from the list of all indicators (defined in SUSDAT tool). Give here your reason why you consider this as important indicator. The goal of this question is to reflect the role of the stakeholders on the design of the chemical plant.

Several new ideas on indicators are obtained and summarized in Table 2.11.1. The results of the most important indicators from the list of indicators defined by SUSDAT according to stakeholders are illustrated in Figure 2.11.1, Figure 2.11.2 and Figure 2.11.3.

Table A.2.8.1: New indicators generated by the stakeholders

New indicators
Energy and materiel efficiencies by a careful management
Location concerning residence area and transport lines (roads and railways)
No land contamination
Safe supply and discharge of feedstock and products
Good feeling from all stakeholders (local residents, workers and clients)
Good maxims of the engineers
Lots of pipelines and tubes
Energy efficiency and heat integration
Total yield (use of raw materials/feedstock)
Use of chemicals
Capital investment
Enlightening for the local residents
Efficiency
Good waste treatment
Less annoyance (noise, odours, logistic)
Subtle
Good working condition and education of their works for the workers
Environment tax
Scale level
Distribution of the impurities
Persistence of the impurities
Degree of impurities
Criticality of environment problems
Satisfaction of specification (input/output) from the clients
Availability of technology of the process on commercial scale
Clean emission in materials, noise and energy
Work opportunities for certain area
Developments and devoting new technology
Cheap as possible
Operation range (flexibility of operation)
Plant capacity towards the prices of the end product and transport cost.
Biomass use competition
Organic component use
Safety for workers and local population
Social acceptance
Satisfy all present and future environmental target/emission
Economic and robust

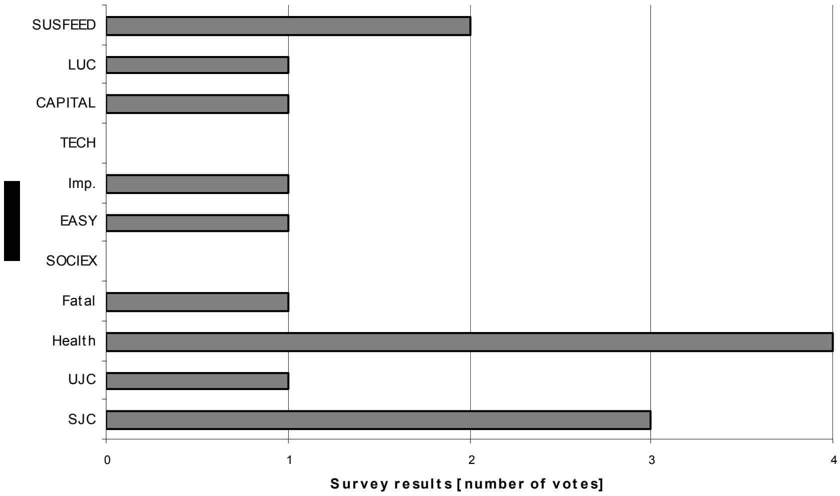


Figure A.2.8.1: Result of stakeholder questionnaire for People indicators

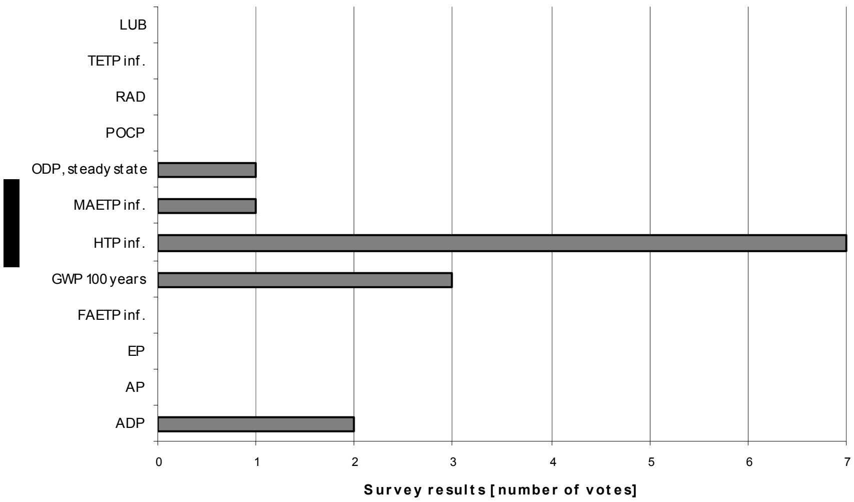


Figure A.2.8.2: Result of stakeholder questionnaire for Planet indicators

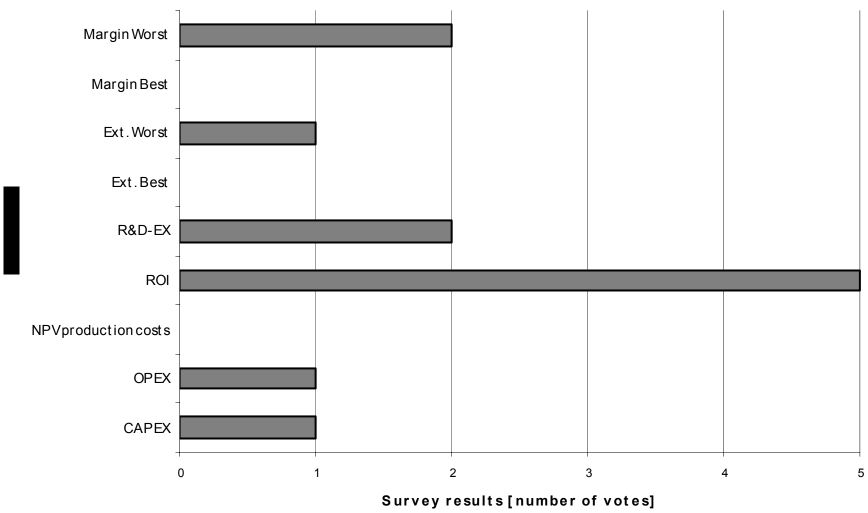


Figure A.2.8.3: Result of stakeholder questionnaire for Profit indicators

The stakeholders are given in Table A.2.8.2 with their group of society and background.

Table A.2.8.2: Stakeholders information

Name	Background/job	Which group of society?
Ruud van Ommen	Reactor engineering /Chemical engineer	Docent, engineer
Max Kwee	Theology/Priest	Theologist, civilian
Ton Meijknecht	Theology/Board of Motiv Studentenpastoraat	Theologist, civilian
Anne Geert van der Neut	Chemical Engineering student	Civilian, future engineer
Alex van der Kleij	Industrial design/student	Civilian, future engineer
Karel Kuijvenhoven	Chemical Engineering student	Civilian, future engineer
Tonny Nooyens	Industrial design/student	Civilian, future engineer
Carolien van der Graaf	Environment specialist Biology student	Civilian, environment activist
Hans Peter Calis	Shell Global Solution Chemical Engineers Reactor engineering	Shell/company
Dries Jansens	Industrial Design-Management Logistic manager	Civilian, engineer
Erik van der Wiel	Aerospace engineering Software salesman	Civilian
Anonymous 1	-	Civilian
Anonymous 2	-	Civilian
Hans Scholten	Secretariat of BVOR	Civilian
BVOR Agro Business Park 38 6708 Pw Wageningen www.bvor.nl	Specialist environmental technique	Environmental expert on emission
Jan Harmsen	Shell experts/professor of DCT	Shell/company

Appendix 2.9 Unit operations for different tasks

PRE-TREATMENT TECHNOLOGY

The results of the brainstorm session and quick selection of different pre-treatment technologies for:

- Removal of H2O from wood (drying)
- Reducing size of wood
- Producing gas
- Producing liquids
- Producing solids/char

are given in Table 2.12.1-2.12.5. The **bold** options are *not* rejected during the quick selection.

Table A.2.9.1: Removal of H2O from wood (drying)

Options generated during brainstorm session:	Quick selection	Remarks
• Lay wood in sun (or greenhouse)	In Baltic States and the Netherlands there is not enough sun and the area (land use) will be very large.	
• Absorb H_2O with salt	The salt gets into the wood stream and should be separated later.	
• Absorb H_2O with absorbent like silica-gel	Large amount of silica is needed, and when this is done in a storage tank, only the wood at the edges will be drying. Maybe this is an optimisation step.	
• Centrifugation of the wood	This is not an easy option to get H_2O out of wood.	
• Squeezing out H_2O	Too much pressure/energy is needed to squeeze H2O out of relative hard wood.	
• Drying with volcano-energy	In the Baltic States and the Netherlands there are no active volcano's.	
• Drying with earth geyser-energy	In the Baltic States and the Netherlands there are no active geysers.	
• Cryogenic drying	Too much energy is needed; this would be an option if 0 wt% wood should be produced.	
• **Oven dryer**	-	
• **Fluidized bed dryer**	-	
• **Steam dryer**	-	
• **Microwave**	-	

Table A.2.9.2: Reducing size of wood

Options generated during brainstorm session:	Quick selection	Remarks
• Dissolve of wood in acid	The output as waste is a large acid stream.	
• Sawyer	The assumption is made that the biomass is delivered with not too big logs. Therefore the some smaller logs can be shredded right away.	
• Sanding machine or belt	There are easier ways to reduce the size of the wood residues.	
• Degradable with bacteria	This option is not suitable for reducing the size of the wood. Namely, the bacteria 'eat' the wood, so there will be no wood anymore. Also large reaction time and large volumes.	
• **Hammer**	Is more or less the same as grinding/milling.	Is an option if wood is crisp, like after torrefaction.
• **Chipper**	-	All logs have to be chipped in smaller parts; wood chips and sawdust do not be shred.
• **Grinding/milling to dust**	-	Depending on sort reactor
• **Pelletising system**	-	Densification of wood. Depending on reactor if pellets can be gasified without further treatment.

Table A.2.9.3: Producing gas

Options generated during brainstorm session:	Quick selection	Remarks
• Rotting or composting the wood	This option is too slow in operation.	
• Heating of wood till it will evaporate	Also this option is too slow and the temperature will be very high till wood evaporates and probable it burns before it evaporates.	
• Producing biogas with bacteria	Also this option is too slow in operation.	
• **Oxidation or partial oxidation**	-	Mainly done in CFB reactor.

Table A.2.9.4: Producing liquid

Options generated during brainstorm session:	Quick selection	Remarks
• Dissolve in solution	The solution should be separated from the wood stream; this means an extra separation step. Also which solution is needed? Maybe a toxic one.	
• Conversion to liquid with bacteria	This option is too slow in operation.	
• Esterification	This is done with the help of bacteria and thus too slow.	
• Condensing after gas is produced	This option uses too much energy.	
• Producing pulp	This option is also too slow in operation.	
• Hydro Thermal Upgrading (HTU)	Operates at too high pressure (100-180 bar). It is also possible to produce biodiesel from the HTU liquid instead of producing syngas from the liquid and afterwards convert it to diesel with the FT process.	
• Compressing with CO2 a la HTU	Same as HTU.	
• **Pyrolyse**	-	Producing mainly liquid, but also gas and char.

Table A.2.9.5: Producing solids/char

Options generated during brainstorm session:	Quick selection	Remarks
• Big hole in ground, with high P and T	This option operates too slow.	
• In furnace till the wood becomes black	This option can be classified as torrefaction.	
• **Torrefaction**	-	Input of logs is also possible and milling of wood after torrefaction will cost less energy.

GASIFICATION TECHNOLOGY [1][2]

The temperature at which the gasification process takes place, determines to great extent what gases are being produced. Above temperatures of about 1300°C, all components are decomposed to H_2, CO, H_2O and CO_2. The alternative is gasification at temperatures from 700-1000°C. The produced gas then contains (large quantities) of carbohydrates like methane and tars.
For the (very) large-scale production of syngas from wood, there are only 2 to 3 serious candidates for the reactor. These are:

- Circulating fluidized bed reactor (CFB)
  - Pressure: 1-20 bar
  - Temperature: 700-1000°C
  - Oxidizing agent: air (allotherm) or oxygen (autotherm)
    (Air = not autotherm, because nitrogen separation is difficult)

    - Wood particles can be a few centimetres
- Entrained flow reactor (EF)
    - Pressure: 1-40 bar
    - Temperature: 1300-1600°C
    - Oxidizing agent: oxygen (autotherm)
    - Wood particles should be dust
- Fixed bed (sometimes called moving-bed) reactor
    - Pressure: 1-40 bar
    - Temperature: 425-850°C
    - Oxidizing agent: air (autotherm)
    - Wood particles should be a few centimetres

For the large-scale production of oxygen, the most common option is cryogenic distillation. The electrolysis of water was also shortly investigated, since this would produce both H_2 and O_2, but this option consumes large amounts of energy and was thus discarded.

AFTER-TREATMENT TECHNOLOGY

The results of the brainstorm session and quick selection of different after-treatment technologies for:

- Separating of solids from gas
- Separating of gas from gas

are given in Table A.2.9.6 and A.2.9.7. The **bold** options are *not* rejected during the quick selection.

Table A.2.9.6: Separating of solids from gas

Options generated during brainstorm session:	Quick selection	Remarks
Cyclone	OK	
Electrostatic Precipitator (ESP)	OK	
Filter	Not for large quantities of solids.	
Precipitating	Gas flow is too large.	
Washing out	OK	= Aqueous scrubber
Reactive filtering	OK	= Sorbents

Table A.2.9.7: Separating of gas from gas

Options generated during brainstorm session:	Quick selection	Remarks
Scrubber	OK	
Condenser	OK	
Absorber	OK	
Membrane	OK	New technology
(Supercritical) distillation	OK	Use a lot of energy.

Unit operations per impurity removal (Done also with literature research)

<u>Removal of tars (after CFB reactor)</u>
Catalytic cracker – High T
Thermal cracker – High T
Tar condenser / Condensing scrubber + droplet removal – Low T

OLGA – Medium T

Removal of solids
Cyclone – can also be used at high temperatures
Electro-Static Precipitator (EPS) – for fine dust

NH3 removal
Decomposition to N2 + H2 = Catalytic cracker
Aqueous scrubber

HCN removal
Decomposition = Catalytic cracker
Hydrolysis (with H2O) to NH3

H2S removal
MDEA scrubber
Rectisol scrubber
Bio Claus / Thiopauq
Absorption onto pellets (Zn2TiO4)
Active coal filter

COS removal
Hydrolysis (with H2O) to H2S
Absorption onto pellets (Zn2TiO4)

HCl removal
Aqueous scrubber
Absorption onto pellets (Ca(OH)2 or NAHCO3)
Active coal filter

Adaptation of H2
Mixing of H2 with syngas
Water-Gas Shift reactor

H2O removal
Water condenser

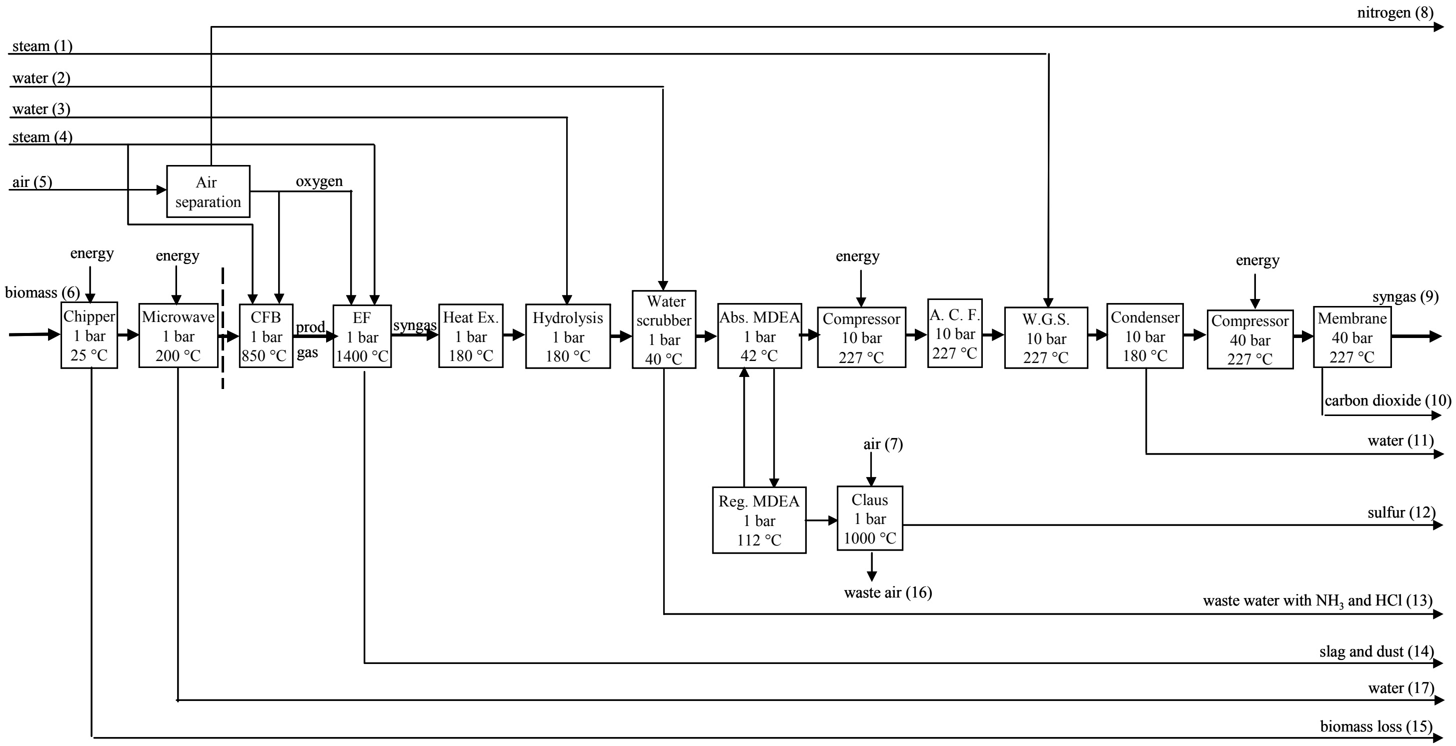
CO2 removal
Membrane
MDEA scrubber

References:
[1] H. den Uil e.a., *Duurzaam synthesegas; een brug naar een duurzame energie- en grondstoffenvoorziening*, Energie Centrum Nederland, Report no. ECN-C-04-015, February 2004.
[2] Personal communication with prof. C. Daey Ouwens, Eindhoven University of Technology

Appendix 2.10: Block schemes SUSDAT cases, mass balances and optimal weight factors for KSI scoring

CASE A: CFB + EF + Cold gas cleaning

Advantages:	Disadvantages
No energy-consuming milling needed Fast drying using microwave Less transport load by chipping in land of origin	Two gasification reactor Low pressure and therefore large volume



TUDelft

	2Mass Balances (average over 5 years)					Margin	
	All Incoming species	Flownumber	Amount (kg/s)	P (Bar)	T (K)	Price (€/kg)	Costs (M€/a)
1	Biomass	6	820.6	1	298	0.007	157.4
2	Steam	4	57.8	1	1673	0.013	21.7
3	Steam	1	162.6	10	500	0.013	61.0
4	Water	3	99.5	1	453	0.000	0.6
5	Water	2	1071.0	1	453	0.000	6.7
6	Air for air separation	5	1219.2	1	298	0.000	0.0
7	Air for Claus plant	7	1.4	1	520	0.000	0.0
8	MDEA makeup	-	0.8	1	313	3.271	70.9
9	WGS catalyst usage	-	0.8	10	500	0.200	4.8
10	Active coal usage	-	4.2E-03	1	313	0.281	0.0
Total			3433.7				323.1
	All Outgoing species	Flownumber	Amount (kg/s)	P (Bar)	T (K)	Price (€/kg)	Revenu (M€/a)
1	Syngas	9	361.3	40	500	0.129	1342.3
2	Carbon dioxide	10	483.6	1	500	0.000	0.0
3	Waste air from Claus	16	112.2	1	520	0.000	0.0
4	Slag and dust	14	6.4	1	1673	-0.020	-3.8
5	Active coal spent	-	8.4E-03	1	313	-0.250	-0.1
6	Sulphur (s)	12	0.5	1	520	0.039	0.6
7	MDEA purge	-	0.8	1	313	-0.250	-5.4
8	Waste water	17	194.1	1	373	-0.050	-279.4
9	Waste water	13	1076.3	1	313	-0.050	-1549.9
10	Waste water	11	247.0	1	500	-0.050	-355.7
11	Biomass loss	15	16.4	1	298	0.000	0.0
12	WGS catalyst spent	-	0.8	10	500	-0.250	-6.0
13	Nitrogen (l)	8	937.1	1	220	0.061	1635.6
Total			3436.6				778.2
Value should be zero			-2.9				

3Economic Margin [M€/a]	455.1

6 Energy Balances

	Incoming Energy streams (>10% of biggest)	Amount (kW)	P (Bar)	T (K)
1	Electricity for chipper	18753	1	298
2	Electricity from natural gas	1466154		
3	Electricity MDEA unit	356019		
4	Electricity for compressor	286997		
5	Electricity for compressor	248000		
6	Electricity for air separation plant	320535		
Total		2696457		
	Outflowing Energy streams (>10% of biggest)	**Amount (kW)**	**P (Bar)**	**T (K)**
Total		0		
	Guestimate Energy Consumption (kW)	2696457		

7 Major Equipment

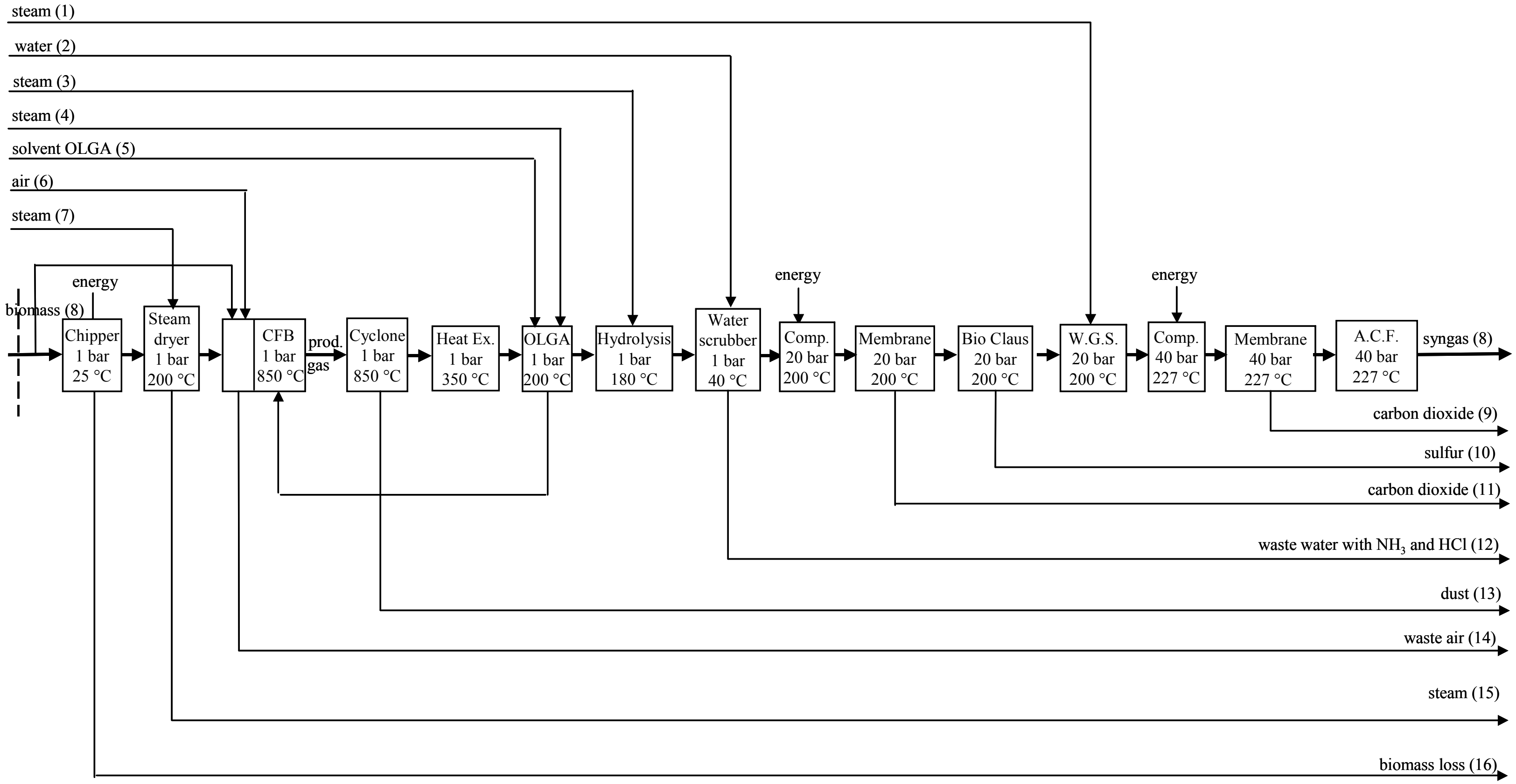
	Equipment name	Type	P (Bar)	T (K)	Price (M€)
1	Microwave		1	373	44.0
2	Circulating Fluidized Bed reactor	oxygen/steam	1	1123	1024.9
3	Entrained Flow reactor	oxygen/steam	1	1673	860.9
4	Water-Gas Shift reactor		10	520	88.0
5	Membrane		40	500	136.0
6	Air separation plant		1	298	110.6
7	Other equipments		1	298	274.0
Total					2538.3

8 New Technology

	New Technology description	R&D Costs (M€)
1	EF for large scale application	133.6
2	Scrubber	6.8
3	MDEA regeneration plant	1.7
4	Claus plant	3.4
5	Membrane	20.4
Total		166.0

CASE B: CFB + OLGA + Bio Claus

Advantages	Disadvantages
Relatively low temperature process, thus less biomass needed No energy-consuming milling needed	Low pressure, therefore large volumes New Technology OLGA



	2Mass Balances (average over 5 years)					**Margin**	
	All Incoming species	**Flownumber**	**Amount (kg/s)**	**P (Bar)**	**T (K)**	**Price (€/kg)**	**Costs (M€/a)**
1	Biomass	8	940.8	1	300	0.007	189.7
2	Water	2	150.4	1	300	0.000	1.0
3	Steam	1	131.1	1	500	0.013	49.1
4	Steam	3	19.5	1	500	0.013	7.3
5	Steam	4	152.5	1	500	0.013	57.1
6	Steam	7	114.0	1	500	0.013	42.7
7	Solvent OLGA	5	0.8	1	300	0.450	10.8
8	Solvent BioClaus makeup	-	0.6	1	400	0.035	0.6
9	Air	6	703.7	1	300	0.000	0.0
10	Active coal usage	-	0.0	1	300	0.281	0.0
11	Hydrolysis catalyst usage	-	0.5	1	300	0.151	2.0
12	WGS catalyst usage	-	0.0	1	300	0.200	0.0
Total			2213.8				360.2
	All Outgoing species	**Flownumber**	**Amount (kg/s)**	**P (Bar)**	**T (K)**	**Price (€/kg)**	**Revenu (M€/a)**
1	Steam	15	295.9	1	400	0.000	0.0
2	Carbon dioxide	9	97.3	1	310	0.000	0.0
3	Carbon dioxide	11	115.0	1	310	0.000	0.0
3	Syngas	8	403.0	40	500	0.129	1497.1
4	Biomass loss	16	15.7	1	300	-0.007	-3.2
5	Dust	13	6.0	1	400	-0.020	-3.5
6	Waste water	12	472.1	1	310	-0.050	-679.9
7	Sulphur (s)	10	0.5	1	300	0.039	0.5
8	Spent solvent BioClaus	-	0.6	1	300	0.000	0.0
9	Active coal spent	-	1.8E-03	40	500	-0.250	0.0
10	Waste air	14	807.4	1	300	-0.002	-46.5
11	WGS catalyst spent	-	1.3E-04	1	300	-0.250	0.0
12	Hydrolysis catalyst spent	-	0.0E+00	1	300	-0.250	0.0
Total			2213.4				764.5
Value should be zero			0.5				

3Economic Margin	**404.3**

6 Energy Balances

	Incoming Energy streams (>10% of biggest)	Amount (kW)	P (Bar)	T (K)
1	Electricity for chipper	25685		
2	Electricity for steam dryer	2343		
3	Electricity for compressor	184523		
Total		212552		
	Outflowing Energy streams (>10% of biggest)	**Amount (kW)**	**P (Bar)**	**T (K)**
Total		0		
	Guestimate Energy Consumption	212552		

7 Major Equipment

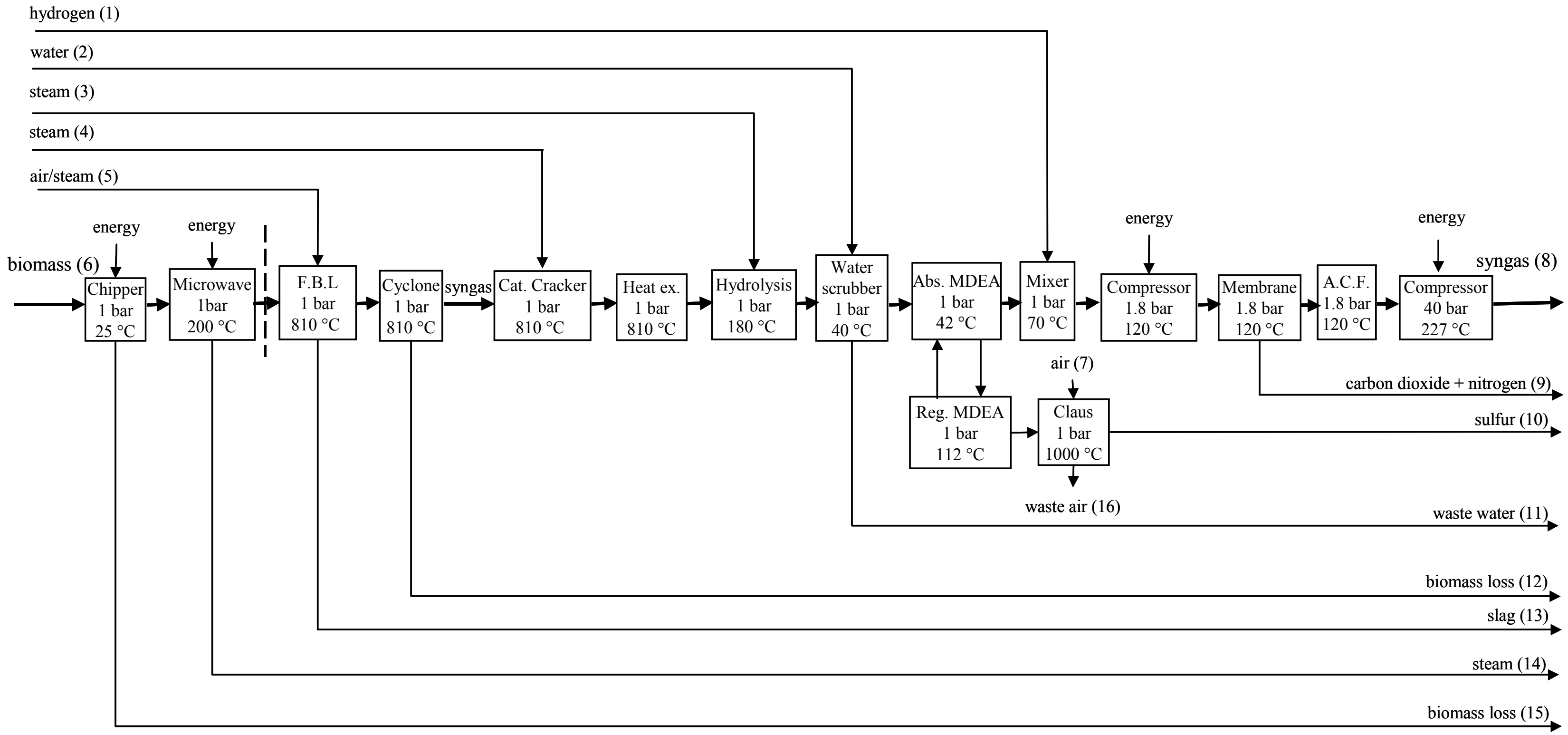
	Equipment name	Type	P (Bar)	T (K)	Price (M€)
1	Steam dryer				418.9
2	Circulating Fluidized Bed reactor	Air/Allotherm	1	1123	2118.2
3	Cyclone				29.0
4	OLGA				25.0
5	Hydrolysis				32.0
6	Membrane1				136.0
7	Water-Gas Shift reactor				88.0
8	Compressor				156.8
9	Membrane2				136.0
10	Other equipments				31.4
Total					3171.3

8 New Technology

	New Technology description	R&D Costs (M€)
1	OLGA	3.8
2	Membrane	20.4
3	CFB, Allotherm, Air	105.9
Total		130.1

CASE C: Fixed bed + Cold Gas Cleaning + Hydrogen mixing

Advantages	Disadvantages
No tar production in the entrained flow reactor Slag contains the minerals Proven technology	Mixing with hydrogen Low pressure, therefore large volumes



2	Mass Balances (average over 5 years)					Margin	
	All Incoming species	Flownumber	Amount (kg/s)	P (Bar)	T (K)	Price (€/kg)	Costs (M€/a)
1	Biomass	6	588.3	1	298	0.007	112.8
2	Steam	3	39.8	1	400	0.013	14.9
3	Steam	4	2.0	1	400	0.013	0.8
4	Steam	5	105.1	1	400	0.013	39.4
5	Air	5	457.7	1	1073	0.000	0.0
6	Air for Claus plant	7	1.4	1	298	0.000	0.0
7	Water	2	64.1	1	298	0.000	0.5
8	Hydrogen	1	17.9	1	343	2.300	1188.5
9	Active coal usage	-	0.0	1	298	0.281	0.0
10	MDEA makeup	-	0.7	1	343	3.271	70.4
Total			1277.0				1427.4
	All Outgoing species	Flownumber	Amount (kg/s)	P (Bar)	T (K)	Price (€/kg)	Revenu (M€/a)
1	Waste air	16	344.8	1	298	0.000	0.0
2	Carbon dioxide+nitrogen	9	142.5	1	298	0.000	0.0
3	Syngas	8	382.3	40	500	0.129	1420.4
4	Biomass Loss	15	16.3	1	298	0.000	0.0
5	Slag	13	4.6	1	1073	-0.020	-2.7
6	Waste water	11	248.1	1	313	-0.050	-357.2
7	Sulphur (s)	10	0.4	1	519	0.039	0.5
8	Active coal spent	-	0.0	1.8	393	-0.250	0.0
9	MDEA purge	-	0.7	1	343	-0.250	-5.4
10	Steam	14	137.2	1	100	0.013	51.5
Total			1277.0				1107.0
Value should be zero			0.0				

3	Economic Margin	-320.4

TUDelft

6 Energy Balances

	Incoming Energy streams (>10% of biggest)	Amount (kW)	P (Bar)	T (K)
1	Electricity for microwave	1498861		
2	Electricity for chipper	19271		
3	Electricity for MDEA unit	449540		
4	Electricity for compressor	42739		
5	Electricity for compressor	213416		
Total		2223827		
	Outflowing Energy streams (>10% of biggest)	**Amount (kW)**	**P (Bar)**	**T (K)**
Total		0		
	Guestimate Energy Consumption	2223827		

7 Major Equipment

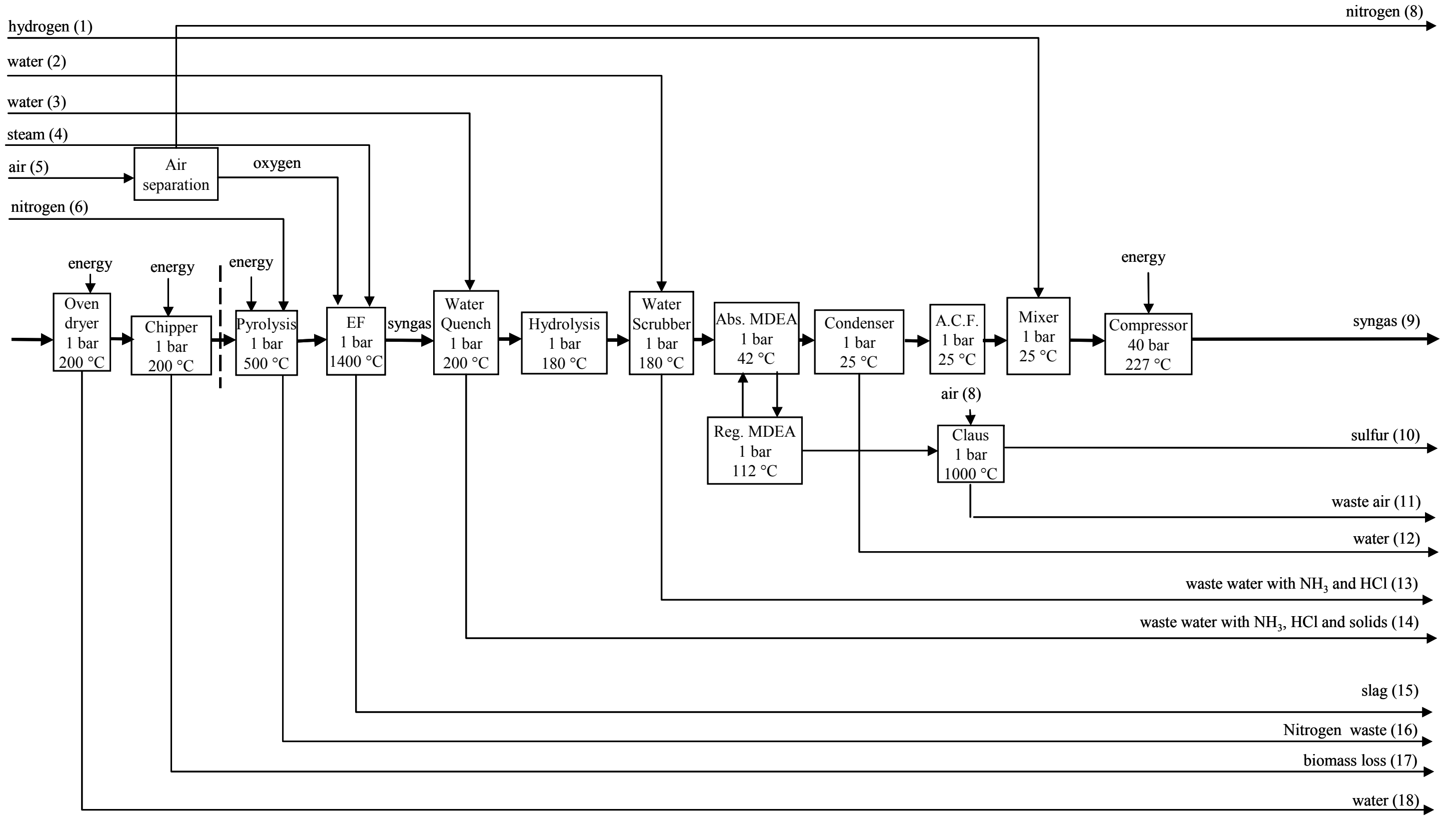
	Equipment name	Type	P (Bar)	T (K)	Price (M€)
1	Fixed bed reactor	BGL	1	1083	738.1
2	Microwave				31.5
3	Cyclone				51.8
4	Catalytic Cracker				40.2
5	Hydrolysis				325.8
6	Other equipments				118.7
Total					1306.1

8 New Technology

	New Technology description	R&D Costs (M€)
1	Microwave	3.2
2	Fixed bed Lurgi	73.8
3	Hydrolysis	16.3
4	MDEA regeneration plant	0.1
5	Claus plant	0.4
Total		93.8

CASE D: Pyrolysis + EF + Cold Gas Cleaning + Hydrogen Mixing

Advantages	Disadvantages
Pyrolysis liquid is easier to handle than solids Less transport due to pyrolysis and EF for good conversion Less biomass input, since hydrogen is added	Large volumes/large equipment Mixing with hydrogen



TUDelft

2	Mass Balances (average over 5 years)					Margin	
	All Incoming species	**Flownumber**	**Amount (kg/s)**	**P (Bar)**	**T (K)**	**Price (€/kg)**	**Costs (M€/a)**
1	Biomass	7	448.3	1	373	0.007	86.0
2	Air	5	662.1	1	288	0.000	0.0
3	Water	2	32.8	1	288	0.000	0.3
4	Water	3	98.4	1	288	0.000	0.0
5	Steam	4	16.8	16	473	0.000	0.0
6	Hydrogen	1	29.0	1	273	2.300	1922.2
7	MDEA makeup	-	0.3	1	288	3.271	29.7
8	Hydrolysis catalyst	-	0.1	1	298	0.151	0.2
9	Active coal usage	-	0.0	1	298	0.281	0.0
10	Nitrogen for pyrolysis	6	1.0	1	773	0.061	1.7
Total			1288.7				2040.2
	All Outgoing species	**Flownumber**	**Amount (kg/s)**	**P (Bar)**	**T (K)**	**Price (€/kg)**	**Revenu (M€/a)**
1	Syngas	9	403.8	40	500	0.129	1500.1
2	Biomass loss	17	6.8	40	500	0.000	0.0
3	Waste water (dryer)	18	106.4	1	298	0.000	0.0
4	Waste water	14	33.3	1	473	-0.050	-48.0
5	Waste water	13	166.1	1	453	-0.050	-239.2
6	Waste water	12	16.7	1	298	-0.050	-24.0
7	Waste air	11	45.8	1	500	0.000	0.0
8	Slag	15	3.5	1	473	-0.020	-2.1
9	Nitrogen (l)	8	507.8	1	298	0.061	885.5
10	Sulphur (s)	10	0.3	1	500	0.039	0.3
11	MDEA spent	-	0.3	1	385	-0.250	-2.3
12	Hydrolysis catalyst spent	-	0.1	1	298	-0.250	-0.7
13	Active coal spent	-	0.0	1	298	-0.250	0.0
14	Nitrogen waste	16	1.0	1	773	0.000	0.0
Total			1291.0				2070.3
Value should be zero			2.3				

3	Economic Margin	30.1

TUDelft

6 Energy Balances

	Incoming Energy streams (>10% of biggest)	Amount [kW]	P (Bar)	T (K)
1	Drying	73613		
2	Chipping	11200		
3	Pyrolysis	44868		
4	MDEA process	143204		
5	Compressor	300800		
6	Air separation	175077		
Total		748761		
	Outflowing Energy streams (>10% of biggest)	**Amount [kW]**	**P (Bar)**	**T (K)**
Total		0		
	Guestimate Energy Consumption	**748761**		

7 Major Equipment

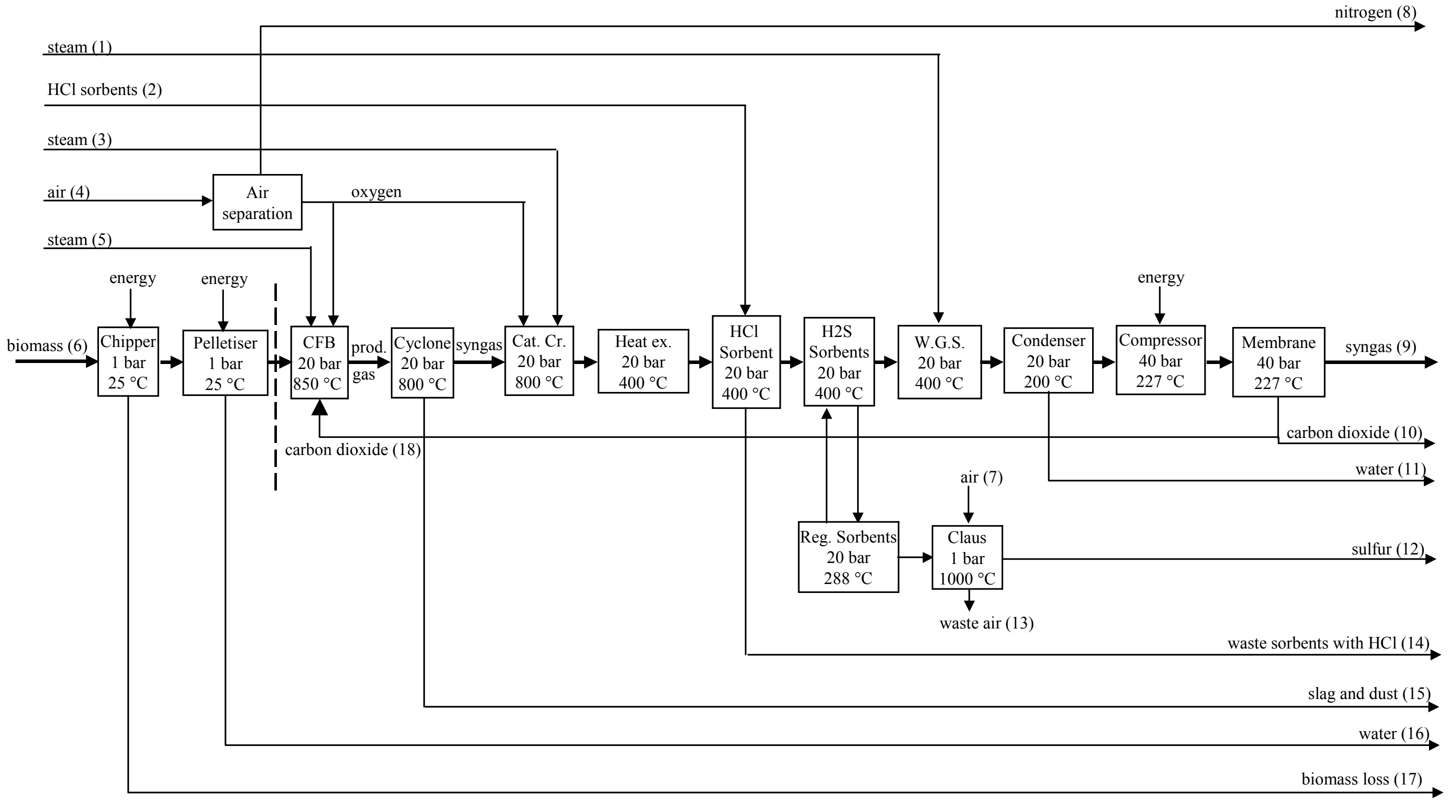
	Equipment name	Type	P (Bar)	T (K)	Price (M€)
1	Steam dryer		1	373	25.8
2	Air separation plant		1	298	453.7
3	Pyrolysis		1	773	36.7
4	Entrained flow reactor	Oxygen	1	1473	472.8
5	Fixed bed for hydrolysis		1	453	208.9
6	Other equipments		-	-	119.8
Total					**1317.8**

8 New Technology

	New Technology description	R&D Costs
1	Pyrolysis	3.7
2	Entrained Flow reactor	47.3
3	Claus plant	0.4
4	MDEA regeneration plant	0.1
Total		**51.5**

CASE E: CFB + hot gas cleaning

Advantages:	Disadvantages
No energy-consuming milling needed High pressure, thus smaller equipment Less waste through the use of sorbent No solvents needed through the use of sorbent and membrane	New technology



2Mass Balances (average over 5 years) / Margin

	All Incoming species	Flownumber	Amount (kg/s)	P (Bar)	T (K)	Price (€/kg)	Costs (M€/a)
1	Biomass	6	690.2	1	293	0.007	132.4
2	Carbon dioxide	18	41.3	20	473	0.000	0.0
3	Steam	5	129.0	20	473	0.013	48.4
4	Air	4	581.2	1	293	0.000	0.0
5	Steam	3	4.5	20	473	0.013	1.7
6	Sorbents for HCl rem.	2	1.5	1	293	0.200	8.6
7	Sorbents for H2S and COS rem.	-	2.4E-02	1	293	7.273	5.0
8	Steam	1	101.0	20	473	0.013	1.3
9	Cracker catalyst usage	-	0.1	1	293	0.200	0.7
10	Claus catalyst usage	-	0.0	1	293	0.200	0.0
11	WGS catalyst usage	-	2.0E-04	1	293	0.200	0.0
12	Air for Claus Unit	7	1.5	1	293	0.000	0.0
Total			1550.2				198.1

	All Outgoing species	Flownumber	Amount (kg/s)	P (Bar)	T (K)	Price (€/kg)	Revenu (M€/a)
1	Biomass	17	13.8	1	293	0.000	0.0
2	Water	11	160.5	1	293	-0.050	-231.1
3	Solids	15	21.0	20	1073	-0.020	-12.4
4	Sorbents with HCl abs.	14	1.8	1	473	-0.250	-12.9
5	Sorbents with H2S and COS abs.	-	0.0	1	293	-0.250	-0.2
6	Water (with tar)	16	112.0	20	473	-0.050	-5.6
7	Carbon dioxide	10	393.2	1	473	0.000	0.0
8	Syngas	9	407.6	40	500	0.129	1514.4
9	Nitrogen (l)	8	445.8	1	293	0.061	778.1
10	Cracker catalyst spent	-	0.3	1	293	-0.250	-1.8
11	Claus catalyst spent	-	0.0	1	293	-0.250	0.0
12	WGS catalyst spent	-	2.0E-04	1	293	-0.250	0.0
13	Air out of Claus unit	13	1.4	1	293	0.000	0.0
14	Sulphur (s)	12	0.4	1	293	0.039	0.5
Total			1557.9				2028.9
Value should be zero			-7.7				

3Economic Margin [M€/a] **1830.8**

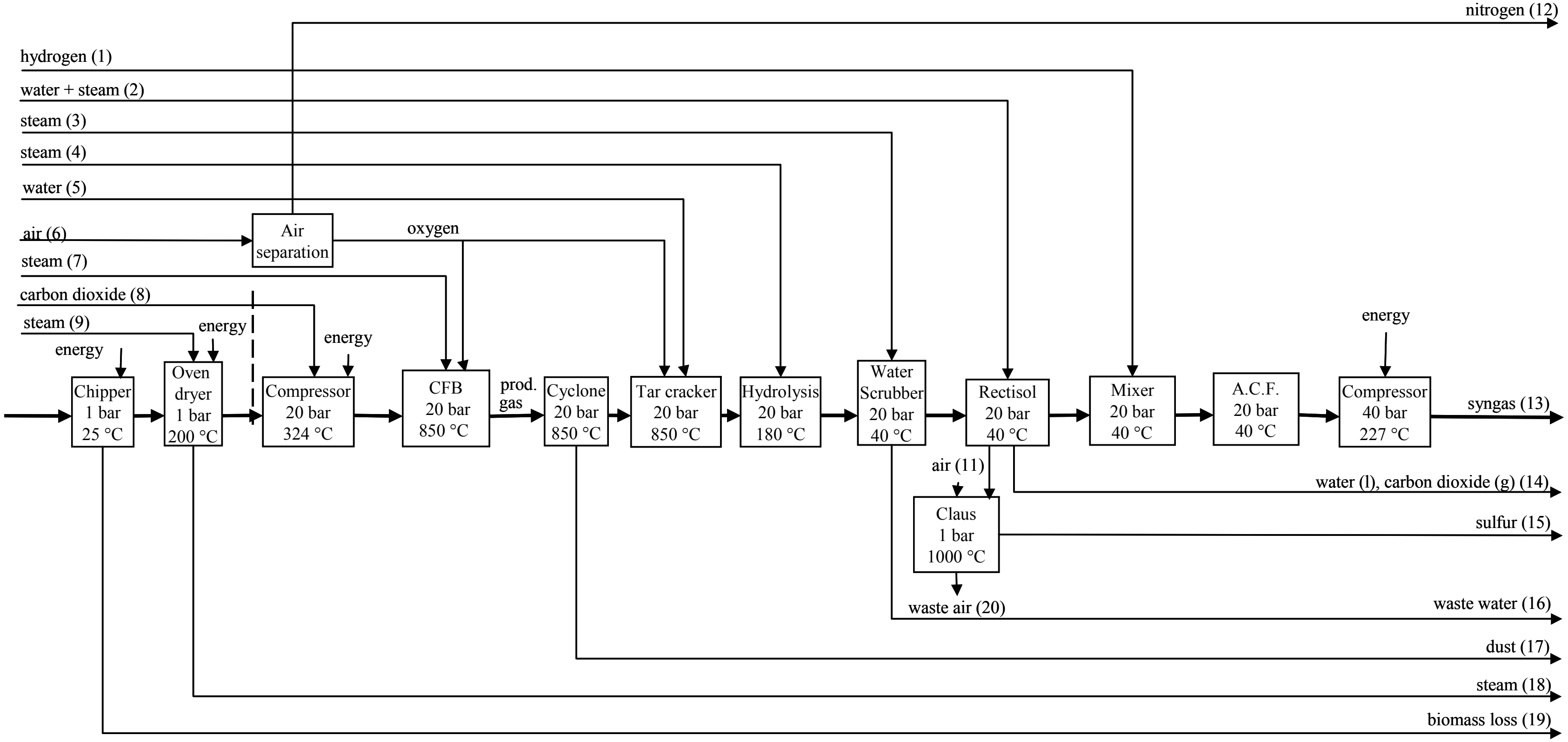
6	Energy Balances			
	Incoming Energy streams (>10% of biggest)	**Amount (kW)**	**P (Bar)**	**T (K)**
1	Electricity for chipper	22611		
2	Electricity for pelleting system	243503		
3	Electricity for compressor (Carbon dioxide)	13608		
4	Electricity for compressor (syngas)	90245		
5	Electricity for air separation plant	153768		
Total		369966		
	Outflowing Energy streams (>10% of biggest)	**Amount (kW)**	**P (Bar)**	**T (K)**
Total		0		
	Guestimate Energy Consumption (kW)	369966		

7	Major Equipment				
	Equipment name	**Type**	**P (Bar)**	**T (K)**	**Price (M€)**
1	Pelleting system		1	298	404.2
2	Circulating Fluidized Bed reactor	Oxygen blown autotherm	20	1123	866.7
3	Catalytic cracker		20	1073	34.5
4	Water-Gas Shift reactor		20	673	88.0
5	Membrane		20	473	136.0
6	Air separation plant		1	298	398.5
7	Other equipments		1	298	192.8
Total					2120.7

8	New Technology	
	New Technology description	**R&D Costs (M€)**
1	Pelleting system	40.4
2	Large scale reactor	43.3
3	Membrane	20.4
4	Sorbents	29.2
5	Claus plant	0.3
Total		133.6

Case F: CFB + Wet Gas Cleaning + Hydrogen mixing

Advantages:	Disadvantages
Relatively low temperature process, thus less biomass needed Rectisol used in this option is a superb purification device for CO_2 and H_2S removal	Rectisol, high energy consumption Use of solvent Hydrogen input



2Mass Balances (average over 5 years)

	All Incoming species	Flownumber	Amount (kg/s)	P (Bar)	T (K)	Price (€/kg)	Costs (M€/a)
1	Biomass	10	626.5	1	298	0.007	120.2
2	Steam BS	9	326.7	1	473	0.013	122.6
3	Air	6	568.9	1	298	0.000	0.0
4	Water + steam	2	7309.7	20	473	0.001	115.8
5	Steam	3	51.8	20	473	0.013	19.4
6	Steam	4	17.3	20	473	0.013	6.5
7	Steam	7	121.0	20	473	0.013	45.4
8	Water	5	3.4	20	335	0.000	0.0
9	Hydrogen	1	7.1	20	298	2.300	469.3
10	Carbon dioxide	8	35.8	1	298	0.000	0.0
11	Air to claus	11	1.3	1	298	0.000	0.0
12	Hydrolysis catalyst usage	-	0.3	1	298	0.151	1.3
13	Tar cracker catalyst usage	-	0.1	1	298	0.130	0.4
14	Catalyst for Claus unit	-	0.0	1	298	0.000	0.0
15	Active coal usage	-	0.3	1	298	0.281	2.7
Total			9070.2				903.5

Margin

	All Outgoing species	Flownumber	Amount (kg/s)	P (Bar)	T (K)	Price (€/kg)	Revenu (M€/a)
1	Biomass loss	19	12.5	1	303	0.000	0.0
2	Dust	17	18.6	1	303	0.000	0.0
3	Syngas	13	335.8	40	500	0.129	1247.6
4	Waste water	16	103.3	1	298	-0.050	-148.8
5	Waste water from Rectisol	14	7668.2	1	298	0.000	0.0
6	Sulfur	15	0.4	1	298	0.039	0.4
7	Active coal spent	-	1.0	1	298	-0.250	-7.0
8	Steam	18	492.7	1	473	0.000	0.0
9	Waste air claus	20	1.3	1	310	0.000	0.0
10	Nitrogen	12	436.6	1	275	0.000	0.0
11	Hydrolysis cat.	-	0.3	1	298	-0.250	-2.2
12	Tar cracker cat.	-	0.1	1	298	-0.250	-0.7
13	Catalyst for Claus unit	-	0.0	1	298	0.000	0.0
Total			9070.8				1089.4
Value should be zero			-0.6				

3Economic Margin [M€/a]

185.9

6 Energy Balances

	Incoming Energy streams (>10% of biggest)	Amount (kW)	P (Bar)	T (K)
1	Electricity for chipper	20524		
2	Electricity for Rotary drum	11951		
3	Electricity for compressor (Carbon dioxide)	17820		
4	Electricity for compressor (syngas)	1349		
5	Electricity for Rectisol unit	1451600		
6	Electricity for air separation plant	150609		
Total		1653854		
	Outflowing Energy streams (>10% of biggest)	**Amount (kW)**	**P (Bar)**	**T (K)**
Total		0		
	Guestimate Energy Consumption (kW)	1653854		

7 Major Equipment

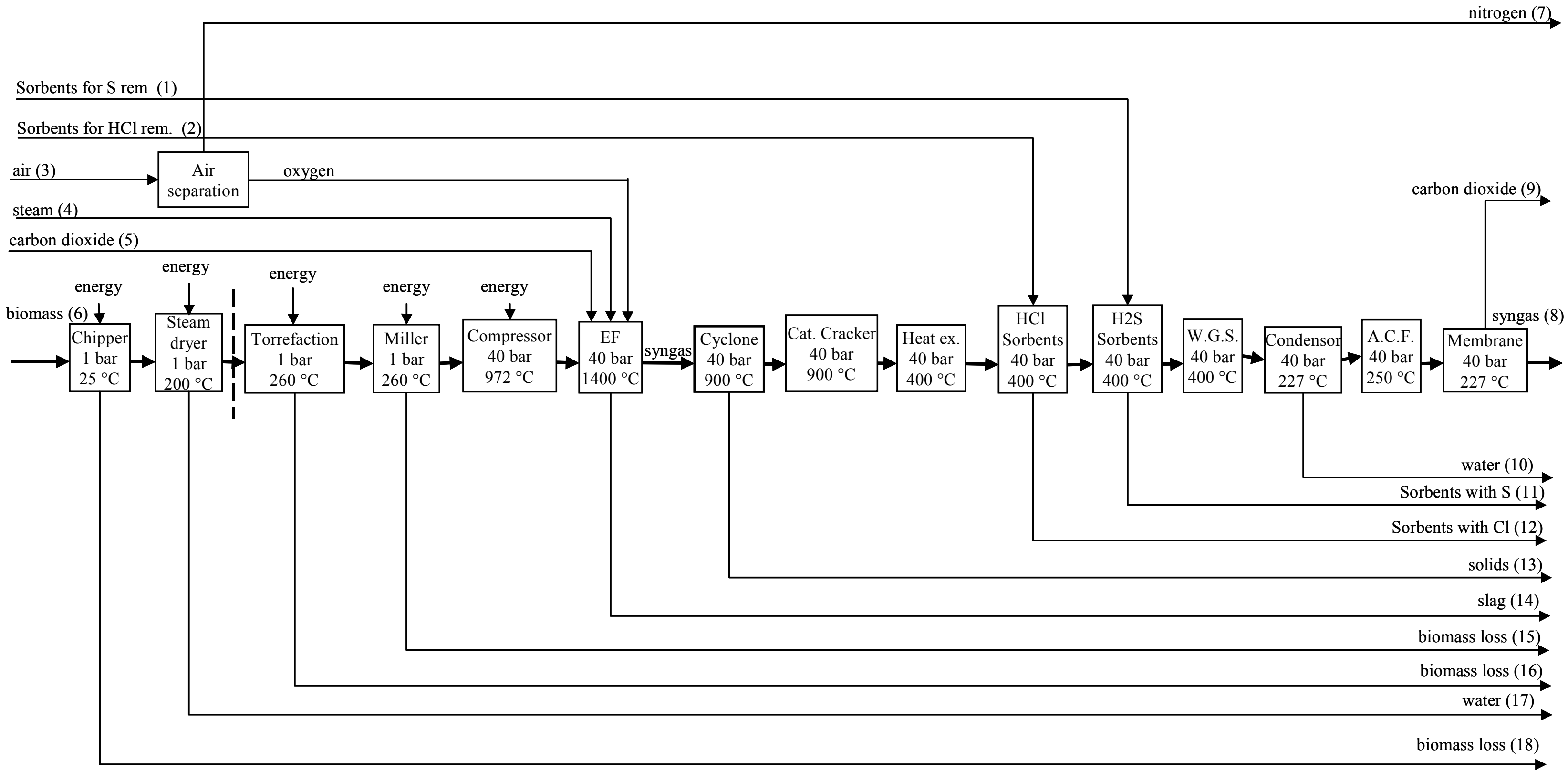
	Equipment name	Type	P (Bar)	T (K)	Price (M€)
1	Chipper		1	298	14.9
2	Rotary drum dryer		1	473	35.4
3	Circulating Fluidized Bed	Oxygen blown autotherm	20	1123	812.8
4	Catalytic cracker		20	1123	31.7
5	Rectisol unit		20	313	167.9
6	Hydrolysis reactor		20	453	260.2
7	Air separation plant		1	298	390.3
8	Other equipments				169.8
Total					1868.2

8 New Technology

	New Technology description	R&D Costs (M€)
1	Rectisol unit	16.8
2	Large reactor	40.6
3	Claus plant	0.3
Total		57.7

CASE G: Torrefaction + EF + Hot gas cleaning

Advantages	Disadvantages
Less waste through the use of sorbent. No solvents needed through the use of sorbent and a membrane Easy milling due to the torrefaction process	



TU Delft

2 Mass Balances (average over 5 years)

	All Incoming species	Flownumber	Amount (kg/s)	P (Bar)	T (K)	Margin Price (€/kg)	Costs (M€)
1	Biomass	6	993.5	1	298	0.007	190.5
2	Steam	4	36.9	40	533	0.013	13.8
3	Carbon dioxide	5	258.1	40	533	0.000	0.0
4	Air	3	1645.8	1	298	0.000	0.0
5	Sorbents for HCl rem.	2	3.4	40	298	0.200	19.6
6	Sorbents for H2S and COS	1	3.1	40	298	7.273	655.5
7	Cracker catalyst usage	-	0.0	40	298	0.151	0.1
8	Active coal usage	-	0.0	40	298	0.281	0.1
Total			2940.9				879.4

	All Outgoing species	Flownumber	Amount (kg/s)	P (Bar)	T (K)	Price (€/kg)	Revenu (M€)
1	Slag	14	6.8	1	300	-0.020	-3.9
2	Water	10	84.5	1	298	-0.050	-121.7
3	Nitrogen	7	1262.3	1	298	0.061	2203.3
4	Carbon dioxide	9	931.3	40	500	0.000	0.0
5	Syngas	8	392.4	40	500	0.129	1458.0
7	Sorbents with HCl abs.	12	4.1	1	300	-0.250	-29.4
8	Sorbents with H2S and COS	11	3.9	1	300	-0.250	-27.9
9	Solids	13	0.8	1	300	-0.020	-0.4
10	Biomass loss	15	15.1	1	298	0.000	0.0
11	Biomass loss	16	7.6	1	298	0.000	0.0
12	Water	17	213.5	1	298	0.000	0.0
13	Biomass loss	18	19.9	1	298	0.000	0.0
14	Cracker catalyst spent	-	0.0	1	300	-0.250	-0.1
15	Active coal spent	-	0.0	1	298	-0.025	0.0
Total			2942.1				3477.9
Value should be zero			1.2				

3 Economic Margin [M€/a] **2598.5**

6 Energy Balances

	Incoming Energy streams (>10% of biggest)	Amount (kW)	P (Bar)	T (K)
1	Electricity for drying	538121		
2	Electricity for chipping	32547		
3	Electricity for milling	22140		
4	Electricity for torrefaction	684127		
5	Electricity for compressor	51820		
6	Electricity for air separation plant	435649		
Total		1764403		
	Outflowing Energy streams (>10% of biggest)	**Amount (kW)**	**P (Bar)**	**T (K)**
Total		0		
	Guestimate Energy Consumption	1764403		

7 Major Equipment

	Equipment name	Type	P (Bar)	T (K)	Price (M€)
1	Fluidized bed dryer		1	373	64.9
2	Air separation plant		1	298	1129.0
3	Torrefaction		1	533	361.5
4	Entrained flow reactor	oxygen/steam	40	1673	1040.7
6	Catalytic cracker for NH3		40	1073	386.4
7	Water-Gas Shift reactor		40	520	88.0
8	Membrane		40	500	136.0
9	Other equipments		-	-	320.7
Total					3527.2

8 New Technology

	New Technology description	R&D Costs (M€)
1	Torrefaction	36.2
2	EF	104.1
3	Decomp. NH3	38.6
4	CO2 membrane	13.6
Total		192.5

Table A.2.10.1: Absolute KSI values for all SUSDAT cases

KSI	Case weight factors						
	A	B	C	D	E	F	G
Sustainability feedstock	8.6	7.9	11.8	10.8	10.8	11.2	7.3
Global Warming Potential	0.0	0.0	0.6	12.2	0.0	0.6	0.0
Human Toxicity Potential	28.4	0.0	0.0	0.0	0.0	0.0	24.2
Return on Investment	0.0	3.2	0.0	0.0	3.2	0.0	0.0
New Technology	6448.7	0.0	9136.9	14750.5	3044.8	8667.5	5490.0

Appendix 2.11.1: Data and assumptions for unit operations SUSDAT

QI = Quality indicators (1=estimations, 2=from internet, 3= communication with expert, 4=from scientific literature or databases)

Table A.2.11.1.1: Data and assumptions for unit operations in pre-treatment step

Pre-treatment technologies	Scale-up?	P [bar]	QI	Ref #	T [°C]	QI	Ref #	Capacity [Mton/a]	QI	Ref #	Auxiliary phase1	Amount phase 1	QI	Ref #
Miller	No	1	1		25	1		0.4	4	[5]	Electricity	147.1 kWh/ton	4	[5]
Chipper	No	1	1		25	1		0.64	4	[5]	Electricity	9.1 kWh/ton	4	[5]
Microwave	No	1	1		100	1		0.108	4	[6]	Natural gas	2.6 MJ gas/kg	4	[6]
Oven dryer	No	1	1		100	1		0.8	4	[5]	Steam	620 MJ/twe	4	[5]
Fluidized bed dryer	Yes	1	1		100	1		0.1168	4	[5]	Steam	2409 MJ/twe	4	[5]
Steam dryer	No	1	1		100	1		0.28	4	[5]	Steam	2990 MJ/twe	4	[5]
Pelletising system	No	>1	1		55-60	2	[4]	0.04	2	[4]	Electricity	100 kWh/ton	2	[4]
Pyrolysis	Yes	1	2	[1]	500	2	[1]	0.1	2	[1]	Electricity	37.2 kWh/ton	2	[2]
Hydrothermal upgrading	Yes	100	2	[2]	350	2	[2]	0.13	2	[2]	Electricity	75 kWh/ton	2	[6]
Torrefaction	Yes	1	2	[3]	260	2	[3]	0.014	2	[3]	Superheated steam	900 MJ/ton	2	[8]

Table A.2.11.1.2: Data and assumptions for unit operations in pre-treatment step (continued)

Pre-treatment technologies	Auxiliary phase2	Amount phase 2	QI	Ref #	Investment costs	QI	Ref #	Mass efficiency %	QI	Ref #	Energy efficiency %	QI	Ref #
Miller					0.370 M€/miller	4	[5]	98	4	[5]	-		
Chipper					0.529 M€/chipper	4	[5]	98	4	[5]	-		
Microwave					0.205 M€/microwave	4	[6]	66	4	[6]	-		
Oven dryer	Electricity	20 kWh/twe	4	[5]	1.6 M€/oven	4	[5]	65	4	[5]	-		
Fluidized bed dryer	Electricity	31 kWh/twe	4	[5]	1.4 M€/dryer	4	[5]	66	4	[5]	-		
Steam dryer	Electricity	15.7 kWh/twe	4	[5]	5.3 M€/dryer	4	[5]	66	4	[5]	-		
Pelletising system					0.83 M€/pelletiser	2	[4]	100	2	[4]	-		
Pyrolysis					1.5 M€/pyrolyser	2	[1]	85	2	[1]	90%	2	[1]
Hydrothermal upgrading	Natural gas	292.3 MJ/ton	2	[2]	30 M€/reactor	2	[2]	80	2	[2]	98.60%	2	[2]
Torrefaction					2.1 M€/reactor	2	[3]	90	2	[8]	97%	2	[8]

Table A.2.11.1.3: Data and assumptions for unit operations in gasification technology

Gasification technology	Scale-up?	P [bar]	QI	Ref #	T [°C]	QI	Ref #	Capacity [Mton/a]	QI	Ref #	Auxiliary phase1	Amount phase 1	QI	Ref #	Auxiliary phase2	Amount phase 2	QI	Ref #
Fixed bed (BGL)	Yes	1	2	[9]	810	2	[8]	498	1		air	1.132 kg / kg biomass	2	[9]	steam	0.26 kg / kg biomass	1	
Circulating Fluidized Bed P = 1 bar air/steam allotherm	Yes	1	4	[10]	850	4	[9]	996	1		air	1.2 kg / kg biomass	1		steam	0.26 kg / kg biomass	1	
Circulating Fluidized Bed P = 1 bar oxygen/steam	Yes	1	4	[11]	850	4	[10]	996	4	[11]	oxygen	0.26 kg / kg biomass	4	[11]	steam	0.26 kg / kg biomass	4	[11]
Circulating Fluidized Bed P = 20 bar oxygen/steam	Yes	20	4	[11]	850	4	[10]	996	4	[11]	oxygen	0.20 kg / kg biomass	4	[11]	steam	0.20 kg / kg biomass	4	[11]
Entrained Flow P = 1 bar oxygen/steam	Yes	1	4	[11]	1400	4	[10]	1661	4	[11]	oxygen	0.46 kg / kg biomass	4	[11]	steam	0.05 kg / kg biomass	4	[11]
Entrained Flow P = 40 bar oxygen/steam	Yes	40	4	[10]	1400	4	[9]	1661	4	[11]	oxygen	0.52 kg / kg biomass	1		steam	0.05 kg / kg biomass	1	

Table A.2.11.1.4: Data and assumptions for unit operations in gasification technology (continued)

Gasification technology	Auxiliary phase3	Amount phase 3	QI	Ref #	Volume reactor	QI	Ref #	Investment costs	QI	Ref #	Mass efficiency %	QI	Ref #	Energy efficiency %	QI	Ref #
Fixed bed (BGL)	-	-			1 min. residence time	1		0.1*16.8*feed (kg/s) M€/reactor	1	[10]	20 vol% CO, 16 vol% CO2, 12 vol% H2, 1 vol% O2, 44 vol% N2, 6 vol% CH4, 0.7 vol% other CH's	2	[9]	73%	2	[9]
Circulating Fluidized Bed P = 1 bar air/steam allotherm	-	-			1 min. residence time	1		0.15*16.8*feed (kg/s) M€/reactor	1	[10]	43 vol% dry CO, 23% H2, 12% CO2, 17% CH4, 6% C2, 37% ar H2O	4	[10]	80.4%	4	[10]
Circulating Fluidized Bed P = 1 bar oxygen/steam	-	-			1 min. residence time	1		0.1*16.8*feed (kg/s) M€/reactor	1	[10]	27 vol% dry CO, 33% H2, 30% CO2, 7% CH4, 1% N2, 2% C2, 32% H2O ar	4	[10]	80.6%	4	[10]
Circulating Fluidized Bed P = 20 bar oxygen/steam	carbon dioxide	0.08 kg / kg biomass	4	[11]	1 min. residence time	1		0.1*16.8*feed (kg/s) M€/reactor	1	[10]	16 vol% dry CO, 18% H2, 47% CO2, 14% CH4, 1% N24% C2, 34% H2O ar	4	[10]	79.1%	4	[10]
Entrained Flow P = 1 bar oxygen/steam	-	-			1-2 sec. residence time	4	[10]	0.084*16.8*feed (kg/s) M€/reactor	1	[10]	53 vol% dry CO, 33% H2, 13% CO2, 19% ar H2O	4	[11]	77%	4	[11]
Entrained Flow P = 40 bar oxygen/steam	carbon dioxide	0.24 kg / kg biomass	1	[10]	1-2 sec. residence time	4	[10]	0.084*16.8*feed (kg/s) M€/reactor	1	[10]	46 vol% dry CO, 27% H2, 27% CO2, 0.4% N2, 17% H2O	4	[10]	77.9%	4	[10]

Table A.2.11.1.5: Data and assumptions for unit operations in after treatment step

After-treatment technologies	Scale-up?	P [bar]	QI	Ref #	T [°C]	QI	Ref #	Capacity	QI	Ref #	Auxiliary phase1	Amount phase 1	QI	Ref #
Cyclone (high T)	No	max. 50	4	[12]	max. 1000	4	[12]	180 m3/s	4	[21]				
Cyclone (low T)	No	max. 50	4	[12]	max. 600	4	[12]	180 m3/s	1					
Electrostatic Precipitator (ESP)	Yes	max. 10	4	[12]	max. 450	4	[12]	180 m3/s	1		electricity	190 kJ/s	1	[25]
Water quench	Yes	variable	1		<900	4	[12]				water	depends on T		
Tar condenser	Yes	variable	1		200	1		64 m3/s	4	[21]	water	2 ml water/m3	1	
Catalytic cracker (tar and NH3/HCN)	Yes	variable	1		800 - 1000	2	[16]	52 m3/s	4	[21]	steam	0.05 kg/kg tar	2	[16]
Thermal cracker (tar)	Yes	variable	1		1400	1		sufficient	1		oxygen	0.5 kg/kg tar	1	
OLGA (tar)	Yes	variable	1		350 in, 100 out	3	[17]	700 N m3/s	1		wax-oil (scrubbing liq.)		3	[17] [34]
Hydrolysis (HCN and COS)	Yes	variable	4	[12]	180	4	[12]	1390 kmol/hr	4	[21]	water	3 vol%	4	[12]
Aqueous scrubber (HCl and NH3)	Yes	favors high P	4	[12]	40	4	[12]	sufficient	1		water	7.4 vol%	4	[12]
MDEA scrubber (CO2 and H2S)	Yes	variable	1		abs 40, reg 110	4	[13]	205 tonne/hr		[22]	MDEA or other amine	2.968 tonne/hr	2	[22]
Bioclaus / Thiopauq (H2S)	Yes	variable	2	[14]	< +/- 400 C	2	[18] [19]	12.5 ton S/day, gas flow=0.35 Mm3/day	2	[23]	Thiobacillus ($NaHCO_3$, NaOH, water), pH = 8-9		2	[18] [19]
Rectisol scrubber (CO2 and H2S)	Yes	>20	2	[15]	neg.	2	[15]	62422 kg produced syngas/day	2	[15]	Methanol	recycle	1	
HCl sorbents (Chemisorption of HCl on Ca(OH)2 sorbents)	Yes	variable	4	[12]	400	4	[12]	recycle	1		Ca(OH)2	5 kg Ca/kg HCl	4	[12]
H2S sorbents (Chemisorption H2S on Zn2TiO4 pellets)	Yes	1-40	1		350-550	2	[12] [20]	33 kg H2S/100 gr ZnO	2	[24]	ZnO	5 kg ZnO/kg H2S	1	
Water-Gas Shift reactor	Yes	1-60	4	[12]	200-475	4	[12]				Fe-Cr, Cu-Zn or Co-Mo		4	[12]
Hydrogen mixing	Yes	1	1		25	1								
Compressor	Yes													
Water condenser	Yes	variable	1		~100	1		unlimited	1		water	depending on delta T	1	
Active Coal Filter	Yes	variable	1		<120						activated coal	1 kg coal/kg ads mat.	1	
Membrane	Yes	25-40	4	[10]	variable	1								
Claus plant	Yes	1	1		246,85	4	[13]	85 ton/day	2	[22]	oxygen	<0.8333 mol O2/mol H2S	2	[22]
Air separation plant	Yes	variable	1								electricity	36000 kW/kmol O2	4	

Table A.2.11.1.6: Data and assumptions for unit operations in after treatment step (continued)

After-treatment technologies	Auxiliary phase2	Amount phase 2	QI	Ref #	Auxiliary phase3	Amount phase 3	QI	Ref #	Volume reactor	QI	Ref #	Investment costs	QI	Ref #
Cyclone (high T)												9.3 M€/cyclone	4	[21]
Cyclone (low T)												6.2 M€/cyclone	1	[27]
Electrostatic Precipitator (ESP)												18.6 M€/ESP	1	[27]
Water quench														
Tar condenser												3.6 M€/condensor	4	[21]
Catalytic cracker (tar and NH3/HCN)	Air	5% of flow in	2	[16]	Nickel and Dolomite	0.1 m3cat/m3hr	2	[13] [16]				5.1 M€/cracker	4	[21]
Thermal cracker (tar)												200 M€/total	1	
OLGA (tar)												25 M€/total	3	[17]
Hydrolysis (HCN and COS)												11.5 M€/reactor	1	[27]
Aqueous scrubber (HCl and NH3)												0.5 M€/total	1	[27]
MDEA scrubber (CO2 and H2S)	Electricity	140 GJ/mol CO2	2	[26]								5100000 US$ in 2000	1	[22]
Bioclaus / Thiopauq (H2S)												5 M$	4	[21]
Rectisol scrubber (CO2 and H2S)	Cooling water	133 m3/h	2	[15]								2.28 M€/total capacity syngas	2	[28]
HCl sorbents (Chemisorption of HCl on Ca(OH)2 sorbents)												10 M€/total	1	
H2S sorbents (Chemisorption H2S on Zn2TiO4 pellets)												10 M€/total	1	
Water-Gas Shift reactor									300-4000 h-1 space velocity	4	[12]	0.011 M€/MWth,syngas	4	[10]
Hydrogen mixing Compressor Water condenser												n.v.t. 850 €/kW 0.7 M€/total	 1 1	 [10] [27]
Active Coal Filter														
Membrane												0.017*8000 M€	4	[10]
Claus plant												14.2 M$ in 2000	1	[22]
Air separation plant												2.9444 M€/(kg/s O2)	1	[10]

Table A.2.11.1.7: Data and assumptions for unit operations in after treatment step (continued)

After-treatment technologies	Production costs	QI	Ref #	Mass efficiency %	QI	Ref #	Energy efficiency %	QI	Ref #
Cyclone (high T)							0% tar; 99.9% dust >0.1 mm; 10% dust <0.1 mm	4	[12]
Cyclone (low T)							<70% tar; 99.9% dust >0.1 mm; 10% dust <0.1 mm	4	[12]
Electrostatic Precipitator (ESP)							<60% tar; 99.9% dust >0.1 mm; 95% dust <0.1 mm	4	[12]
Water quench							removes 50% of tars, all dust, 50% NH_3 and 80% of HCl	4	[12]
Tar condenser							removes 65% tars, all dust, 50% NH_3 and 80% of HCl	4	[12]
Catalytic cracker (tar and NH_3/HCN)							Benzene 82%, Napthalene 99%, Phenol 96%, Ammonia 99% Total: Aromatic 94%, Phenols 98%, Tar 96%	2	[16]
Thermal cracker (tar)				sufficient	1				
OLGA (tar)							100% tars, 99 % heterocyclic compounds	4	[32]
Hydrolysis (HCN and COS)				max. 5 mg/Nm3 HCl	4	[12]	converts 98% of COS and HCN into NH_3 and H_2S	4	[12]
Aqueous scrubber (HCl and NH_3)							removes 99% HCl, 90% NH_3	4	[12]
MDEA scrubber (CO_2 and H_2S)				<4-54 ppmV for H_2S and 2 mol% CO_2	2	[22]	99.3% sulphur recovery, almost all CO_2 and H_2S is removed	2	[22] [33]
Bioclaus / Thiopauq (H_2S)	510 k$/year (chem. costs: 40 - 60 €/ton S) in 1999	2	[14] [18] [19]	< 1 ppmV	2	[18] [19]	99% puur sulfur	1	
Rectisol scrubber (CO_2 and H_2S)				0.1 ppm sulphur and 2 ppm CO_2	2	[15]			
HCl sorbents (Chemisorption of HCl on $Ca(OH)_2$ sorbents)	50 €/ton	2	[29]				HCl/HF removal efficiency = 80%	4	[12]
H_2S sorbents (Chemisorption H_2S on Zn_2TiO_4 pellets)	1703.5 €/ton	4	[30]				99% removal	1	
Water-Gas Shift reactor Hydrogen mixing	0.018 €/MJ	2	[31]				$K_{eq}=p_{H2}*p_{CO2}/p_{H2O}*p_{CO} = \exp\{(4577.8/T)-4.33\}$	4	[12]
Compressor									
Water condenser				sufficient	1				
Active Coal Filter				99% tars, 99% HCl, H_2S	4	[12]			
Membrane				90% CO_2 removal	4	[10]			
Claus plant				99.5% conv. to sulphur	4	[13]			
Air separation plant									

Reference:

Ref #	Source
[1]	http://www.fzk.de/stellent/groups/itc-cpv/documents/published_pages/itccpv__20_90__publikationenst.pdf E. Henrich et al., Tar-free, *high pressure synthesis gas from biomass*, Expert Meeting on pyrolysis and gasification of biomass; Strasbourg, France; 30 sept - 1 oct 2002; read: 9 June 2004
[2]	http://www.novem.nl/default.asp?menuId=10&documentId=28269 F. Goudriaan et al., *Thermal efficiency of the HTU process for biomass liquefaction*, Progress in Thermochemical Biomass Conversion, Austria, 18-21 sept 2002, read: 9 June 2004
[3]	http://www.techtp.com/twpapers/fao_paper.htm FAO paper, *Developements on torrefied wood*, read: 6 May 2004.
[4]	http://www.eubia.org/pdf/Lamnet_Pellets.pdf LAMNET (Latin America Thematic Network on Bioenergy), *Refined Bio-fuels Pellets and Briquettes*, read: 20 May 2004
[5]	http://www.chem.uu.nl/nws/www/publica/Carlo%20e2003-26.pdf Carlo N. Hamelinck, *International bioenergy transport costs and energy balance*, Universiteit Utrecht, Copernicus Institute, August 2003
[6]	T. Kudra and A.S. Mujumbar, *Advanced Drying Technologies*, Dekker, New York, 2002
[7]	http://students.chem.tue.nl/ifp02/downloads/Final_Report.pdf *Green energy, from wood or torrefied wood?*, University of Technology Eindhoven, read: 90 June 2004
[8]	http://www.ecn.nl/docs/library/report/2004/rx04046.pdf P. Bergman et al., *Torrefaction for entrained-flow gasification of biomass*, ECN-RX--04-046 Presented at "The 2nd World Conference and Technology Exhibition on Biomass for Energy, Industry and Climate Protection" Italy, 10-14 May 2004, read: 10 June 2004
[9]	http://matdb.jrc.nl/prewin/bergen2003/present/IE_opening.pdf CLEANWEB Workshop on Recovered Fuels in Collaboration with EU Candidate Countries, read: 9 June 2004
[10]	http://www.ecn.nl/docs/library/report/2004/c04001.pdf H. Boerrigter et al., *High efficiency co-production of Fischer-Tropsch (FT) transportation fuels and Substitute Natural Gas (SNG) from biomass* ECN-C--04-001, February 2004
[11]	http://www.ecn.nl/docs/library/report/2004/c04015.pdf H. den Uil et al., Duurzaam synthesegas, *Een brug naar een duurzame energie-en grondstoffenvoorziening*, ECN-C--04-015, February 2004
[12]	*Unit operations of biomass gasification*, Report number 2DEN-02.20, Utrecht, June 2002, NOVEM
[13]	J.A. Moulijn e.a., *Chemical Process Technology*, John Wiley & Sons Ltd, England, 2001
[14]	http://www.shellglobalsolutions.com/gasevents/gas_treat/H2S_Removal_from_High_Pressure_Natural_Gas.pdf

	W.S. Kijlstra et al., *New commercial process for H2S removal from high pressure natural gas: The Shell-Thiopaq Gas Desulphurisation process* Paper prepared for the 1999 Gas Processing Conference, April 26-28th 1999, read: 8 June 2003
[15]	http://www.lurgi-oel.de/deutsch/nbsp/menu/medien/newsletter/rectisol.pdf Rectisol process for gas purification, MGEngineering Lurgi Oel Gas Chemie, read: 11 June 2003
[16]	http://www.btgworld.com/technologies/tar-removal.html Biomass Technology Group, *Tar & Tar removal*, read: 3 June 2004
[17]	Expert H. Boerrigter OLGA, contact via email at ….
[18]	http://www.npgas.ca/parent-p2.htm T. Beasley et al., *Natural gas purification and sulfur recovery - Mother nature's process*, read: 8 June 2003
[19]	http://www.npgas.ca/techdev-p.htm *The technology*, read: 8 June 2003
[20]	http://www.netl.doe.gov/publications/proceedings/96/96ps/ps_pdf/96pspb12.pdf K.C. Kwon et al., *Reactivity of Metal Oxide Sorbents for Removal of H2S*, read: 9 June 2004
[21]	http://www.chem.uu.nl/nws/www/publica/e2001-49.pdf C.N. Hamelinck, A.P.C. Faaij, *Future prospects for production of methanol and hydrogen from biomass*, Universiteit Utrecht, Copernicus Institute, September 2001
[22]	http://www.netl.doe.gov/coalpower/gasification/system/shell3x_.pdf Shell Gasifier IGCC Base Cases, PED-IGCC-98-002, June 2000, read: 10 June 2004
[23]	http://www.natcogroup.com/PDFContent/Gas-Conditioning/Bio-Desulfuriation.pdf Natco Group, *Shell-Paques Bio-Desulfurization Process*, read: 10 June 2004
[24]	http://www.aiche.org/conferences/techprogram/paperdetail.asp?PaperID=2223&DSN=annual02 AIChE Sulfur free H2 for fuel cell: *A novel absorbent for H2S removal*, read: 11 June 2003
[25]	http://www.ppcesp.com/ppcart.html G. Graham, *Controlling stach emissions in the wood products industry*, read: 11 June 2003
[26]	www.uop.com, read: 10 June 2003
[27]	D.E. Garrett, *Chemical Engineering Economics*, Van Nostrand Reinholf, New York, 1989
[28]	http://www.ieagreen.org.uk/capt4.htm *Carbon dioxide capture from power stations, absorption technologies*, read: 10 June 2003
[29]	http://www.solvaychemicals.us/pdf/AWMA_pres.pdf J. Maziuk et al., *Comparison of dry injection acid-gas control technologies*

	Conference: Air & waste management association, Maryland, June 23-27 2002, read: 9 June 2003
[30]	http://www.chemicalmarketreporter.com/home/Default.asp?type=25&liSectionID=27&sQuery=Z Chemical Market Report, read: 11 June 2003
[31]	http://www.phoenixproject.net/releases/calch2prdcst.htm H. Braun, *Calculating hydrogen production costs*, read: 9 June 2003
[32]	http://www.ecn.nl/docs/library/report/2002/rx02043.pdf H. Boerrigter, *Gas cleaning at ECN; lessons learned and results achieved*, ECN Biomass contribution to the GasNET & IEA Bioenergy Agreement Meeting, Strasbourg, France, 2-3 October 2002, ECN-RX--02-043
[33]	http://www.gasprocessors.com/GlobalDocuments/E02Sept_13.pdf *Deep removal of CO2 and H2S from natural gas in LNG production facilities*, read: 10 June 2003
[34]	http://www.ecn.nl/_files/bio/Paper_OLGA_Straatsburg.pdf P.C.A. Bergman et.al., *The novel OLGA technology for complete tar removal from biomass producer gas* Paper presented at: Pyrolysis and gasification of biomass and waste, expert meeting, 30 sept-1 oct 2002, Strasbourg, France

Appendix 2.11.2 Assumptions made for calculations of main balances of all cases

- Scale up factor for equipment = 0.7 [1]
- Investment costs below 20M€ are ignored
- Other equipment except the major equipment is estimated 10% of the total major equipment investment cost. Total investment costs = 1.1 x investment costs all major equipment
- R&D costs
    - Very much research needed: 15% of the equipment cost
    - Much research needed: 10% of the equipment cost
    - Little research needed: 5% of the equipment cost
- Currency conversion factor Euro to US dollar: €/US$ = 1.1
- Inflation factor = 1.03 [2]
- Waste treatment companies deal with responsible and sustainable with the waste
- Hydrogen producer is a certified and sustainable company

References:

[1] R.K. Sinnott, *Coulson and Richardson's chemical engineering. Vol. 6. Chemical engineering design*, Butterworth-Heinemann, Oxford, 3rd edition, 1999.

[2] W. Shelton and J. Lyons, Shell Gasifier IGCC Base Cases, NETL, Process Engineering Division, PED-IGCC-98-002, July 1998, revisited in June 2000, http://www.netl.doe.gov/coalpower/gasification/system/shell3x_.pdf

Appendix 2.11.3 Chemical prices

Table A.2.11.3.1: The used or assumed chemical prices and their references

Chemical	Price [€/kg]	Reference
Biomass (forest residues)	0.007	[1]
Steam	0.013	[2]
Water	0.00022	[2]
Hydrogen	2.3	GaBi software
MDEA	3.271	[3]
OLGA solvent	0.45	Estimated from biodiesel price
BioClaus solvent	0.035	[4]
Sorbents for HCl removal	0.2	Assumption
Sorbents for H_2S and COS removal	7.273	[5]
Active coal	0.281	[3]
Catalyst for catalytic cracker	0.151	Assumption
Catalyst for hydrolysis reactor	0.151	[3]
Catalyst for water-gas shift reactor	0.2	Assumption
Catalyst for Claus reactor	0	Assumption
Syngas	0.129	Calculated from data SMDS process [6]
Waste biomass	0	Assumption
Slag/dust	-0.02	[3]
Waste water	-0.05	Assumption
Sulphur	0.039	[5]
Spent active coal	-0.025	Assumption
Waste air	0	Assumption
Spent catalyst	-0.25	Assumption
Spent MDEA	-0.25	Assumption
Nitrogen	0.061	[2]

References:

[3] H. Boerrigter, H. den Uil, H.P. Calis, *Green Diesel from Biomass via Fischer-Tropsch synthesis: New Insights in Gas Cleaning and Process Design*, Pyrolysis and Gasification of Biomass and Waste, Expert Meeting, Strasbourg, France, 2002.

[4] R.K. Sinnott, *Coulson and Richardson's chemical engineering. Vol. 6. Chemical engineering design*, Butterworth-Heinemann, Oxford, 3rd edition, 1999.

[5] W. Shelton and J. Lyons, Shell Gasifier IGCC Base Cases, NETL, Process Engineering Division, PED-IGCC-98-002, July 1998, revisited in June 2000, http://www.netl.doe.gov/coalpower/gasification/system/shell3x_.pdf

[6] Gas Processing Ltd., *Some of Our News Development – The Technology*, visited: 30 June 2004, http://www.npgas.ca/techdev-p.htm

[7] Online Chemical Market Reporter, Schnell, New York, visited: 11 June 2004, http://www.chemicalmarketreporter.com/home/Default.asp?type=0&liSectionID=12

[8] Shell MDS (Malaysia) SDN BHD, *The Shell Middle Distillate Synthesis – Plant at Bintulu*, Shell Malaysia, 1992.

Appendix 2.12 Values of all indicators for winning case SUSDAT against the current practice

Table A.2.17.1: Values of all indicators for winning case SUSDAT against the chosen benchmark process

Indicator	Unit	Value winning case	Data source	Value benchmark	Data source
Skilled labour jobs created	[Manhour / functional unit]	5.E-02	[1]	5.E-02	[1]
Unskilled labour jobs created	[Manhour / functional unit]	3.E-03	[19]	6.E-03	[2]
Health issues	[health issues / functional unit]	1.E+00	[20]	3.E+00	[3]
Total Fatalities (employees and neighbours)	[fatalities / functional unit]	1.E-07	[4]	1.E-07	[4]
Room for SOCIALEX	[Margin for social investments M€/ functional unit]	4.E-08	[21]	7.E-07	[5]
Ease of Operation	Qualitative	7.E+00	[22]	1.E+01	[6]
Harmful impurities in product	Qualitative	1.E+00	[7]	1.E+00	[7]
New Technology	[€ / functional unit]	1.E-02	[23]	2.E-08	[8]
Capital created	[M€ / functional unit]	2.E-07	[24]	1.E-07	[9]
Land use: Competitive	[Land Use / functional unit]	4.E+00	[10]	4.E+00	[10]
Sustainability feedstock	[biomass use / functional unit]	9.E+00	[25]	3.E+03	[11]
Abiotic Depletion	[kg Sb-Equiv. / functional unit]	9.E-03	[12]	7.E-02	[12]
Acidification Potential	[kg SO2-Equiv. / functional unit]	3.E-03	[12]	2.E-03	[12]
Eutrophication Potential	[kg Phosphate-Equiv. / functional unit]	4.E-04	[12]	3.E+00	[12]
Freshwater Aquatic Ecotoxicity Pot.	[kg DCB-Equiv. / functional unit]	7.E-03	[12]	6.E-06	[12]
Global Warming Potential	[kg CO2-Equiv. / functional unit]	7.E+00	[12]	2.E+00	[12]
Human Toxicity Potential	[kg DCB-Equiv. / functional unit]	3.E-02	[12]	9.E-04	[12]
Marine Aquatic Ecotoxicity Pot.	[kg DCB-Equiv. / functional unit]	2.E+01	[12]	1.E-06	[12]
Ozone Layer Depletion Potential	[kg R11-Equiv. / functional unit]	3.E-09	[12]	0.E+00	[12]
Photochem. Ozone Creation Potential	[kg Ethene-Equiv. / functional unit]	2.E-04	[12]	1.E-04	[12]
Radioactive Radiation	DALY	1E-15	[12]	0.E+00	[12]
Terrestric Ecotoxicity Potential	[kg DCB-Equiv. / functional unit]	8.E-04	[12]	1.E-06	[12]
Land use: Loss of Biodiversity	[Max. Contribution to extinction of species i / functional unit]	0.E+00	[12]	0.E+00	[12]
Capital expenditure	[M€] / Functional unit	2.E-07	[24]	1.E-07	[9]
Operational expenditure	[M€] / Functional unit	4.E-08	[26]	1.E-09	[13]
Net Present Value	[M€] / Functional unit	8.E+00	[27]	9.E-02	[5]

Return on Investment	[%]	2.E+01	[28]	1.E+01	[14]
Research & Development Expenditure	[€] / Functional unit	1.E-08	[29]	2.E-08	[8]
Externalities Best case scenario	[€] / Functional unit	1.E-01	[30]	0.E+00	[15]
Externalities Worst case scenario	[-€] / Functional unit	0.E+00	[31]	3.E+01	[16]
Margin Best Case Scenario	[€] / Functional unit	9.E-01	[32]	1.E-02	[17]
Margin Worst Case Scenario	[€] / Functional unit	8.E-01	[33]	7.E-03	[18]

1. Shell MDS (Malaysia) SDN BHD, The Shell Middle Distillate Synthesis – Plant at Bintulu, Shell Malaysia, 1992.
2. Assumption: 10% of total labour is unskilled labour
3. Assumed not to be worse than normal case, scale: 0-10 qualitative, reason: solvent use is higher than our best case and also water use
4. Risk: 1e-7 for people fatalities, assumption
5. Assumption: 5% of margin for SOCIEX, product prices: 20US$ in 2003, margin: 5000 US$ in 2003, sources: A. Brown, *Gas to Liquid – a paradigm shift or a opportunity in the margin?*, 4th International Conference Oil, Gas and Petroleum in Qatar: Opportunities and Developments, September 2003, http://www.shellglobalsolutions.com/gasevents/quicklinks/2003_09_Gas_to_Liquids_-_A_paradigm_shift_or_an_opportunity.pdf
6. Scale: 0-10 qualitative, SMDS technology is proven technology but it has also a lot of downstream processes to remove all impurities, almost the same as wet gas cleaning
7. Scale: 0-10 qualitative, Almost no S, Cl, N in syngas, due to complete downstream process. We can assume here that this impact is low but not zero because there is still impurities within the specs but we don't have enough information on this issue.
8. 20% of CAPEX as assumption where it is 5 times higher than 4.13% Total Shell R&D investment according to Shell Annual and Account report 2003, Reason: Bintulu is pilot plant and need more R&D
9. http://www.shell.com/home/Framework?siteId=qatar&FC2=/qatar/html/iwgen/leftnavs/zzz_lhn4_0_0.html&FC3=/qatar/html/iwgen/qatar_shell_gtl_project/qatar_shell_gtl_project_22092003_1430.html
10. No info on actual land use of SMDS plant. Scale: 0-10 qualitative. SMDS is quite new plant, which was designed compactable than normal refinery. No land is used due to the LNG (feedstock) use
11. Natural gas use [kg LNG /kg diesel], PWC LCA report
12. GaBi software database and mass balance source: Price Waterhouse Coopers, *Shell Middle Distillate Synthesis (SMDS) - Update of a Life Cycle Approach to Assess the Environmental Inputs and Outputs, and Associated Environmental Impacts, of Production and Use of Distillates from a Complex Refinery and SMDS Route*, Final LCA report for Shell International Gas Limited, v.3.1. issued on 21 May 2003.
13. R.K. Sinnott, Coulson & Richardson's Chemical Engineering, Vol. 6, *Chemical engineering design*, Butterworth-Heinemann, Oxford, 3rd edition, 1999
14. Personal communication with Jeroen Coppelmans, Shell
15. Assumption there is no CO_2 tax
16. CO2 tax 20€/ton and no subsidies, 11490 ton CO2/day SMDS, Price Waterhouse Coopers, *Shell Middle Distillate Synthesis (SMDS) - Update of a Life Cycle Approach to Assess the Environmental Inputs and Outputs, and Associated Environmental Impacts, of Production and Use of Distillates from a Complex Refinery and SMDS Route*, Final LCA report for Shell International Gas Limited, v.3.1. issued on 21 May 2003.
17. Annual profit becomes higher 20%, sulphur and nitrogen can be sold.
18. Annual profit becomes lower 20%, sulphur and nitrogen can not be sold.
19. Assumption: 5% of total labour is unskilled labour
20. Assumed not to be worse than normal case, scale: 0-10 qualitative
21. Assumption: 5% of annual profit
22. Assumption: large scale biomass gasification is new technology and therefore more difficult to operate
23. Calculated from calculated R&D investments
24. Calculated from calculated major equipment costs
25. Calculated from mass balance winning case
26. Assumption: 20% of capital expenditure
27. Calculated from annual profit over 20 years
28. Calculated from annual profit and major equipment costs
29. Calculated from calculated R&D investments and diesel production
30. Assumption: revenues from CO_2 trading
31. Assumption: no revenues from CO_2 trading
32. Nitrogen and sulphur can be sold in the market. Biomass prices becomes lower due to a lot of wood residue producers. Annual profit becomes 20% higher
33. Nitrogen and sulphur cannot be sold in the market. Biomass prices becomes higher due to competition with other biomass use of other gasification plant where the wood residue comes from

Appendix 2.13: Data and calculation functional unit

Table A.2.13.1: Data of Fischer Tropsch process and calculated SMDS products

Product	Gasoil mode wt%	LHV [MJ/kg]	LHV*mass%	Product in mass [kg/s]	Data source
Tops/Naphta	15.0%	50.0	7.5	18.6	[1][2]
Kerosene	25.0%	43.1	10.8	31.0	[1][2]
Gasoil/diesel	60.0%	43.1	25.9	74.3	[1][2]
LHV of products			44.1	123.9	[1][2]
Syngas	8000	MW	334.5		
Product	**LHV eff %**	**Energy [MW]**			
FT products	68.4%	5468			[3]
Electricity	6.4%	508			
Heat	25.3%	2024			

Table A.2.13.2: The capacities of commercialized or reported SMDS plant

Location	SMDS capacity		in m3		FT products		Literature
Bintulu	14700	bbl/d	2337	m3/d	21.6	kg/s	[1]
Qatar	70000	bbl/d	11130	m3/d	103.0	kg/s	[4]
Middle East	13060	tonne/d			0.2	kg/s	[5]

Table A.2.13.3: Data and assumptions for the calculation of economic indicators

Economic Indicator	Data or assumption for calculation
Return on Investment	Annual profit/total investment (CAPEX) [6]
Capital expenditure	CAPEX is calculated with factor 4 of the total major investment, [7]
Operational expenditure	OPEX is assumed to be 20% of the total expenditure, [7]
Energy Cost	Electricity costs according to Essent [8]
Annual Profit	Economic margin – energy costs – operational expenditure

Table A.2.13.4: Electricity cost and taxes given by Essent [7]

Electricity cost and taxes		Unit
Use during normal our	0.0693	[€ /kWh]
Use during low our	0.0291	[€ /kWh]
Tax under 10000 kWh	0.0654	[€ /kWh]
Tax between 10000-50000 kWh	0.0212	[€ /kWh]
Tax between 50000-10e6 kWh	0.0065	[€ /kWh]
Tax >10e6 kWh	0.0005	[€ /kWh]

References:

[1] Shell MDS (Malaysia) SDN BHD, *The Shell Middle Distillate Synthesis – Plant at Bintulu*, Shell Malaysia, 1992.

[2] *Energy content, energy units and prefixes*, natural Resources and the Environment, 1998, pp.28, provided by the clients.

[3] H. Boerrigter, H. den Uil, H.P. Calis, *Green Diesel from Biomass via Fischer-Tropsch synthesis: New Insights in Gas Cleaning and Process Design*, Pyrolysis and Gasification of Biomass and Waste, Expert Meeting, Strasbourg, France, 2002.

[4] Shell Qatar website, www.shell.com/qatar, News and library, *Shell awards design contract for $5 billion Gas to Liquids project to JGC*, 9 March 2004, visited: 20 June 2004.

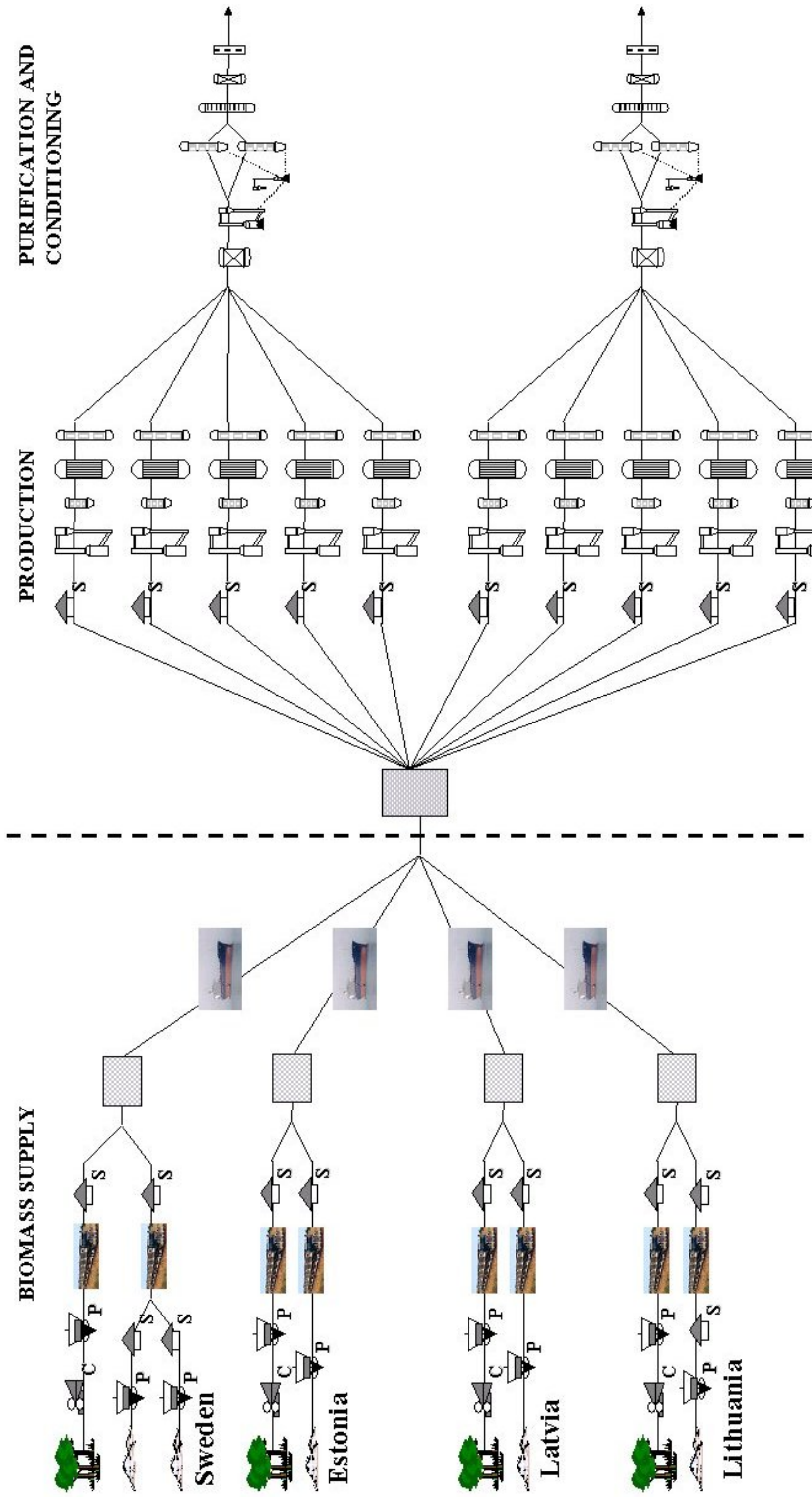
[5] http://www.shell.com/static/shellgasandpower-en/downloads/what_is_gas_to_liquids/PwC%, Price Waterhouse Coopers, *Shell Middle Distillate Synthesis (SMDS) - Update of a Life Cycle Approach to Assess the Environmental Inputs and Outputs, and Associated Environmental Impacts, of Production and Use of Distillates from a Complex Refinery and SMDS Route*, Final LCA report for Shell International Gas Limited, v.3.1. issued on 21 May 2003, visited 27 July 2004.

[6] J.M. Douglas, *Conceptual Design of Chemical Processes*, McGraw-Hill, Singapore, International editions, 1988.

[7] R.K. Sinnott, *Coulson and Richardson's chemical engineering. Vol. 6. Chemical engineering design*, Butterworth-Heinemann, Oxford, 3rd edition, 1999.

[8] Essent, *Electricity cost and tax in the Netherlands*, www.essent.nl/essent/nl/Images/42_33677_tcm4-35223.swf

Appendix 3.1 Overview of process with different chains



Appendix 3.2 Pure Component Properties

PURE COMPONENT PROPERTIES

Component Name		Technological Data								Health &Safety data								
Design	Systematic	Formula	Mol. Weight g/mol	Phase	Boiling Point [1] °C	Melting Point [1] °C	Flash Point [1] °C	Liquid Density [2] kg/l	Vapour Density [3] kg/m³	Auto-ignition Temp. [1] °C	Flammable Limits % by vol in air	Lower Explosion Limit (LEL) %	Upper Explosion Limit (UEL) %	LC_{50} In air/ water Mg/m³	MAC Value Mg/m³	LD_{50} Oral [4] g	Chemical Reactivity	Notes
wood				S														
water		H2O	18	V/L	100	0		1		n.a.	n.a.	n.a.	n.a.					
oxygen		O2	32	V	-183	-219			1.1	n.a.	n.a.	n.a.	n.a.					
carbonmonoxide		CO	28	V	-191.5	-205.1			0.97	605	12.5-74	12.5	74.2	6526.5	35.34			
hydrogen		H2	2	V	-253	-259			0.07	570	4-74.5	4	74					
carbondioxide		CO2	44	V	-79	unknown		1.1	1.5	n.a.	n.a.	n.a.	n.a.	2E+05	9000			
sulphur		S2	64.14	S	445	114	180	2.07		235		30	1400				chance of dust explosion	
salts				S														
hydrogen chloride [7]		HCl	36.5	L	108	-50		1.1	1.3						8			
carbonyl sulphide		COS	60.1	V	-50	-138		1.1	2.1	> 250		6.5	29					
hydrogen cyanide		HCN	27	V	26	-13		0.7	0.93	535		5.4	46.6		11			
tars	methylbenzene	C7H8	92.1	V	111	-95	4	0.9	3.2	480		1.2	7		150			[6]
hydrogen sulphide		H2S	34	V	-60	-86	-82	0.9	1.2	260	4.3-46	4	44	840	15		reacts with oxidators and metals	
sulfur dioxide		SO2	64	V	-10	-76		1.4	2.3	n.a.	n.a.	n.a.	n.a.		5		reacts with ammonia, bases, amines and chlorine	
ammonia		NH3	17	V	-33	-78	11	0.8	0.6	651		16	25	4176	13.92			
zincoxide		ZnO	81.4	S		1800		5.5							5		dissolves in acids	
titanium dioxide		TiO2	79.9	S	2500	1840		4.3		n.a.	n.a.	n.a.	n.a.		10		reacts with some metals	
zinc sulfide		ZnS	97.4	S		1180												
methane		CH4	16	V	-162	-182	-221 [5]	0.5	0.6	537	5-15	4.4	16				lighter than air, forms easily explosive mixtures	
ethane		C2H6	30.1	V	-89	-183		0.4	1.04	515		2.7	12.5					
ash				S														

Notes:

[1] At 101.3 kPa
[2] Relative density (water = 1)
[3] Relative density (air = 1)
[4] Oral ingestion in (g) for a male of 70kg weight
[5] Flammable gas
[6] Tar consists of many components, toluene is one of the major components
[7] 30% in water

Project ID Number: CPD3309
Completion Date: July 30 2004

Appendix 3.3 Production location

Figure A.3.3.1: Tweede Maasvlakte

Appendix 3.4 IN GOING streams crossing battery limits

Stream Name :	**Wood residues <101>**				
Comp.	Units	Specification		Notes	Additional Information
		Available	Design		(also ref. note numbers)
sawdust	%wt		33.3	(2)	(1) Data taken from ECN's database "Phyllis", id number = 1995, forest residues http://www.phyllis.nl
forest residues	%wt		66.7	(2)	
C	%wt ar		33.9	(1)	
H	%wt ar		4.2	(1)	
O	%wt ar		31.4	(1)	
N	%wt ar		0.49	(1)	
S	%wt ar		0.07	(1)	
Cl	%wt ar		0.07	(1)	
water	%wt ar		29.6	(1)	
ash	%wt ar		0.8	(1)	(2) Part of the wood comes from sawmills, as sawdust. The other part comes from forests, as large chips.
LHV	kJ/kg ar		11098	(1)	
Total					
Process Conditions and Price					
Temp.	oC		15		
Press.	Bara		1		
Phase	V/L/S		S		
Price	€/ton		6.7		

Stream Name :	**Air <224>+<501>**				
Comp.	Units	Specification		Notes	Additional Information
		Available	Design		(also ref. note numbers)
nitrogen	%vol		78.1	(1)	(1) CRC Handbook of Chemistry and Physics, 83rd edition.
oxygen	%vol		21.0		
argon	%vol		0.9		
Total			100.0		
Process Conditions and Price					
Temp.	oC		15		
Press.	Bara		1		
Phase	V/L/S		V		
Price	€/ton		0		

Stream Name : **FT-steam <202>+<210>**					
Comp.	Units	Specification			Additional Information
		Available	Design	Notes	(also ref. note numbers)
steam	%wt		100	(1)	(1) Steam comes from the neighbouring SMDS process, as stated in the CPD assignment, through a pipeline.
Total			100.0		
Process Conditions and Price					
Temp.	oC		200		
Press.	Bara		15.5		
Phase	V/L/S		V		
Price	€/ton		0		

Stream Name : **Cooling water**					
Comp.	Units	Specification			Additional Information
		Available	Design	Notes	(also ref. note numbers)
water	%wt		100	(1)	(1) Cooling water is taken from surface water
Total			100.0		
Process Conditions and Price					
Temp.	oC		15		
Press.	Bara		1		
Phase	V/L/S		L		
Price	€/ton		0		

Stream Name : **Make up sorbent <238>+<239>**					
Comp.	Units	Specification			Additional Information
		Available	Design	Notes	(also ref. note numbers)
ZnO	%wt	15	15	(1)	(1) Sorbents are tiny spheres; size for bulk-desulphuriser is 130 μ, size for ultra-desulphuriser is 20μ. Density = 1800 kg/m^3.
inerts	%wt		85		
different metals, TiO_2, Ni, Co etc.	%wt	85			(2) The sorbents are supplied by truck or vessel (e.g. from GTI in USA)
Total			100.0		(3) R.A. Newby et al., *Novel gas cleaning/conditioning for integrated gasification combined cycle, Based program final report, Siemens Westinghouse Power Corporation & Gas Technology Institute*, August 2001
Process Conditions and Price					
Temp.	oC		15		
Press.	Bara		1		
Phase	V/L/S		S		
Price	€/ton		3600		

Stream Name :	**Catalyst tar cracker**				
Comp.	Units	Specification		Notes	Additional Information
		Available	Design		(also ref. note numbers)
NiO-alumina	%wt		100	(1)	(1) Tar cracker catalyst is a monolith, which is entirely replaced once every 5 years. (2) Density is 1610 kg/m^3.
Total			100.0		(3) The sorbents are supplied by truck or vessel
Process Conditions and Price					
Temp.	oC		15		(4) Data assumed with use of: P. Simell, *Gasification gas cleaning with nickel monolith catalyst*, A.V. Bridgewater & D.G.B Boocock, Developments in thermodynamic biomass conversion, vol.2, Blackie Academic & Professional
Press.	Bara		1		
Phase	V/L/S		S		
Price	€/ton		900		

Stream Name :	**Catalyst sour water-gas shift reactor**				
Comp.	Units	Specification		Notes	Additional Information
		Available	Design		(also ref. note numbers)
CoMoS	%wt		100	(1)	(1) The catalyst is small spheres, size is 4 mm and density is 600 kg /m3. (2) The sorbents are supplied by truck or vessel
Total			100.0		(3) C. Higman, M van der Burgt, *Gasification*, Elsevier, 2003
Process Conditions and Price					
Temp.	oC		15		
Press.	Bara		1		
Phase	V/L/S		S		
Price	€/ton		900		

Stream Name :	**Catalyst Claus plant**				
Comp.	Units	Specification		Notes	Additional Information
		Available	Design		(also ref. note numbers)
alumina	%wt		100	(1)	(1) Details of this catalyst are unknown.
Total			100.0		
Process Conditions and Price					(2) The sorbents are supplied by truck or vessel
Temp.	oC		15		
Press.	Bara		1		
Phase	V/L/S		S		
Price	€/ton		900		

Stream Name :	**Active coal**				
Comp.	Units	Specification		Notes	Additional Information
		Available	Design		(also ref. note numbers)
C	%wt		100		(1) Under steady state design conditions, active coal beds are not needed. When things go wrong, e.g. in the cleanup, guard beds of active coal are needed. (2) The sorbents are supplied by truck or vessel
Total			100.0		(3) R. Meijer, H. Koetzier, A.J.A Konings, L.H.J. Vredenbergt, W.F. van den Broeke, *Unit operations biomass gasification*, Novem, 2DEN-02.20, Utrecht, June 2002
Process Conditions and Price					
Temp.	oC		15		
Press.	Bara		1		
Phase	V/L/S		S		
Price	€/ton		360		

Appendix 3.5 OUT GOING streams crossing battery limits

Stream Name :	**Syngas <237>**				
Comp.	Units	Specification			Additional Information
		Available	Design	Notes	(also ref. note numbers)
CO	%vol		31.9	(1)	(1) The syngas goes directly through a pipeline to the neighbouring SMDS plant.
H_2	%vol		64.6		
inerts (CO_2, Ar, N_2, CH_4)	%vol		3.5		
S-components	ppmV		< 1		
N-components	ppmV		< 1		
Cl-components	ppbV		< 10		
solids	ppbV		0		
tars	ppbV		0		
Total			100.0		
Process Conditions and Price					
Temp.	oC		227		
Press.	Bara		40		
Phase	V/L/S		V		
Price	€/ton		129		

Stream Name :	**Sulphur <601>**				
Comp.	Units	Specification			Additional Information
		Available	Design	Notes	(also ref. note numbers)
sulphur	%wt		100	(1)	(1) Sulphur will be stored outdoors, roofed. (2) It will be transported from the plant with either trucks or vessels
Total			100.0		
Process Conditions and Price					
Temp.	oC		25		
Press.	Bara		1		
Phase	V/L/S		S		
Price	€/ton		39		

Stream Name :	**Carbon dioxide <233>**				
Comp.	Units	Specification			Additional Information
		Available	Design	Notes	(also ref. note numbers)
CO_2	%wt		100	(1)	(1) CO_2 is released into the air.
Total			100.0		
Process Conditions and Price					
Temp.	oC		95		
Press.	Bara		1		
Phase	V/L/S		V		
Price	€/ton		0		

Stream Name :	**Nitrogen to atmosphere <505>**				
Comp.	Units	Specification			Additional Information
		Available	Design	Notes	(also ref. note numbers)
N_2	%wt		100	(1)	(1) N_2 is released into the air.
Total			100.0		
Process Conditions and Price					
Temp.	oC		25		
Press.	Bara		1		
Phase	V/L/S		V		
Price	€/ton		0		

Stream Name :	**Waste gas to atmosphere <602>**				
Comp.	Units	Specification			Additional Information
		Available	Design	Notes	(also ref. note numbers)
N_2	%vol		33	(1)	(1) Waste air is released into the air.
CO_2	%vol		33		
H_2S+SO_2	%vol		<15 ppmV	(2)	(2) Claus removes all H_2S and SO_2 to below environmental legislation
H_2O	%vol		33		(3) J.A. Moulijn et al., *Chemical Process Technology*, Wiley, 2001
Total			100.0		
Process Conditions and Price					
Temp.	oC		25		(4) The gas leaving the Claus plant is first sent through a flare, in which it is combusted to CO_2, SO_2 and H_2O.
Press.	Bara		1		
Phase	V/L/S		V		
Price	€/ton		0		

Stream Name :	**Water purge <406>**				
Comp.	Units	Specification			Additional Information
		Available	Design	Notes	(also ref. note numbers)
H_2O	%wt		100	(1)	(1) Water is released onto surface water. This water comes from the wastewater treatment and is clean.
Total			100.0		
Process Conditions and Price					
Temp.	oC		25		
Press.	Bara		1		
Phase	V/L/S		L		
Price	€/ton		0		

Stream Name :	**Cooling water**				
Comp.	Units	Specification			Additional Information
		Available	Design	Notes	(also ref. note numbers)
H_2O	%wt		100	(1)	(1) Water is released onto surface water. This water is clean.
Total			100.0		
Process Conditions and Price					
Temp.	oC		35		
Press.	Bara		1		
Phase	V/L/S		L		
Price	€/ton		0		

Stream Name :	**Wood residue loss <103>**				
Comp.	Units	Specification			Additional Information
		Available	Design	Notes	(also ref. note numbers)
wood residues	%wt		100	(1)	(1) Biomass is lost during pre-treatment. This is considered as (green) waste. It can be used as landfill.
Total			100.0		
Process Conditions and Price					
Temp.	oC		10		
Press.	Bara		1		
Phase	V/L/S		S		
Price	€/ton		0		

Stream Name :	**Zn/Ti sorbent spent <240>**				
Comp.	Units	Specification			Additional Information
		Available	Design	Notes	(also ref. note numbers)
ZnO	%wt	15	15	(1)	(1) Sorbents need to be replaced because of erosion and pollution.
inerts	%wt		85		
different metals, TiO_2, Ni, Co etc.	%wt	85			(2) Spent sorbents become landfill
Total			100.0		(3) R.A. Newby et al., *Novel gas cleaning/conditioning for integrated gasification combined cycle, Based program final report, Siemens Westinghouse Power Corporation & Gas Technology Institute*, August 2001
Process Conditions and Price					
Temp.	oC		25		
Press.	Bara		19.5		
Phase	V/L/S		S		
Price	€/ton		20		

Stream Name :	**Catalyst tar cracker**				
Comp.	Units	Specification			Additional Information
		Available	Design	Notes	(also ref. note numbers)
NiO-alumina	%wt		100	(1)	(1) Tar cracker catalyst is a monolith, which is entirely replaced once every 5 years. (2) Spent catalyst becomes landfill (3) Data assumed with use of: P. Simell, *Gasification gas cleaning with nickel monolith catalyst*, A.V. Bridgewater & D.G.B Boocock, Developments in thermodynamic biomass conversion, vol.2, Blackie Academic & Professional
Total			100.0		
Process Conditions and Price					
Temp.	oC		25		
Press.	Bara		1		
Phase	V/L/S		S		
Price	€/ton		20		

Stream Name :	**Catalyst sour gas shift**				
Comp.	Units	Specification			Additional Information
		Available	Design	Notes	(also ref. note numbers)
CoMoS	%wt		100	(1)	(1) C. Higman, M van der Burgt, *Gasification*, Elsevier, 2003 (2) Spent catalyst becomes landfill
Total			100.0		
Process Conditions and Price					
Temp.	oC		25		
Press.	Bara		1		
Phase	V/L/S		S		
Price	€/ton		20		

Stream Name :	**Catalyst Claus plant**				
Comp.	Units	Specification			Additional Information
		Available	Design	Notes	(also ref. note numbers)
alumina				(1)	(1) Details of this catalyst are unknown.
Total			100.0		
Process Conditions and Price					(2) Spent catalyst becomes landfill
Temp.	oC		25		
Press.	Bara		1		
Phase	V/L/S		S		
Price	€/ton		20		

Stream Name :	**Salts <404>**				
Comp.	Units	Specification			Additional Information
		Available	Design	Notes	(also ref. note numbers)
Different minerals and mostly NH_3 and Cl.	%wt		100	(1)	(1) Details are unknown.
Total			100.0		
Process Conditions and Price					(2) This salt could be used as salt for roads, as long as it contains no exotic (radioactive) elements
Temp.	oC		25		
Press.	Bara		1		
Phase	V/L/S		S		
Price	€/ton		0		

Stream Name :	**Ash and char <205>+<207>**				
Comp.	Units	Specification			Additional Information
		Available	Design	Notes	(also ref. note numbers)
ash (different metals and minerals)	%wt		15	(1)	(1) Ash and char becomes ingredient for asphalt.
char (C)	%wt		85		
Total			100.0		
Process Conditions and Price					(2) source: personal communication with Nuon Buggenum.
Temp.	oC		25		
Press.	Bara		1		
Phase	V/L/S		S		
Price	€/ton		0		

Stream Name :	**Water <104>**				
Comp.	Units	Specification			Additional Information
		Available	Design	Notes	(also ref. note numbers)
water	%wt		100	(1)	(1) This is water that is “squeezed” out of the wood residues in the pelletiser. It is assumed to be pure water.
wood	%wt		<0.1		
Total			100.0		
Process Conditions and Price					
Temp.	oC		50		
Press.	Bara		1		
Phase	V/L/S		L		
Price	€/ton		0		

Appendix 5.1 Calculation of storage facilities and number of transports with trucks

Table A.5.1.1: Storage facilities and truck transport

Wood residues		20,000,000	ton/a		
1/3 from sawmills		6,666,667	ton/a		
2/3 from forestry		13,333,333	ton/a		
Baltic States and Sweden					
Storage saw mills	1 week	256,410	m3		
Storage forestry	3 months	6,666,667	m3		
Rotterdam	1 week	443,077	m3		
Transportation of pellets from sawmills to harbour		5,000,000	ton/a		m3/a
Transportation of chips from forestry to harbour			ton/a	55,555,556	m3/a
Number of trucks with pellets		125,000	#/a		
Number of trucks with chips				427,350	#/a

Appendix 5.2 Heat integration

Table A.5.2.1: Hot streams which should be cooled

	Stream nr.	T in[K]	T out [K]	dT [K]	FCp [kW/K]	H [kW]
1	212-213	1179	474	-705	1796	1265900
2	221-226	773	298	-475	2403	1141600
3	231-232	403	368	-35	1569	54900
4	302-303	582	353	-229	4348	995700
5	403-405	374	298	-76	2878	218700

Table A.5.2.2: Cold streams which should be heated

	Stream nr.	T in [K]	T out [K]	dT [K]	FCp [kW/K]	H [kW]
6	202-203	474	763	289	285	-82500
7	210-211	474	763	289	72	-20930
8	234-235	368	500	132	995	-131400
9	401-402	298	374	76	2878	-218700

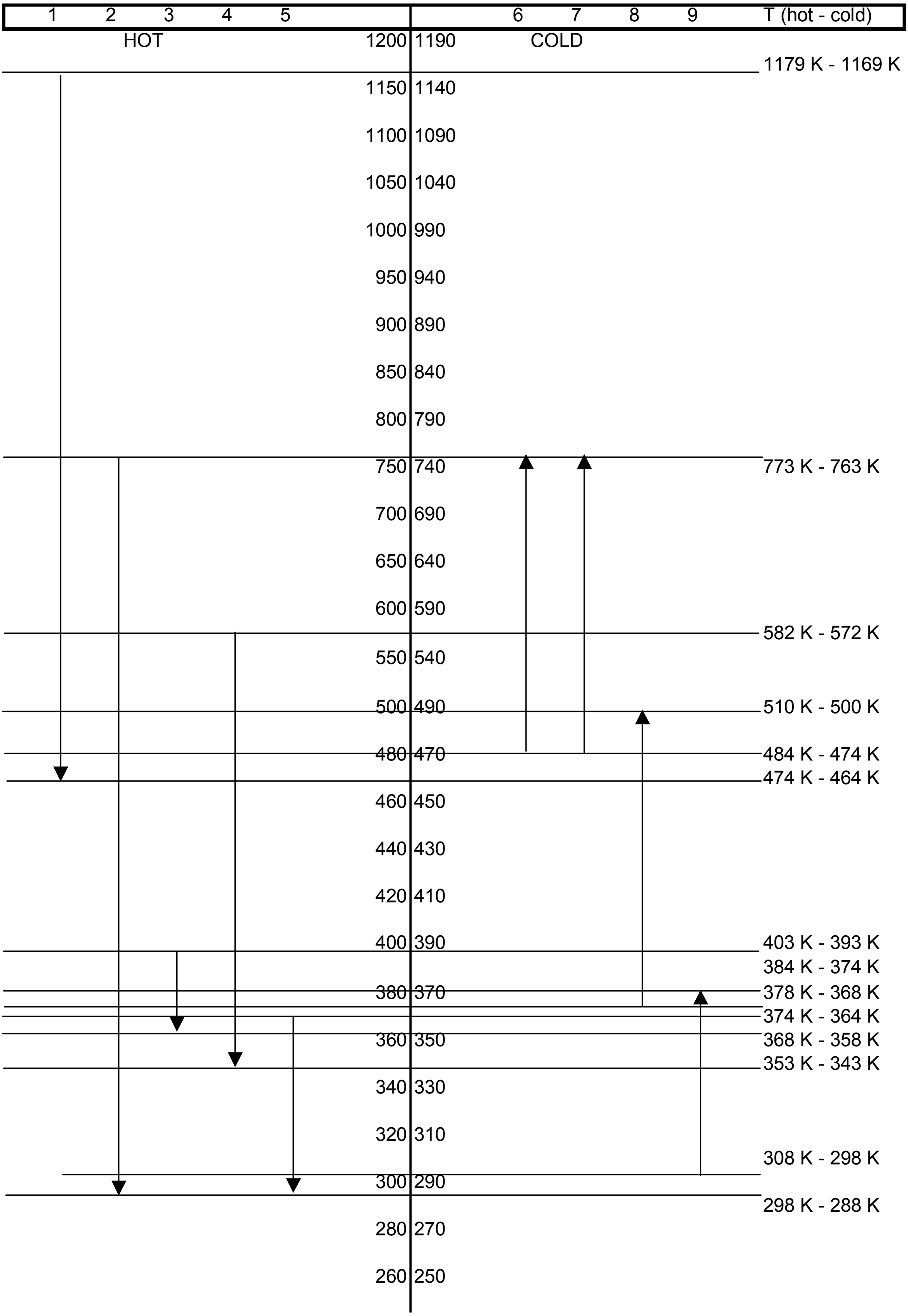


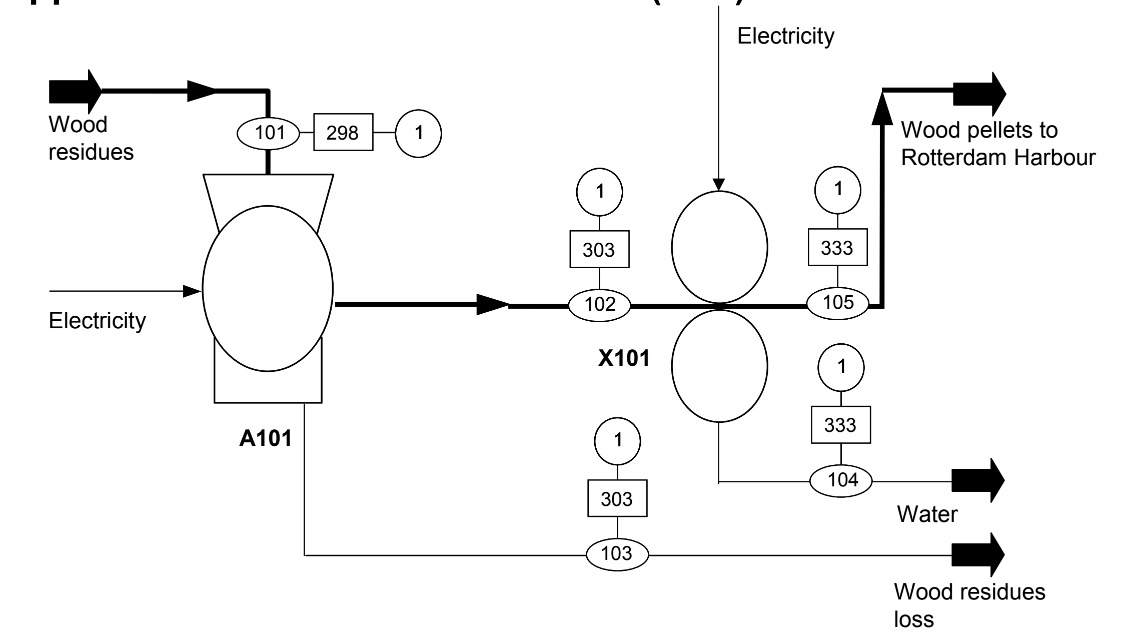
Figure A.5.2.1: Cascade diagram for Pinch Technology

Table A.5.2.3: Continuation of Cascade diagram per temperature interval

T hot [K]	T cold [K]	1	2	3	4	5	6	7	8	9	Sum	Acc
1179	1168											
773	763	729015									0	0
582	572	342960	459043				-54524	-13833			390687	390687
510	500	129283	173043		-313059		-20554	-5214			-165784	224903
484	474	46686	62488		-113049		-7422	-1883	-25882		-85748	139154
474	464	17956	24034		-43480				-9955		-29401	109753
403	393		170639		-308710				-70677		-208749	-98996
384	374		45664	29803	-82613				-18914		-26059	-125055
378	368		14420	9411	-26088				-5973	-17266	-25495	-150550
374	364		9613	6274	-17392					-11511	-13015	-163565
368	358		14420	9411	-26088	-17266				-17266	-36788	-200353
353	343		36051		-65221	-43164				-43164	-115499	-315852
308	298		108152			-129493				-129493	-150835	-466687
298	288		24034			-28776					-4743	-471430
		1265900	1141600	54900	-995700	-218700	-82500	-20930	-131400	-218700		

T_{pinch} = 773 K

Appendix 5.3 Process Flow Scheme (PFS)



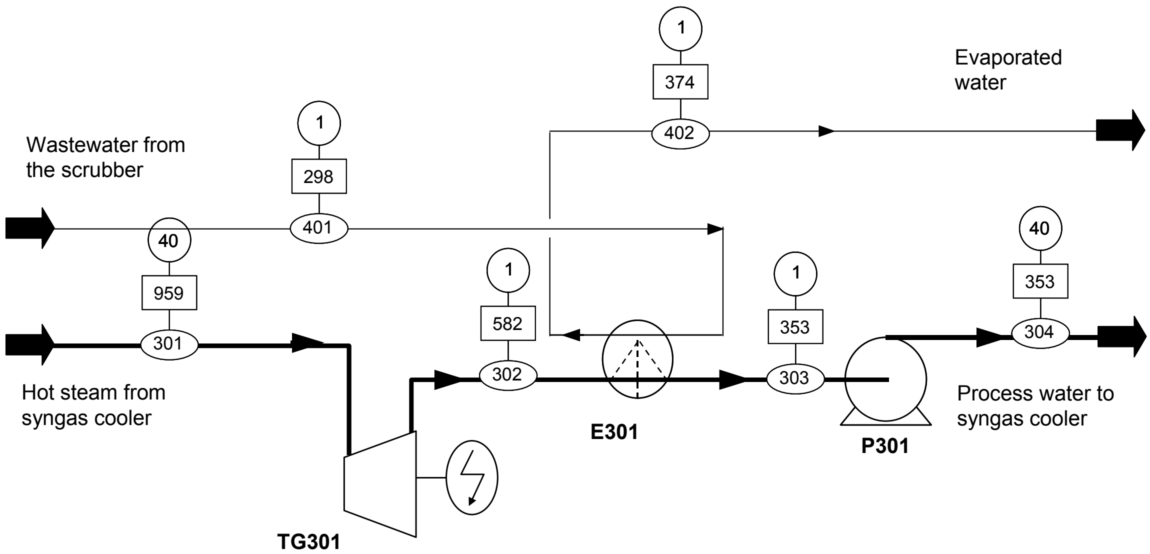
Process Equipment Summary	
A101:	Wood chipper
X101:	Pelletiser

Designers

Process Flow Scheme	
Project	: Syngas from gasification of wood residue
Proj. ID Number	: CPD 3309
Completion Date	: July 30th, 2004

Stream number Temperature (K) Pressure (Bara)

Figure A.5.3.1: Proces Flow Scheme of the pre-treatment step in Baltic States and Sweden (100)



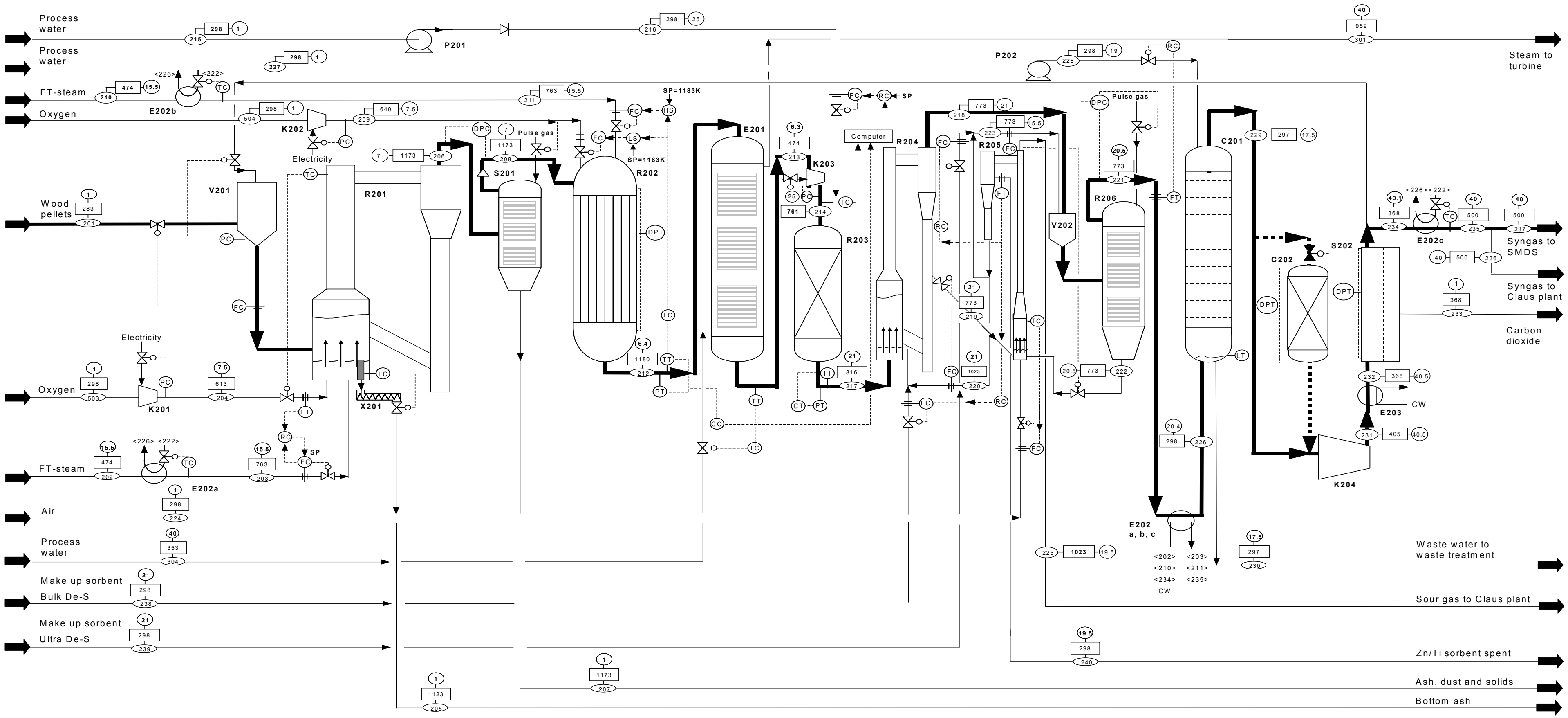
Process Equipment Summary	
E301:	Evaporator for wastewater
P301:	Water pump to E201
TG301:	Steam turbine for electricity

Designers

Process Flow Scheme	
Project	: Syngas from gasification of wood residue
Proj. ID Number	: CPD 3309
Completion Date	: July 30th, 2004

Stream number Temperature (K) Pressure (Bara)

Figure A.5.3.2: Proces Flow Scheme of the electricity plant (300)



Process Equipment Summary			
$C201_H$:	NH_3/HCl scrubber	$P202_H$:	Process water pump to C201
C202 :	Active coal filter bed	$R201_J$:	Circulating Fluidized Bed reactor
$E201_J$:	Syngas cooler	$R202_J$:	Monolith tar cracker
E202abc:	Combined heat ex. for gas to C201	$R203_H$:	Sour water-gas shift reactor
E202a:	Heat ex. for steam to R201	$R204_H$:	Bulk desulphurizer
E202b:	Heat ex. for steam to R202	$R205_H$:	Zn/Ti sorbent regenerator
E202c:	Heat ex. for produced syngas	$R206_I$:	Ultra desulphurizer
E203 :	Heat ex. for gas to S202	$S201_J$:	Candle filter
K201 :	Oxygen compressor	$S202_H$:	CO_2-selective membrane
K202 :	Oxygen compressor	$V201_J$:	Lock hopper
$K203_H$:	Cooled gas compressor	$V202_H$:	Mix hopper for Ultra desulphurizer
$K204_H$:	Syngas compressor to 40 bar	$X201_J$:	Screw transporter for bottom ash
$P201_H$:	Steam pump to R203		

Designers

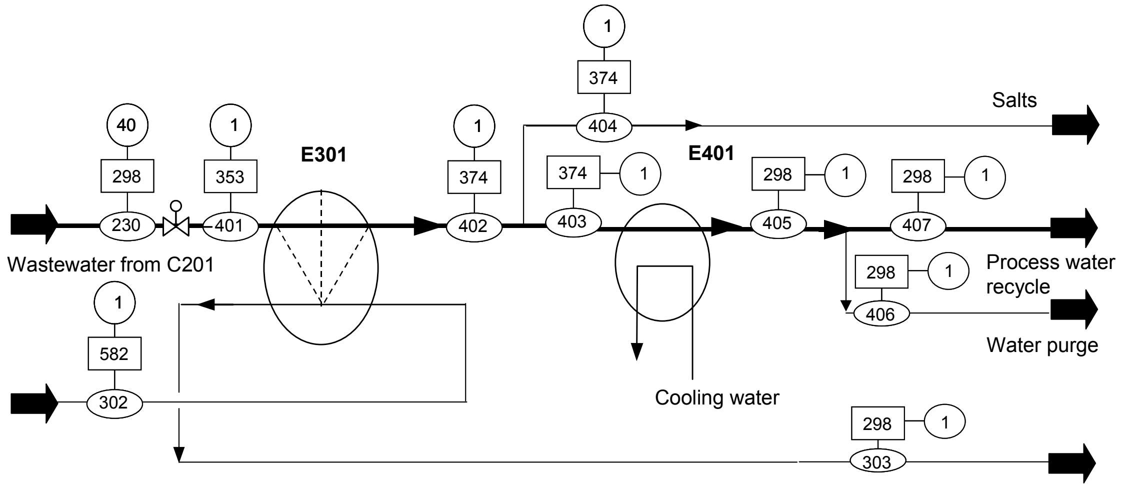
Process Flow Scheme	
Project	: Syngas from gasification of wood residue
Proj. ID Number	: CPD 3309
Completion Date	: July 30th, 2004

Stream number — Temperature (K) — Pressure (Bara)

- - - - - - - - Control line

Subcripts:
H: 2 units of equipment
I : 4 units of equipment
J : 10 units of equipment

Figure A.5.3.3: Process Flow Scheme of the gasification of wood pellets to syngas (200)

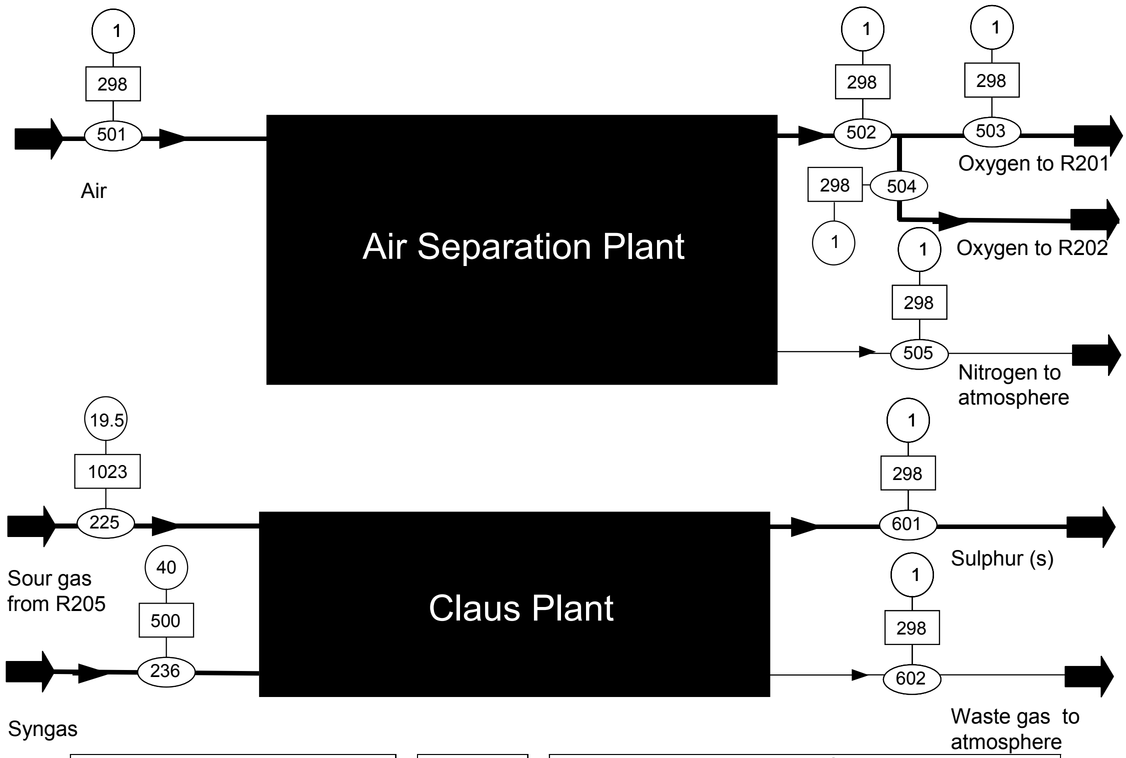


Process Equipment Summary	
E301:	Heat exchanger to evaporate water
E401:	Cooler

Designers

Process Flow Scheme	
Project	: Syngas from gasification of wood residue
Proj. ID Number	: CPD 3309
Completion Date	: July 30th, 2004
Stream number	Temperature (K) Pressure (Bara)

Figure A.5.3.4: Process Flow Scheme of the wastewater treatment plant (400)



Process Equipment Summary	
Black box 1:	Air separation plant
Black box 2:	Claus plant

Designers

Process Flow Scheme	
Project	: Syngas from gasification of wood residue
Proj. ID Number	: CPD 3309
Completion Date	: July 30th, 2004
Stream number	Temperature (K) Pressure (Bara)

Figure A.5.3.5: Process Flow Scheme of the air separation plant (500) and the Claus plant (600

Appendix 5.4 Process Stream Summary

On the following pages the process stream summary is given for the plant sections

- 100: Pre-treatment step in Baltic States and Sweden
- 200: Gasification of wood pellets to syngas
- 300: Electricity plant
- 400: Waste water treatment plant
- 500: Air separation plant
- 600: Claus plant.

Plant section 100: Pre-treatment step in Baltic States and Sweden

STEAM Nr.:		101	IN	102		103	OUT	104	OUT	105	
Name:		Wood residues to A101		Wood to X101		Wood residues loss		Water from X101		Pellets to 200	
COMP	MW	kg/s	kmol/s	kg/s	kmol/s	kg/s	kmol/s	kg/s	kmol/s	kg/s	kmol/s
Biomass	24.8	575.9	23.26	564.4	22.79	11.5	0.47	0	0	564.4	22.79
CO	28.0	0	0	0	0	0	0	0	0	0	0
H2	2.0	0	0	0	0	0	0	0	0	0	0
CO2	44.0	0	0	0	0	0	0	0	0	0	0
CH4	16.0	0	0	0	0	0	0	0	0	0	0
C2H6	30.1	0	0	0	0	0	0	0	0	0	0
C7H8	92.1	0	0	0	0	0	0	0	0	0	0
H2O	18.0	244.9	13.60	240.0	13.32	4.9	0.27	197.1	10.9	43.0	2.39
O2	32.0	0	0	0	0	0	0	0	0	0	0
N2	28.0	0	0	0	0	0	0	0	0	0	0
NH3	17.0	0	0	0	0	0	0	0	0	0	0
HCN	27.0	0	0	0	0	0	0	0	0	0	0
H2S	34.1	0	0	0	0	0	0	0	0	0	0
COS	60.1	0	0	0	0	0	0	0	0	0	0
HCL	36.5	0	0	0	0	0	0	0	0	0	0
AR	39.9	0	0	0	0	0	0	0	0	0	0
ZNO	81.4	0	0	0	0	0	0	0	0	0	0
ZNS	97.4	0	0	0	0	0	0	0	0	0	0
SO2	64.1	0	0	0	0	0	0	0	0	0	0
TiO2	79.9	0	0	0	0	0	0	0	0	0	0
Ash	100.0	6.6	0.07	6.5	0.06	0.1	0.00	0	0	6.5	0.06
Char	24.8	0	0	0	0	0	0	0	0	0	0
S2	64.0	0	0	0	0	0	0	0	0	0	0
Total		827.5	36.92	811.0	36.18	16.55	0.74	197.1	10.94	613.9	25.24
Enthalpy	kW		-6729307		-6594722		-134586		-3161851		-3432870
Phase		SOLID		SOLID		SOLID		LIQUID		SOLID	
Press.	Bara		1		1		1		1		1
Temp.	°C		10		10		10		10		10

Plant section 200: Gasification of wood pellets to syngas

STEAM Nr.:		201		202	IN	203		503		204		205	OUT
Name:		Feed R201		Steam from FT		Steam to R201		Oxygen from 500		Oxygen to R201		Discharge R201	
COMP	MW	kg/s	kmol/s	kg/s	kmol/s	kg/s	kmol/s	kg/s	kmol/s	kg/s	kmol/s	kg/s	kmol/s
Biomass	24.8	564.4	22.79	0	0	0	0	0	0	0	0	0	0
CO	28.0	0	0	0	0	0	0	0	0	0	0	0	0
H2	2.0	0	0	0	0	0	0	0	0	0	0	0	0
CO2	44.0	0	0	0	0	0	0	0	0	0	0	0	0
CH4	16.0	0	0	0	0	0	0	0	0	0	0	0	0
C2H6	30.1	0	0	0	0	0	0	0	0	0	0	0	0
C7H8	92.1	0	0	0	0	0	0	0	0	0	0	0	0
H2O	18.0	43.0	2.39	134.9	7.49	134.9	7.49	0	0	0	0	0	0
O2	32.0	0	0	0	0	0	0	134.9	4.22	134.9	4.22	0	0
N2	28.0	0	0	0	0	0	0	2.5	0.09	2.5	0.09	0	0
NH3	17.0	0	0	0	0	0	0	0	0	0	0	0	0
HCN	27.0	0	0	0	0	0	0	0	0	0	0	0	0
H2S	34.1	0	0	0	0	0	0	0	0	0	0	0	0
COS	60.1	0	0	0	0	0	0	0	0	0	0	0	0
HCL	36.5	0	0	0	0	0	0	0	0	0	0	0	0
AR	39.9	0	0	0	0	0	0	5.3	0.13	5.3	0.13	0	0
ZNO	81.4	0	0	0	0	0	0	0	0	0	0	0	0
ZNS	97.4	0	0	0	0	0	0	0	0	0	0	0	0
SO2	64.1	0	0	0	0	0	0	0	0	0	0	0	0
TiO2	79.9	0	0	0	0	0	0	0	0	0	0	0	0
Ash	100.0	6.5	0.06	0	0	0	0	0	0	0	0	3.2	0.03
Char	24.8	0	0	0	0	0	0	0	0	0	0	0	0
S2	64.0	0	0	0	0	0	0	0	0	0	0	0	0
Total		613.9	25.24	134.9	7.49	134.9	7.49	142.7	4.44	142.7	4.44	3.2	0.03
Enthalpy	kW		-3432870		-1772900		-1690400		-42		42522		0
Phase		SOLID		VAPOUR		VAPOUR		VAPOUR		VAPOUR		SOLID	
Press.	Bara		7.0		15.5		15.5		1.0		7.5		1.0
Temp.	°C		10		201		490		25		340		850

STEAM Nr.:		206		206		207	OUT	208		504		209	
Name:		Product gas to S201		Product gas to S201		Discharge S201		Product gas to R202		Oxygen from 500		Oxygen to R202	
COMP	MW	kg/s	kmol/s	wfrac	mfrac	kg/s	kmol/s	kg/s	kmol/s	kg/s	kmol/s	kg/s	kmol/s
Biomass	24.8	0	0	0	0	0	0	0	0	0	0	0	0
CO	28.0	215.6	7.70	0.243	0.200	0	0	215.6	7.70	0	0	0	0
H2	2.0	18.4	9.12	0.021	0.237	0	0	18.4	9.12	0	0	0	0
CO2	44.0	363.9	8.27	0.410	0.215	0	0	363.9	8.27	0	0	0	0
CH4	16.0	36.6	2.28	0.041	0.059	0	0	36.6	2.28	0	0	0	0
C2H6	30.1	25.7	0.86	0.029	0.022	0	0	25.7	0.86	0	0	0	0
C7H8	92.1	33.9	0.37	0.038	0.010	0	0	33.9	0.37	0	0	0	0
H2O	18.0	143.8	7.98	0.162	0.208	0	0	143.8	7.98	0	0	0	0
O2	32.0	0	0	0	0	0	0	0	0	84.8	2.65	84.8	2.65
N2	28.0	4.3	1.55E-01	4889 ppm	4034 ppmV	0	0	4.34	1.55E-01	1.6	0.06	1.6	0.06
NH3	17.0	2.1	1.26E-01	2415 ppm	3277 ppmV	0	0	2.14	1.26E-01	0	0	0	0
HCN	27.0	1.79E-01	6.63E-03	202 ppm	172 ppmV	0	0	1.79E-01	6.63E-03	0	0	0	0
H2S	34.1	5.07E-01	1.49E-02	571 ppm	387 ppmV	0	0	5.07E-01	1.49E-02	0	0	0	0
COS	60.1	9.94E-02	1.65E-03	112 ppm	43 ppmV	0	0	9.94E-02	1.65E-03	0	0	0	0
HCL	36.5	5.46E-01	1.50E-02	614 ppm	389 ppmV	0	0	5.46E-01	1.50E-02	0	0	0	0
AR	39.9	5.3	1.33E-01	5987 ppm	3464 ppmV	0	0	5.32	1.33E-01	3.3	0.08	3.3	0.08
ZNO	81.4	0	0	0	0	0	0	0	0	0	0	0	0
ZNS	97.4	0	0	0	0	0	0	0	0	0	0	0	0
SO2	64.1	0	0	0	0	0	0	0	0	0	0	0	0
TiO2	79.9	0	0	0	0	0	0	0	0	0	0	0	0
Ash	100.0	3.2	0.03	0.004	0.001	3.2	0.03	0	0	0	0	0	0
Char	24.8	33.9	1.37	0.038	0.036	33.9	1.37	0	0	0	0	0	0
S2	64.0	0	0	0	0	0	0	0	0	0	0	0	0
Total		888.2	38.4	1	1	37.1	1.40	851.1	37.03	89.7	2.79	89.7	2.79
Enthalpy	kW		-5092180		-4927586		-164780		-4927400		-38		29092
Phase		VAPOUR/SOLID		VAPOUR/SOLID		SOLID		VAPOUR		VAPOUR		VAPOUR	
Press.	Bara		7.0		7.0		7.0		7.0		1.0		7.5
Temp.	°C		900		900		900		900		25		367

STEAM Nr.:		210	IN	211		212		212		213		214	
Name:		Steam from FT		Steam to R202		Raw syngas to E201		Raw syngas to E201		Raw syngas to K203		Raw syngas to R203	
COMP	MW	kg/s	kmol/s	kg/s	kmol/s	kg/s	kmol/s	wfrac	mfrac	kg/s	kmol/s	kg/s	kmol/s
Biomass	24.8	0	0	0	0	0	0	0	0	0	0	0	0
CO	28.0	0	0	0	0	440.6	15.73	0.452	0.310	440.6	15.73	440.6	15.73
H2	2.0	0	0	0	0	35.1	17.39	0.036	0.343	35.1	17.39	35.1	17.39
CO2	44.0	0	0	0	0	296.0	6.72	0.304	0.133	296.0	6.72	296.0	6.72
CH4	16.0	0	0	0	0	1.3	0.08	0.001	0.002	1.3	0.08	1.3	0.08
C2H6	30.1	0	0	0	0	0.0	0.00	0.000	0.000	0.0	0.00	0.0	0.00
C7H8	92.1	0	0	0	0	0.0	0.00	0.000	0.000	0.0	0.00	0.0	0.00
H2O	18.0	34.2	1.90	34.2	1.90	184.5	10.24	0.189	0.202	184.5	10.24	184.5	10.24
O2	32.0	0	0	0	0	0	0	0	0	0	0	0	0
N2	28.0	0	0	0	0	7.7	2.7E-01	7852 ppm	5391 ppmV	7.7	2.73E-01	7.7	2.73E-01
NH3	17.0	0	0	0	0	1.66E-02	9.8E-04	17 ppm	19 ppmV	1.66E-02	9.78E-04	1.66E-02	9.78E-04
HCN	27.0	0	0	0	0	1.79E-01	6.6E-03	184 ppm	130 ppmV	1.79E-01	6.63E-03	1.79E-01	6.63E-03
H2S	34.1	0	0	0	0	5.07E-01	1.5E-02	520 ppm	294 ppmV	5.07E-01	1.49E-02	5.07E-01	1.49E-02
COS	60.1	0	0	0	0	9.94E-02	1.7E-03	102 ppm	33 ppmV	9.94E-02	1.65E-03	9.94E-02	1.65E-03
HCL	36.5	0	0	0	0	5.46E-01	1.5E-02	560 ppm	295 ppmV	5.46E-01	1.50E-02	5.46E-01	1.50E-02
AR	39.9	0	0	0	0	8.7	2.2E-01	8883 ppm	4277 ppmV	8.7	2.17E-01	8.7	2.17E-01
ZNO	81.4	0	0	0	0	0	0	0	0	0	0	0	0
ZNS	97.4	0	0	0	0	0	0	0	0	0	0	0	0
SO2	64.1	0	0	0	0	0	0	0	0	0	0	0	0
TiO2	79.9	0	0	0	0	0	0	0	0	0	0	0	0
Ash	100.0	0	0	0	0	0	0	0	0	0	0	0	0
Char	24.8	0	0	0	0	0	0	0	0	0	0	0	0
S2	64.0	0	0	0	0	0	0	0	0	0	0	0	0
Total		34.2	1.90	34.2	1.90	975.0	50.70	1	1	975.0	50.70	975.0	50.70
Enthalpy	kW		-449890		-428960		-5327300		-5327300		-6593200		-6103100
Phase		VAPOUR		VAPOR		VAPOUR		VAPOUR		VAPOUR		VAPOUR	
Press.	Bara		15.5		15.5		6.4		6.4		6.3		25.0
Temp.	°C		201		490		907		907		201		488

STEAM Nr.:		215		216		217		217		218		218	
Name:		Process water to P201		Process water to R203		Syngas to R204		Syngas to R204		Syngas to R206		Syngas to R206	
COMP	MW	kg/s	kmol/s	kg/s	kmol/s	kg/s	kmol/s	wfrac	mfrac	kg/s	kmol/s	wfrac	mfrac
Biomass	24.8	0	0	0	0	0	0	0	0	0	0	0	0
CO	28.0	0	0	0	0	305.8	10.92	0.307	0.210	305.8	10.92	0.307	0.210
H2	2.0	0	0	0	0	44.8	22.21	0.045	0.428	44.8	22.21	0.045	0.428
CO2	44.0	0	0	0	0	508.0	11.54	0.510	0.222	508.0	11.54	0.509	0.222
CH4	16.0	0	0	0	0	1.3	0.08	0.001	0.002	1.3	0.08	0.001	0.002
C2H6	30.1	0	0	0	0	0.0	0.00	0.000	0.000	0.0	0.00	0.000	0.000
C7H8	92.1	0	0	0	0	0.0	0.00	0.000	0.000	0.0	0.00	0.000	0.000
H2O	18.0	21.6	1.20	21.6	1.20	119.2	6.62	0.120	0.128	119.5	6.63	0.120	0.128
O2	32.0	0	0	0	0	0	0	0	0	0	0	0	0
N2	28.0	0	0	0	0	7.7	2.73E-01	7682 ppm	5266 ppmV	7.7	2.73E-01	7676 ppm	5265 ppmV
NH3	17.0	0	0	0	0	1.29E-01	7.58E-03	130 ppm	146 ppmV	1.29E-01	7.58E-03	130 ppm	146 ppmV
HCN	27.0	0	0	0	0	5.67E-04	2.10E-05	569 ppb	404 ppbV	5.67E-04	2.10E-05	568 ppb	404 ppbV
H2S	34.1	0	0	0	0	5.55E-01	1.63E-02	557 ppm	314 ppmV	9.07E-03	2.66E-04	9 ppm	5 ppmV
COS	60.1	0	0	0	0	1.56E-02	2.59E-04	16 ppm	5 ppmV	2.54E-04	4.24E-06	255 ppb	81 ppbV
HCL	36.5	0	0	0	0	5.46E-01	1.50E-02	547 ppm	288 ppmV	5.46E-01	1.50E-02	547 ppm	288 ppmV
AR	39.9	0	0	0	0	8.7	2.17E-01	8691 ppm	4178 ppmV	8.7	2.17E-01	8684 ppm	4177 ppmV
ZNO	81.4	0	0	0	0	0	0	0	0	3.97E-01	4.88E-03	398 ppm	94 ppmV
ZNS	97.4	0	0	0	0	0	0	0	0	3.17E-03	3.25E-05	3 ppm	627 ppbV
SO2	64.1	0	0	0	0	0	0	0	0	0	0	0	0
TiO2	79.9	0	0	0	0	0	0	0	0	5.89E-01	7.38E-03	591 ppm	142 ppmV
Ash	100.0	0	0	0	0	0	0	0	0	0	0	0	0
Char	24.8	0	0	0	0	0	0	0	0	0	0	0	0
S2	64.0	0	0	0	0	0	0	0	0	0	0	0	0
Total		21.6	1.2	21.6	1.20	996.6	51.90	1	1	997.4	51.91	1	1
Enthalpy	kW		-345500		-345430		-6448600		-6448600		-6530900		-6530900
Phase		LIQUID		LIQUID		VAPOUR		VAPOUR		VAPOUR/SOLID		VAPOUR/SOLID	
Press.	Bara		1.0		25.0		21.0		21.0		21.0		21.0
Temp.	°C		25		25		543		543		500		500

STEAM Nr.:		219		220		221		221		222		223	
Name:		Spent sorbents to R205		Sorbents from R205		Syngas to E202		Syngas to E202		Spent sorbents to R205		Sorbents from R205	
COMP	MW	kg/s	kmol/s	kg/s	kmol/s	kg/s	kmol/s	wfrac	mfrac	kg/s	kmol/s	kg/s	kmol/s
Biomass	24.8	0	0	0	0	0	0	0	0	0	0	0	0
CO	28.0	0	0	0	0	305.8	10.92	0.307	0.210	0	0	0	0
H2	2.0	0	0	0	0	44.8	22.21	0.045	0.428	0	0	0	0
CO2	44.0	0	0	0	0	508.0	11.54	0.510	0.222	0	0	0	0
CH4	16.0	0	0	0	0	1.3	0.08	0.001	0.002	0	0	0	0
C2H6	30.1	0	0	0	0	0.0	0.00	0.000	0.000	0	0	0	0
C7H8	92.1	0	0	0	0	0.0	0.00	0.000	0.000	0	0	0	0
H2O	18.0	0	0	0	0	119.5	6.63	0.120	0.128	0	0	0	0
O2	32.0	0	0	0	0	0	0	0	0	0	0	0	0
N2	28.0	0	0	0	0	7.7	2.73E-01	7684 ppm	5266 ppmV	0	0	0	0
NH3	17.0	0	0	0	0	1.29E-01	7.58E-03	130 ppm	146 ppmV	0	0	0	0
HCN	27.0	0	0	0	0	5.67E-04	2.10E-05	569 ppb	404 ppbV	0	0	0	0
H2S	34.1	0	0	0	0	1.13E-03	3.32E-05	1 ppm	640 ppbV	0	0	0	0
COS	60.1	0	0	0	0	3.17E-05	5.28E-07	32 ppb	10 ppbV	0	0	0	0
HCL	36.5	0	0	0	0	5.46E-01	1.50E-02	548 ppm	288 ppmV	0	0	0	0
AR	39.9	0	0	0	0	8.7	2.17E-01	8693 ppm	4178 ppmV	0	0	0	0
ZNO	81.4	25.1	0.31	26.9	0.33	0	0	0	0	4.05E-01	4.98E-03	5.30E-03	6.51E-05
ZNS	97.4	1.6	0.02	0	0	0	0	0	0	2.62E-02	2.69E-04	0	0
SO2	64.1	0	0	0	0	0	0	0	0	0	0	0	0
TiO2	79.9	39.0	0.49	39.6	0.50	0	0	0	0	5.97E-01	7.47E-03	7.80E-03	9.76E-05
Ash	100.0	0	0	0	0	0	0	0	0	0	0	0	0
Char	24.8	0	0	0	0	0	0	0	0	0	0	0	0
S2	64.0	0	0	0	0	0	0	0	0	0	0	0	0
Total		65.7	0.81	66.5	0.83	996.4	51.90	1	1	1.0	0.01	0.0	0.00
Enthalpy	kW		-383640		-317420		-6532700		-6532700		-5876		-82
Phase		VAPOUR/SOLID		SOLID		VAPOUR		VAPOUR		SOLID		SOLID	
Press.	Bara		21.0		21.0		20.5		20.5		20.5		21.0
Temp.	°C		500		750		500		500		500		500

STEAM Nr.:		224	IN	225		226		227		228		229	
Name:		Air to R205		Sour gas to 600		Syngas to C201		Process water to P202		Process water to C201		Syngas to K204	
COMP	MW	kg/s	kmol/s	kg/s	kmol/s	kg/s	kmol/s	kg/s	kmol/s	kg/s	kmol/s	kg/s	kmol/s
Biomass	24.8	0	0	0	0	0	0	0	0	0	0	0	0
CO	28.0	0	0	0	0	305.8	10.92	0	0	0	0	305.8	10.92
H2	2.0	0	0	0	0	44.8	22.21	0	0	0	0	44.8	22.21
CO2	44.0	2.40E-03	5.45E-05	2.40E-03	5.45E-05	508.0	11.54	0	0	0	0	506.7	11.51
CH4	16.0	0	0	0	0	1.3	0.08	0	0	0	0	1.3	0.08
C2H6	30.1	0	0	0	0	0.0	0.00	0	0	0	0	0.0	0.00
C7H8	92.1	0	0	0	0	0.0	0.00	0	0	0	0	0.0	0.00
H2O	18.0	0	0	0	0	119.5	6.63	197.8	10.98	197.8	10.98	0.0	0.00
O2	32.0	1.2	0.04	0.4	0.01	0	0	0	0	0	0	0	0
N2	28.0	4.0	0.14	4.0	0.14	7.7	2.73E-01	0	0	0	0	7.7	2.73E-01
NH3	17.0	0	0	0	0	1.29E-01	7.58E-03	0	0	0	0	0	0
HCN	27.0	0	0	0	0	5.67E-04	2.10E-05	0	0	0	0	5.67E-04	2.10E-05
H2S	34.1	0	0	0	0	1.13E-03	3.32E-05	0	0	0	0	1.12E-03	3.29E-05
COS	60.1	0	0	0	0	3.17E-05	5.28E-07	0	0	0	0	3.17E-05	5.28E-07
HCL	36.5	0	0	0	0	5.46E-01	1.50E-02	0	0	0	0	1.09E-05	2.99E-07
AR	39.9	6.75E-02	1.69E-03	0.1	0.00	8.7	2.17E-01	0	0	0	0	8.7	2.17E-01
ZNO	81.4	0	0	0	0	0	0	0	0	0	0	0	0
ZNS	97.4	0	0	0	0	0	0	0	0	0	0	0	0
SO2	64.1	0	0	0.9	0.02	0	0	0	0	0	0	0	0
TiO2	79.9	0	0	0	0	0	0	0	0	0	0	0	0
Ash	100.0	0	0	0	0	0	0	0	0	0	0	0	0
Char	24.8	0	0	0	0	0	0	0	0	0	0	0	0
S2	64.0	0	0	0	0	0	0	0	0	0	0	0	0
Total		5.3	0.18	5.3	0.17	996.4	51.90	197.8	10.98	197.8	10.98	874.9	45.21
Enthalpy	kW		2582		1		-7674300		-3161500		-3161000		-5753700
Phase		VAPOUR		VAPOR/SOLID		VAPOUR/LIQUID		LIQUID		LIQUID		VAPOUR	
Press.	Bara		1.0		19.5		20.4		1.0		20.0		17.5
Temp.	°C		25		750		25		25		25		24

STEAM Nr.:		229		230		231		232		233	OUT	234	
Name:		Syngas to K204		Waste water to 400		Syngas to E203		Syngas to S202		Discharge S202		Syngas to E202C	
COMP	MW	wfrac	mfrac	kg/s	kmol/s	kg/s	kmol/s	kg/s	kmol/s	kg/s	kmol/s	kg/s	kmol/s
Biomass	24.8	0	0	0	0	0	0	0	0	0	0	0	0
CO	28.0	0.350	0.241	2.14E-02	7.64E-04	305.8	10.92	305.8	10.92	5.9	0.21	299.9	10.71
H2	2.0	0.051	0.491	2.69E-03	1.33E-03	44.8	22.21	44.8	22.21	1.1	0.54	43.7	21.67
CO2	44.0	0.579	0.255	1.25E+00	2.85E-02	506.7	11.51	506.7	11.51	479.9	10.90	26.8	0.61
CH4	16.0	0.001	0.002	1.25E-04	7.81E-06	1.3	0.08	1.3	0.08	0	0	1.3	0.08
C2H6	30.1	0.000	0.000	0	0	0.0	0.00	0.0	0.00	0	0	0.0	0.00
C7H8	92.1	0.000	0.000	0	0	0.0	0.00	0.0	0.00	0	0	0.0	0.00
H2O	18.0	0.000	0.000	317.3	17.61	0.0	0.00	0.0	0.00	0	0	0.0	0.00
O2	32.0	0	0	0	0	0	0	0	0	0	0	0	0
N2	28.0	8751 ppm	6045 ppmV	0	0	7.7	2.73E-01	7.7	2.73E-01	0	0	7.7	2.73E-01
NH3	17.0	0	0	1.29E-01	7.58E-03	0	0	0	0	0	0	0	0
HCN	27.0	648 ppb	464 ppbV	0	0	5.67E-04	2.10E-05	5.67E-04	2.10E-05	0	0	5.67E-04	2.10E-05
H2S	34.1	1 ppm	729 ppbV	8.57E-06	2.51E-07	1.12E-03	3.29E-05	1.12E-03	3.29E-05	0	0	1.12E-03	3.29E-05
COS	60.1	36 ppb	12 ppbV	0	0	3.17E-05	5.28E-07	3.17E-05	5.28E-07	0	0	3.17E-05	5.28E-07
HCL	36.5	12 ppb	7 ppbV	5.46E-01	1.50E-02	1.09E-05	2.99E-07	1.09E-05	2.99E-07	0	0	1.09E-05	2.99E-07
AR	39.9	9899 ppm	4795 ppmV	8.66E-04	2.17E-05	8.7	2.17E-01	8.7	2.17E-01	0	0	8.7	2.17E-01
ZNO	81.4	0	0	0	0	0	0	0	0	0	0	0	0
ZNS	97.4	0	0	0	0	0	0	0	0	0	0	0	0
SO2	64.1	0	0	0	0	0	0	0	0	0	0	0	0
TiO2	79.9	0	0	0	0	0	0	0	0	0	0	0	0
Ash	100.0	0	0	0	0	0	0	0	0	0	0	0	0
Char	24.8	0	0	0	0	0	0	0	0	0	0	0	0
S2	64.0	0	0	0	0	0	0	0	0	0	0	0	0
Total		1	1	319.3	17.67	874.9	45.21	874.9	45.21	486.9	11.66	388.0	33.55
Enthalpy	kW		-5753700		-5084900		-5601000		-5655900		-4299000		-1362800
Phase		VAPOUR		VAPOUR/LIQUID		VAPOUR		VAPOUR		VAPOUR		VAPOUR	
Press.	Bara		17.5		17.5		40.5		40.5		40.5		40.5
Temp.	°C		24		24		132		95		95		95

STEAM Nr.:		234		235		236		237	OUT	237		238	IN
Name:		Syngas to E202C		Syngas		Syngas to 600		Syngas to SMDS		Syngas to SMDS		Make up sorbent R204	
COMP	MW	wfrac	mfrac	kg/s	kmol/s	kg/s	kmol/s	kg/s	kmol/s	wfrac	mfrac	kg/s	kmol/s
Biomass	24.8	0	0	0	0	0	0	0	0	0	0	0	0
CO	28.0	0.773	0.319	299.9	10.71	2.3	0.08	297.6	10.62	0.773	0.319	0	0
H2	2.0	0.113	0.646	43.7	21.67	0.3	0.17	43.3	21.50	0.113	0.646	0	0
CO2	44.0	0.069	0.018	26.8	0.61	0.2	0.00	26.6	0.61	0.069	0.018	0	0
CH4	16.0	0.003	0.002	1.3	0.08	0.0	0.00	1.2	0.08	0.003	0.002	0	0
C2H6	30.1	0.000	0.000	0.0	0.00	0.0	0.00	0.0	0.00	0.000	0.000	0	0
C7H8	92.1	0.000	0.000	0.0	0.00	0.0	0.00	0.0	0.00	0.000	0.000	0	0
H2O	18.0	0.000	0.000	0.0	0.00	0.0	0.00	0.0	0.00	0.000	0.000	0	0
O2	32.0	0	0	0	0	0	0	0	0	0	0	0	0
N2	28.0	19732 ppm	8146 ppmV	7.7	2.73E-01	0.1	2.11E-03	7.6	2.71E-01	19732 ppm	8146 ppmV	0	0
NH3	17.0	0	0	0	0	0	0	0	0	0	0	0	0
HCN	27.0	1 ppm	625 ppbV	5.67E-04	2.10E-05	4.38E-06	1.62E-07	5.62E-04	2.08E-05	1 ppm	625 ppbV	0	0
H2S	34.1	3 ppm	982 ppbV	1.12E-03	3.29E-05	8.68E-06	2.55E-07	1.11E-03	3.27E-05	3 ppm	982 ppbV	0	0
COS	60.1	82 ppb	16 ppbV	3.17E-05	5.28E-07	2.45E-07	4.08E-09	3.15E-05	5.24E-07	82 ppb	16 ppbV	0	0
HCL	36.5	28 ppb	9 ppbV	1.09E-05	2.99E-07	8.44E-08	2.31E-09	1.08E-05	2.97E-07	28 ppb	9 ppbV	0	0
AR	39.9	22321 ppm	6462 ppmV	8.7	2.17E-01	0.1	1.68E-03	8.6	2.15E-01	22321 ppm	6462 ppmV	0	0
ZNO	81.4	0	0	0	0	0	0	0	0	0	0	7.95E-03	9.77E-05
ZNS	97.4	0	0	0	0	0	0	0	0	0	0	0	0
SO2	64.1	0	0	0	0	0	0	0	0	0	0	0	0
TiO2	79.9	0	0	0	0	0	0	0	0	0	0	1.17E-02	1.46E-04
Ash	100.0	0	0	0	0	0	0	0	0	0	0	0	0
Char	24.8	0	0	0	0	0	0	0	0	0	0	0	0
S2	64.0	0	0	0	0	0	0	0	0	0	0	0	0
Total				388.0	33.55	3.0	0.26	385.0	33.29	1	1	0.020	0.0002
Enthalpy	kW		-1362800		-1231400		-12100		-1219300		-1219300		-123
Phase		VAPOUR		VAPOUR		VAPOUR		VAPOUR		VAPOUR		SOLID	
Press.	Bara		40.5		40.4		40.4		40.4		40.4		21
Temp.	°C		95		227		227		227		227		25

STEAM Nr.:		239	IN	240	OUT
Name:		Make up sorbent R206		Discharge R205	
COMP	MW	kg/s	kmol/s	kg/s	kmol/s
Biomass	24.8	0	0	0	0
CO	28.0	0	0	0	0
H2	2.0	0	0	0	0
CO2	44.0	0	0	0	0
CH4	16.0	0	0	0	0
C2H6	30.1	0	0	0	0
C7H8	92.1	0	0	0	0
H2O	18.0	0	0	0	0
O2	32.0	0	0	0	0
N2	28.0	0	0	0	0
NH3	17.0	0	0	0	0
HCN	27.0	0	0	0	0
H2S	34.1	0	0	0	0
COS	60.1	0	0	0	0
HCL	36.5	0	0	0	0
AR	39.9	0	0	0	0
ZNO	81.4	5.30E-03	6.51E-05	1.32E-02	1.63E-04
ZNS	97.4	0	0	0	0
SO2	64.1	0	0	0	0
TiO2	79.9	7.80E-03	9.76E-05	1.95E-02	2.44E-04
Ash	100.0	0	0	0	0
Char	24.8	0	0	0	0
S2	64.0	0	0	0	0
Total		0.013	0.0002	0.033	0.0004
Enthalpy	kW		-82		-205
Phase		SOLID		SOLID	
Press.	Bara		21.0		19.5
Temp.	°C		25		25

Plant section 300: Electricity plant

STEAM Nr.:		301		302		303		304	
Name:		Water to TG301		Steam to E301		Water to P301		Water to E203	
COMP	MW	kg/s	kmol/s	kg/s	kmol/s	kg/s	kmol/s	kg/s	kmol/s
Biomass	24.8	0	0	0	0	0	0	0	0
CO	28.0	0	0	0	0	0	0	0	0
H2	2.0	0	0	0	0	0	0	0	0
CO2	44.0	0	0	0	0	0	0	0	0
CH4	16.0	0	0	0	0	0	0	0	0
C2H6	30.1	0	0	0	0	0	0	0	0
C7H8	92.1	0	0	0	0	0	0	0	0
H2O	18.0	350.0	19.43	350.0	19.43	350.0	19.43	350.0	19.43
O2	32.0	0	0	0	0	0	0	0	0
N2	28.0	0	0	0	0	0	0	0	0
NH3	17.0	0	0	0	0	0	0	0	0
HCN	27.0	0	0	0	0	0	0	0	0
H2S	34.1	0	0	0	0	0	0	0	0
COS	60.1	0	0	0	0	0	0	0	0
HCL	36.5	0	0	0	0	0	0	0	0
AR	39.9	0	0	0	0	0	0	0	0
ZNO	81.4	0	0	0	0	0	0	0	0
ZNS	97.4	0	0	0	0	0	0	0	0
SO2	64.1	0	0	0	0	0	0	0	0
TiO2	79.9	0	0	0	0	0	0	0	0
Ash	100.0	0	0	0	0	0	0	0	0
Char	24.8	0	0	0	0	0	0	0	0
S2	64.0	0	0	0	0	0	0	0	0
Total		350.0	19.43	350.0	19.43	350.0	19.43	350.0	19.43
Enthalpy	kW		-4240500		-4510600		-5506300		-5504600
Phase		VAPOUR		VAPOUR		LIQUID		LIQUID	
Press.	Bara		40.0		1.0		1.0		40.0
Temp.	°C		686		309		80		80

Plant section 400: Waste water treatment plant

STEAM Nr.:		401		402		403		404	OUT	405		406	OUT
Name:		Waste water to E301		Steam from E301		Steam to E401		Salt discharge		Process water from E401		Water purge	
COMP	MW	kg/s	kmol/s	kg/s	kmol/s	kg/s	kmol/s	kg/s	kmol/s	kg/s	kmol/s	kg/s	kmol/s
Biomass	24.8	0	0	0	0	0	0	0	0	0	0	0	0
CO	28.0	2.14E-02	7.64E-04	2.14E-02	7.64E-04	0	0	2.14E-02	7.64E-04	0	0	0	0
H2	2.0	2.69E-03	1.33E-03	2.69E-03	1.33E-03	0	0	2.69E-03	1.33E-03	0	0	0	0
CO2	44.0	1.25E+00	2.85E-02	1.25E+00	2.85E-02	0	0	1.25E+00	2.85E-02	0	0	0	0
CH4	16.0	0	0	0	0	0	0	0	0	0	0	0	0
C2H6	30.1	0	0	0	0	0	0	0	0	0	0	0	0
C7H8	92.1	0	0	0	0	0	0	0	0	0	0	0	0
H2O	18.0	317.3	17.61	317.3	17.61	317.3	17.61	0	0	317.3	17.61	97.9	5.43
O2	32.0	0	0	0	0	0	0	0	0	0	0	0	0
N2	28.0	0	0	0	0	0	0	0	0	0	0	0	0
NH3	17.0	1.29E-01	7.58E-03	1.29E-01	7.58E-03	0	0	1.29E-01	7.58E-03	0	0	0	0
HCN	27.0	0	0	0	0	0	0	0	0	0	0	0	0
H2S	34.1	8.57E-06	2.51E-07	8.57E-06	2.51E-07	0	0	8.57E-06	2.51E-07	0	0	0	0
COS	60.1	4.84E-08	8.05E-10	4.84E-08	8.05E-10	0	0	4.84E-08	8.05E-10	0	0	0	0
HCL	36.5	5.46E-01	1.50E-02	5.46E-01	1.50E-02	0	0	5.46E-01	1.50E-02	0	0	0	0
AR	39.9	8.66E-04	2.17E-05	8.66E-04	2.17E-05	0	0	8.66E-04	2.17E-05	0	0	0	0
ZNO	81.4	0	0	0	0	0	0	0	0	0	0	0	0
ZNS	97.4	0	0	0	0	0	0	0	0	0	0	0	0
SO2	64.1	0	0	0	0	0	0	0	0	0	0	0	0
TiO2	79.9	0	0	0	0	0	0	0	0	0	0	0	0
Ash	100.0	0	0	0	0	0	0	0	0	0	0	0	0
Char	24.8	0	0	0	0	0	0	0	0	0	0	0	0
S2	64.0	0	0	0	0	0	0	0	0	0	0	0	0
Total		319.3	17.67	319.3	17.67	317.3	17.61	2.0	0.05	317.3	17.61	97.9	5.43
Enthalpy	kW		-5085500		-4866800		-4958400		109800		-5068200		-1563600
Phase		LIQUID		VAPOUR/SOLID		VAPOUR		SOLID		LIQUID		LIQUID	
Press.	Bara		1.0		1.0		1.0		1.0		1.0		1.0
Temp.	°C		25		101		101		25		25		25

STEAM Nr.:		407	
Name:		Process water to 215/227	
COMP	MW	kg/s	kmol/s
Biomass	24.8	0	0
CO	28.0	0	0
H2	2.0	0	0
CO2	44.0	0	0
CH4	16.0	0	0
C2H6	30.1	0	0
C7H8	92.1	0	0
H2O	18.0	219.4	12.18
O2	32.0	0	0
N2	28.0	0	0
NH3	17.0	0	0
HCN	27.0	0	0
H2S	34.1	0	0
COS	60.1	0	0
HCL	36.5	0	0
AR	39.9	0	0
ZNO	81.4	0	0
ZNS	97.4	0	0
SO2	64.1	0	0
TiO2	79.9	0	0
Ash	100.0	0	0
Char	24.8	0	0
S2	64.0	0	0
Total		219.4	12.18
Enthalpy	kW		-3504600
Phase		LIQUID	
Press.	Bara		1.0
Temp.	°C		25

Plant section 500: Air separation plant

STEAM Nr.:		501	IN	502		503		504		505	OUT
Name:		Air to 500		Oyxgen from 500		Oxygen to R201		Oxygen to R202		Nitrogen from 500	
COMP	MW	kg/s	kmol/s	kg/s	kmol/s	kg/s	kmol/s	kg/s	kmol/s	kg/s	kmol/s
Biomass	24.8	0	0	0	0	0	0	0	0	0	0
CO	28.0	0	0	0	0	0	0	0	0	0	0
H2	2.0	0	0	0	0	0	0	0	0	0	0
CO2	44.0	0	0	0	0	0	0	0	0	0	0
CH4	16.0	0	0	0	0	0	0	0	0	0	0
C2H6	30.1	0	0	0	0	0	0	0	0	0	0
C7H8	92.1	0	0	0	0	0	0	0	0	0	0
H2O	18.0	0	0	0	0	0	0	0	0	0	0
O2	32.0	220.8	6.90	219.7	6.87	134.9	4.22	84.8	2.65	1.1	0.03
N2	28.0	720.5	25.72	4.0	0.14	2.5	0.09	1.6	0.06	716.5	25.58
NH3	17.0	0	0	0	0	0	0	0	0	0	0
HCN	27.0	0	0	0	0	0	0	0	0	0	0
H2S	34.1	0	0	0	0	0	0	0	0	0	0
COS	60.1	0	0	0	0	0	0	0	0	0	0
HCL	36.5	0	0	0	0	0	0	0	0	0	0
AR	39.9	12.2	0.31	8.7	0.22	5.3	0.13	3.3	0.08	3.6	0.09
ZNO	81.4	0	0	0	0	0	0	0	0	0	0
ZNS	97.4	0	0	0	0	0	0	0	0	0	0
SO2	64.1	0	0	0	0	0	0	0	0	0	0
TiO2	79.9	0	0	0	0	0	0	0	0	0	0
Ash	100.0	0	0	0	0	0	0	0	0	0	0
Char	24.8	0	0	0	0	0	0	0	0	0	0
S2	64.0	0	0	0	0	0	0	0	0	0	0
Total		953.5	32.93	232.4	7.23	142.7	4.44	89.7	2.79	721.1	25.70
Enthalpy	kW		-265		-80		-42		-38		-186
Phase		VAPOUR		VAPOUR		VAPOUR		VAPOUR		VAPOUR	
Press.	Bara		1		1.0		1.0		1.0		1.0
Temp.	°C		25		25		25		25		25

Plant section 600: Claus plant

STEAM Nr.:		601	OUT	602	OUT
Name:		Discharge from 600		Discharge from 600	
COMP	MW	kg/s	kmol/s	kg/s	kmol/s
Biomass	24.8	0	0	0	0
CO	28.0	0	0	2.3	8.28E-02
H2	2.0	0	0	3.38E-01	1.68E-01
CO2	44.0	0	0	2.10E-01	4.77E-03
CH4	16.0	0	0	9.69E-03	6.04E-04
C2H6	30.1	0	0	0	0
C7H8	92.1	0	0	0	0
H2O	18.0	0	0	0	0
O2	32.0	0	0	9.53E-01	2.98E-02
N2	28.0	0	0	4.0	1.44E-01
NH3	17.0	0	0	0	0
HCN	27.0	0	0	0	0
H2S	34.1	0	0	8.68E-06	2.55E-07
COS	60.1	0	0	2.45E-07	4.08E-09
HCL	36.5	0	0	8.44E-08	2.31E-09
AR	39.9	0	0	1.34E-01	3.37E-03
ZNO	81.4	0	0	0	0
ZNS	97.4	0	0	0	0
SO2	64.1	0	0	0	0
TiO2	79.9	0	0	0	0
Ash	100.0	0	0	0	0
Char	24.8	0	0	0	0
S2	64.0	0.26	0.01	0	0
Total		0.26	0.01	8.0	0.43
Enthalpy	kW		530		-12629
Phase		SOLID		VAPOUR	
Press.	Bara		1.0		1.0
Temp.	°C		25		25

Appendix 5.5 Summary of utilities

SUMMARY OF UTILITIES											
EQUIPMENT		UTILITIES									
		Cooling					Power				
Nr.	Name	Load	Consumption (t/h)				Actual	Consumption			
			Cooling	Air	Refirg.	Hot	Load	Steam		Electr.	Hot
		kW	water			oil	kW	HP	MP	kWh/h	oil
E202A	Heat ex. for steam to R201	53371	4597								
E202B	Heat ex. for steam to R202	511152	44023								
E202C	Heat ex. for produced syngas	342248	29476								
E203	Heat ex. for gas to S202	54900	4728								
E301	Evaporator for wastewater	777000	66919								
E401	Cooler	218700	18835								
P201	Steam pump to R203						70			70	
P202	Process water pump to C201						500			500	
P301	Water pump to E201						1700			1700	
K201	Oxygen compressor						42563			42563	
K202	Oxygen compressor						29130			29130	
K203	Cooled gas compressor						490100			490100	
K204	Syngas compressor to 40 bar						152700			152700	
TG301	Steam turbine for electricity						-270100			-270100	
100	Process in BS and Sweden						271108			271108	
500	Air sep. plant						261450			261450	
Total			**168577**							**979221**	

Appendix 5.6 Process Yields

Process Streams							
Name	Ref.	kg/s		t/h		t/t syngas	
	Stream	IN	OUT	IN	OUT	IN	OUT
Wood residues	<101>	827.5		2979		2.15	
Air	<224>+<501>	958.8		3452		2.49	
Steam	<202>+<210>	169.1		609		0.44	
Process water *	<215>+<227>+<406>+<407>	219.4	317.3	790	1142	0.57	0.82
Make up sorbents	<238>+<239>	0.033	0.033	0.118	0.118	0.00	0.00
Syngas	<237>		385.0		1386		1.00
Biomass loss	<103>		16.6		60		0.04
Water	<104>		197.1		709		0.51
Salts	<404>		2.0		7		0.01
Carbon dioxide	<233>		486.9		1753		1.26
Ash and char	<205>+<207>		40.4		145		0.10
Sulphur	<601>		0.3		1		0.00
Waste air	<602>		8.0		29		0.02
Nitrogen	<505>		721.1		2596		1.87
Total		2175	2175	7830	7829	5.65	5.65

Utilities							
Name	Ref. Stream	kg/s	kW	t/h	kWh/h	t/t syngas	kWh/t syngas
Cooling water	-	46827		168577		122	
Electricity BS and Sweden	-		271108		271108		196
Electricity Rotterdam	-		708113		708113		511

* Process water is recycled back into the plant, the difference between out and in is purged.

Appendix 7 Mass and heat balances

Table A.7.1: Mass and Heat balances per equipment

IN						OUT				
Plant		EQUIPMENT			EQUIPM.	EQUIPMENT			Plant	
Mass kg/s	Heat kW	Mass kg/s	Heat kW	Stream Nr.	IDENTIF.	Stream Nr.	Mass kg/s	Heat kW	Mass kg/s	Heat kW
					100					
827.5	-6729307	827.5	-6729307	<101>	A101	<102>	811.0	-6594722		
						<103>	16.6	-134586	16.6	-134586
		827.5	-6729307		Total		827.5	-6729308		
		811.0	-6594722	<102>	X101	<104>	197.1	-3161851	197.1	-3161851
						<105>	613.9	-3432870	613.9	-3432870
		811.0	-6594722		Total		811.0	-6594722		
827.5	-6729307								827.5	-6729308
					200					
134.9	-1772900	134.9	-1772900	<202>	E202A	<203>	134.9	-1690400		
	82500		82500							
		134.9	-1690400		Total		134.9	-1690400		
142.7	-42	142.7	-42	<503>	K201	<204>	142.7	42522		
	42563		42563							
		142.7	42522		Total		142.7	42522		
613.9	-3432870	613.9	-3432870	<201>	R201	<205>	3.2	0	3.2	0
		134.9	-1690400	<203>		<206>	888.2	-5092180		
		142.7	42522	<204>						
		891.5	-5080748		Total		891.5	-5092180		
		888.2	-5092180	<206>	S201	<207>	37.1	-164780	37.1	-164779.8
						<208>	851.1	-4927400		
		888.2	-5092180		Total		888.2	-5092180		
89.7	-38	89.7	-38	<504>	K202	<209>	89.7	29092		
	29130		29130							
		89.7	29092		Total		89.7	29092		
34.2	-449890	34.2	-449890	<210>	E202B	<211>	34.2	-428960		
	20930		20930							
		34.2	-428960		Total		34.2	-428960		
		851.1	-4927400	<208>	R202	<212>	975.0	-5327300		
		89.7	29092	<209>						
		34.2	-428960	<211>						
		975.0	-5327268		Total		975.0	-5327300		
		975.0	-5327300	<212>	E201	<213>	975.0	-6593200		
								1265900		1265900
		975.0	-5327300		Total		975.0	-5327300		
		975.0	-6593200	<213>	K203	<214>	975.0	-6103100		
	490100		490100							
		975.0	-6103100		Total		975.0	-6103100		
21.6	-345500	21.6	-345500	<215>	P201	<216>	21.6	-345430		

	70		70							
		21.6	-345430		Total		21.6	-345430		
		975.0	-6103100	<214>	R203	<217>	996.6	-6448600		
		21.6	-345430	<216>						
		996.6	-6448530		Total		996.6	-6448600		
		996.6	-6448600	<217>	R204	<218>	997.4	-6530900		
		66.5	-317420	<220>		<219>	65.7	-383640		
0.0	-123	0.0	-123	<238>						
		1063.1	-6766020		Total		1063.0	-6914540		
		997.4	-6530900	<218>	R206	<221>	996.4	-6532700		
0.0	-82	0.0	-82	<223>		<222>	1.0	-5876		
		997.4	-6530982		Total		997.4	-6538576		
		65.7	-383640	<219>	R205	<220>	66.5	-317420		
		1.0	-5876	<222>		<225>	5.3	1	5.3	1
5.3	2582	5.3	2582	<224>		<240>	0.033	-205	0.0	-205
		72.0	-386934		Total		71.8	-317624		
		996.4	-6532700	<221>	E202	<226>	996.4	-7674300		
								1141600		1141600
		996.4	-6532700		Total		996.4	-6532700		
197.8	-3161500	197.8	-3161500	<227>	P202	<228>	197.8	-3161000		
	500		500							
		197.8	-3161000		Total		197.8	-3161000		
		996.4	-7674300	<226>	C201	<229>	874.9	-5753700		
		197.8	-3161000	<228>		<230>	319.3	-5084900	319.3	-5084900
		1194.2	-10835300		Total		1194.2	-10838600		
		874.9	-5753700	<229>	K204	<231>	874.9	-5601000		
	152700		152700							
		874.9	-5601000		Total		874.9	-5601000		
		874.9	-5601000	<231>	E203	<232>	874.9	-5655900		
								54900		54900
		874.9	-5601000		Total		874.9	-5601000		
		874.9	-5655900	<232>	S202	<233>	486.9	-4299000	486.9	-4299000
						<234>	388.0	-1362800		
		874.9	-5655900		Total		874.9	-5661800		
		388.0	-1362800	<234>	E202C	<235>	388.0	-1231400		
	131400		131400							
		388.0	-1231400		Total		388.0	-1231400		
		388.0	-1231400	<235>		<236>	3	-12100	3	-12100
						<237>	385	-1219300	385	-1219300
		388.0	-1231400		Total		388	-1231400		
1240.1	-8210470								1239.9	-8317884
					300					
		350	-5504600	<301>	E201	<302>	350	-4240500		
	1264100		1264100							
		350	-5504600		Total		350	-4240500		
		350	-4240500	<302>	T301	<303>	350	-4510600		
								270100		270100

		350	-4240500		Total		350	-4240500		
		350	-4510600	<303>	E301	<304>	350	-5506300		
								995700		995700
		350	-4510600		Total		350	-4510600		
		350	-5506300	<304>	P301	<301>	350	-5504600		
	1700		1700							
		350	-5504600		Total		350	-5504600		
	1265800									1265800
					400					
319.3	-5084900	319.3	-5084900	<230>	V401	<401>	319.3	-5085500		
								600		600
		319.3	-5084900		Total		319.3	-5084900		
		319.3	-5085500	<401>	E301	<402>	319.3	-4866800		
	218700		218700							
		319.3	-4866800		Total		319.3	-4866800		
		319.3	-4866800	<402>		<403>	317.3	-4958400		
						<404>	1.955	109800	1.955	109800
		319.3	-4866800		Total		319.3	-4848600		
		317.3	-4958400	<403>	E401	<405>	317.3	-5068200		
								109800		109800
		317.3	-4958400		Total		317.3	-4958400		
		317.3	-5068200	<405>		<406>	97.9	-1563600	97.9	-1563600
						<407>	219.4	-3504600	219.4	-3504600
		317.3	-5068200		Total		317.3	-5068200		
319.3	-4866200								319.3	-4848000
					500					
953.5	-265	953.5	-265	<501>	500	<502>	232.4	-80		
						<505>	721.1	-186	721.1	-186
		953.5	-265		Total		953.5	-266		
		232.4	-80	<502>	500	<503>	142.7	-42	142.7	-42
						<504>	89.7	-38	89.7	-38
		232.4	-80		Total		232.4	-80		
953.5	-265								953.5	-266
					600					
5.3	1	5.3	1	<225>	600	<601>	0.264	530	0.3	530
3.0	-12100	3.0	-12100	<236>		<602>	7.996	-12629	8.0	-12629
		8.3	-12099		Total		8.3	-12099		
8.3	-12099								8.3	-12099

Table A.7.2 Heat input and output

Equipment	kW IN	Equipment	kW OUT	kW OUT-IN
E202A	82500	E203	1265900	
K201	42563	E202	1141600	
K202	29130	E203	54900	
E202B	20930	T301	270100	
K203	490100	E301	995700	
P201	70	V401	600	
P202	500	E401	109800	
K204	152700			
E202C	131400			
E201	1264100			
P301	1700			
E301	218700			
Total	2434394		3838600	1404206

Table A.7.3 Process Stream Summary over the two battery limits

STEAM Nr.:			IN		OUT		OUT-IN
Name:		<101> <202> <210> <224> <238> <239> <501>		<103> <104> <205> <207> <233> <237> <240> <404> <406> <505> <601> <602>			
COMP	MW	kg/s	kmol/s	kg/s	kmol/s	kg/s	kmol/s
Biomass	24.8	575.9	23.26	11.5	4.65E-01	-564	-22.8
CO	28.0	0	0	305.8	10.9	306	10.9
H2	2.0	0	0	44.8	22.2	45	22.2
CO2	44.0	2.40E-03	5.45E-05	508.0	11.5	508	11.5
CH4	16.0	0	0	1.3	7.81E-02	1	7.81E-02
C2H6	30.1	0	0	7.84E-06	2.61E-07	7.84E-06	2.61E-07
C7H8	92.1	0	0	0	0	0	0
H2O	18.0	414.1	22.98	299.9	16.6	-114	-6.3
O2	32.0	222.0	6.94	2.1	6.42E-02	-220	-6.9
N2	28.0	724.5	25.86	728.1	26.0	4	1.29E-01
NH3	17.0	0	0	1.29E-01	7.58E-03	1.29E-01	7.58E-03
HCN	27.0	0	0	5.67E-04	2.10E-05	5.67E-04	2.10E-05
H2S	34.1	0	0	1.13E-03	3.32E-05	1.13E-03	3.32E-05
COS	60.1	0	0	3.17E-05	5.29E-07	3.17E-05	5.29E-07
HCL	36.5	0	0	0.5	1.50E-02	5.46E-01	1.50E-02
AR	39.9	12.3	3.08E-01	12.3	3.08E-01	-8.56E-07	-2.14E-08
ZNO	81.4	1.32E-02	1.63E-04	1.32E-02	1.63E-04	0	0
ZNS	97.4	0	0	0	0	0	0
SO2	64.1	0	0	0	0	0	0
TiO2	79.9	1.95E-02	2.44E-04	1.95E-02	2.44E-04	0	0
Ash	100.0	6.6	0.07	6.6	6.62E-02	0	0.0
Char	24.8	0	0	33.9	1.4	34	1.4
S2	64.0	0	0	2.64E-01	8.26E-03	2.64E-01	8.26E-03
Total		1955	79	1955	90	0	10
Enthalpy	kW		-8949986		-10445807		-1495822
Phase							
Press.	Bara						
Temp.	°C						

Appendix 8.1 ASPEN model

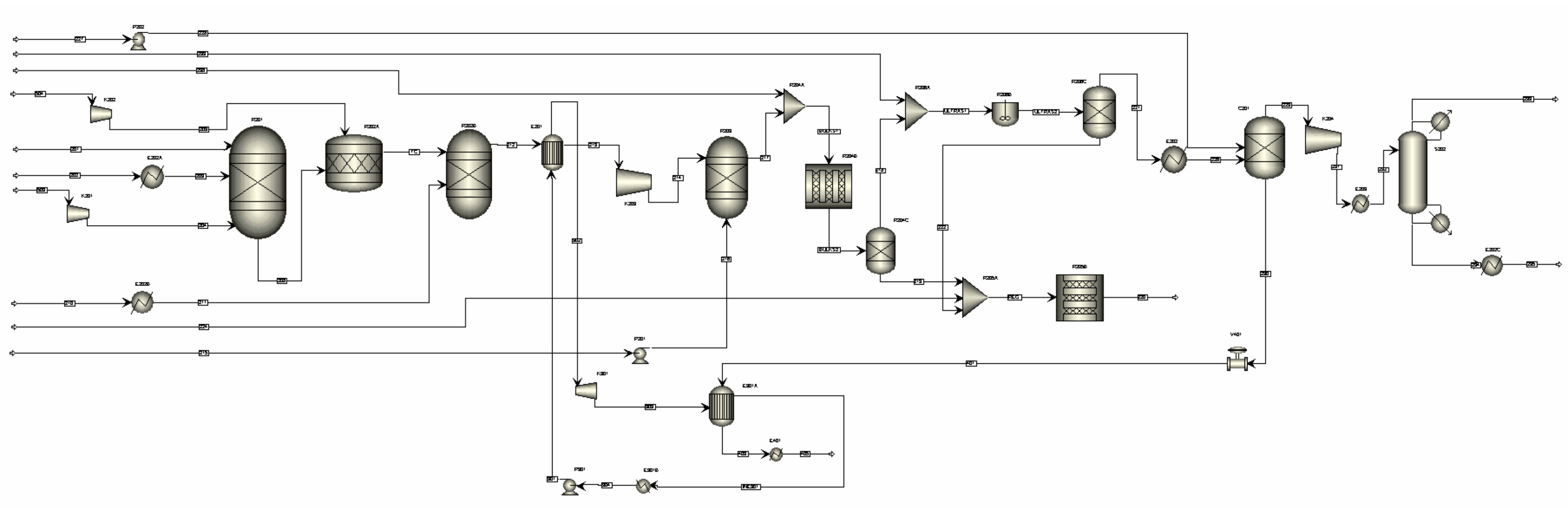


Figure A.8.1: ASPEN PLUS model for biomass gasification

Appendix 8.2 Equipment design calculation

1. Circulating Fluidized Bed Reactor (R201)

Calculation of the volume of 1 CFB:

$N_{CFB} := 10$ — number of CFB's

$\phi_V := 516.7\frac{m^3}{s}$ — total gas outlet flow

$\tau := 60s$ — average residence time

$V_{CFB} := \frac{\phi_V}{N_{CFB}}\cdot\tau$ $\quad V_{CFB} = 3100m^3$ — volume of 1 CFB

Volume relations of the riser and the downer of the CFB:

$V_{CFB} := V_{riser} + V_{downer}$ — CFB consists of riser and downer

$V_{riser} := 2\cdot V_{downer}$ — assumption

$V_{riser} := V_{CFB}\cdot\frac{2}{3}$

Calculation of the CFB volume using a residence time of 60 seconds:

$V_{riser} := V_{CFB}\cdot\frac{2}{3}$

Given

$V_{riser} = H_{CFB}\cdot\pi\cdot\left(\frac{D_{CFB}}{2}\right)^2$

$\frac{H_{CFB}}{D_{CFB}} = 6$ — correlation estimated from literature

$\begin{pmatrix} H_{CFB} \\ D_{CFB} \end{pmatrix} := \text{Find}(H_{CFB}, D_{CFB})$ $\quad H_{CFB} = 45.6m \quad D_{CFB} = 7.6m$

2. Candle Filter for solids/ash (S201)

Calculation of the candle filter:
Total volumetric flow rate 162 m^3/s. Number of vessel is 10 (1 after each CFB).
The calculation is based on candle filter designed by Westinghouse. Calculation is done by assuming a face velocity of 4 cm/s for 1 reactor.

$$\upsilon_{face} = \frac{\phi_V}{A_{filter}}$$
$$0.04 = \frac{9.8}{A_{filter}}$$
$$A_{filter} = 245\ m^2$$

$$A_{candle} = \pi \cdot d_{candle} \cdot h_{candle} = 3.144 \cdot 0.15 \cdot 1.5 = 0.71\ m^2$$

$$N_{candle} = \frac{A_{filter}}{A_{candle}} = 347$$

$$N_{plenum} = \frac{N_{candle}}{61} = 5.7$$

Assuming a cluster of 4 plenums, 2 clusters are needed (5.7 → 8)

Dimension of the candle filter using dimension from literature:

Diameter is 3.05 m, Height is 7 m and V is 52.8 m^3

Symbols list and values (calculated, literature, modeling, round up, estimated or assumed):

υ_{face}	: Face velocity through the candle	(ass.)	0.04	[m s^{-1}]
ϕ_v	: Volumetric flowrate of the feed	(mod.)	9.8	[m^3 s^{-1}]
A_{filter}	: Total filter area	(calc.)	245	[m^2]
A_{candle}	: Candle surface area	(calc.)	0.71	[m^2]
d_{candle}	: Candle diameter	(est.)	0.15	[m]
h_{candle}	: Candle height	(lit.)	1.5	[m]
N_{candle}	: Number of candle	(calc.)	347	[-]
N_{plenum}	: Number of plenum	(r.u.)	8	[-]

3. Monolith Tar Cracker (R202)

Calculation for monolith tar cracker:

The calculation is done per reactor

Plug flow reactor model:

$$Catalyst\,load = W = \frac{F}{k}\ln\left(\frac{1}{1-X}\right)$$

W for packed bed

$X_{tar} = 0.999 \rightarrow W = 43120$ kg cat

fraction cat from packed bed used (assumed that it is only the shell) = 0.10

$W_{monolith} = 4312$ kg cat

density cat $=1600\frac{\text{kg}}{\text{m3}}$

volume cat in monolith = 2.69 m^3

Cell density Monolith: 500 cells/in^2 $\rightarrow d_{cell} = 0.001136m$

In laminar regime: Re = 1000 = $\frac{\rho \text{v} \text{d}_{\text{cell}}}{\mu}$

$\rho = 1.65\frac{kg}{m^3}$

$\mu = 2.00 \cdot 10^5\,Pa.s$

$\rightarrow v = 10.69\frac{m}{s}$

A = area of bed = $\frac{\text{F}}{\text{v}} = 4.84m^2 \rightarrow diameter = 2.48m$

number of cells in area = 3746120

thickness of cat layer in monolith = $5.00 \cdot 10^{-5}m$

$$\text{L}=\frac{\text{vol. cat in monolith}}{\text{thickness of cat layer}\cdot 4 \cdot \text{number of cells in area}} = 3.17m$$

$V = L \cdot A = 48.1m^3$

$$\Delta P = 4f\frac{L}{d}\frac{1}{2}\rho v^2$$

$$f = \frac{14.9}{\text{Re}} \rightarrow \Delta P = 0.156bar$$

4. Syngas Cooler (S201)

Calculation of the dimension of the syngas cooler:

$A := 6872m^2$ — required heat exchanger area from ASPEN PLUS

$H := 16.4m$ — iteration

$D_{tube} := 10cm$ — max. tube diameter according to Coulson & Richardson's

$A_{tube} := \pi \cdot D_{tube} \cdot H$ — area 1 tube

$N_{tubes} := \frac{A}{A_{tube}}$ — number of tubes

$D := D_{tube} \cdot \left(\frac{N_{tubes}}{0.32}\right)^{\frac{1}{2.14}}$ — diameter syngas cooler correlation from Coulson & Richardson's

$H := 7.5 \cdot D$ — heigth syngas cooler, correlation from Coulson & Richardson's

$H = 36.9m$ $\quad$ $D = 4.9m$

5. Sour Water Gas Shift Reactor (R203)

Volume and catalyst weight calculation:

$$V_R = \phi_V \cdot \tau = 64.5 \cdot 1.636$$
$$= 105.5\ m^3$$
$$W_{cat} = V_{cat} \cdot \rho_{cat} = \left(V_R - \varepsilon \cdot V_R\right) \cdot \rho_{cat} = \left(105.5 - 0.4 \cdot 105.5\right) \cdot 600$$
$$W_{cat} = 37972\ kg$$

Calculation of vessel diameter:
Using a constant pressure drop of 4 bar, the vessel diameter is calculated using iteration.

$$-\Delta P = 4\ bar$$
$$\upsilon = \frac{4 \cdot \phi_V}{\pi \cdot D^2} = \frac{4 \cdot 64.5}{\pi \cdot 6.19^2}$$
$$= 2.14\ \frac{m}{s}$$
$$H_{bed} = \tau \cdot \upsilon = 1.63 \cdot 2.14$$
$$= 3.5\ m$$
$$\frac{-\Delta P}{H_{bed}} = 150 \cdot \frac{\mu \cdot \upsilon}{d^2} \cdot \frac{(1-\varepsilon)^2}{\varepsilon^3} + 1.75 \cdot \frac{\rho_f . \upsilon^2}{d} \cdot \frac{(1-\varepsilon)}{\varepsilon^3}$$
$$= 150 \cdot \frac{1e^{-5} \cdot 2.14}{\left(4e^{-3}\right)^2} \cdot \frac{\left(1-0.4\right)^2}{0.4^3} + 1.75 \cdot \frac{5.98 \cdot 2.14^2}{\left(4e^{-3}\right)} \cdot \frac{\left(1-0.4\right)}{0.4^3}$$

Symbols list and values (calculated, literature, modeling or assumed):

V_r	: Volume of the reactor	(calc.)	105.5	[m^3]
D	: Diameter	(calc.)	6.19	[m]
H_{bed}	: Bed height	(calc)	3.5	[m]
ΔP	: Pressure drop	(ass.)	4	[bar]
V_{cat}	: Volume of catalyst	-	-	[m^3]
d	: Particle diameter	(ass.)	4E-3	[m]
ϕ_v	: Volumetric flowrate of the feed	(mod.)	64.5	[m^3 s^{-1}]
υ	: Superficial gas velocity	(calc.)	2.14	[m s^{-1}]
τ	: Residence time	(lit,)	1.636	[s]
W_{cat}	: Catalyst weight	(calc.)	37972	[kg]
μ	: Viscosity	(ass.)	1.E-5	[Pa s]
ρ_{cat}	: Catalyst density	(lit.)	600	[kg m^{-3}]
ρ_f	: Gas density	(mod.)	5.98	[kg m^{-3}]
ε	: Bed porosity	(ass.)	0.4	[-]

6. Bulk Desulphurizer (R204)

Optimal gas residence time:
An optimal gas residence time is approximately 2 seconds, see figure below.

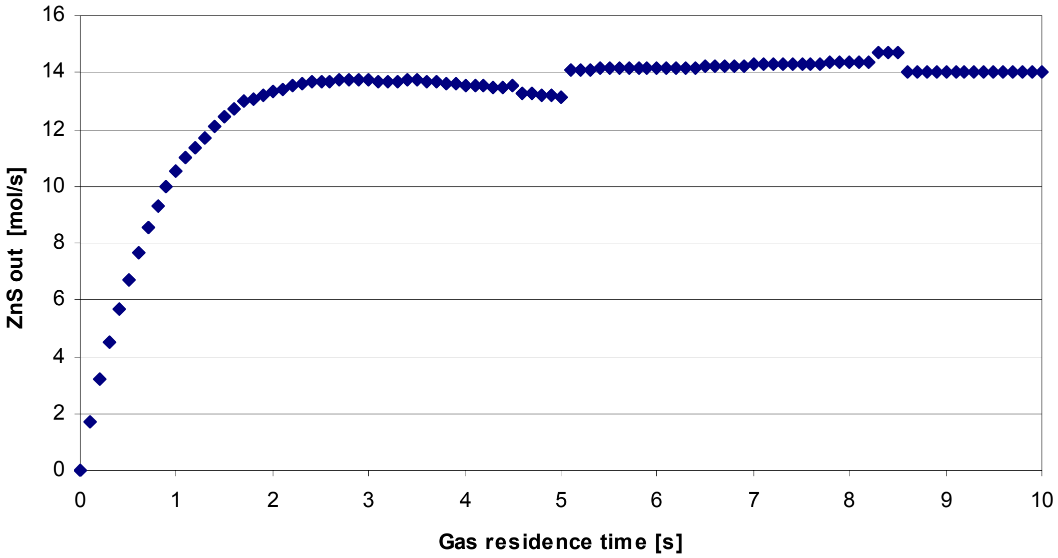


Figure A.8.2.2: Sulphidation of ZnO at increasing gas residence time

Calculation of the dimension of the transport bulk desulphurizer:
Total volumetric flow rate 385 m^3/s. Number of vessel is 2 (in 2 trains gas cleaning). Calculation is done for 1 reactor.

$$H = \tau \cdot v_0 = 2 \cdot 10 = 20\ m \qquad A = \frac{\phi_v}{H} = 9.625\ m^2$$

$$D = 2 \cdot \sqrt{\frac{A}{\pi}} = 3.5 \qquad V = \frac{\pi \cdot D^2}{4} \cdot H = 141.4\ m^3$$

Calculation of the pressure drop:

$$\begin{aligned}\Delta P &= H \cdot (1-\varepsilon) \cdot \left(\rho_p - \rho_f\right) \cdot g \\ &= 20 \cdot (1-0.995) \cdot (1800-5.98) \cdot 9.81 \\ &= 196.2\ Pa = 0.002\ bar\end{aligned}$$

Symbols list and values (calculated, literature, modeling, estimated or assumed):

V_r	: Volume of the reactor	(calc.)	141.4	[m^3]
D	: Diameter	(calc.)	3.5	[m]
H	: Bed height	(calc.)	20	[m]
ΔP	: Pressure drop	(calc.)	0.02	[bar]
ϕ_v	: Volumetric flowrate of the feed	(mod.)	192.5	[$m^3\ s^{-1}$]
υ_0	: Superficial gas velocity	(ass.)	10	[$m\ s^{-1}$]
τ	: Residence time	(est.)	2	[s]
g	: gravity	(ass.)	9.81	[$m\ s^{-2}$]
ρ_p	: Particle density	(lit.)	1800	[$kg\ m^{-3}$]
ρ_f	: Gas density	(mod.)	5.98	[$kg\ m^{-3}$]
ε	: Bed porosity	(ass.)	0.995	[-]

7. Regenerator for Zn/Ti (R205)

Calculation of the dimension of the transport bulk desulphurizer:
Number of vessel is 2 (in 2 trains gas cleaning).
Calculation is done for 1 reactor.

$$H = \tau \cdot v_0 = 2 \cdot 6 = 12\ m \qquad A = \frac{\phi_v}{H} = 2.9\ m^2$$

$$D = 2 \cdot \sqrt{\frac{A}{\pi}} = 2 \qquad V = \frac{\pi \cdot D^2}{4} \cdot H = 37.7\ m^3$$

Calculation of the pressure drop:

$$\begin{aligned} \Delta P &= H \cdot (1-\varepsilon) \cdot (\rho_p - \rho_f) \cdot g \\ &= 20 \cdot (1-0.85) \cdot (1800 - 0.346) \cdot 9.81 \\ &= 52964\ Pa = 0.53\ bar \end{aligned}$$

Symbols list and values (calculated, literature, estimated or assumed):

V_r	: Volume of the reactor	(calc.)	37.7	[m^3]
D	: Diameter	(calc.)	2	[m]
H	: Bed height	(calc)	12	[m]
ΔP	: Pressure drop	(calc.)	0.53	[bar]
ϕ_v	: Volumetric flowrate of the feed	(est.)	35.8	[m^3 s^{-1}]
v_0	: Superficial gas velocity	(ass.)	6	[m s^{-1}]
τ	: Residence time	(ass.)	2	[s]
g	: gravity	(lit.)	9.81	[m s^{-2}]
ρ_p	: Particle density	(lit.)	1800	[kg m^{-3}]
ρ_f	: Gas density	(lit.)	0.346	[kg m^{-3}]
ε	: Bed porosity	(ass.)	0.85	[-]

8. Ultra Desulphurizer (R206)

Calculation of the ultra desulphurizer:
Total volumetric flow rate 162 m^3/s. Number of vessel is 4 (in 2 trains gas cleaning). The calculation is based on candle filter designed by Westinghouse. Calculation is done per reactor by assuming a face velocity of 5 cm/s.

$$\upsilon_{face} = \frac{\phi_V}{A_{filter}}$$

$$0.05 = \frac{81}{A_{filter}}$$

$$A_{filter} = 1620\ m^2$$

$$A_{candle} = \pi \cdot d_{candle} \cdot h_{candle}$$
$$= 3.144 \cdot 0.15 \cdot 1.5$$
$$= 0.71\ m^2$$

$$N_{candle} = \frac{A_{filter}}{A_{candle}}$$
$$= 2295$$

$$N_{plenum} = \frac{N_{candle}}{61}$$
$$= 37.6$$

Assuming a cluster of 4 plenums, 5 clusters are needed (37.6 → 20)

Dimension of the candle filter, using dimension from literature:

Diameter is 3.05 m, Height is 18 m and V is 73 m^3

Symbols list and values (calculated, literature, modeling, round up or assumed):

υ_{face}	: Face velocity through the candle	(ass.)	0.05	[$m\ s^{-1}$]
ϕ_v	: Volumetric flowrate of the feed	(mod.)	81	[$m^3\ s^{-1}$]
A_{filter}	: Total filter area	(calc.)	1620	[m^2]
A_{candle}	: Candle surface area	(calc.)	0.71	[m^2]
d_{candle}	: Candle diameter	(est.)	0.15	[m]
h_{candle}	: Candle height	(lit.)	1.5	[m]
N_{candle}	: Number of candle	(calc.)	2295	[-]
N_{plenum}	: Number of plenum	(r.u.)	20	[-]

9. NH_3/HCl Scrubber (C201)

Calculation of the dimensions of the NH3/HCl scrubber

Number of scrubber columns is 2. Tray spacing is 24 in.. The liquid is pure water. The calculations are based on the method given in Seader and Henley [1]. For determining the theoretical number of stages the shortcut method in Douglas is used [2]. HCl is the key component.

	HCl	
Mol fraction in gas ($y_{in,HCl}$)	0.0002884	
Mol fraction out of scrubber ($y_{out,HCl}$)	1.00E-08	
Fraction absorbed	0.999965	
Number of theoretical stages (N)	25	
Henry's law constant ($H_{0,HCl}$)	19	[M/atm]
Henry's law constant (H_{HCl})	2.911	[atm]
K-value (K)	0.153	
Temperature (T)	298	[K]
Pressure (P)	19	[atm]
Absorption factor (A_{HCl})	1.4	
Mol. weight of liquid (M_l)	18.016	[kg/kmol]
Viscosity of liquid (μ_l)	1.002	[cP]
Density of liquid (ρ_l)	62.30	[lb/ft3]
Overall column efficiency (E_0)	0.72	[%]
Number of actual stages (N_{actual})	34	
H	**24.0**	**[m]**

	2	columns
Gas flowrate (V)	25.94	[kmol/s]
Liquid flowrate (L)	5.57	[kmol/s]
Mol. weight of gas (M_v)	18.76	[kg/kmol]
Density of gas (ρ_v)	14.36	[kg/m3]
Density of liquid (ρ_l)	998	[kg/m3]
Kinetic-energy ratio (F_{LV})	0.0247	[-]
Entrainment flooding factor (C_f)	0.5	[ft/s]
Surface tension (σ)	0.07	[N/m]
	70	[dyne/cm]
Surface tension factor (F_{st})	1.285	[-]
Foaming factor (F_f) - assumed	0.9	[-]
Hole-area factor (F_{HA})	1	[-]
Capacity parameter (C)	0.578	[ft/s]
Flooding velocity (U_f)	4.784	[ft/s]
Vessel diameter (D_t)	**5.7**	**[m]**

Calculation of the pressure drop

Vapor velocity (u)	1.33	[m/s]
Hole velocity (u_0)	13.26	[m/s]
	43.49	[ft/s]
Dry tray pressure drop (h_d)	9.50	[in. of liquid]
Weir length (L_w)	4.17	[m]
	13.67	[in]
Liquid flowrate (q_L)	1594.62	[gpm]
A_d/A	0.10	[-]
Active area of a sieve tray (A_a)	0.80	[-]
Superficial vapor velocity based on active bubbling area (U_a)	1.66	[m/s]
	5.44	[ft/s]
Capacity parameter (K_s)	0.66	[ft/s]
Effective relative froth density (Φ_e)	0.75	[-]
Constant in tray liquid holdup (C)	0.36	[-]
Equivalent head of clear liquid on tray (h_l)	9.35	[in]
Max. bubble diameter ($D_{b,max}$)	0.00476	[in]
Pressure drop due to surface tension (h_o)	9.01	[in]
Total pressure drop/tray (h_t)	27.86	[in]
Density of liquid (ρ_l)	0.04	[lb/in3]
Total pressure drop/tray	1.00	[psi/tray]
Total pressure drop/tray	0.06	[bar/tray]
ΔP	**1.53**	**[bar/column]**

Removal efficiency (Yield) of components other than HCl
Calculation on basis of the design of the key component HCl (the liquid flowrate is already fixed)

	NH3	H2S	CO2	COS	H2	CO
y in	0.00015	0.00000	0.22364	1.79E-08	0.43865	0.20043
Henry's law constant (H0) [M/atm]	5.80E+01	0.1	0.034	2.10E-02	7.80E-03	9.50E-04
Henry's Law constant (H) [atm]	9.53E-01	5.53E+02	1.63E+03	2.63E+03	7.09E+03	5.82E+04
K-value (K)	5.03E-02	2.92E+01	8.57E+01	1.39E+02	3.74E+02	3.07E+03
Absorption factor (A)	4.27E+00	7.37E-03	2.51E-03	1.55E-03	0.0006	0.0001
y out	2.76E-20	9.43E-07	2.23E-01	1.79E-08	0.4384	0.200421
Removal efficiency	1.00000	0.007368	0.00251	0.001547	0.0057	0.00007

10. Active Coal Filter Bed (C202)

Assumptions used in the calculations:

Several assumptions must be considered for the calculation of the fixed bed size [1] in order to assume an ideal fixed bed adsorption.
Other assumptions on several data in Table A8.1 are made, since the adsorption equilibrium data for the adsorption of impurities on an active coal filter is not available.

Table A8.1: Assumptions for bed parameters

Variable	Value	Unit
Pressure	40	[bar]
Temperature	500	[K]
Bed depth	0.013	[m]
Time to breakthrough	100	[min]
Bed utilization	90	[%]
Particle density of active coal [1]	0.9	[g/cm^3]
Bed density	450	[kg/m^3]
Bed void fraction	0.5	[-]

Used inputs for calculation of active coal filter bed dimension:

Feed pressure: $Pf := 40\cdot 10^{5}\,Pa$

Bed temperature: $T := (273.15 + 40)K$

Gas constant: $R := 8.3144\dfrac{J}{mol\cdot K}$

Molecular weight of entering gas:

$MWgas := 19.13\dfrac{gm}{mole}$

Density of entering gas:

$\rho gas := 23.06\dfrac{kg}{m^3}$ $\quad \rho gas = 23.06\dfrac{kg}{m^3}$

Gas flowrate:

$\phi m := 871.187\dfrac{kg}{s}$

$\phi v := \dfrac{\phi m}{\rho gas}$ $\quad \phi v = 37.779\dfrac{m^3}{s}$

Impurities (tars, HCl and H_2S) flowrate in entering gas:

$$Cimp := 1.133\times 10^{-6}$$

$$MWimp := 3.607\times 10^{-5}\,\frac{gm}{mole}$$

$$\phi mimp := \frac{\phi m\cdot Cimp\cdot MWimp}{MWgas} \qquad \phi mimp = 1.861\times 10^{-9}\,\frac{kg}{s}$$

$$cF := \frac{\phi mimp}{\phi v} \qquad cF = 4.926\times 10^{-11}\,\frac{kg}{m^3}$$

Assumed bed parametersize:

$dbed := 0.5m$ bed diameter

$\varepsilon bed := 0.5$ bed porosity

$\rho p := 0.9\,\frac{gm}{cm^3}$ active coal particle density

$\rho bed := (1-\varepsilon bed)\rho p$ bed density

$$\rho bed = 450\,\frac{kg}{m^3} \qquad beddepth := \frac{0.88}{2}\cdot 10^{-1}\cdot ft \qquad tideal := 100\cdot min \qquad cF = 4.926\times 10^{-11}\,\frac{kg}{m^3}$$

Calculation of active coal filter bed dimension:

$$qF := \left(\frac{\phi v\cdot cF\cdot tideal}{\frac{\pi}{4}\cdot dbed^2\cdot beddepth\cdot \rho bed}\right) + \frac{1}{1000} \qquad qF = 1.009\times 10^{-3}$$

$$LES := \frac{cF\cdot \phi v}{qF}\cdot\frac{tideal}{(qF-0.001)\cdot \rho bed\cdot \frac{\pi}{4}\cdot dbed^2} \qquad LES = 13.286m$$

Bed utilization: 90%

$$Lbed := \frac{LES}{0.90}$$

$Lbed = 14.762m$ $\qquad beddepth = 0.013m$

$$Vbed := \frac{\pi\cdot dbed^2\cdot Lbed}{4}$$

$$Vbed = 2.899m^3$$

11. CO_2-selective membrane (S202)

Inputs for the calculation of CO_2-selective membrane:

Ambient pressure: $P := 1 \cdot 10^{5} Pa$

$MCO2 := 44 \cdot 10^{-3} \frac{kg}{mole}$ $MCO := 28 \cdot 10^{-3} \frac{kg}{mole}$ $MH2 := 2.011 \cdot 10^{-3} \frac{kg}{mole}$

$R := 8.3144 \frac{J}{mole \cdot K}$

$T := 273.15K + 95K$

Pressure on the feed side:

$Pf := 40.5 \cdot 10^{5} \cdot Pa$

Pressure on the permeate side:

$Pp := 1 \cdot 10^{5} \cdot Pa$

Molar fraction on the feed side

$yCOf := 0.2387389$

$yH2f := 0.4929$

$yCO2f := 1 - yCOf - yH2f$ $yCO2f = 0.268$

Molar fraction on the permeate side:

$yCOp := 0.018$

$yH2p := 0.047$

$yCO2p := 1 - yCOp - yH2p$ $yCO2p = 0.935$

Permeability of components for PDMS membrane:

$$PCO := 27 \cdot \frac{400}{940} \cdot \left[\frac{10^{-15}}{2.99} \cdot \frac{(mole \cdot m)}{\left(m^{2} \cdot Pa \cdot s\right)} \right]$$

$$PCO2 := 577 \cdot \left[\frac{10^{-15}}{2.99} \cdot \frac{(mole \cdot m)}{\left(m^{2} \cdot Pa \cdot s\right)} \right]$$

$$PH2 := 27 \cdot \frac{500}{940} \cdot \left[\frac{10^{-15}}{2.99} \cdot \frac{(mole \cdot m)}{\left(m^{2} \cdot Pa \cdot s\right)} \right]$$

Membrane thickness

$$l := 50\cdot 10^{-6}\cdot m$$

Required removed CO2 flows:

$$phimgas := 876.4450\frac{kg}{s} \qquad yCO2fm := 0.5824998$$

$$phimCO2 := 0.94\cdot yCO2fm\cdot phimgas \qquad totalmolegas := \frac{phimCO2}{MCO2\cdot yCOf} \qquad totalmolegas = 4.568\times 10^{4}\frac{mol}{s}$$

$$phimCO2 = 479.897\frac{kg}{s}$$

$$\alpha CO2 := \frac{PCO2}{PH2} \qquad \alpha CO2 = 40.176 \qquad \alpha CO := \frac{PCO}{PCO2} \qquad \alpha CO = 0.02 \qquad \frac{1}{\alpha CO} = 50.22$$

$$\beta := \frac{Pf}{Pp} \qquad \beta = 40.5$$

Calculation of the fluxes through the CO_2-selective membrane:

Partial pressures:

$$pCOf := yCOf\cdot Pf \qquad pCOp := yCOp\cdot Pp$$

$$pH2f := yH2f\cdot Pf \qquad pH2p := yH2p\cdot Pp$$

$$pCO2f := yCO2f\cdot Pf \qquad pCO2p := yCO2p\cdot Pp$$

Calculation fluxes through the membrane:

$$JCO := \frac{PCO}{l}\cdot(pCOf - pCOp) \qquad JCO = 7.417\times 10^{-5}\frac{mol}{m^2 s}$$

$$JH2 := \frac{PH2}{l}\cdot(pH2f - pH2p) \qquad JH2 = 1.913\times 10^{-4}\frac{mol}{m^2 s}$$

$$JCO2 := \frac{PCO2}{l}\cdot(pCO2f - pCO2p) \qquad JCO2 = 3.834\times 10^{-3}\frac{mol}{m^2 s}$$

Mass fluxes through the membrane:

$$FCO := \frac{xCOpphimCO2 \cdot MCO}{xCO2p MCO2}$$

$$FCO = 5.908 \frac{kg}{s}$$

$$FCO2 := phimCO2$$

$$FCO2 = 479.897 \frac{kg}{s}$$

$$FH2 := \frac{xH2pphimCO2 \cdot MH2}{xCO2p MCO2}$$

$$FH2 = 1.095 \frac{kg}{s}$$

$$Fpermeate := FCO + FH2 + FCO2$$

$$Fpermeate = 486.9 \frac{kg}{s}$$

Syngas loss in the permeate

$$Fsyngasin := (292.2 + 42.2) \cdot \frac{kg}{s}$$

$$Fretentate := phimgas - Fpermeate$$

$$Fretentate = 389.545 \frac{kg}{s} \qquad Fsyngasin = 334.4 \frac{kg}{s}$$

$$\%syngasloss := \frac{(FCO + FH2) \cdot 100}{Fsyngasin} \qquad \%syngasloss = 2.094$$

Calculation of the dimension of CO_2-selective membrane:

$$Amembrane := \frac{phimCO2}{JCO2 \cdot MCO2}$$

$$Amembrane = 2.845\times 10^{6}\, m^{2}$$

Hollow fibre membrane:

Packing density: $\rho hf := 10000 \frac{m^2}{m^3}$

Required volume: $Vhf := \frac{Amembrane}{\rho hf}$ $\quad Vhf = 284.481 m^3$

Number of units: 2 $\quad nu := 2$

Height of the module:

$dhf := 6.5m$ $\quad Hhf := \frac{Vhf}{\frac{\pi}{4}\cdot dhf^{2}\cdot nu}$ $\quad Hhf = 4.287m$

Reference:

[1] J.D. Seader and E.J. Henley, *Separation Process Principles*, John Wiley & Sons, 1998

[2] J.M. Douglas, *Conceptual Design of Chemical Processes*, McGraw-Hill, 1988

Appendix 8.3 Equipment Summary and Specification Sheets

REACTORS & COLUMNS – SUMMARY

EQUIPMENT NR. : NAME :	R201 Circulating fluidized bed reactor	R202 Monolith tar cracker	R203 Sour Water Gas Shift Reactor	R204 Bulk desulphurizer	R205 Zn/Ti sorbent Regenerator
Pressure [bara] :	7	7/6.4	25/21	21	20.5
Temp. [^oC] :	900	900/907	488/543	500	750
Volume [m^3] :	3100	48.1	105.5	141.4	37.7
Diameter [m] :	7.6	2.5	3.5	3	2
L or H [m] :	45.6	3.2	6.19	20	12
Internals					
- Tray Type :					
- Tray Number :					
- Fixed Packing					
Type :					
Shape :					
- Catalyst					
Type :			CoMoS	Zink titanate	Zink titanate
Shape :			Spherical	Spherical	Spherical
Size [mm] :			4	0.130	0.130
-					
-					
Number					
- Series :					
- Parallel :	10	10	2	2	2
Materials of Construction :	SS, bricks	Incoloy	SS	SS	Incoloy
Other :	Sand as heat carrier				

Remarks:
(1) SS = Stainless Steel; CS = Carbon Steel; Incoloy = Nickel-Chromium Alloy

Designers :	L. Djatmiko, W. Hensen, E. Herben, A. Kurniawan, B. Vreugdenhil	Project ID-Number :	**CPD3309**
		Date :	July 31st 2004

REACTORS & COLUMNS, CONT'D – SUMMARY

EQUIPMENT NR. : NAME :	R206 Ultra desulphurizer	C201 NH_3/HCl scrubber	C202 Active coal filter bed	S201 Candle filter	S202 CO_2-selective membrane
Pressure [bara] :	21/20.5	20.4	17.5/17	6.4	40.5/40.0
Temp. [^oC] :	500	25	40	900	95
Volume [m^3] : **Diameter [m] :** **L or H [m] :**	73 3.1 18	609.9 5.7 23.9	2.9 0.5 14.8	52.8 3.1 7	284.5 6.5 4.3
Internals					
- Tray Type :		Sieve			
- Tray Number :		34			
- Fixed Packing					
Type :			Active Coal		
Shape :					
- Catalyst					
Type :	Zinc titanate				
Shape :	spherical				
Size [mm] :	0.020			Candle filter	
- Filter shape :	Candle filter			1.5 x 0.15	
- Filter number :	1.5 x 0.15			488	
- Membrane type :	1220				PDMS
Number **- Series :** **- Parallel :**	4	2	2	10	2
Materials of Construction :	Si-SS RA85H	Tray = SS314 Column = CS	CS	Si-SS RA85H	CS
Other :					

Remarks:
(1) SS = Stainless Steel; CS = Carbon Steel; Si-SS = Silica Stainless Alloy

Designers : L. Djatmiko, W. Hensen, E. Herben, A. Kurniawan, B. Vreugdenhil	Project ID-Number : **CPD3309** Date : July 31st 2004

HEAT EXCHANGERS – SUMMARY

EQUIPMENT NR. : **NAME :**	**E201** **Syngas Cooler**				
	Coils Water cooled				
Substance **[1] Tubes :** **[2] Shell :**	Water Syngas				
Duty [kW] :	1264154				
Heat Exchange area [m^2] :	6872				
Number **- Series :** **- Parallel :**	10				
Pressure [bara] **- Tubes :** **- Shell :**					
Temperature In / Out [^oC] **- Tubes :** **- Shell :**	80.3 / 685.6 907 / 201				
Special Materials of Construction *(2)* **:**	Tubes : Al-Br Shell : S/incoloy				
Other :					

Remarks:

(1) S = Steel;Al-Br = Aluminum Bronze

Designers : L. Djatmiko, W. Hensen, E. Herben, A. Kurniawan, B. Vreugdenhil	Project ID-Number : **CPD3309** Date : July 31st 2004

CIRCULATING FLUIDIZED BED REACTOR – SPECIFICATION SHEET

EQUIPMENT NUMBER :	**R201**	**In Series :**	none
NAME :	**Circulating Fluidised Bed reactor**	**In Parallel :**	10

General Data

Service		:	**- ~~Buffer~~ / ~~Storage~~ / ~~Separation~~ / Reaction**
Type		:	**- Circulating Fluidised Bed**
Position		:	**- ~~Horizontal~~ - Vertical**
Internals		:	**- ~~Demister~~ / ~~Plate~~ / ~~Coil~~ / Cyclone__**
Heating/Cooling medium		:	**- none / ~~Open~~ / ~~Closed~~ / ~~External Hxgr~~ /________**
- Type		:	n.a.
- Quantity	**[kg/s]**	:	n.a.
- Press./Temp.'s	**[bara/°C]**	:	n.a.
Vessel Diameter (ID)	**[m]**	:	**7.6**
Vessel Height	**[m]**	:	**45.6**
Vessel Tot. Volume	**[m^3]**	:	**3100**
Vessel Material		:	**two layers of bricks (1), outer layer of steel**
Other		:	**vessel consists of riser and downer**

Process Conditions

Stream Data		**Feed**		**Top**		**Bottom**	
Temperature	**[°C]**	**: 10**		**: 900**		**: 490^1, 340^2, 850^3**	
Pressure	**[bara]**	**: 7**		**: 7**		**: 15.5^1, 7.5^2, 1^3**	
Density	**[kg/m^3]**	**: 2267**		**: 6.3**		**: 1.2^1, 5.9^2, 20.9^3**	
Mass Flow	**[kg/s]**	**: 613.9**		**: 871.3**		**: 134.9^1, 142.7^2, 3.2^3**	
Composition		mol%	wt%	mol%	wt%	mol%	wt%
biomass		**90**	**92**				
water		**9**	**7**				
ash		**0**	**1**			**100^3**	**100^3**
CO				**20**	**25**		
CO_2				**22**	**42**		
H_2O				**21**	**17**	**100^1**	**100^1**
H_2				**24**	**2**		
O_2						**95^2**	**95^2**

Remarks:
(1) inner layer of heat resistant bricks, second layer of insulating bricks
1,2 ingoing stream bottom part   3 outgoing stream bottom part

Designers :	L. Djatmiko, W. Hensen, E. Herben, A. Kurniawan, B. Vreugdenhil	Project ID-Number :	**CPD3309**
		Date :	July 31st 2004

MONOLITH TAR CRACKER – SPECIFICATION SHEET

EQUIPMENT NUMBER :	**R202**	**In Series :**	**none**
NAME :	**Monolith tar cracker**	**In Parallel :**	**10**

General Data

Service		:	**- ~~Buffer~~ / ~~Storage~~ / ~~Separation~~ / Reaction**
Type		:	**- Monolith Fixed Bed**
Position		:	**- ~~Horizontal~~** **- Vertical**
Internals		:	**- ~~Demister~~ / ~~Plate~~ / ~~Coil~~ / _________**
Heating/Cooling medium		:	**- none / ~~Open~~ / ~~Closed~~ / ~~External Hxgr~~ /________**
- Type		:	n.a.
- Quantity	**[kg/s]**	:	n.a.
- Press./Temp.'s	**[bara/^{o}C]**	:	n.a.
Vessel Diameter (ID)	**[m]**	:	**2.48**
Vessel Height	**[m]**	:	**3.17**
Vessel Tot. Volume	**[m^3]**	:	**48.1**
Vessel Material		:	**Incoloy (nickel chromium alloy)**
Other		:	

Process Conditions

Stream Data		**Feed**		**Top**		**Bottom**	
Temperature	**[^{o}C]**	**: 900**		**: n.a.**		**: 907**	
Pressure	**[bara]**	**: 7**		**: n.a.**		**: 6.4**	
Density	**[kg/m^3]**	**: 1.65**		**: n.a.**		**: 1.25**	
Mass Flow	**[kg/s]**	**: 851.1**		**: n.a.**		**: 975.0**	
Composition		mol%	wt%	mol%	wt%	mol%	wt%
Tar		**0.01**	**0.04**			**0**	**0**
NH3		**0.003**	**0.003**			**1.7e-5**	**1.9e-5**
CH4		**0.06**	**0.04**			**0.002**	**0.001**

Remarks:

Designers : L. Djatmiko, W. Hensen, E. Herben, A. Kurniawan, B. Vreugdenhil	Project ID-Number : **CPD3309** Date : July 31st 2004

SOUR WATER GAS SHIFT REACTOR – SPECIFICATION SHEET

EQUIPMENT NUMBER : R203 NAME : Sour Water Gas Shift reactor			In Series : none In Parallel : 2					
General Data								
Service		: - ~~Buffer~~ / ~~Storage~~ / ~~Separation~~ / Reaction						
Type		: - Packed bed						
Position		: - ~~Horizontal~~ - Vertical						
Internals		: - ~~Demister~~ / ~~Plate~~ / ~~Coil~~ / _________						
Heating/Cooling medium		: - none / ~~Open~~ / ~~Closed~~ / ~~External Hxgr~~ /________						
- Type		: n.a.						
- Quantity	[kg/s]	: n.a.						
- Press./Temp.'s	[bara/^{o}C]	: n.a.						
Vessel Diameter (ID)	[m]	: 6.19						
Vessel Height	[m]	: 3.50						
Vessel Tot. Volume	[m^3]	: 105.5						
Vessel Material		: Stainless steel						
Other		:						
Process Conditions								
Stream Data		Feed		Top		Bottom		
Temperature	[^{o}C]	: 488		: n.a.		: 543		
Pressure	[bara]	: 25		: n.a.		: 21		
Density	[kg/m^3]	: 7.56		: n.a.		: 5.92		
Mass Flow	[kg/s]	: 975.0		: n.a.		: 996.6		
Composition		mol%	wt%	mol%	wt%	mol%	wt%	
CO		0.31	0.452			0.21	0.307	
H_2		0.34	0.036			0.43	0.045	
H_2O		0.20	0.189			0.13	0.120	
CO_2		0.13	0.304			0.22	0.510	
H_2S (ppm)		294				314		
COS (ppm)		33				5		
NH_3 (ppm)		19				146		
HCN (ppm)		13				0.4		
Remarks:								

Designers : L. Djatmiko, W. Hensen, E. Herben, A. Kurniawan, B. Vreugdenhil	Project ID-Number : **CPD3309** Date : July 31st 2004

TU Delft

BULK DESULPHURIZER – SPECIFICATION SHEET

EQUIPMENT NUMBER :	**R204**	**In Series :**	**none**
NAME :	**Bulk desulphurizer**	**In Parallel :**	**2**

General Data

Service		:	**- ~~Buffer~~ / ~~Storage~~ / ~~Separation~~ / Reaction**
Type		:	**- Transport reactor**
Position		:	**- ~~Horizontal~~** **- Vertical**
Internals		:	**- ~~Demister~~ / ~~Plate~~ / ~~Coil~~ / _________**
Heating/Cooling medium		:	**- none / ~~Open~~ / ~~Closed~~ / ~~External Hxgr~~ /_________**
- Type		:	n.a.
- Quantity	**[kg/s]**	:	n.a.
- Press./Temp.'s	**[bara/°C]**	:	n.a.
Vessel Diameter (ID)	**[m]**	:	**3**
Vessel Height	**[m]**	:	**20**
Vessel Tot. Volume	**[m^3]**	:	**141.4**
Vessel Material		:	**Stainless steel**
Other		:	

Process Conditions

Stream Data		**Feed**		**Top**		**Bottom**	
Temperature	**[°C]**	**: 500**		**: 500**		**: n.a.**	
Pressure	**[bara]**	**: 21**		**: 21**		**: n.a.**	
Density	**[kg/m^3]**	**: 5.92**		**: 6.26**		**: n.a.**	
Mass Flow	**[kg/s]**	**: 1063.0**		**: 996.5**		**: n.a.**	
Composition		mol%	wt%	mol%	wt%	mol%	wt%
H_2S (ppm)		**319**	**557**	**5**	**9**	**-**	**-**
COS (ppm)		**5**	**16**	**0.081**	**0.255**		

Remarks:

Designers :	L. Djatmiko, W. Hensen, E. Herben, A. Kurniawan, B. Vreugdenhil	Project ID-Number Date	: :	**CPD3309** July 31st 2004

TUDelft

Zn/Ti SORBENT REGENERATOR – SPECIFICATION SHEET

EQUIPMENT NUMBER :	**R205**	**In Series :**	**none**
NAME :	**Zn/Ti sorbent regenerator**	**In Parallel :**	**2**

General Data

Service		:	**- ~~Buffer~~ / ~~Storage~~ / ~~Separation~~ / Reaction**
Type		:	**- Entrained flow reactor**
Position		:	**- ~~Horizontal~~** **- Vertical**
Internals		:	**- ~~Demister~~ / ~~Plate~~ / ~~Coil~~ / _________**
Heating/Cooling medium		:	**- none / ~~Open~~ / ~~Closed~~ / ~~External Hxgr~~ /_________**
- Type		:	n.a.
- Quantity	**[kg/s]**	:	n.a.
- Press./Temp.'s	**[bara/^{o}C]**	:	n.a.
Vessel Diameter (ID)	**[m]**	:	**2**
Vessel Height	**[m]**	:	**12**
Vessel Tot. Volume	**[m^3]**	:	**37.7**
Vessel Material		:	**Incoloy (nickel chromium alloy)**
Other		:	

Process Conditions

Stream Data		**Feed**		**Top**		**Bottom**	
Temperature	**[^{o}C]**	**: 750**		**: 750**		**: 750**	
Pressure	**[bara]**	**: 20.5**		**: 20.5**		**: 1**	
Density	**[kg/m^3]**	**: 1800**		**: 1800**		**: 2000**	
Mass Flow	**[kg/s]**	**: 71.8**		**: 71.8**		**: 0.033**	
Composition		mol%	wt%	mol%	wt%	mol%	wt%
ZnS		**0.03**	**0.03**	**0**	**0**	**0**	**0**
SO_2		**0**	**0**	**0.02**	**0.07**	**0**	**0**
Sorbent rest		**0.97**	**0.97**	**0.98**	**0.93**	**1**	**1**

Remarks:

Designers :	L. Djatmiko, W. Hensen, E. Herben, A. Kurniawan, B. Vreugdenhil	Project ID-Number : Date :	**CPD3309** July 31st 2004

ULTRA DESULPHURIZER – SPECIFICATION SHEET

EQUIPMENT NUMBER : R206			**In Series : none**			
NAME : Ultra desulphurizer			**In Parallel : 4**			
General Data						
Service		**: - ~~Buffer~~ / ~~Storage~~ / Reaction + Separation**				
Type		**: - Barrier (candle) filter reactor**				
Position		**: - ~~Horizontal~~ - Vertical**				
Internals		**: - ~~Demister~~ / ~~Plate~~ / ~~Coil~~ / 1220 SiC Candles**				
Heating/Cooling medium		**: - none / ~~Open~~ / ~~Closed~~ / ~~External Hxgr~~ /________**				
- Type		: n.a.				
- Quantity	**[kg/s]**	: n.a.				
- Press./Temp.'s	**[bara/°C]**	: n.a.				
Vessel Diameter (ID)	**[m]**	**: 3.05**				
Vessel Height	**[m]**	**: 18**				
Vessel Tot. Volume	**[m^3]**	**: 73**				
Vessel Material		**: Si-Stainless steel (RA85H)**				
Other		**: SiC Candles**				
Process Conditions						
Stream Data		**Feed**		**Top**		**Bottom**
Temperature	**[°C]**	**: 500**		**: 500**		**: 500**
Pressure	**[bara]**	**: 21**		**: 20.5**		**: 20.5**
Density	**[kg/m^3]**	**: 6.26**		**: 6.26**		**: 1800**
Mass Flow	**[kg/s]**	**: 997.4**		**: 996.4**		**: 1**

Composition	mol%	wt%	mol%	wt%	mol%	wt%
H_2S (ppm)	**319**	**557**	**3**	**0.982**	**-**	**-**
COS (ppm)	**5**	**16**	**0.016**	**0.082**	**-**	**-**
Remarks:						

Designers : L. Djatmiko, W. Hensen, E. Herben, A. Kurniawan, B. Vreugdenhil	Project ID-Number : **CPD3309** Date : July 31st 2004

NH_3/HCl SCRUBBER – SPECIFICATION SHEET

EQUIPMENT NUMBER :	**C201**	**In Series :**	**none**
NAME :	**NH_3/HCl scrubber**	**In Parallel :**	**2**

General Data

Service	: - ~~distillation~~ / ~~extraction~~ / absorption / ———			
Column Type	: - ~~packed~~ / tray / ~~spray~~ / ———			
Tray Type	: - ~~cap~~ / sieve / ~~valve~~ / ———			
Tray Number *(1)*				
- Theoretical	: 25			
- Actual	: 34			
- Feed (actual)	: 34			
Tray Distance (HETP) [m]	: 0.96	**Tray Material**	: SS314	*(2)*
Column Diameter [m]	: 5.7	**Column Material**	: CS	*(2)*
Column Height [m]	: 23.9			
Heating	: - none / ~~open steam~~ / ~~reboiler~~ / ———			

Process Conditions

Stream Details	Feed		Top		Bottom		~~Reflux~~ / Absorbent		~~Extractant~~ / ~~side stream~~	
Temp. [°C]	: 25		: 24		: 24		: 25			
Pressure [bara]	: 20.4		: 17.5		: 17.5		: 20			
Density [kg/m^3]	: 18.2		: 13.8		: 880.9		: 993.0			
Mass Flow [kg/s]	: 996.4		: 874.9		: 319.3		: 197.8			
Composition	**mol%**	**wt%**	**mol%**	**wt%**	**mol%**	**wt%**	**mol%**	**wt%**	**mol%**	**wt%**
Water	0.13	0.12	0	0	99.7	99.4	1	1		
HCl	28ppm		7ppb		847ppm		0			
NH3	15ppm		0		430ppm		0			
———										
———										
———										

Column Internals

Trays *(3)*		**Packing** *Not Applicable*	
Number of		**Type**	:
~~caps~~ / sieve holes / ———	: 10% of area	**Material**	:
Active Tray Area [m^2]	: 0.80	**Volume [m^3]**	:
Weir Length [mm]	: 4.17	**Length [m]**	:
Diameter of		**Width [m]**	:
~~chute pipe~~ / hole / ———[mm]	: 4.76	**Height [m]**	:

Remarks:

(1) Tray numbering from top to bottom.
(2) SS = Stainless Steel; CS = Carbon Steel.
(3) Tray layout valid for whole column.

Designers :	L. Djatmiko, W. Hensen, E. Herben, A. Kurniawan, B. Vreugdenhil	Project ID-Number :	**CPD3309**
		Date :	July 31st 2004

TU Delft

ACTIVE COAL FILTER BED – SPECIFICATION SHEET

EQUIPMENT NUMBER :	**C202**	**In Series :**	none
NAME :	**Active Coal Filter (ACF) bed**	**In Parallel :**	2

General Data

Service		:	- ~~Buffer~~ / ~~Storage~~ / Separation / ~~Reaction~~
Type		:	- Packed Bed
Position		:	- ~~Horizontal~~ - Vertical
Internals		:	- ~~Demister~~ / ~~Plate~~ / ~~Coil~~ / _________
Heating/Cooling medium		:	- none / ~~Open~~ / ~~Closed~~ / ~~External Hxgr~~ /________
- Type		:	n.a.
- Quantity	**[kg/s]**	:	n.a.
- Press./Temp.'s	**[bara/^{o}C]**	:	n.a.
Vessel Diameter (ID)	**[m]**	:	**0.5**
Vessel Height	**[m]**	:	**14.8**
Vessel Tot. Volume	**[m^3]**	:	**2.9**
Vessel Material		:	**Mild –carbon steel**
Other		:	-

Process Conditions

Stream Data		**Feed**		**Top**		**Bottom**	
Temperature	**[^{o}C]**	**: 40**		**:**		**: 40**	
Pressure	**[bara]**	**: 17.5**		**:**		**: 17.0**	
Density	**[kg/m^3]**	**:**		**:**		**:**	
Mass Flow	**[kg/s]**	**:**		**:**		**:**	
Composition		mol%	wt%	mol%	wt%	mol%	wt%

Remarks:
Only used for back up if the impurities concentration exceeds the design criteria of other gas cleaning treatment

Designers :	L. Djatmiko, W. Hensen, E. Herben, A. Kurniawan, B. Vreugdenhil	Project ID-Number : Date :	**CPD3309** July 31st 2004

CANDLE FILTER – SPECIFICATION SHEET

EQUIPMENT NUMBER :	**S201**	**In Series :**	none
NAME :	**Candle filter**	**In Parallel :**	10

General Data

Service		:	- ~~Buffer~~ / ~~Storage~~ / Separation / ~~Reaction~~
Type		:	-
Position		:	- ~~Horizontal~~ - Vertical
Internals		:	- ~~Demister~~ / ~~Plate~~ / ~~Coil~~ / 488 SiC Candles
Heating/Cooling medium		:	- none / ~~Open~~ / ~~Closed~~ / ~~External Hxgr~~ /________
- Type		:	n.a.
- Quantity	**[kg/s]**	:	n.a.
- Press./Temp.'s	**[bara/°C]**	:	n.a.
Vessel Diameter (ID)	**[m]**	:	**3.05**
Vessel Height	**[m]**	:	**7**
Vessel Tot. Volume	**[m³]**	:	**52.8**
Vessel Material		:	**Si-Stainless steel (RA85H)**
Other		:	**SiC Candles**

Process Conditions

Stream Data		**Feed**		**Top**		**Bottom**	
Temperature	**[°C]**	**: 900**		**: 900**		**: 900**	
Pressure	**[bara]**	**: 6.4**		**: 6.4**		**: 6.4**	
Density	**[kg/m³]**	**: 6.5**		**: 1.65**		**: 600**	
Mass Flow	**[kg/s]**	**: 888.2**		**: 851.1**		**: 37.1**	
Composition		mol%	wt%	mol%	wt%	mol%	wt%
Ash + char		**0.037**	**0.042**	**0**	**0**	**1**	**1**
Product gas		**0.963**	**0.958**	**1**	**1**	**0**	**0**

Remarks:

Designers :	L. Djatmiko, W. Hensen, E. Herben, A. Kurniawan, B. Vreugdenhil	Project ID-Number : Date :	**CPD3309** July 31st 2004

CO_2-SELECTIVE MEMBRANE – SPECIFICATION SHEET

EQUIPMENT NUMBER :	**S202**	**In Series :**	none
NAME :	**CO_2-selective membrane**	**In Parallel :**	2

General Data

Service		: - ~~Buffer~~ / ~~Storage~~ / Separation / ~~Reaction~~
Type		: - Hollow fibre
Position		: - Horizontal - ~~Vertical~~
Internals		: - ~~Demister~~ / ~~Plate~~ / ~~Coil~~ / _________
Heating/Cooling medium		: - none / ~~Open~~ / ~~Closed~~ / ~~External Hxgr~~ /________
- Type		: n.a.
- Quantity	**[kg/s]**	: n.a.
- Press./Temp.'s	**[bara/^{o}C]**	: n.a.
Vessel Diameter (ID)	**[m]**	: **6.5**
Vessel Height	**[m]**	: **4.3**
Vessel Tot. Volume	**[m^3]**	: **284.5**
Vessel Material		: **Mild-carbon steel**
Other		: **Fluorinated acrylate urethane polydimethylsiloxane (PDMS) membrane**

Process Conditions

Stream Data		**Feed**		**Top**		**Bottom**	
Temperature	**[^{o}C]**	: **95**		:		: **95**	
Pressure	**[bara]**	: **40.5**		:		: **40.1**	
Density	**[kg/m^3]**	:		:		:	
Mass Flow	**[kg/s]**	:		:		:	
Composition		mol%	wt%	mol%	wt%	mol%	wt%
CO_2						**93.5**	
CO						**1.8**	
H_2						**4.7**	

Remarks:
Only used for back up if the impurities concentration exceeds the design criteria of other gas cleaning treatment

Designers :	L. Djatmiko, W. Hensen, E. Herben, A. Kurniawan, B. Vreugdenhil	Project ID-Number : Date :	**CPD3309** July 31st 2004

SYNGAS COOLER – SPECIFICATION SHEET

EQUIPMENT NUMBER :	**E201**	**In Series**	**:** 0
NAME :	**Syngas Cooler**	**In Parallel**	**:** 10

General Data

Service	:	- **~~Heat Exchanger~~** - **Cooler** - **~~Condenser~~**	- **~~Vaporizer~~** - **~~Reboiler~~**
Type	:	- **Fixed Tube Sheets** - **~~Floating Head~~** - **~~Hair Pin~~** - **~~Double Tube~~**	- **~~Plate Heat Exchanger~~** - **~~Finned Tubes~~** - **~~Thermosyphon~~** -
Position	:	- **~~Horizontal~~** - **Vertical**	

Capacity	**[kW]**	:1264154	**(Calc.)**
Heat Exchange Area	**[m^2]**	: 6872	**(Calc.)**
Overall Heat Transfer Coefficient	**[$W/m^2 \cdot {}^oC$]**	: 850	**(Estim.)**
Log. Mean Temperature Diff. (LMTD)	**[^oC]**	: 216.4	
Passes Tube Side		: 1	
Passes Shell Side		: 1	
Correction Factor LMTD (min. 0.75)		: 1.00	
Corrected LMTD	**[^oC]**	: 216.4	

Process Conditions

			Shell Side	**Tube Side**
Medium		:	Syngas	Cooling water
Mass Stream	**[kg/s]**	:	975	350
Mass Stream to				
- Evaporize	**[kg/s]**	:	-	-
- Condense	**[kg/s]**	:	-	-
Average Specific Heat	**[$kJ/kg \cdot {}^oC$]**	:	-	4.18
Heat of Evap. / Condensation	**[kJ/kg]**	:		1713
Temperature IN	**[^oC]**	:	907	80.3
Temperature OUT	**[^oC]**	:	201	685.6
Pressure	**[bara]**	:	6.4	40
Material *(1)*		:	CS	Al-Br

Remarks:
(1) CS = Carbon Steel; Al-Br = Aluminum-Bronze.

Designers : L. Djatmiko, W. Hensen, E. Herben, A. Kurniawan, B. Vreugdenhil	Project ID-Number	:	**CPD3309**
	Date	:	July 31st 2004

Appendix 10.1 F&EI, LCCF and Process Unit Risk Summary

Fire & Explosion Index

Area/Country: Baltic States	**Division:** -	**Location** Local collecting point	**Date** July 30, 2004
Site -	**Manufacturing Unit** Biomass to Syngas	**Process Unit** Chipper (A101)	
Materials in Process Unit Wood			
State of Operation Normal Operation	**Basic Materials for Material Factor** Wood branch and small logs		

Material Factor		16
1. General Process Hazards	**Penalty Factor Range**	**Penalty Used**
Base Factor	1.00	
A. Exothermic Chemical Reactions	0.30 - 1.25	
B. Endothermic Processes	0.20 - 0.40	
C. Material Handling and Transfer	0.25 - 1.05	
D. Enclosed or Indoor Process Units	0.25 - 0.90	
E. Acces	0.20 - 0.35	0.20
F. Drainage and Spill Control	0.25 - 0.50	
General Process Hazards Factor (F1)		0.20
2. Special Process Hazards	**Penalty Factor Range**	**Penalty Used**
Base Factor	1.00	
A. Toxic Material(s)	0.20 - 0.80	
B. Sub-Atmosferic Pressure (< 500 mm Hg)	0.50	
C. Operation In or Near Flammable Range		
1. Tank Farms Storage Flammable Liquids	0.50	
2. Process Upset or Purge Failure	0.30	
3. Always in Flammable Range	0.80	
D. Dust Explosion	0.25 - 2.00	0.50
E. Pressure — Operating Pressure: 1.00E+02 kPa; Relief Setting: kPa		
F. Low Temperature	0.20 - 0.30	
G. Quantity of Flammable Material: 160000 kg; Hc = BTU/lb		
1. Liquids or Gases in Process		0.00
2. Liquids or Gases in Storage		
3. Combustible Solids in Storage, Dust in Process		0.06
H. Corrosion and Erosion	0.10 - 0.75	
I. Leakage - Joints and Packing	0.10 - 1.50	
J. Use of Fired Equipment		
K. Hot Oil Heat Exchange System	0.15 - 1.15	
L. Rotating Equipment	0.50	0.50
Special Process Hazards Factor (F2)		1.06
Process Units Hazards Factor (F1 x F2) = F3		0.21
Fire and Explosion Index (F3 x MF = F&EI)		3

Loss Control Credit Factors

Area/Country: Baltic States	**Division:** -	**Location** Local collecting point	**Date** July 30, 2004
Site -	**Manufacturing Unit** Biomass to Syngas	**Process Unit** Chipper (A101)	
Materials in Process Unit Wood 0			
State of Operation Normal Operation	**Basic Materials for Material Factor** Wood branch and small logs		

1. Process Control Credit Factor (C1)	**Credit Factor Range**	**Credit Used**
A. Emergency Power	0.98	1.00
B. Cooling	0.97 - 0.99	1.00
C. Explosion Control	0.84 - 0.98	0.98
D. Emergency Shutdown	0.96 - 0.99	1.00
E. Computer Control	0.93 - 0.99	1.00
F. Inert Gas	0.94 - 0.96	1.00
G. Operating Instructions/Procedures	0.91 - 0.99	0.99
H. Reactive Chemical Review	0.91 - 0.98	1.00
I. Other Process Hazards Analysis	0.91 - 0.98	0.94
Loss Control Credit Factor (C1)		0.91

2. Material Isolation Credit Factor (C2)	**Credit Factor Range**	**Credit Used**
A. Remote Control Valves	0.96 - 0.98	1.00
B. Dump/Blowdown	0.96 - 0.98	1.00
C. Drainage	0.91 - 0.97	1.00
D. Interlock	0.98	1.00
Material Isolation Credit Factor (C2)		1.00

3. Fire Protection Credit Factor (C3)	**Credit Factor Range**	**Credit Used**
A. Leak Detection	0.94 - 0.98	1.00
B. Structural Steel	0.95 - 0.98	1.00
C. Fire Water Supply	0.94 - 0.97	0.97
D. Special Systems	0.91	1.00
E. Sprinkler Systems	0.74 - 0.97	1.00
F.Water Curtains	0.97 - 0.98	1.00
G. Foam	0.92 - 0.97	1.00
H. Hand Extinguishers/Monitors	0.93 - 0.98	1.00
I. Cable Protection	0.94 - 0.98	1.00
Loss Control Credit Factor (C3)		0.97
Loss Control Credit Factor (C1 x C2 x C3)		**0.88**

Process Unit Risk Analysis

Area/Country: Baltic States	**Division:** -	**Location** Local collecting point	**Date** July 30, 2004
Site -	**Manufacturing Unit** Biomass to Syngas	**Process Unit** Chipper (A101)	
Materials in Process Unit Wood 0			
State of Operation Normal Operation	**Basic Materials for Material Factor** Wood branch and small logs		

1. Fire & Explosion Index (F&EI)	3	[-]
2. Radius of Exposure	1	[m]
3. Area of Exposure	2	[m^2]
4. Value of Exposure	0.45	M€
5. Damage Factor	0.17	[-]
6. Base Maximum Probable Property Damage	0.08	M€
7. Loss Control Credit Factor	0.88	[-]
8. Actual Maximum Probable Property Damage	0.07	M€
9. Maximum Probable Days Outage	5	days
10. Business Interruption	0.27	M€

Fire & Explosion Index

Area/Country: Baltic States	**Division:** -	**Location** Collecting point/harbours	**Date** July 30, 2004
Site -	**Manufacturing Unit** Biomass to Syngas	**Process Unit** Pelletiser (X101)	
Materials in Process Unit Wood			
State of Operation Normal Operation	**Basic Materials for Material Factor** Wood chips and saw dust		

Material Factor		16
1. General Process Hazards	**Penalty Factor Range**	**Penalty Used**
Base Factor	1.00	
A. Exothermic Chemical Reactions	0.30 - 1.25	
B. Endothermic Processes	0.20 - 0.40	
C. Material Handling and Transfer	0.25 - 1.05	
D. Enclosed or Indoor Process Units	0.25 - 0.90	
E. Acces	0.20 - 0.35	0.20
F. Drainage and Spill Control	0.25 - 0.50	
General Process Hazards Factor (F1)		0.20
2. Special Process Hazards	**Penalty Factor Range**	**Penalty Used**
Base Factor	1.00	
A. Toxic Material(s)	0.20 - 0.80	
B. Sub-Atmosferic Pressure (< 500 mm Hg)	0.50	
C. Operation In or Near Flammable Range		
1. Tank Farms Storage Flammable Liquids	0.50	
2. Process Upset or Purge Failure	0.30	
3. Always in Flammable Range	0.80	
D. Dust Explosion	0.25 - 2.00	0.25
E. Pressure — Operating Pressure: kPa; Relief Setting: kPa		
F. Low Temperature	0.20 - 0.30	
G. Quantity of Flammable Material: kg; Hc = BTU/lb		
1. Liquids or Gases in Process		
2. Liquids or Gases in Storage		
3. Combustible Solids in Storage, Dust in Process		0.06
H. Corrosion and Erosion	0.10 - 0.75	
I. Leakage - Joints and Packing	0.10 - 1.50	
J. Use of Fired Equipment		
K. Hot Oil Heat Exchange System	0.15 - 1.15	
L. Rotating Equipment	0.50	0.50
Special Process Hazards Factor (F2)		0.81
Process Units Hazards Factor (F1 x F2) = F3		0.16
Fire and Explosion Index (F3 x MF = F&EI)		3

Loss Control Credit Factors

Area/Country: Baltic States	**Division:** -	**Location** Collecting point/harbours	**Date** July 30, 2004
Site -	**Manufacturing Unit** Biomass to Syngas	**Process Unit** Pelletiser (X101)	
Materials in Process Unit Wood 0			
State of Operation Normal Operation	**Basic Materials for Material Factor** Wood chips and saw dust		

1. Process Control Credit Factor (C1)	**Credit Factor Range**	**Credit Used**
A. Emergency Power	0.98	1.00
B. Cooling	0.97 - 0.99	1.00
C. Explosion Control	0.84 - 0.98	0.98
D. Emergency Shutdown	0.96 - 0.99	1.00
E. Computer Control	0.93 - 0.99	1.00
F. Inert Gas	0.94 - 0.96	1.00
G. Operating Instructions/Procedures	0.91 - 0.99	0.99
H. Reactive Chemical Review	0.91 - 0.98	1.00
I. Other Process Hazards Analysis	0.91 - 0.98	0.94
Loss Control Credit Factor (C1)		0.91
2. Material Isolation Credit Factor (C2)	**Credit Factor Range**	**Credit Used**
A. Remote Control Valves	0.96 - 0.98	1.00
B. Dump/Blowdown	0.96 - 0.98	1.00
C. Drainage	0.91 - 0.97	1.00
D. Interlock	0.98	1.00
Material Isolation Credit Factor (C2)		1.00
3. Fire Protection Credit Factor (C3)	**Credit Factor Range**	**Credit Used**
A. Leak Detection	0.94 - 0.98	1.00
B. Structural Steel	0.95 - 0.98	1.00
C. Fire Water Supply	0.94 - 0.97	0.97
D. Special Systems	0.91	1.00
E. Sprinkler Systems	0.74 - 0.97	1.00
F.Water Curtains	0.97 - 0.98	1.00
G. Foam	0.92 - 0.97	1.00
H. Hand Extinguishers/Monitors	0.93 - 0.98	1.00
I. Cable Protection	0.94 - 0.98	1.00
Loss Control Credit Factor (C3)		0.97
Loss Control Credit Factor (C1 x C2 x C3)		**0.88**

Process Unit Risk Analysis

Area/Country: Baltic States	**Division:** -	**Location** Collecting point/harbours	**Date** July 30, 2004
Site -	**Manufacturing Unit** Biomass to Syngas	**Process Unit** Pelletiser (X101)	
Materials in Process Unit Wood 0			
State of Operation Normal Operation	**Basic Materials for Material Factor** Wood chips and saw dust		

1. Fire & Explosion Index (F&EI)	3	[-]
2. Radius of Exposure	1	[m]
3. Area of Exposure	1	[m^2]
4. Value of Exposure	0.81	M€
5. Damage Factor	0.63	[-]
6. Base Maximum Probable Property Damage	0.15	M€
7. Loss Control Credit Factor	0.88	[-]
8. Actual Maximum Probable Property Damage	0.13	M€
9. Maximum Probable Days Outage	8	days
10. Business Interruption	0.40	M€

Fire & Explosion Index

Area/Country: South West Netherlands	**Division:** -	**Location** Rotterdam Harbour, Maasvlakte	**Date** July 30, 2004
Site -	**Manufacturing Unit** Biomass to Syngas	**Process Unit** Storage column 1 bar 288K	
Materials in Process Unit Wood			
State of Operation Normal Operation	**Basic Materials for Material Factor** Wood pellets		

Material Factor		16
1. General Process Hazards	**Penalty Factor Range**	**Penalty Used**
Base Factor	1.00	
A. Exothermic Chemical Reactions	0.30 - 1.25	
B. Endothermic Processes	0.20 - 0.40	
C. Material Handling and Transfer	0.25 - 1.05	0.40
D. Enclosed or Indoor Process Units	0.25 - 0.90	
E. Acces	0.20 - 0.35	0.20
F. Drainage and Spill Control	0.25 - 0.50	
General Process Hazards Factor (F1)		0.60
2. Special Process Hazards	**Penalty Factor Range**	**Penalty Used**
Base Factor	1.00	
A. Toxic Material(s)	0.20 - 0.80	
B. Sub-Atmosferic Pressure (< 500 mm Hg)	0.50	
C. Operation In or Near Flammable Range		
1. Tank Farms Storage Flammable Liquids	0.50	
2. Process Upset or Purge Failure	0.30	
3. Always in Flammable Range	0.80	
D. Dust Explosion	0.25 - 2.00	0.50
E. Pressure — Operating Pressure: kPa; Relief Setting: kPa		0.16
F. Low Temperature	0.20 - 0.30	
G. Quantity of Flammable Material: 266716800 pound; Hc = BTU/lb		
1. Liquids or Gases in Process		
2. Liquids or Gases in Storage		
3. Combustible Solids in Storage, Dust in Process		0.25
H. Corrosion and Erosion	0.10 - 0.75	
I. Leakage - Joints and Packing	0.10 - 1.50	
J. Use of Fired Equipment		
K. Hot Oil Heat Exchange System	0.15 - 1.15	
L. Rotating Equipment	0.50	
Special Process Hazards Factor (F2)		0.91
Process Units Hazards Factor (F1 x F2) = F3		0.55
Fire and Explosion Index (F3 x MF = F&EI)		**9**

Loss Control Credit Factors

Area/Country:	Division:	Location	Date
South West Netherlands	-	Rotterdam Harbour, Maasvlakte	July 30, 2004

Site	Manufacturing Unit	Process Unit
-	Biomass to Syngas	Storage column

Materials in Process Unit
Wood
0

State of Operation	Basic Materials for Material Factor
Normal Operation	Wood pellets

1. Process Control Credit Factor (C1)	Credit Factor Range	Credit Used
A. Emergency Power	0.98	0.98
B. Cooling	0.97 - 0.99	1.00
C. Explosion Control	0.84 - 0.98	0.98
D. Emergency Shutdown	0.96 - 0.99	0.98
E. Computer Control	0.93 - 0.99	0.97
F. Inert Gas	0.94 - 0.96	1.00
G. Operating Instructions/Procedures	0.91 - 0.99	0.99
H. Reactive Chemical Review	0.91 - 0.98	1.00
I. Other Process Hazards Analysis	0.91 - 0.98	0.94
Loss Control Credit Factor (C1)		0.85

2. Material Isolation Credit Factor (C2)	Credit Factor Range	Credit Used
A. Remote Control Valves	0.96 - 0.98	0.98
B. Dump/Blowdown	0.96 - 0.98	1.00
C. Drainage	0.91 - 0.97	1.00
D. Interlock	0.98	1.00
Material Isolation Credit Factor (C2)		0.98

3. Fire Protection Credit Factor (C3)	Credit Factor Range	Credit Used
A. Leak Detection	0.94 - 0.98	1.00
B. Structural Steel	0.95 - 0.98	1.00
C. Fire Water Supply	0.94 - 0.97	0.97
D. Special Systems	0.91	1.00
E. Sprinkler Systems	0.74 - 0.97	1.00
F.Water Curtains	0.97 - 0.98	1.00
G. Foam	0.92 - 0.97	1.00
H. Hand Extinguishers/Monitors	0.93 - 0.98	1.00
I. Cable Protection	0.94 - 0.98	1.00
Loss Control Credit Factor (C3)		0.97
Loss Control Credit Factor (C1 x C2 x C3)		**0.81**

Process Unit Risk Analysis

Area/Country:	Division:	Location	Date
South West Netherlands	-	Rotterdam Harbour, Maasvlakte	July 30, 2004

Site	Manufacturing Unit	Process Unit
-	Biomass to Syngas	Storage column

Materials in Process Unit
Wood
0

State of Operation	Basic Materials for Material Factor
Normal Operation	Wood pellets

1. Fire & Explosion Index (F&EI)	9	[-]
2. Radius of Exposure	2	[m]
3. Area of Exposure	16	[m^2]
4. Value of Exposure	5.57	M€
5. Damage Factor	0.36	[-]
6. Base Maximum Probable Property Damage	2.00	M€
7. Loss Control Credit Factor	0.81	[-]
8. Actual Maximum Probable Property Damage	1.62	M€
9. Maximum Probable Days Outage	34	days
10. Business Interruption	1.75	M€

Fire & Explosion Index

Area/Country: South West Netherlands	**Division:** -	**Location** Rotterdam Harbour, Maasvlakte	**Date** July 30, 2004
Site -	**Manufacturing Unit** Biomass to Syngas	**Process Unit** Circulating Fluidized Bed reactor (R201)	

Materials in Process Unit
Wood pellets, CO, CO2, H2, CH4, N2, Ar, H2O (g), O2 (g), NH3, HCN, H2S, HCl, COS, SO2
Tars (BTX), Char, Ash

State of Operation	**Basic Materials for Material Factor**
Normal Operation	CO

Material Factor		21
1. General Process Hazards	**Penalty Factor Range**	**Penalty Used**
Base Factor	1.00	
A. Exothermic Chemical Reactions	0.30 - 1.25	0.50
B. Endothermic Processes	0.20 - 0.40	0.40
C. Material Handling and Transfer	0.25 - 1.05	0.50
D. Enclosed or Indoor Process Units	0.25 - 0.90	
E. Acces	0.20 - 0.35	0.20
F. Drainage and Spill Control	0.25 - 0.50	
General Process Hazards Factor (F1)		1.60
2. Special Process Hazards	**Penalty Factor Range**	**Penalty Used**
Base Factor	1.00	
A. Toxic Material(s)	0.20 - 0.80	0.80
B. Sub-Atmosferic Pressure (< 500 mm Hg)	0.50	
C. Operation In or Near Flammable Range		
1. Tank Farms Storage Flammable Liquids	0.50	
2. Process Upset or Purge Failure	0.30	
3. Always in Flammable Range	0.80	0.80
D. Dust Explosion	0.25 - 2.00	
E. Pressure — Operating Pressure: 7.00E+02 kPa; Relief Setting: kPa		0.31
F. Low Temperature	0.20 - 0.30	
G. Quantity of Flammable Material: 3000.88 kg; Hc = 4.30E+03 BTU/lb		
1. Liquids or Gases in Process		0.00
2. Liquids or Gases in Storage		
3. Combustible Solids in Storage, Dust in Process		
H. Corrosion and Erosion	0.10 - 0.75	
I. Leakage - Joints and Packing	0.10 - 1.50	
J. Use of Fired Equipment		
K. Hot Oil Heat Exchange System	0.15 - 1.15	
L. Rotating Equipment	0.50	
Special Process Hazards Factor (F2)		1.91
Process Units Hazards Factor (F1 x F2) = F3		3.06
Fire and Explosion Index (F3 x MF = F&EI)		**64**

Loss Control Credit Factors

Area/Country:	Division:	Location	Date
South West Netherlands	-	Rotterdam Harbour, Maasvlakte	July 30, 2004
Site	**Manufacturing Unit**	**Process Unit**	
-	Biomass to Syngas	Circulating Fluidized Bed reactor (R201)	

Materials in Process Unit
Wood pellets, CO, CO2, H2, CH4, N2, Ar, H2O (g), O2 (g), NH3, HCN, H2S, HCl, COS, SO2
Tars (BTX), Char, Ash

State of Operation	Basic Materials for Material Factor
Normal Operation	CO

1. Process Control Credit Factor (C1)	Credit Factor Range	Credit Used
A. Emergency Power	0.98	0.98
B. Cooling	0.97 - 0.99	1.00
C. Explosion Control	0.84 - 0.98	0.98
D. Emergency Shutdown	0.96 - 0.99	0.98
E. Computer Control	0.93 - 0.99	0.97
F. Inert Gas	0.94 - 0.96	1.00
G. Operating Instructions/Procedures	0.91 - 0.99	0.98
H. Reactive Chemical Review	0.91 - 0.98	0.98
I. Other Process Hazards Analysis	0.91 - 0.98	0.94
Loss Control Credit Factor (C1)		0.82

2. Material Isolation Credit Factor (C2)	Credit Factor Range	Credit Used
A. Remote Control Valves	0.96 - 0.98	0.98
B. Dump/Blowdown	0.96 - 0.98	0.98
C. Drainage	0.91 - 0.97	0.97
D. Interlock	0.98	1.00
Material Isolation Credit Factor (C2)		0.93

3. Fire Protection Credit Factor (C3)	Credit Factor Range	Credit Used
A. Leak Detection	0.94 - 0.98	0.98
B. Structural Steel	0.95 - 0.98	1.00
C. Fire Water Supply	0.94 - 0.97	0.97
D. Special Systems	0.91	1.00
E. Sprinkler Systems	0.74 - 0.97	1.00
F.Water Curtains	0.97 - 0.98	1.00
G. Foam	0.92 - 0.97	1.00
H. Hand Extinguishers/Monitors	0.93 - 0.98	1.00
I. Cable Protection	0.94 - 0.98	1.00
Loss Control Credit Factor (C3)		0.95
Loss Control Credit Factor (C1 x C2 x C3)		**0.73**

Process Unit Risk Analysis

Area/Country:	Division:	Location	Date
South West Netherlands	-	Rotterdam Harbour, Maasvlakte	July 30, 2004
Site	**Manufacturing Unit**	**Process Unit**	
-	Biomass to Syngas	Circulating Fluidized Bed reactor (R201)	

Materials in Process Unit
Wood pellets, CO, CO2, H2, CH4, N2, Ar, H2O (g), O2 (g), NH3, HCN, H2S, HCl, COS, SO2
Tars (BTX), Char, Ash

State of Operation	Basic Materials for Material Factor
Normal Operation	CO

1. Fire & Explosion Index (F&EI)	64	[-]
2. Radius of Exposure	16	[m]
3. Area of Exposure	849	[m^2]
4. Value of Exposure	68.85	M€
5. Damage Factor	0.63	[-]
6. Base Maximum Probable Property Damage	43.38	M€
7. Loss Control Credit Factor	0.73	[-]
8. Actual Maximum Probable Property Damage	31.66	M€
9. Maximum Probable Days Outage	198	days
10. Business Interruption	10.16	M€

Fire & Explosion Index

Area/Country:	Division:	Location	Date
South West Netherlands	-	Rotterdam Harbour, Maasvlakte	July 30, 2004

Site	Manufacturing Unit	Process Unit
-	Biomass to Syngas	Candle filter (S201)

Materials in Process Unit
Wood pellets, CO, CO2, H2, CH4, N2, Ar, H2O (g), O2 (g), NH3, HCN, H2S, HCl, COS, SO2
Tars (BTX), Char, Ash

State of Operation	Basic Materials for Material Factor
Normal Operation	CO

Material Factor		21
1. General Process Hazards	**Penalty Factor Range**	**Penalty Used**
Base Factor	1.00	
A. Exothermic Chemical Reactions	0.30 - 1.25	
B. Endothermic Processes	0.20 - 0.40	
C. Material Handling and Transfer	0.25 - 1.05	0.50
D. Enclosed or Indoor Process Units	0.25 - 0.90	
E. Acces	0.20 - 0.35	0.20
F. Drainage and Spill Control	0.25 - 0.50	
General Process Hazards Factor (F1)		0.70
2. Special Process Hazards	**Penalty Factor Range**	**Penalty Used**
Base Factor	1.00	
A. Toxic Material(s)	0.20 - 0.80	0.80
B. Sub-Atmosferic Pressure (< 500 mm Hg)	0.50	
C. Operation In or Near Flammable Range		
1. Tank Farms Storage Flammable Liquids	0.50	
2. Process Upset or Purge Failure	0.30	
3. Always in Flammable Range	0.80	0.80
D. Dust Explosion	0.25 - 2.00	
E. Pressure — Operating Pressure: 7.00E+02 kPa; Relief Setting: kPa		0.31
F. Low Temperature	0.20 - 0.30	
G. Quantity of Flammable Material: 3000.88 kg; Hc = 4.30E+03 BTU/lb		
1. Liquids or Gases in Process		0.00
2. Liquids or Gases in Storage		
3. Combustible Solids in Storage, Dust in Process		
H. Corrosion and Erosion	0.10 - 0.75	
I. Leakage - Joints and Packing	0.10 - 1.50	
J. Use of Fired Equipment		
K. Hot Oil Heat Exchange System	0.15 - 1.15	
L. Rotating Equipment	0.50	
Special Process Hazards Factor (F2)		1.91

Loss Control Credit Factors

Area/Country: South West Netherlands	**Division:** -	**Location** Rotterdam Harbour, Maasvlakte	**Date** July 30, 2004
Site -	**Manufacturing Unit** Biomass to Syngas	**Process Unit** Candle filter (S201)	
Materials in Process Unit Wood pellets, CO, CO2, H2, CH4, N2, Ar, H2O (g), O2 (g), NH3, HCN, H2S, HCl, COS, SO2 Tars (BTX), Char, Ash			
State of Operation Normal Operation	**Basic Materials for Material Factor** CO		

1. Process Control Credit Factor (C1)	**Credit Factor Range**	**Credit Used**
A. Emergency Power	0.98	1.00
B. Cooling	0.97 - 0.99	1.00
C. Explosion Control	0.84 - 0.98	0.98
D. Emergency Shutdown	0.96 - 0.99	0.98
E. Computer Control	0.93 - 0.99	0.97
F. Inert Gas	0.94 - 0.96	1.00
G. Operating Instructions/Procedures	0.91 - 0.99	0.98
H. Reactive Chemical Review	0.91 - 0.98	1.00
I. Other Process Hazards Analysis	0.91 - 0.98	0.94
Loss Control Credit Factor (C1)		0.86

2. Material Isolation Credit Factor (C2)	**Credit Factor Range**	**Credit Used**
A. Remote Control Valves	0.96 - 0.98	0.98
B. Dump/Blowdown	0.96 - 0.98	1.00
C. Drainage	0.91 - 0.97	1.00
D. Interlock	0.98	1.00
Material Isolation Credit Factor (C2)		0.98

3. Fire Protection Credit Factor (C3)	**Credit Factor Range**	**Credit Used**
A. Leak Detection	0.94 - 0.98	0.98
B. Structural Steel	0.95 - 0.98	1.00
C. Fire Water Supply	0.94 - 0.97	0.97
D. Special Systems	0.91	1.00
E. Sprinkler Systems	0.74 - 0.97	1.00
F.Water Curtains	0.97 - 0.98	1.00
G. Foam	0.92 - 0.97	1.00
H. Hand Extinguishers/Monitors	0.93 - 0.98	1.00
I. Cable Protection	0.94 - 0.98	1.00
Loss Control Credit Factor (C3)		0.95
Loss Control Credit Factor (C1 x C2 x C3)		**0.80**

Process Unit Risk Analysis

Area/Country: South West Netherlands	**Division:** -	**Location** Rotterdam Harbour, Maasvlakte	**Date** July 30, 2004
Site -	**Manufacturing Unit** Biomass to Syngas	**Process Unit** Candle filter (S201)	
Materials in Process Unit Wood pellets, CO, CO2, H2, CH4, N2, Ar, H2O (g), O2 (g), NH3, HCN, H2S, HCl, COS, SO2 Tars (BTX), Char, Ash			
State of Operation Normal Operation	**Basic Materials for Material Factor** CO		

1. Fire & Explosion Index (F&EI)	28	[-]
2. Radius of Exposure	7	[m]
3. Area of Exposure	162	[m^2]
4. Value of Exposure	3.05	M€
5. Damage Factor	0.45	[-]
6. Base Maximum Probable Property Damage	1.37	M€
7. Loss Control Credit Factor	0.80	[-]
8. Actual Maximum Probable Property Damage	1.10	M€
9. Maximum Probable Days Outage	27	days
10. Business Interruption	1.39	M€

Fire & Explosion Index

Area/Country:	**Division:**	**Location**	**Date**
South West Netherlands	-	Rotterdam Harbour, Maasvlakte	July 30, 2004
Site	**Manufacturing Unit**	**Process Unit**	
-	Biomass to Syngas	Monolith tars cracker (R202)	

Materials in Process Unit
CO, CO2, H2, CH4, N2, Ar, H2O (g), O2 (g), NH3, HCN, H2S, HCl, COS, SO2
Tars (BTX), Char, Ash

State of Operation	**Basic Materials for Material Factor**
Normal Operation	CO

Material Factor		21
1. General Process Hazards	**Penalty Factor Range**	**Penalty Used**
Base Factor	1.00	
A. Exothermic Chemical Reactions	0.30 - 1.25	
B. Endothermic Processes	0.20 - 0.40	0.40
C. Material Handling and Transfer	0.25 - 1.05	0.50
D. Enclosed or Indoor Process Units	0.25 - 0.90	
E. Acces	0.20 - 0.35	0.20
F. Drainage and Spill Control	0.25 - 0.50	
General Process Hazards Factor (F1)		1.10
2. Special Process Hazards	**Penalty Factor Range**	**Penalty Used**
Base Factor	1.00	
A. Toxic Material(s)	0.20 - 0.80	0.80
B. Sub-Atmosferic Pressure (< 500 mm Hg)	0.50	
C. Operation In or Near Flammable Range		
1. Tank Farms Storage Flammable Liquids	0.50	
2. Process Upset or Purge Failure	0.30	
3. Always in Flammable Range	0.80	0.80
D. Dust Explosion	0.25 - 2.00	
E. Pressure — Operating Pressure: 7.00E+02 kPa; Relief Setting: kPa		0.31
F. Low Temperature	0.20 - 0.30	
G. Quantity of Flammable Material: 594 kg; Hc = 4.30E+03 BTU/lb		
1. Liquids or Gases in Process		0.00
2. Liquids or Gases in Storage		
3. Combustible Solids in Storage, Dust in Process		
H. Corrosion and Erosion	0.10 - 0.75	
I. Leakage - Joints and Packing	0.10 - 1.50	
J. Use of Fired Equipment		
K. Hot Oil Heat Exchange System	0.15 - 1.15	
L. Rotating Equipment	0.50	
Special Process Hazards Factor (F2)		1.91
Process Units Hazards Factor (F1 x F2) = F3		2.10
Fire and Explosion Index (F3 x MF = F&EI)		**44**

Loss Control Credit Factors

Area/Country: South West Netherlands	**Division:** -	**Location** Rotterdam Harbour, Maasvlakte	**Date** July 30, 2004
Site -	**Manufacturing Unit** Biomass to Syngas	**Process Unit** Monolith tars cracker (R202)	
Materials in Process Unit CO, CO2, H2, CH4, N2, Ar, H2O (g), O2 (g), NH3, HCN, H2S, HCl, COS, SO2 Tars (BTX), Char, Ash			
State of Operation Normal Operation Before HAZOP	**Basic Materials for Material Factor**		

1. Process Control Credit Factor (C1)	**Credit Factor Range**	**Credit Used**
A. Emergency Power	0.98	0.98
B. Cooling	0.97 - 0.99	1.00
C. Explosion Control	0.84 - 0.98	0.98
D. Emergency Shutdown	0.96 - 0.99	0.98
E. Computer Control	0.93 - 0.99	0.97
F. Inert Gas	0.94 - 0.96	1.00
G. Operating Instructions/Procedures	0.91 - 0.99	0.98
H. Reactive Chemical Review	0.91 - 0.98	0.98
I. Other Process Hazards Analysis	0.91 - 0.98	0.94
Loss Control Credit Factor (C1)		0.82
2. Material Isolation Credit Factor (C2)	**Credit Factor Range**	**Credit Used**
A. Remote Control Valves	0.96 - 0.98	0.98
B. Dump/Blowdown	0.96 - 0.98	0.98
C. Drainage	0.91 - 0.97	1.00
D. Interlock	0.98	1.00
Material Isolation Credit Factor (C2)		0.96
3. Fire Protection Credit Factor (C3)	**Credit Factor Range**	**Credit Used**
A. Leak Detection	0.94 - 0.98	0.98
B. Structural Steel	0.95 - 0.98	1.00
C. Fire Water Supply	0.94 - 0.97	0.97
D. Special Systems	0.91	1.00
E. Sprinkler Systems	0.74 - 0.97	1.00
F.Water Curtains	0.97 - 0.98	1.00
G. Foam	0.92 - 0.97	1.00
H. Hand Extinguishers/Monitors	0.93 - 0.98	1.00
I. Cable Protection	0.94 - 0.98	1.00
Loss Control Credit Factor (C3)		0.95
Loss Control Credit Factor (C1 x C2 x C3)		**0.75**

Process Unit Risk Analysis

Area/Country: South West Netherlands	**Division:** -	**Location** Rotterdam Harbour, Maasvlakte	**Date** July 30, 2004
Site -	**Manufacturing Unit** Biomass to Syngas	**Process Unit** Monolith tars cracker (R202)	
Materials in Process Unit CO, CO2, H2, CH4, N2, Ar, H2O (g), O2 (g), NH3, HCN, H2S, HCl, COS, SO2 Tars (BTX), Char, Ash			
State of Operation Normal Operation	**Basic Materials for Material Factor** CO		

1. Fire & Explosion Index (F&EI)	44	[-]
2. Radius of Exposure	11	[m]
3. Area of Exposure	401	[m^2]
4. Value of Exposure	32.05	M€
5. Damage Factor	0.50	[-]
6. Base Maximum Probable Property Damage	16.02	M€
7. Loss Control Credit Factor	0.75	[-]
8. Actual Maximum Probable Property Damage	12.06	M€
9. Maximum Probable Days Outage	112	days
10. Business Interruption	5.74	M€

Fire & Explosion Index

Area/Country: South West Netherlands	**Division:** -	**Location** Rotterdam Harbour, Maasvlakte	**Date** July 30, 2004
Site -	**Manufacturing Unit** Biomass to Syngas	**Process Unit** Sour water-gas shift (R203)	
Materials in Process Unit CO, CO2, H2, CH4, N2, Ar, H2O (g), NH3, HCN, H2S, HCl, COS, SO2,			
State of Operation Normal Operation	**Basic Materials for Material Factor** CO		

Material Factor		21
1. General Process Hazards	**Penalty Factor Range**	**Penalty Used**
Base Factor	1.00	
A. Exothermic Chemical Reactions	0.30 - 1.25	0.30
B. Endothermic Processes	0.20 - 0.40	
C. Material Handling and Transfer	0.25 - 1.05	0.50
D. Enclosed or Indoor Process Units	0.25 - 0.90	
E. Acces	0.20 - 0.35	0.20
F. Drainage and Spill Control	0.25 - 0.50	
General Process Hazards Factor (F1)		1.00
2. Special Process Hazards	**Penalty Factor Range**	**Penalty Used**
Base Factor	1.00	
A. Toxic Material(s)	0.20 - 0.80	0.80
B. Sub-Atmosferic Pressure (< 500 mm Hg)	0.50	
C. Operation In or Near Flammable Range		
1. Tank Farms Storage Flammable Liquids	0.50	
2. Process Upset or Purge Failure	0.30	
3. Always in Flammable Range	0.80	0.80
D. Dust Explosion	0.25 - 2.00	
E. Pressure Operating Pressure: 2.50E+03 kPa Relief Setting: kPa		0.58
F. Low Temperature	0.20 - 0.30	
G. Quantity of Flammable Material: kg Hc = 4.30E+03 BTU/lb		
1. Liquids or Gases in Process		0.00
2. Liquids or Gases in Storage		
3. Combustible Solids in Storage, Dust in Process		
H. Corrosion and Erosion	0.10 - 0.75	
I. Leakage - Joints and Packing	0.10 - 1.50	
J. Use of Fired Equipment		
K. Hot Oil Heat Exchange System	0.15 - 1.15	
L. Rotating Equipment	0.50	
Special Process Hazards Factor (F2)		2.18
Process Units Hazards Factor (F1 x F2) = F3		2.18
Fire and Explosion Index (F3 x MF = F&EI)		**46**

Loss Control Credit Factors

Area/Country: South West Netherlands	**Division:** -	**Location** Rotterdam Harbour, Maasvlakte	**Date** July 30, 2004
Site -	**Manufacturing Unit** Biomass to Syngas	**Process Unit** Sour water-gas shift (R203)	
Materials in Process Unit CO, CO2, H2, CH4, N2, Ar, H2O (g), NH3, HCN, H2S, HCl, COS, SO2,			
State of Operation Normal Operation Before HAZOP	**Basic Materials for Material Factor**		

1. Process Control Credit Factor (C1)	**Credit Factor Range**	**Credit Used**
A. Emergency Power	0.98	0.98
B. Cooling	0.97 - 0.99	1.00
C. Explosion Control	0.84 - 0.98	0.98
D. Emergency Shutdown	0.96 - 0.99	0.98
E. Computer Control	0.93 - 0.99	0.97
F. Inert Gas	0.94 - 0.96	1.00
G. Operating Instructions/Procedures	0.91 - 0.99	0.98
H. Reactive Chemical Review	0.91 - 0.98	0.98
I. Other Process Hazards Analysis	0.91 - 0.98	0.94
Loss Control Credit Factor (C1)		0.82

2. Material Isolation Credit Factor (C2)	**Credit Factor Range**	**Credit Used**
A. Remote Control Valves	0.96 - 0.98	0.98
B. Dump/Blowdown	0.96 - 0.98	0.98
C. Drainage	0.91 - 0.97	1.00
D. Interlock	0.98	1.00
Material Isolation Credit Factor (C2)		0.96

3. Fire Protection Credit Factor (C3)	**Credit Factor Range**	**Credit Used**
A. Leak Detection	0.94 - 0.98	0.98
B. Structural Steel	0.95 - 0.98	1.00
C. Fire Water Supply	0.94 - 0.97	0.97
D. Special Systems	0.91	1.00
E. Sprinkler Systems	0.74 - 0.97	1.00
F.Water Curtains	0.97 - 0.98	1.00
G. Foam	0.92 - 0.97	1.00
H. Hand Extinguishers/Monitors	0.93 - 0.98	1.00
I. Cable Protection	0.94 - 0.98	1.00
Loss Control Credit Factor (C3)		0.95
Loss Control Credit Factor (C1 x C2 x C3)		**0.75**

Process Unit Risk Analysis

Area/Country: South West Netherlands	**Division:** -	**Location** Rotterdam Harbour, Maasvlakte	**Date** July 30, 2004
Site -	**Manufacturing Unit** Biomass to Syngas	**Process Unit** Sour water-gas shift (R203)	
Materials in Process Unit CO, CO2, H2, CH4, N2, Ar, H2O (g), NH3, HCN, H2S, HCl, COS, SO2,			
State of Operation Normal Operation	**Basic Materials for Material Factor** CO		

1. Fire & Explosion Index (F&EI)	46	[-]
2. Radius of Exposure	12	[m]
3. Area of Exposure	433	[m^2]
4. Value of Exposure	99.37	M€
5. Damage Factor	0.50	[-]
6. Base Maximum Probable Property Damage	49.69	M€
7. Loss Control Credit Factor	0.75	[-]
8. Actual Maximum Probable Property Damage	37.39	M€
9. Maximum Probable Days Outage	218	days
10. Business Interruption	11.22	M€

Fire & Explosion Index

Area/Country: South West Netherlands	**Division:** -	**Location** Rotterdam Harbour, Maasvlakte	**Date** July 30, 2004
Site -	**Manufacturing Unit** Biomass to Syngas	**Process Unit** Bulk desulphurizer (R204)	
Materials in Process Unit CO, CO2, H2, N2, Ar, H2O (g), O2 (g), NH3, H2S, HCl, SO2			
State of Operation Normal Operation	**Basic Materials for Material Factor** CO		

Material Factor		21
1. General Process Hazards	**Penalty Factor Range**	**Penalty Used**
Base Factor	1.00	
A. Exothermic Chemical Reactions	0.30 - 1.25	
B. Endothermic Processes	0.20 - 0.40	0.20
C. Material Handling and Transfer	0.25 - 1.05	0.50
D. Enclosed or Indoor Process Units	0.25 - 0.90	
E. Acces	0.20 - 0.35	0.20
F. Drainage and Spill Control	0.25 - 0.50	
General Process Hazards Factor (F1)		0.90
2. Special Process Hazards	**Penalty Factor Range**	**Penalty Used**
Base Factor	1.00	
A. Toxic Material(s)	0.20 - 0.80	0.80
B. Sub-Atmosferic Pressure (< 500 mm Hg)	0.50	
C. Operation In or Near Flammable Range		
1. Tank Farms Storage Flammable Liquids	0.50	
2. Process Upset or Purge Failure	0.30	
3. Always in Flammable Range	0.80	0.80
D. Dust Explosion	0.25 - 2.00	0.00
E. Pressure — Operating Pressure: 2.10E+03 kPa; Relief Setting: kPa		0.54
F. Low Temperature	0.20 - 0.30	
G. Quantity of Flammable Material: kg; Hc = 4.30E+03 BTU/lb		
1. Liquids or Gases in Process		
2. Liquids or Gases in Storage		
3. Combustible Solids in Storage, Dust in Process		
H. Corrosion and Erosion	0.10 - 0.75	
I. Leakage - Joints and Packing	0.10 - 1.50	
J. Use of Fired Equipment		
K. Hot Oil Heat Exchange System	0.15 - 1.15	
L. Rotating Equipment	0.50	
Special Process Hazards Factor (F2)		2.14
Process Units Hazards Factor (F1 x F2) = F3		1.92
Fire and Explosion Index (F3 x MF = F&EI)		**40**

Loss Control Credit Factors

Area/Country: South West Netherlands	**Division:** -	**Location** Rotterdam Harbour, Maasvlakte	**Date** July 30, 2004
Site -	**Manufacturing Unit** Biomass to Syngas	**Process Unit** Bulk desulphurizer (R204)	
Materials in Process Unit CO, CO_2, H_2, N_2, Ar, H_2O (g), O_2 (g), NH_3, H_2S, HCl, SO_2			
State of Operation Normal Operation Before HAZOP	**Basic Materials for Material Factor**		

1. Process Control Credit Factor (C1)	**Credit Factor Range**	**Credit Used**
A. Emergency Power	0.98	0.98
B. Cooling	0.97 - 0.99	1.00
C. Explosion Control	0.84 - 0.98	0.98
D. Emergency Shutdown	0.96 - 0.99	0.98
E. Computer Control	0.93 - 0.99	0.97
F. Inert Gas	0.94 - 0.96	1.00
G. Operating Instructions/Procedures	0.91 - 0.99	0.98
H. Reactive Chemical Review	0.91 - 0.98	0.98
I. Other Process Hazards Analysis	0.91 - 0.98	0.94
Loss Control Credit Factor (C1)		0.82

2. Material Isolation Credit Factor (C2)	**Credit Factor Range**	**Credit Used**
A. Remote Control Valves	0.96 - 0.98	0.98
B. Dump/Blowdown	0.96 - 0.98	0.98
C. Drainage	0.91 - 0.97	0.97
D. Interlock	0.98	1.00
Material Isolation Credit Factor (C2)		0.93

3. Fire Protection Credit Factor (C3)	**Credit Factor Range**	**Credit Used**
A. Leak Detection	0.94 - 0.98	0.98
B. Structural Steel	0.95 - 0.98	1.00
C. Fire Water Supply	0.94 - 0.97	0.97
D. Special Systems	0.91	1.00
E. Sprinkler Systems	0.74 - 0.97	1.00
F.Water Curtains	0.97 - 0.98	1.00
G. Foam	0.92 - 0.97	1.00
H. Hand Extinguishers/Monitors	0.93 - 0.98	1.00
I. Cable Protection	0.94 - 0.98	1.00
Loss Control Credit Factor (C3)		0.95
Loss Control Credit Factor (C1 x C2 x C3)		**0.73**

Process Unit Risk Analysis

Area/Country: South West Netherlands	**Division:** -	**Location** Rotterdam Harbour, Maasvlakte	**Date** July 30, 2004
Site -	**Manufacturing Unit** Biomass to Syngas	**Process Unit** Bulk desulphurizer (R204)	
Materials in Process Unit CO, CO_2, H_2, N_2, Ar, H_2O (g), O_2 (g), NH_3, H_2S, HCl, SO_2			
State of Operation Normal Operation	**Basic Materials for Material Factor** CO		

1. Fire & Explosion Index (F&EI)	40	[-]
2. Radius of Exposure	10	[m]
3. Area of Exposure	335	[m^2]
4. Value of Exposure	19.48	M€
5. Damage Factor	0.50	[-]
6. Base Maximum Probable Property Damage	9.74	M€
7. Loss Control Credit Factor	0.73	[-]
8. Actual Maximum Probable Property Damage	7.11	M€
9. Maximum Probable Days Outage	82	days
10. Business Interruption	4.19	M€

Fire & Explosion Index

Area/Country: South West Netherlands	**Division:** -	**Location** Rotterdam Harbour, Maasvlakte	**Date** July 30, 2004	
Site -	**Manufacturing Unit** Biomass to Syngas	**Process Unit** Zn/Ti sorbent regenerator (R205)		
Materials in Process Unit H2S, SO2, air				
State of Operation Normal Operation	**Basic Materials for Material Factor** Zn/Ti sorbents NR 2 NF 2			

Material Factor		24
1. General Process Hazards	**Penalty Factor Range**	**Penalty Used**
Base Factor	1.00	
A. Exothermic Chemical Reactions	0.30 - 1.25	0.75
B. Endothermic Processes	0.20 - 0.40	
C. Material Handling and Transfer	0.25 - 1.05	
D. Enclosed or Indoor Process Units	0.25 - 0.90	
E. Acces	0.20 - 0.35	0.20
F. Drainage and Spill Control	0.25 - 0.50	
General Process Hazards Factor (F1)		0.95
2. Special Process Hazards	**Penalty Factor Range**	**Penalty Used**
Base Factor	1.00	
A. Toxic Material(s)	0.20 - 0.80	0.80
B. Sub-Atmosferic Pressure (< 500 mm Hg)	0.50	0.50
C. Operation In or Near Flammable Range		
1. Tank Farms Storage Flammable Liquids	0.50	
2. Process Upset or Purge Failure	0.30	
3. Always in Flammable Range	0.80	0.80
D. Dust Explosion	0.25 - 2.00	2.00
E. Pressure — Operating Pressure: 2.10E+03 kPa; Relief Setting: kPa		0.54
F. Low Temperature	0.20 - 0.30	
G. Quantity of Flammable Material: kg; Hc = 6.50E+03 BTU/lb		
1. Liquids or Gases in Process		
2. Liquids or Gases in Storage		
3. Combustible Solids in Storage, Dust in Process		
H. Corrosion and Erosion	0.10 - 0.75	
I. Leakage - Joints and Packing	0.10 - 1.50	
J. Use of Fired Equipment		
K. Hot Oil Heat Exchange System	0.15 - 1.15	
L. Rotating Equipment	0.50	
Special Process Hazards Factor (F2)		4.64
Process Units Hazards Factor (F1 x F2) = F3		4.40
Fire and Explosion Index (F3 x MF = F&EI)		**106**

Loss Control Credit Factors

Area/Country: South West Netherlands	**Division:** -	**Location** Rotterdam Harbour, Maasvlakte	**Date** July 30, 2004
Site -	**Manufacturing Unit** Biomass to Syngas	**Process Unit** Zn/Ti sorbent regenerator (R205)	
Materials in Process Unit H2S, SO2, air			
State of Operation Normal Operation Before HAZOP	**Basic Materials for Material Factor**		

1. Process Control Credit Factor (C1)	Credit Factor Range	Credit Used
A. Emergency Power	0.98	0.98
B. Cooling	0.97 - 0.99	0.99
C. Explosion Control	0.84 - 0.98	0.98
D. Emergency Shutdown	0.96 - 0.99	0.98
E. Computer Control	0.93 - 0.99	0.97
F. Inert Gas	0.94 - 0.96	1.00
G. Operating Instructions/Procedures	0.91 - 0.99	0.98
H. Reactive Chemical Review	0.91 - 0.98	0.98
I. Other Process Hazards Analysis	0.91 - 0.98	0.94
Loss Control Credit Factor (C1)		0.82

2. Material Isolation Credit Factor (C2)	Credit Factor Range	Credit Used
A. Remote Control Valves	0.96 - 0.98	0.98
B. Dump/Blowdown	0.96 - 0.98	0.98
C. Drainage	0.91 - 0.97	0.97
D. Interlock	0.98	1.00
Material Isolation Credit Factor (C2)		0.93

3. Fire Protection Credit Factor (C3)	Credit Factor Range	Credit Used
A. Leak Detection	0.94 - 0.98	0.98
B. Structural Steel	0.95 - 0.98	1.00
C. Fire Water Supply	0.94 - 0.97	0.97
D. Special Systems	0.91	1.00
E. Sprinkler Systems	0.74 - 0.97	1.00
F.Water Curtains	0.97 - 0.98	1.00
G. Foam	0.92 - 0.97	1.00
H. Hand Extinguishers/Monitors	0.93 - 0.98	1.00
I. Cable Protection	0.94 - 0.98	1.00
Loss Control Credit Factor (C3)		0.95
Loss Control Credit Factor (C1 x C2 x C3)		**0.72**

Process Unit Risk Analysis

Area/Country: South West Netherlands	**Division:** -	**Location** Rotterdam Harbour, Maasvlakte	**Date** July 30, 2004
Site -	**Manufacturing Unit** Biomass to Syngas	**Process Unit** Zn/Ti sorbent regenerator (R205)	
Materials in Process Unit H2S, SO2, air			
State of Operation Normal Operation	**Basic Materials for Material Factor** Zn/Ti sorbents		

1. Fire & Explosion Index (F&EI)	106	[-]
2. Radius of Exposure	27	[m]
3. Area of Exposure	2300	[m^2]
4. Value of Exposure	8.98	M€
5. Damage Factor	0.67	[-]
6. Base Maximum Probable Property Damage	6.01	M€
7. Loss Control Credit Factor	0.72	[-]
8. Actual Maximum Probable Property Damage	4.35	M€
9. Maximum Probable Days Outage	61	days
10. Business Interruption	3.13	M€

Fire & Explosion Index

Area/Country: South West Netherlands	**Division:** -	**Location** Rotterdam Harbour, Maasvlakte	**Date** July 30, 2004
Site -	**Manufacturing Unit** Biomass to Syngas	**Process Unit** Ultra desulphurizer (R206)	

Materials in Process Unit
CO, CO2, H2, CH4, C2H6, N2, Ar, H2O (g), O2 (g), NH3, H2S, HCl, SO2

State of Operation Normal Operation	**Basic Materials for Material Factor** CO

Material Factor		21
1. General Process Hazards	**Penalty Factor Range**	**Penalty Used**
Base Factor	1.00	
A. Exothermic Chemical Reactions	0.30 - 1.25	
B. Endothermic Processes	0.20 - 0.40	0.20
C. Material Handling and Transfer	0.25 - 1.05	0.50
D. Enclosed or Indoor Process Units	0.25 - 0.90	
E. Acces	0.20 - 0.35	0.20
F. Drainage and Spill Control	0.25 - 0.50	
General Process Hazards Factor (F1)		0.90
2. Special Process Hazards	**Penalty Factor Range**	**Penalty Used**
Base Factor	1.00	
A. Toxic Material(s)	0.20 - 0.80	0.80
B. Sub-Atmosferic Pressure (< 500 mm Hg)	0.50	
C. Operation In or Near Flammable Range		
1. Tank Farms Storage Flammable Liquids	0.50	
2. Process Upset or Purge Failure	0.30	
3. Always in Flammable Range	0.80	0.80
D. Dust Explosion	0.25 - 2.00	
E. Pressure — Operating Pressure: 6.30E+02 kPa; Relief Setting: kPa		0.30
F. Low Temperature	0.20 - 0.30	
G. Quantity of Flammable Material: kg; Hc = 4.30E+03 BTU/lb		
1. Liquids or Gases in Process		
2. Liquids or Gases in Storage		
3. Combustible Solids in Storage, Dust in Process		
H. Corrosion and Erosion	0.10 - 0.75	
I. Leakage - Joints and Packing	0.10 - 1.50	
J. Use of Fired Equipment		
K. Hot Oil Heat Exchange System	0.15 - 1.15	
L. Rotating Equipment	0.50	
Special Process Hazards Factor (F2)		1.90
Process Units Hazards Factor (F1 x F2) = F3		1.71
Fire and Explosion Index (F3 x MF = F&EI)		**36**

Loss Control Credit Factors

Area/Country: South West Netherlands	**Division:** -	**Location** Rotterdam Harbour, Maasvlakte	**Date** July 30, 2004
Site -	**Manufacturing Unit** Biomass to Syngas	**Process Unit** Ultra desulphurizer (R206)	
Materials in Process Unit CO, CO2, H2, CH4, C2H6, N2, Ar, H2O (g), O2 (g), NH3, H2S, HCl, SO2			
State of Operation Normal Operation Before HAZOP	**Basic Materials for Material Factor**		

1. Process Control Credit Factor (C1)	**Credit Factor Range**	**Credit Used**
A. Emergency Power	0.98	0.98
B. Cooling	0.97 - 0.99	1.00
C. Explosion Control	0.84 - 0.98	0.98
D. Emergency Shutdown	0.96 - 0.99	0.98
E. Computer Control	0.93 - 0.99	0.97
F. Inert Gas	0.94 - 0.96	1.00
G. Operating Instructions/Procedures	0.91 - 0.99	0.98
H. Reactive Chemical Review	0.91 - 0.98	0.98
I. Other Process Hazards Analysis	0.91 - 0.98	0.94
Loss Control Credit Factor (C1)		0.82
2. Material Isolation Credit Factor (C2)	**Credit Factor Range**	**Credit Used**
A. Remote Control Valves	0.96 - 0.98	0.98
B. Dump/Blowdown	0.96 - 0.98	0.98
C. Drainage	0.91 - 0.97	0.97
D. Interlock	0.98	1.00
Material Isolation Credit Factor (C2)		0.93
3. Fire Protection Credit Factor (C3)	**Credit Factor Range**	**Credit Used**
A. Leak Detection	0.94 - 0.98	0.98
B. Structural Steel	0.95 - 0.98	1.00
C. Fire Water Supply	0.94 - 0.97	0.97
D. Special Systems	0.91	1.00
E. Sprinkler Systems	0.74 - 0.97	1.00
F.Water Curtains	0.97 - 0.98	1.00
G. Foam	0.92 - 0.97	1.00
H. Hand Extinguishers/Monitors	0.93 - 0.98	1.00
I. Cable Protection	0.94 - 0.98	1.00
Loss Control Credit Factor (C3)		0.95
Loss Control Credit Factor (C1 x C2 x C3)		**0.73**

Process Unit Risk Analysis

Area/Country: South West Netherlands	**Division:** -	**Location** Rotterdam Harbour, Maasvlakte	**Date** July 30, 2004
Site -	**Manufacturing Unit** Biomass to Syngas	**Process Unit** Ultra desulphurizer (R206)	
Materials in Process Unit CO, CO2, H2, CH4, C2H6, N2, Ar, H2O (g), O2 (g), NH3, H2S, HCl, SO2			
State of Operation Normal Operation	**Basic Materials for Material Factor** CO		

1. Fire & Explosion Index (F&EI)	36	[-]
2. Radius of Exposure	9	[m]
3. Area of Exposure	265	[m^2]
4. Value of Exposure	20.29	M€
5. Damage Factor	0.63	[-]
6. Base Maximum Probable Property Damage	12.78	M€
7. Loss Control Credit Factor	0.73	[-]
8. Actual Maximum Probable Property Damage	9.33	M€
9. Maximum Probable Days Outage	96	days
10. Business Interruption	4.93	M€

Fire & Explosion Index

Area/Country:	Division:	Location	Date
South West Netherlands	-	Rotterdam Harbour, Maasvlakte	July 30, 2004

Site	Manufacturing Unit	Process Unit
-	Biomass to Syngas	NH_3/HCl scrubber (C201)

Materials in Process Unit
CO, CO2, H2, N2, Ar, H2O (g), NH3, HCl, H2S

State of Operation	Basic Materials for Material Factor
Normal Operation	CO

Material Factor		21
1. General Process Hazards	**Penalty Factor Range**	**Penalty Used**
Base Factor	1.00	
A. Exothermic Chemical Reactions	0.30 - 1.25	0.30
B. Endothermic Processes	0.20 - 0.40	
C. Material Handling and Transfer	0.25 - 1.05	0.50
D. Enclosed or Indoor Process Units	0.25 - 0.90	
E. Acces	0.20 - 0.35	0.20
F. Drainage and Spill Control	0.25 - 0.50	
General Process Hazards Factor (F1)		1.00
2. Special Process Hazards	**Penalty Factor Range**	**Penalty Used**
Base Factor	1.00	
A. Toxic Material(s)	0.20 - 0.80	0.80
B. Sub-Atmosferic Pressure (< 500 mm Hg)	0.50	
C. Operation In or Near Flammable Range		
1. Tank Farms Storage Flammable Liquids	0.50	
2. Process Upset or Purge Failure	0.30	
3. Always in Flammable Range	0.80	0.80
D. Dust Explosion	0.25 - 2.00	
E. Pressure Operating Pressure: 6.30E+02 kPa Relief Setting: kPa		0.30
F. Low Temperature	0.20 - 0.30	
G. Quantity of Flammable Material: kg Hc = 4.30E+03 BTU/lb		
1. Liquids or Gases in Process		
2. Liquids or Gases in Storage		
3. Combustible Solids in Storage, Dust in Process		
H. Corrosion and Erosion	0.10 - 0.75	
I. Leakage - Joints and Packing	0.10 - 1.50	
J. Use of Fired Equipment		
K. Hot Oil Heat Exchange System	0.15 - 1.15	
L. Rotating Equipment	0.50	
Special Process Hazards Factor (F2)		1.90
Process Units Hazards Factor (F1 x F2) = F3		1.90
Fire and Explosion Index (F3 x MF = F&EI)		**40**

Loss Control Credit Factors

Area/Country:	Division:	Location	Date
South West Netherlands	-	Rotterdam Harbour, Maasvlakte	July 30, 2004
Site	**Manufacturing Unit**	**Process Unit**	
-	Biomass to Syngas	NH3/HCl scrubber (C201)	
Materials in Process Unit			
CO, CO2, H2, N2, Ar, H2O (g), NH3, HCl, H2S			
State of Operation	**Basic Materials for Material Factor**		
Normal Operation Before HAZOP			

1. Process Control Credit Factor (C1)	Credit Factor Range	Credit Used
A. Emergency Power	0.98	0.98
B. Cooling	0.97 - 0.99	1.00
C. Explosion Control	0.84 - 0.98	0.98
D. Emergency Shutdown	0.96 - 0.99	0.98
E. Computer Control	0.93 - 0.99	0.97
F. Inert Gas	0.94 - 0.96	1.00
G. Operating Instructions/Procedures	0.91 - 0.99	0.98
H. Reactive Chemical Review	0.91 - 0.98	0.98
I. Other Process Hazards Analysis	0.91 - 0.98	0.94
Loss Control Credit Factor (C1)		0.82
2. Material Isolation Credit Factor (C2)	**Credit Factor Range**	**Credit Used**
A. Remote Control Valves	0.96 - 0.98	0.98
B. Dump/Blowdown	0.96 - 0.98	1.00
C. Drainage	0.91 - 0.97	0.97
D. Interlock	0.98	1.00
Material Isolation Credit Factor (C2)		0.95
3. Fire Protection Credit Factor (C3)	**Credit Factor Range**	**Credit Used**
A. Leak Detection	0.94 - 0.98	0.98
B. Structural Steel	0.95 - 0.98	1.00
C. Fire Water Supply	0.94 - 0.97	0.97
D. Special Systems	0.91	1.00
E. Sprinkler Systems	0.74 - 0.97	1.00
F.Water Curtains	0.97 - 0.98	1.00
G. Foam	0.92 - 0.97	1.00
H. Hand Extinguishers/Monitors	0.93 - 0.98	1.00
I. Cable Protection	0.94 - 0.98	1.00
Loss Control Credit Factor (C3)		0.95
Loss Control Credit Factor (C1 x C2 x C3)		**0.74**

Process Unit Risk Analysis

Area/Country:	Division:	Location	Date
South West Netherlands	-	Rotterdam Harbour, Maasvlakte	July 30, 2004
Site	**Manufacturing Unit**	**Process Unit**	
-	Biomass to Syngas	NH3/HCl scrubber (C201)	
Materials in Process Unit			
CO, CO2, H2, N2, Ar, H2O (g), NH3, HCl, H2S			
State of Operation	**Basic Materials for Material Factor**		
Normal Operation	CO		

1. Fire & Explosion Index (F&EI)	40	[-]
2. Radius of Exposure	10	[m]
3. Area of Exposure	327	[m^2]
4. Value of Exposure	4.04	M€
5. Damage Factor	0.50	[-]
6. Base Maximum Probable Property Damage	2.02	M€
7. Loss Control Credit Factor	0.74	[-]
8. Actual Maximum Probable Property Damage	1.50	M€
9. Maximum Probable Days Outage	33	days
10. Business Interruption	1.67	M€

Fire & Explosion Index

Area/Country: South West Netherlands	**Division:** -	**Location** Rotterdam Harbour, Maasvlakte	**Date** July 30, 2004
Site -	**Manufacturing Unit** Biomass to Syngas	**Process Unit** Active coal filter bed (C202)	
Materials in Process Unit CO, CO2, H2, N2, Ar, H2O (g), HCl, H2S			
State of Operation Normal Operation	**Basic Materials for Material Factor** CO		

Material Factor		21
1. General Process Hazards	**Penalty Factor Range**	**Penalty Used**
Base Factor	1.00	
A. Exothermic Chemical Reactions	0.30 - 1.25	
B. Endothermic Processes	0.20 - 0.40	
C. Material Handling and Transfer	0.25 - 1.05	0.50
D. Enclosed or Indoor Process Units	0.25 - 0.90	
E. Acces	0.20 - 0.35	0.20
F. Drainage and Spill Control	0.25 - 0.50	
General Process Hazards Factor (F1)		0.70
2. Special Process Hazards	**Penalty Factor Range**	**Penalty Used**
Base Factor	1.00	
A. Toxic Material(s)	0.20 - 0.80	0.80
B. Sub-Atmosferic Pressure (< 500 mm Hg)	0.50	
C. Operation In or Near Flammable Range		
1. Tank Farms Storage Flammable Liquids	0.50	
2. Process Upset or Purge Failure	0.30	
3. Always in Flammable Range	0.80	0.80
D. Dust Explosion	0.25 - 2.00	
E. Pressure — Operating Pressure: 6.30E+02 kPa; Relief Setting: kPa		0.30
F. Low Temperature	0.20 - 0.30	
G. Quantity of Flammable Material: kg; Hc = 4.30E+03 BTU/lb		
1. Liquids or Gases in Process		0.00
2. Liquids or Gases in Storage		
3. Combustible Solids in Storage, Dust in Process		
H. Corrosion and Erosion	0.10 - 0.75	
I. Leakage - Joints and Packing	0.10 - 1.50	
J. Use of Fired Equipment		
K. Hot Oil Heat Exchange System	0.15 - 1.15	
L. Rotating Equipment	0.50	
Special Process Hazards Factor (F2)		1.90
Process Units Hazards Factor (F1 x F2) = F3		1.33
Fire and Explosion Index (F3 x MF = F&EI)		**28**

Loss Control Credit Factors

Area/Country: South West Netherlands	**Division:** -	**Location** Rotterdam Harbour, Maasvlakte	**Date** July 30, 2004
Site -	**Manufacturing Unit** Biomass to Syngas	**Process Unit** Active coal filter bed (C202)	
Materials in Process Unit CO, CO2, H2, N2, Ar, H2O (g), HCl, H2S			
State of Operation Normal Operation Before HAZOP	**Basic Materials for Material Factor**		

1. Process Control Credit Factor (C1)	**Credit Factor Range**	**Credit Used**
A. Emergency Power	0.98	0.98
B. Cooling	0.97 - 0.99	1.00
C. Explosion Control	0.84 - 0.98	0.98
D. Emergency Shutdown	0.96 - 0.99	0.98
E. Computer Control	0.93 - 0.99	0.97
F. Inert Gas	0.94 - 0.96	1.00
G. Operating Instructions/Procedures	0.91 - 0.99	0.98
H. Reactive Chemical Review	0.91 - 0.98	0.98
I. Other Process Hazards Analysis	0.91 - 0.98	0.94
Loss Control Credit Factor (C1)		0.82
2. Material Isolation Credit Factor (C2)	**Credit Factor Range**	**Credit Used**
A. Remote Control Valves	0.96 - 0.98	0.98
B. Dump/Blowdown	0.96 - 0.98	0.98
C. Drainage	0.91 - 0.97	1.00
D. Interlock	0.98	1.00
Material Isolation Credit Factor (C2)		0.96
3. Fire Protection Credit Factor (C3)	**Credit Factor Range**	**Credit Used**
A. Leak Detection	0.94 - 0.98	0.98
B. Structural Steel	0.95 - 0.98	1.00
C. Fire Water Supply	0.94 - 0.97	0.97
D. Special Systems	0.91	1.00
E. Sprinkler Systems	0.74 - 0.97	1.00
F.Water Curtains	0.97 - 0.98	1.00
G. Foam	0.92 - 0.97	1.00
H. Hand Extinguishers/Monitors	0.93 - 0.98	1.00
I. Cable Protection	0.94 - 0.98	1.00
Loss Control Credit Factor (C3)		0.95
Loss Control Credit Factor (C1 x C2 x C3)		**0.75**

Process Unit Risk Analysis

Area/Country: South West Netherlands	**Division:** -	**Location** Rotterdam Harbour, Maasvlakte	**Date** July 30, 2004
Site -	**Manufacturing Unit** Biomass to Syngas	**Process Unit** Active coal filter bed (C202)	
Materials in Process Unit CO, CO2, H2, N2, Ar, H2O (g), HCl, H2S			
State of Operation Normal Operation	**Basic Materials for Material Factor** CO		

1. Fire & Explosion Index (F&EI)	28	[-]
2. Radius of Exposure	7	[m]
3. Area of Exposure	160	[m^2]
4. Value of Exposure	1.89	M€
5. Damage Factor	0.45	[-]
6. Base Maximum Probable Property Damage	0.85	M€
7. Loss Control Credit Factor	0.75	[-]
8. Actual Maximum Probable Property Damage	0.64	M€
9. Maximum Probable Days Outage	20	days
10. Business Interruption	1.01	M€

Fire & Explosion Index

Area/Country:	**Division:**	**Location**	**Date**
South West Netherlands	-	Rotterdam Harbour, Maasvlakte	July 30, 2004

Site	**Manufacturing Unit**	**Process Unit**
-	Biomass to Syngas	CO_2-selective membrane (S202)

Materials in Process Unit
CO, CO2, H2, N2, Ar, H2O (g)

State of Operation	**Basic Materials for Material Factor**
Normal Operation	CO

	Penalty Factor Range	Penalty Used
Material Factor		21
1. General Process Hazards	**Penalty Factor Range**	**Penalty Used**
Base Factor	1.00	
A. Exothermic Chemical Reactions	0.30 - 1.25	
B. Endothermic Processes	0.20 - 0.40	
C. Material Handling and Transfer	0.25 - 1.05	0.50
D. Enclosed or Indoor Process Units	0.25 - 0.90	
E. Acces	0.20 - 0.35	0.20
F. Drainage and Spill Control	0.25 - 0.50	
General Process Hazards Factor (F1)		0.70
2. Special Process Hazards	**Penalty Factor Range**	**Penalty Used**
Base Factor	1.00	
A. Toxic Material(s)	0.20 - 0.80	0.80
B. Sub-Atmosferic Pressure (< 500 mm Hg)	0.50	
C. Operation In or Near Flammable Range		
1. Tank Farms Storage Flammable Liquids	0.50	
2. Process Upset or Purge Failure	0.30	
3. Always in Flammable Range	0.80	0.80
D. Dust Explosion	0.25 - 2.00	
E. Pressure — Operating Pressure: 6.30E+02 kPa; Relief Setting: kPa		0.30
F. Low Temperature	0.20 - 0.30	
G. Quantity of Flammable Material: kg; Hc = 4.30E+03 BTU/lb		
1. Liquids or Gases in Process		
2. Liquids or Gases in Storage		
3. Combustible Solids in Storage, Dust in Process		
H. Corrosion and Erosion	0.10 - 0.75	
I. Leakage - Joints and Packing	0.10 - 1.50	
J. Use of Fired Equipment		
K. Hot Oil Heat Exchange System	0.15 - 1.15	
L. Rotating Equipment	0.50	
Special Process Hazards Factor (F2)		1.90
Process Units Hazards Factor (F1 x F2) = F3		1.33
Fire and Explosion Index (F3 x MF = F&EI)		**28**

Loss Control Credit Factors

Area/Country: South West Netherlands	**Division:** -	**Location** Rotterdam Harbour, Maasvlakte	**Date** July 30, 2004
Site -	**Manufacturing Unit** Biomass to Syngas	**Process Unit** CO2-selective membrane (S202)	
Materials in Process Unit CO, CO2, H2, N2, Ar, H2O (g)			
State of Operation Normal Operation Before HAZOP	**Basic Materials for Material Factor**		

1. Process Control Credit Factor (C1)	**Credit Factor Range**	**Credit Used**
A. Emergency Power	0.98	0.98
B. Cooling	0.97 - 0.99	1.00
C. Explosion Control	0.84 - 0.98	0.98
D. Emergency Shutdown	0.96 - 0.99	0.98
E. Computer Control	0.93 - 0.99	0.97
F. Inert Gas	0.94 - 0.96	1.00
G. Operating Instructions/Procedures	0.91 - 0.99	0.98
H. Reactive Chemical Review	0.91 - 0.98	0.98
I. Other Process Hazards Analysis	0.91 - 0.98	0.94
Loss Control Credit Factor (C1)		0.82

2. Material Isolation Credit Factor (C2)	**Credit Factor Range**	**Credit Used**
A. Remote Control Valves	0.96 - 0.98	0.98
B. Dump/Blowdown	0.96 - 0.98	1.00
C. Drainage	0.91 - 0.97	1.00
D. Interlock	0.98	1.00
Material Isolation Credit Factor (C2)		0.98

3. Fire Protection Credit Factor (C3)	**Credit Factor Range**	**Credit Used**
A. Leak Detection	0.94 - 0.98	0.98
B. Structural Steel	0.95 - 0.98	1.00
C. Fire Water Supply	0.94 - 0.97	0.97
D. Special Systems	0.91	1.00
E. Sprinkler Systems	0.74 - 0.97	1.00
F.Water Curtains	0.97 - 0.98	1.00
G. Foam	0.92 - 0.97	1.00
H. Hand Extinguishers/Monitors	0.93 - 0.98	1.00
I. Cable Protection	0.94 - 0.98	1.00
Loss Control Credit Factor (C3)		0.95
Loss Control Credit Factor (C1 x C2 x C3)		**0.77**

Process Unit Risk Analysis

Area/Country: South West Netherlands	**Division:** -	**Location** Rotterdam Harbour, Maasvlakte	**Date** July 30, 2004
Site -	**Manufacturing Unit** Biomass to Syngas	**Process Unit** CO2-selective membrane (S202)	
Materials in Process Unit CO, CO2, H2, N2, Ar, H2O (g)			
State of Operation Normal Operation	**Basic Materials for Material Factor** CO		

1. Fire & Explosion Index (F&EI)	28	[-]
2. Radius of Exposure	7	[m]
3. Area of Exposure	160	[m^2]
4. Value of Exposure	127.65	M€
5. Damage Factor	0.45	[-]
6. Base Maximum Probable Property Damage	57.44	M€
7. Loss Control Credit Factor	0.77	[-]
8. Actual Maximum Probable Property Damage	44.10	M€
9. Maximum Probable Days Outage	241	days
10. Business Interruption	12.37	M€

Fire & Explosion Index

Area/Country: South West Netherlands	**Division:** -	**Location** Rotterdam Harbour, Maasvlakte	**Date** July 30, 2004
Site -	**Manufacturing Unit** Biomass to Syngas	**Process Unit** Syngas cooler column + turbine	

Materials in Process Unit
CO, CO2, H2, CH4, N2, Ar, H2O (g), O2 (g), NH3, HCN, H2S, HCl, COS, SO2
Tars (BTX), Char, Ash

State of Operation Normal Operation	**Basic Materials for Material Factor** CO

Material Factor		21
1. General Process Hazards	**Penalty Factor Range**	**Penalty Used**
Base Factor	1.00	
A. Exothermic Chemical Reactions	0.30 - 1.25	
B. Endothermic Processes	0.20 - 0.40	
C. Material Handling and Transfer	0.25 - 1.05	0.50
D. Enclosed or Indoor Process Units	0.25 - 0.90	
E. Acces	0.20 - 0.35	0.20
F. Drainage and Spill Control	0.25 - 0.50	
General Process Hazards Factor (F1)		0.70
2. Special Process Hazards	**Penalty Factor Range**	**Penalty Used**
Base Factor	1.00	
A. Toxic Material(s)	0.20 - 0.80	0.80
B. Sub-Atmosferic Pressure (< 500 mm Hg)	0.50	
C. Operation In or Near Flammable Range		
1. Tank Farms Storage Flammable Liquids	0.50	
2. Process Upset or Purge Failure	0.30	
3. Always in Flammable Range	0.80	0.80
D. Dust Explosion	0.25 - 2.00	
E. Pressure — Operating Pressure: 6.30E+02 kPa; Relief Setting: kPa		0.30
F. Low Temperature	0.20 - 0.30	
G. Quantity of Flammable Material: 594 kg; Hc = 4.30E+03 BTU/lb		
1. Liquids or Gases in Process		0.00
2. Liquids or Gases in Storage		
3. Combustible Solids in Storage, Dust in Process		
H. Corrosion and Erosion	0.10 - 0.75	
I. Leakage - Joints and Packing	0.10 - 1.50	
J. Use of Fired Equipment		
K. Hot Oil Heat Exchange System	0.15 - 1.15	
L. Rotating Equipment	0.50	
Special Process Hazards Factor (F2)		1.90
Process Units Hazards Factor (F1 x F2) = F3		1.33
Fire and Explosion Index (F3 x MF = F&EI)		**28**

Loss Control Credit Factors

Area/Country: South West Netherlands	**Division:** -	**Location** Rotterdam Harbour, Maasvlakte	**Date** July 30, 2004
Site -	**Manufacturing Unit** Biomass to Syngas	**Process Unit** Syngas cooler column + turbine	
Materials in Process Unit CO, CO_2, H_2, CH_4, N_2, Ar, H_2O (g), O_2 (g), NH_3, HCN, H_2S, HCl, COS, SO_2 Tars (BTX), Char, Ash			
State of Operation Normal Operation Before HAZOP	**Basic Materials for Material Factor**		

1. Process Control Credit Factor (C1)	**Credit Factor Range**	**Credit Used**
A. Emergency Power	0.98	0.98
B. Cooling	0.97 - 0.99	0.90
C. Explosion Control	0.84 - 0.98	0.98
D. Emergency Shutdown	0.96 - 0.99	0.98
E. Computer Control	0.93 - 0.99	0.97
F. Inert Gas	0.94 - 0.96	1.00
G. Operating Instructions/Procedures	0.91 - 0.99	0.98
H. Reactive Chemical Review	0.91 - 0.98	0.98
I. Other Process Hazards Analysis	0.91 - 0.98	0.94
Loss Control Credit Factor (C1)		0.74
2. Material Isolation Credit Factor (C2)	**Credit Factor Range**	**Credit Used**
A. Remote Control Valves	0.96 - 0.98	0.98
B. Dump/Blowdown	0.96 - 0.98	1.00
C. Drainage	0.91 - 0.97	1.00
D. Interlock	0.98	1.00
Material Isolation Credit Factor (C2)		0.98
3. Fire Protection Credit Factor (C3)	**Credit Factor Range**	**Credit Used**
A. Leak Detection	0.94 - 0.98	0.98
B. Structural Steel	0.95 - 0.98	1.00
C. Fire Water Supply	0.94 - 0.97	0.97
D. Special Systems	0.91	1.00
E. Sprinkler Systems	0.74 - 0.97	1.00
F.Water Curtains	0.97 - 0.98	1.00
G. Foam	0.92 - 0.97	1.00
H. Hand Extinguishers/Monitors	0.93 - 0.98	1.00
I. Cable Protection	0.94 - 0.98	1.00
Loss Control Credit Factor (C3)		0.95
Loss Control Credit Factor (C1 x C2 x C3)		**0.69**

Process Unit Risk Analysis

Area/Country: South West Netherlands	**Division:** -	**Location** Rotterdam Harbour, Maasvlakte	**Date** July 30, 2004
Site -	**Manufacturing Unit** Biomass to Syngas	**Process Unit** Syngas cooler column + turbine	
Materials in Process Unit CO, CO_2, H_2, CH_4, N_2, Ar, H_2O (g), O_2 (g), NH_3, HCN, H_2S, HCl, COS, SO_2 Tars (BTX), Char, Ash			
State of Operation Normal Operation	**Basic Materials for Material Factor** CO		

1. Fire & Explosion Index (F&EI)	28	[-]
2. Radius of Exposure	7	[m]
3. Area of Exposure	160	[m^2]
4. Value of Exposure	32.85	M€
5. Damage Factor	0.45	[-]
6. Base Maximum Probable Property Damage	14.78	M€
7. Loss Control Credit Factor	0.69	[-]
8. Actual Maximum Probable Property Damage	10.22	M€
9. Maximum Probable Days Outage	101	days
10. Business Interruption	5.20	M€

Fire & Explosion Index

Area/Country: South West Netherlands	**Division:** -	**Location** Rotterdam Harbour, Maasvlakte	**Date** July 30, 2004
Site -	**Manufacturing Unit** Biomass to Syngas	**Process Unit** Compressor, 6.3 bar to 40 bar	
Materials in Process Unit CO, CO2, H2, N2, Ar, H2O (g)			
State of Operation Normal Operation	**Basic Materials for Material Factor** CO		

Material Factor		21
1. General Process Hazards	**Penalty Factor Range**	**Penalty Used**
Base Factor	1.00	
A. Exothermic Chemical Reactions	0.30 - 1.25	
B. Endothermic Processes	0.20 - 0.40	
C. Material Handling and Transfer	0.25 - 1.05	0.50
D. Enclosed or Indoor Process Units	0.25 - 0.90	
E. Acces	0.20 - 0.35	0.20
F. Drainage and Spill Control	0.25 - 0.50	
General Process Hazards Factor (F1)		0.70
2. Special Process Hazards	**Penalty Factor Range**	**Penalty Used**
Base Factor	1.00	
A. Toxic Material(s)	0.20 - 0.80	0.80
B. Sub-Atmosferic Pressure (< 500 mm Hg)	0.50	
C. Operation In or Near Flammable Range		
1. Tank Farms Storage Flammable Liquids	0.50	
2. Process Upset or Purge Failure	0.30	
3. Always in Flammable Range	0.80	0.80
D. Dust Explosion	0.25 - 2.00	
E. Pressure — Operating Pressure: 4.00E+03 kPa; Relief Setting: kPa		0.72
F. Low Temperature	0.20 - 0.30	
G. Quantity of Flammable Material: kg; Hc = 4.30E+03 BTU/lb		
1. Liquids or Gases in Process		0.00
2. Liquids or Gases in Storage		
3. Combustible Solids in Storage, Dust in Process		
H. Corrosion and Erosion	0.10 - 0.75	
I. Leakage - Joints and Packing	0.10 - 1.50	
J. Use of Fired Equipment		
K. Hot Oil Heat Exchange System	0.15 - 1.15	
L. Rotating Equipment	0.50	0.50
Special Process Hazards Factor (F2)		2.82
Process Units Hazards Factor (F1 x F2) = F3		1.97
Fire and Explosion Index (F3 x MF = F&EI)		**41**

Loss Control Credit Factors

Area/Country: South West Netherlands	**Division:** -	**Location** Rotterdam Harbour, Maasvlakte	**Date** July 30, 2004
Site -	**Manufacturing Unit** Biomass to Syngas	**Process Unit** Compressor, 6.3 bar to 40 bar	
Materials in Process Unit CO, CO2, H2, N2, Ar, H2O (g)			
State of Operation Normal Operation Before HAZOP	**Basic Materials for Material Factor**		

1. Process Control Credit Factor (C1)	**Credit Factor Range**	**Credit Used**
A. Emergency Power	0.98	0.98
B. Cooling	0.97 - 0.99	1.00
C. Explosion Control	0.84 - 0.98	0.98
D. Emergency Shutdown	0.96 - 0.99	0.98
E. Computer Control	0.93 - 0.99	0.97
F. Inert Gas	0.94 - 0.96	1.00
G. Operating Instructions/Procedures	0.91 - 0.99	0.98
H. Reactive Chemical Review	0.91 - 0.98	1.00
I. Other Process Hazards Analysis	0.91 - 0.98	0.94
Loss Control Credit Factor (C1)		0.84
2. Material Isolation Credit Factor (C2)	**Credit Factor Range**	**Credit Used**
A. Remote Control Valves	0.96 - 0.98	0.98
B. Dump/Blowdown	0.96 - 0.98	1.00
C. Drainage	0.91 - 0.97	1.00
D. Interlock	0.98	1.00
Material Isolation Credit Factor (C2)		0.98
3. Fire Protection Credit Factor (C3)	**Credit Factor Range**	**Credit Used**
A. Leak Detection	0.94 - 0.98	0.98
B. Structural Steel	0.95 - 0.98	1.00
C. Fire Water Supply	0.94 - 0.97	0.97
D. Special Systems	0.91	1.00
E. Sprinkler Systems	0.74 - 0.97	1.00
F.Water Curtains	0.97 - 0.98	1.00
G. Foam	0.92 - 0.97	1.00
H. Hand Extinguishers/Monitors	0.93 - 0.98	1.00
I. Cable Protection	0.94 - 0.98	1.00
Loss Control Credit Factor (C3)		0.95
Loss Control Credit Factor (C1 x C2 x C3)		**0.78**

Process Unit Risk Analysis

Area/Country: South West Netherlands	**Division:** -	**Location** Rotterdam Harbour, Maasvlakte	**Date** July 30, 2004
Site -	**Manufacturing Unit** Biomass to Syngas	**Process Unit** Compressor, 6.3 bar to 40 bar	
Materials in Process Unit CO, CO2, H2, N2, Ar, H2O (g)			
State of Operation Normal Operation	**Basic Materials for Material Factor** CO		

1. Fire & Explosion Index (F&EI)	41	[-]
2. Radius of Exposure	11	[m]
3. Area of Exposure	353	[m^2]
4. Value of Exposure	1.08	M€
5. Damage Factor	0.50	[-]
6. Base Maximum Probable Property Damage	0.54	M€
7. Loss Control Credit Factor	0.78	[-]
8. Actual Maximum Probable Property Damage	0.42	M€
9. Maximum Probable Days Outage	15	days
10. Business Interruption	0.79	M€

Appendix 10.2 HAZOP analysis of all major equipments

Baltic States

Equipment type:	**Mill/grinder**		**Equipment name:**	Chipper (A101)
Intention:	Reducing wood size			
Guide word	Deviation	Cause	Consequences	Action
Stream no. Intention:	<101>			
Only wood is the input	OTHER THAN	Metals and hand	Operators mistakes	Screening feedstock
			Impurities in the feedstock	Safety instruction
Stream no. Intention:	<102>			
Wood distribution size	NOT	Mechanical problems	Large size wood size	Recycle to chipper
				Maintenance
Keeping the chipper temperature at acceptable level	MORE	Friction	Fire	Maintenance and temperature controller
				Fire extinguisher

Equipment type:			**Equipment name:**	Pelletiser (X101)
Intention:	Reducing volume			
Guide word	Deviation	Cause	Consequences	Action
Stream no. Intention:	<102>			
Only wood is the input	OTHER THAN	Metals and hand	Operators mistakes	Screening feedstock
			Impurities in the feedstock	Safety instruction
Stream no. Intention:	<103>			
Pellets distribution size	NOT	Mechanical problems	Large size wood size	Maintenance
Keeping the pelletiser temperature at acceptable level	MORE	Friction	Fire	Maintenance/temperature control

Equipment type:	Transportation		**Equipment name:**	Truck, ship and load/unload
Intention:	Safe and efficient transportation			
Guide word	Deviation	Cause	Consequences	Action
Dry transport for pellets	LESS	Rain	Moisture content of pellets increases	Closed container
		Humidity		Closed cargo

Rotterdam

Equipment type:	Hopper		**Equipment name:**	Lock hopper (V201)
Intention:	Pressurized the feedstock with syngas			
Guide word	Deviation	Cause	Consequences	Action
Stream no.	<201>			
Intention:				
Avoid explosion, reaction and fire	MORE	Pressure	Explosion risk	Pressure controller
		Temperature	Explosion risk	Temperature controller
			Reaction	Temperature controller
	REVERSE	Flow	Lower pressure than CFB	Pressure controller

Equipment type:	Fluidized bed reactor		**Equipment name:**	Circulating fluidized bed reactor (R201)
Intention:	Gasification with highest yields as possible			
Guide word	Deviation	Cause	Consequences	Action
Stream no.	<201>			
Intention:				
Constant flow and conditions	LESS	Blockage in extruder	No constant syngas production	Maintenance
	MORE/LESS	Failure in lock hopper	Temperature increases/decreases	Maintenance
Constant flow of O_2 and steam	LESS	Failure in piping	Temperature decreases	Flow controller
				Of wood stream
		Failure in air separation plant	Choking in the reactor	Buffer tank for O_2
Stream no.	<206>			
Intention:				
Constant condition	MORE/LESS	O_2	More/less combustion	Steam adjustment in tar cracker
		Wood	More/less combustion	Adjust the ratio O_2/wood
		Steam	More/less combustion	Adjust the ratio H_2O/wood
Constant composition	PART OF	Other wood composition	Other syngas composition	Oversize design
Stream no.	<205>			
Intention:				
Constant removal	No	Ash screw failure	Accumulation of ash	Maintenance
			Choking in the reactor	

Equipment type:	Filter		**Equipment name:**	Candle filter
Intention:	Remove dust, ash and particulates above 1 micron			(S201)
Guide word	Deviation	Cause	Consequences	Action
Stream no.	<208>			
Intention:				
Clean product gas from solids	MORE	Large particulates, dust or ash	Blockage in the filter	Knocking on the filter
No reverse flow	REVERSE	Pressure fluctuation	Back flow to candle filter	Reverse flow valve

Equipment type:	Monolith reactor		**Equipment name:**	Monolith tar cracker
Intention:	Crack all tars and large part of light alkane			(R202)
Guide word	Deviation	Cause	Consequences	Action
Stream no.	<208>			
Intention:				
Dust free	NOT	Failure of the candle filter	Blockage in monolith	Pressure sensor
				Candle filter maintenance
Stream no.	<212>			
Intention:				
No tars and small amount of light alkenes	MORE	Deactivation of catalyst due to fouling etc	Tars deposition in and after syngas cooler	Changing monolith catalyst
				More steam or O_2 (thermal cracking)

Equipment type:	Packed bed reactor		**Equipment name:**	Sour water-gas shift
Intention:	Adjust H_2/CO ratio and hydrolysis COS+HCN			reactor (R203)
Guide word	Deviation	Cause	Consequences	Action
Stream no.	<214>			
Intention:				
No tars	MORE	Deactivation in tar cracker	Deactivation of Sour WGS catalyst	Replace and regenerate the deactivated catalyst
Stream no.	<217>			
Intention:				
H_2/CO=1.9-2.2	MORE/LESS	Temperature fluctuation	Off spec ratio	Temperature controller
		Composition fluctuation	Off spec ratio	H_2 low-more, H_2 high-Temperature higher
		Catalyst deactivation	Off spec ratio	Replace and regenerate the deactivated catalyst More steam

Equipment type:	Fluidized bed sorbent		**Equipment name:**	Bulk Desulphurizer (R204)
Intention:	Remove large part of H2S and COS			
Guide word	Deviation	Cause	Consequences	Action
Stream no. Intention:	<218>			
H2S and COS to 20-50ppm	MORE	Inactive sorbent	Removal duty at Ultra De-S	Regeneration sorbent in the bulk
		Less sorbent	Becomes higher	Ultra De-S and ACF as back up
			Off spec	

Equipment type:	Fluidized bed sorbent		**Equipment name:**	Ultra Desulphurizer (R206)
Intention:	Remove S-compound to about 1 ppm			
Guide word	Deviation	Cause	Consequences	Action
Stream no. Intention:	<221>			
H2S and COS to 1 ppm	MORE	Inactive	Off spec	ACF as back-up
		Less sorbent	ACF saturated faster	New active coal
Prevent dust explosion	NOT	Dispersed solid forming a flammable cloud	Dust explosion, shutdown	Pressure controller
		Solid specific surface area increases to a level where a flame can propagate		Temperature controller / cooling possibility

Equipment type:	Entrained flow		**Equipment name:**	Zn/Ti sorbent regenerator (R205)
Intention:	Sorbent regeneration continuously			
Guide word	Deviation	Cause	Consequences	Action
Stream no. Intention:	<224>			
Active sorbent	LESS	Insufficient regeneration	Inactive sorbent	More air
Safe operation	NOT	Temperature increases	Explosion	Temperature controller
Prevent dust explosion	NOT	Dispersed solid forming a flammable cloud	Dust explosion, shutdown	Bursting disk
		Solid specific surface area increases to a level where a flame can propagate		Temperature controller by adjusting the air stream

Equipment type:	Scrubber		**Equipment name:**	NH_3/HCl scrubber (C201)
Intention:	Remove NH_3 and HCl			
Guide word	Deviation	Cause	Consequences	Action
Stream no. Intention:	<226>			
Low temperature of raw syngas	MORE	Less heat removal By heat exchanger	Evaporation water in the scrubber	Temperature controller
Stream no. Intention:	<229>			
NH_3 to 1 ppm + HCl to 10 ppbv	MORE	Temperature fluctuation Less water input	Off spec ACF saturated faster by HCl	Temperature controller Flow controller

Equipment type:	Filter bed		**Equipment name:**	Active coal filter bed (ACF) (C202)
Intention:	Back up removal for all impurities			
Guide word	Deviation	Cause	Consequences	Action
Stream no. Intention:	<229A>			
Less impurities input	MORE	Failure of other gas cleaning Equipments	ACF saturated faster	Replacement with new filter
Stream no. Intention:	<229B>			
On spec syngas	NOT	Saturated ACF	Off spec	Replacement with new filter

Equipment type:	Membrane		**Equipment name:**	CO_2-selective membrane (S202)
Intention:	Remove CO_2 to 5 %v/v inert			
Guide word	Deviation	Cause	Consequences	Action
Stream no. Intention:	<232>			
Very small amount of impurities	MORE	Failure of other gas cleaning	Membrane fouling	Maintenance with reverse flow
Stream no. Intention:	<234>			
Less 5 % inert incl. CO_2	MORE	Membrane fouling	Off spec	Maintenance with reverse flow

Equipment type:	Heat exchanger		**Equipment name:**	Syngas cooler (E201)
Intention:	Cooling down syngas			
Guide word	Deviation	Cause	Consequences	Action
Stream no.	<212>			
Intention:				
No tars and no solids	MORE	Failure of candle filter Failure of tar cracker	Sticky wall Bad heat transfer	Knocking on the tubes
Stream no.	<213>			
Intention:				
Constant outlet gas temperature	MORE	Less heat removal	extra cooling needed	More steam input

Equipment type:	Compressor		**Equipment name:**	Syngas compressor (K204)
Intention:	Pressurized gas stream			
Guide word	Deviation	Cause	Consequences	Action
Stream no.	<229>			
Intention:				
No solids and liquid, T above dew point of the gas	MORE	Low temperature	Compressor failure	repair the compressor
		Low temperature	Compressor failure	Pressure and temperature controller
		Failure of candle filter	Compressor failure	Rapping
Stream no.	<231>			
Intention:				
Desired P	NO	Compressor failure	Lower performance of other equipment	Pressure controller Repair the compressor
Equipment No leakage	NOT	Leakage on compressor	Syngas leakage, less production Unsafe for the worker	Valve

Appendix 11.1 Major equipment cost calculation

Table A 11.1.1 Major equipment cost calculation

Major Equipment	Price	Unit	Year	Capacity	Unit	Source	Capacity needed	Unit	Scale factor	costs @ 2004	unit
Chipper	0.529	M€/chipper	2003	0.64	Mton/a	[1]	19.9	Mton/a	1	0.5	M€/unit
Pelletiser	0.83	M€/pelletiser	2003	0.04	Mton/a	[2]	19.9	Mton/a	1	0.9	M€/unit
Circulating Fluidised Bed	0.08	M€/MWth,dry,in	2004	800	MW syngas	[3], [8]	959	MWth,dry,in		76.7	M€/unit
Candle filter	2.6	M$/cyclone	2001	34.2	m3 gas/s	[4], [9]	52	m3/s	0.7	3.4	M€/unit
Monolith Tar Cracker	9.4	M$/reformer	2001	1390	kmol/hr	[4], [11]	13320	kmol/hr	0.6	35.7	M€/unit
Sour Water-Gas Shift Reactor	0.009	M€/MWth syngas	2001			[3]	4000	MW syngas		110.7	M€/unit
Bulk desulphurizer + regenerator	3675	k$/unit	2001	80	ton syngas/hr	[6]	1794	ton/hr	0.7	31.7	M€/unit
Ultra desulphurizer	4256	k$/unit	2001	80	ton syngas/hr	[6]	897	ton/hr	0.7	22.6	M€/unit
Ammonia/HCl Scrubber	2.6	M$/scrubber	2001	12.1	m3 gas/s	[4]	27	m3/s	0.7	4.5	M€/unit
CO2-selective Membrane	50	€/m2	2004			[13]				71.1	M€/unit
Compressor	850	€/kW	2001			[4], [12]	29771	kW	0.7	1.2	M€/unit
Air separation plant	2.944	M€/(kg O2/s)	2001			[4], [12]	222	kg O2/s	0.7	139.2	M€
Claus plant	14.2	M$/Claus	2000	85	ton S/day	[5]	45.7	ton S/day	0.7	9.2	M€
Waste water treatment	300000	$/waste treatment	1987			[7]	73000	gallon/min.		0.4	M€
Steam turbine	5.1	M$/unit	2001	10.3	MWe	[4]	135.05	MWe	0.7	30.2	M€/unit
Storage tank	0.108	M€/unit	2003	3000	m3	[1]	7800000	m3	0.9	6.2	M€
Syngas cooler	6.99	M$/unit	2001	39.2	kg steam/s	[4]	35	kg water/s	0.6	6.4	M€/unit
Active coal filter bed	1.6	M$/unit	2001	12.1	m3/s	[4], [10]	18.9	m3/s	0.65	2.1	M€/unit
Pump	The design contains 5 heat exchangers and 2 pumps.										
Heat exchanger	These units are assumed as minor equipment and thus ignored in this major equipment list.										

Assumptions

[1] Inflation = 2.5%, http://inflationdata.com, read: July 23rd 2004
[2] €/$ = 1.1
[3] Supply window of forest residues is 9 months/a, supply windows of sawdust is 12 months/a
[4] Storage required in Baltic States is 2 weeks for sawdust/pellets, 3 months for forest residues/pellets
[5] Storage required in Rotterdam is 1 week
[6] 1/3 of all wood is sawdust
[7] Average truck distance is50 km

Sources

[1] http://www.chem.uu.nl/nws/www/publica/Carlo%20e2003-26.pdf, C. N. Hamelinck, *International bioenergy transport costs and energy balance*, Universiteit Utrecht, Copernicus Institute, August 2003
[2] http://www.eubia.org/pdf/Lamnet_Pellets.pdf, LAMNET (Latin America Thematic Network on Bioenergy), *Refined Bio-fuels Pellets and Briquettes*, read: 20 May 2004
[3] http://www.ecn.nl/docs/library/report/2004/c04001.pdf, H. Boerrigter et al., *High efficiency co-production of Fischer-Tropsch (FT) transportation fuels and Substitute Natural Gas (SNG) from biomass,* ECN-C--04-001, February 2004
[4] http://www.chem.uu.nl/nws/www/publica/e2001-49.pdf, C.N. Hamelinck, A.P.C. Faaij, *Future prospects for production of methanol and hydrogen from biomass*, Universiteit Utrecht, Copernicus Institute, September 2001
[5] http://www.netl.doe.gov/coalpower/gasification/system/shell3x_.pdf, *Shell Gasifier IGCC Base Cases*, PED-IGCC-98-002, June 2000, read: 10 June 2004
[6] http://www.netl.doe.gov/coalpower/gasification/projects/gas-clean/docs/BaseProgramFinalReport.PDF, Richard A. Newby et al., *NOVEL GAS CLEANING/ CONDITIONING FOR INTEGRATED GASIFICATION COMBINED CYCLE*, August 2001
[7] Donald Garrett, *Chemical Engineering Economics*, 1989, p. 350
[8] Size of 1 CFB is estimated from current sizes in practice
[9] Price of cyclone is taken as price for candle filter
[10] Price of baghouse filter is taken as price for active coal filter
[11] Price of tar cracker is price of a steam reformer
[12] Price is given per flow; still an economic scale factor of 0.7 is used here because of the large scales used in this design
[13] A membrane price of 50€/m^2 is assumed due to the expected decreasing in the membrane production cost, since a normal PDMS membrane cost is approximately 125€/m^2 in 1996 [57]. M. Leemann , G. Eigenberger, H. Strathmann, *Vapour permeation for the recovery of organic solvents from waste air streams: separation capacities and process optimization*, Journal of Membrane Science, Vol. 113, pp. 313-322, 1996

Appendix 11.2 Investment cost calculation

Table A 11.2.2 Investment cost calculation

PCE, Purchase Costs of Equipment			
Item	**Cost/unit [M€ @ 2004]**	**# of equipment**	**Total Cost [M€ @ 2004]**
Chipper	0.5	21	10.5
Pelletiser	0.9	497	447.3
Circulating Fluidised Bed	76.7	10	767.0
Candle filter	3.4	10	34.0
Monolith Tar Cracker	35.7	10	357.0
Sour Water-Gas Shift Reactor	110.7	2	221.4
Bulk desulphurizer + regenerator	31.7	2	63.4
Ultra desulphurizer	22.6	4	90.4
Ammonia/HCl Scrubber	4.5	2	9.0
CO2-selective Membrane	71.1	2	142.2
Compressor	1.2	6	28.8
Air separation plant	139.2	1	139.2
Claus plant	9.2	1	9.2
Waste water treatment	0.4	1	0.4
Steam turbine	30.2	2	60.4
Storage tank	6.2	70	6.2
Syngas cooler	6.4	10	64.0
Active coal filter bed	2.1	2	4.2
			2,454.6
PPC, Total Physical Plant Cost			
Item	**Lang factor (f1…f9)**	**Costs relative to PCE**	**Cost [M€ @ 2004]**
PCE	1.00	x PCE	2,454.6
Equipment erection	0.40	x PCE	981.8
Piping	0.70	x PCE	1,718.2
Instrumentation	0.20	x PCE	490.9
Electrical	0.10	x PCE	245.5
Buildings, process	0.15	x PCE	368.2
Utilities	0.50	x PCE	1,227.3
Storages	0.15	x PCE	368.2
Site development	0.05	x PCE	122.7
Ancillary buildings	0.15	x PCE	368.2
			8,345.6
IDC, Indirect Capital Costs			
Item	**Lang factor (f10…f12)**	**Costs relative to PCE**	**Cost [M€ @ 2004]**
Design and Engineering	0.30	x DCC	2,503.7
Contactor's fee	0.05	x DCC	417.3
Contingency	0.10	x DCC	834.6
			3,755.5
Total Investment Required			
Item			**Cost [M€ @ 2004]**
FCC			12,101.2
Working Capital		2 months of tot. oper. costs	674.7
Total Investment			**12,775.8**

Appendix 11.3 Operating costs calculation

Table A 11.3.3 Operating costs calculation

Variable Costs	**Cost [M€ @ 2004]**	**Unit**	**Amount**	**Unit**	**Total Cost [M€ @ 2004]**
Raw materials					
Biomass	6.7	€/ton	23832000	ton/a	158.7
Cat. monolith tar cracker	900	€/ton	9.0	ton/a	0.0
Cat. sour water-gas shift	900	€/ton	15.2	ton/a	0.0
Cat. Claus plant	900	€/ton	0.01	ton/a	0.0
Desulphurizer sorbents	3600	€/ton	950	ton/a	3.4
Active coal	360	€/ton	10	ton/a	0.0
Miscellaneous materials			10% x maintenance		60.5
Utilities					
Electricity Rotterdam	0.04	€/kWh	5664904000	kWh/a	226.6
Electricity chippers					4.8
Electricity pelletisers					79.5
Wastes					
Spent desulphurizer sorbents	20	€/ton	950	ton/a	0.0
Spent monolith tar cracker cat.	200	€/ton	9.0	ton/a	0.0
Spent sour water-gas shift cat.	200	€/ton	15.2	ton/a	0.0
Spent Claus plant cat.	200	€/ton	0.01	ton/a	0.0
Transport					
236 ships					72.4
552000 trucks					59.4
					665.4
Fixed Costs					
Maintenance			5% x FCC		605.1
Operating labour			educated guess		37.5
Laboratory costs			20% x operating labour		7.5
Supervision			20% x operating labour		7.5
Plant overheads			50% x operating labour		18.8
Capital charges			15% x FCC		1,815.2
Insurance			1% x FCC		121.0
Local taxes			2% x FCC		242.0
Royalties			0% x FCC		-
					2,854.5
Sales expenses			no sales expenses		-
General overheads			15% of the		528.0
Research and development			direct production costs		
					528.0
Total Operating Costs					
Operating costs				M€/a	**4,047.9**
Operating costs				€/GJ	**17.6**
Operating costs				€/ton	**365.1**

Appendix 11.4: Variable costs

Table A 11.4.4 Variable costs details

	Cost/Price	Unit	Amount	Unit	Source
Biomass	6.7	€/ton	23832000	ton/a	[1]
Cat. monolith tar cracker	900	€/ton	9.0	ton/a	[4]
Cat. sour water-gas shift	900	€/ton	15.2	ton/a	[4]
Cat. Claus plant	900	€/ton	0.01	ton/a	[2]
Desulphurizer sorbents	3600	€/ton	950	ton/a	[2]
Active coal	360	€/ton	10	ton/a	[3], [5]
Spent desulphurizer sorbents	20	€/ton	950	ton/a	[2]
Spent monolith tar cracker cat.	200	€/ton	9.0	ton/a	[16]
Spent sour water-gas shift cat.	200	€/ton	15.2	ton/a	[16]
Spent Claus plant cat.	200	€/ton	0.01	ton/a	[16]
Syngas	129	€/ton	11088000	ton/a	[8]
Sulphur	39	€/ton	7488	ton/a	[9]
CO2	0	€/ton	14022720	ton/a	[12]
Nitrogen	0	€/ton	20767680	ton/a	[13]
Salts	0	€/ton	57600	ton/a	[14]
Ash	0	€/ton	1163520	ton/a	[15]
Electricity Rotterdam	0.04	€/kWh	5664904000	kWh/a	[7]
Electricity chippers			4.8	M€	[1]
Electricity pelletisers			79.5	M€	[11]
236 ships			72.4	M€	[10]
552000 trucks			59.4	M€	[10]
Operating labour	75	k€/p	500	people	[2]

Sources

1 http://www.novem.nl/default.asp?menuId=10&documentId=28279
HP Calis e.a., *Preliminary techno-economic analysis of large-scale synthesis gas manufacturing from imported biomass*, 2002
2 http://www.netl.doe.gov/coalpower/gasification/projects/gas-clean/docs/BaseProgramFinalReport.PDF
Richard A. Newby et al., N*OVEL GAS CLEANING/ CONDITIONING FOR INTEGRATED GASIFICATION COMBINED CYCLE*, August 2001
3 http://www.netl.doe.gov/publications/proceedings/00/ubc00/VALER.PDF
M. Mercedes Maroto-Valer et al., Utilization of unburned carbon from fly ash as precursor for high-value materials, 2000
4 Assumption, same as Claus catalyst. All catalysts have a lifetime of 5 years, after which they are completely replaced.
5 Amount per year is assumption. Amount is dependent on the number of times the gas cleaning would fall
6 Steam is free and comes from FT process, max. 750 kg/s
7 http://www.ecn.nl/docs/library/report/2004/c04001.pdf
H. Boerrigter et al., *High efficiency co-production of Fischer-Tropsch (FT) transportation fuels and Substitute Natural Gas (SNG) from biomass*
8 Estimated from SMDS production
9 Chemical Market Reporter, June 14 2004
10 http://www.chem.uu.nl/nws/www/publica/Carlo%20e2003-26.pdf
C. N. Hamelinck, *International bioenergy transport costs and energy balance*, Universiteit Utrecht, Copernicus Institute, August 2003
11 http://www.eubia.org/pdf/Lamnet_Pellets.pdf
LAMNET (Latin America Thematic Network on Bioenergy), *Refined Bio-fuels Pellets and Briquettes*, read: 20 May 2004
12 No CO2 taxes have to be paid for processes using biomass as feedstock. Source: Lecture from H. Harmsen, KPMG Netherlands
13 There is no market for the huge amounts of nitrogen this process produces. Source: personal communication, NUON Power Buggenum
14 Best case scenario that salts can be used as roadsalts. Source: personal communication, NUON Power Buggenum
15 Best case scenario that ash can be used in cement. Source: personal communication, Vliegasunie
16 Personal communication, Jan vd Berg, Vliegasunie

Appendix 11.5 Project cash-flow calculation

Table 5 Project cash-flow calculation

End of year	Production [hours/a]	Net Cash Flow [M€]	Project Net Future Worth [M€]	Net Present Worth [M€, r=20%]
1	0	1,540-	1,540-	1,283-
2	0	1,540-	3,080-	1,069-
3	0	2,281-	5,361-	1,320-
4	0	2,281-	7,642-	1,100-
5	0	2,686-	10,328-	1,079-
6	4000	286	10,042-	96
7	4000	286	9,756-	80
8	6000	429	9,327-	100
9	8000	572	8,755-	111
10	8000	572	8,183-	92
11	8000	572	7,611-	77
12	8000	572	7,039-	64
13	8000	572	6,466-	53
14	8000	572	5,894-	45
15	8000	572	5,322-	37
16	8000	572	4,750-	31
17	8000	572	4,178-	26
18	8000	572	3,606-	21
19	8000	572	3,034-	18
20	8000	572	2,462-	15
21	8000	572	1,890-	12
22	8000	572	1,318-	10
23	8000	572	746-	9
24	8000	572	174-	7
25	8000	572	398	6
26	0	405	803	4

Appendix 12.1 BAWEL tool

This creativity tool is moulded using the inspiration gathered from the Drs. D.H. Grunwald creativity tool for CPD [1] and the Perpetual Challenging Theory [2].

BAWEL
Creativity Tool

Group's Process	**Exploration**	**Revealing Confrontation**	**Mutual Involvement**
• Expectation o *Socializing* o *Group's rules* • Favoured Belbin's Role • Situation Sensitivity • Personal Obligation • Group's Profile	• Introspecting • Scenario Making • Experimenting • Alert Notation • Incremental Risk Taking • Mistake Making	• Deadline/Constraints • Priority • Introduction of Alternative • Brainstorming • Visual Expression • Analysis o *Knowledge* o *Assumptions + formulas* o *Possible mistakes* o *Strength* o *Weakness* o *Opportunity* o *Threats*	• Simultaneous Involvement • Sequential Involvement • Variation of Work o *Intellectual* o *Managerial*

Group's Process

- ***Expectation***, group member's expectation of each other regarding working method, cooperation and mutual supplementation.
  - *Socializing* means group's recreational time, also a bit of team building, to prevent burnouts and creativity clogging.
  - *Group's rules* give a guideline about what was expected of the group member, which have been determined together within the group.
- ***Favoured Belbin's Role*** of a group member is obtained using the Belbin's test.
- ***Situation Sensitivity*** gives a situation boundary where the group can or cannot function creatively, but also how a team member reacts in the normal or abnormal situation.
- ***Personal Obligation***, e.g. work, of the team member other than the project has to be taken in to account in the group's creative thinking process.
- The ***Group's Profile*** assessed using the 'CPD Designer's Profile Test' results in a general idea of the strong and weak points of the group.

Exploration

- ***Introspecting*** refers to exploring the uncertainties by working from what is already known.
- ***Scenario Making*** means the development of a possible route to tackle the problem to be solved, this is including the identification of the unknowns.
- ***Experimenting*** refers to personal trial en error process while utilizing his/her full creative potential.

- ***Alert Notation*** means noting all the ideas related to the project even when they seem stupid at that time. People tend to get brilliant ideas unexpectedly due to change of environment, visual influence, etc.
- ***Incremental Risk Taking*** is to make no radical changes in a too short time. Spreading the changes over a longer period can save time if the change has to be discarded, e.g. by selection process.
- ***Mistake Making*** refers to an expression of an environment crucial in the creative functionality of a group where mistakes made are not directly penalized, providing that the agreed creative and group's process guidelines are followed.

Revealing Confrontation

- ***Deadline / Constraints*** gives the group members justified pressure to stimulate the creativity process inside a predetermined boundary.
- ***Priority*** gives a guide to creativity process, to be creative on the right time.
- ***Introduction of Alternatives*** intentionally can lead to debate that can enhance the creativity of the group.
- ***Brainstorming*** can push the creativity of the group, as a group, to the upper limit.
- ***Visual Expression*** refers to the fact that the use of graphical, schematically given expression (on the right subject) gives a clear and simple overview of the subject.
- ***Analysis*** of the results is the following step to be considered, the points to be analyzed are:
  - *Knowledge*
  - *Assumptions and formulas*
  - *Possible mistakes*
  - *Strength*
  - *Weakness*
  - *Opportunity*
  - *Threats*

Mutual Involvement

- ***Simultaneous Involvement*** refers to the group member ability to deal with different things at the same time, including assisting other group members assigned to other tasks.
- ***Sequential Involvement*** means that a group member would work on a task sequentially. In other words a group member finishes one task before starting the involvement on other tasks.
- ***Variation of Work*** stands for the varying type of work assigned to a group member to prevent boredom that impairs or even eliminates the creativity process. Two situation can be distinguished:
  - *Intellectual*, where variation of the type of skill and knowledge is expected.
  - *Managerial*, where the variation of time, material and people is expected.

Reference:

[1] J. Grievink, C.P. Luteijn, P.L.J. Swinkels, *Instruction manual, Conceptual Process Design*, August 2003, Technische Universiteit Delft

[2] http://www.un.org.pk/undp/management/creativity-in-orgs.pdf, C. Adriopoulos, A. Lowe, *Enhancing organisational creativity: the process of perpetual challenging*, Management Decision 38/10, pp. 734-742, 2000, visited: 27 July 2004

Appendix 12.2 Summary of important activity in Active Activity Assistant (AAA)

	Activity Description	Objective of Activity	Start Date	Finished date	Number of man hours
1000	Design Space 0	Group formation and work processes	19/04/2004	26/04/2004	150.35
0.0102	Introduction meeting Mon	Starting with CPD project	19/04/2004	-	15.00
0.0302	Structuring the meeting a	Organizing the project	21/04/2004	21/04/2004	2.50
0.0305	Analysing the group profil	Rules for clear group structure and task	21/04/2004	21/04/2004	3.00
0.0306	Drawing up group rules	Rules for clear group structure and task	22/04/2004	21/04/2004	1.00
0.0308	Drawing up a template fo	Organizing the project	22/04/2004	4/23/2004	2.00
0.0501	Explanation tool of Timo with principals		23/04/2004		15.00
2000	Design Space 1+2	I/O structure + sub processes	26/04/2004	4/5/2004	127.10
1.0101	kick-off meeting	Presenting approach	26/04/2004	4/26/2004	1.50
1.0103	Brainstorm session about	Organizing the project	26/04/2004	-	7.50
1.0104	Analysing feed options	Organizing the project	26/04/2004	-	10.00
1.0303	Research biomass types	Organizing the project	28/04/2004	29/04/2004	22.50
1.0402	Daily team meeting	Organizing the project	29/04/2004	29/04/2004	7.50
1.0404	Get laymen using	Get public opinion	29/04/2004	3/5/2004	5.00
2000	Design Space 3	I/O structure + sub processes	4/5/2004	2/27/2003	236.20
3.0104	GABI learning process	Apply CPD SAT	4/5/2004		20.00
3.0107	Brainstorming session of t	Define states and tasks for phase 3	4/5/2004	4/5/2004	15.00
3.0402	Research conversion of ea	Make mass and heat balances	7/5/2004	11/5/2004	5.00
3.0403	Research conversion and	Make mass and heat balances	7/5/2004	7/5/2004	12.00
3.0502	Finishing GABI simulation	Application CPD SAT	10/5/2004	11/5/2004	16.00
3.0602	Ranking	CPD SAT application / Process selection	11/5/2004	11/5/2004	1.50
3.0607	Sustainability chapter BO	BOD report	11/5/2004	13/5/2004	1.00
3.0901	Pre-BOD presentation	Pre-BOD presentation	18/5/2004	18/5/2004	12.50
3.0903	Review meeting part1	Review phase 1-3	18/5/2004	18/5/2004	5.00
3.0904	pre phase 4 (SUS-DAT ex	SUS-DAT explanation	18/5/2004	18/5/2004	11.50
3.0905	Review meeting part2	ToDo	18/5/2004	18/5/2004	1.00
3.0906	Belbin test	Belbin test	18/5/2004	24/5/2004	3.00
3.1001	Explanation Timo	Explanation Timo	19/5/2004	19/5/2004	8.00
3.1003	Design options	Ranking of design options	19/5/2004	19/5/2004	
4000	Design Space 4	Unit operations selection	25/05/2004	2/7/2004	1788.75
4.0101	Susdat management	Tasks assignments and SUS-DAT mana	25/5/2004	25/5/2004	6.00
4.0105	Finishing table phase 3 (T	CPD SAT application / Process	24/5/2004	25/5/2004	10.00
4.0301	Brainstorm meeting		26/5/2004	26/5/2004	32.00
4.0401	Brainstorm meeting		27/5/2004	27/5/2004	32.00
4.0501	Brainstorm meeting		28/5/2004	28/5/2004	32.00
4.0601	Susdat management	SUSDAT	1/6/2004	15/2004	2.50
4.0602	Working on Benchmark pr	SUSDAT	1/6/2004	11/5/2004	40.00
4.0603	Working on different case	SUSDAT	1/6/2004		40.00
4.1001	Susdat management	SUSDAT	7/6/2004	7/6/2004	2.50
4.1904	Discussion with environm	Discussion with environmental group	18/06/2004	19/06/2004	15.00
4.2101	Meeting with principal Tim	Best case option	22/06/2004	22/06/2004	15.00
4.2201	Meeting with coach	Analyzing base case selection	23/06/2004	23/06/2004	4.50
4.2302	Non-KSI of benchmark pr	Non-KSI determination of the benchma	24/06/2004		40.00
4.2305	Reporting SUSDAT	Start reporting of selection process and	24/06/2004		32.00
4.2402	Bring more detail in unit operations of Case E		6/28/2004		20.00
4.2501	Bring more detail in unit operations of Case E		6/29/2004		50.00
4.2701	Visit C. Daey Ouwens TU/	Excurstion to expert (heat integration)	1/7/2004		10.00
4.2702	Start simulation with ASPEN		1/7/2004		16.00
4.2801	Visit Nuon plant in Bugge	Excurstion to experts	2/7/2004		30.00
5000	Design Phase 5+6+7		5/7/2004	6/8/2004	1057.00
5.0101	Aspen preparation of 3 m	Obtain an idea for the case modelling	5/7/2004	26/7/2004	170.00
5.0103	Writing a report about CP	Finishing phase 3 with a report	5/7/2004	23/7/2004	20.00
5.0104	Writing a report about SU	Finishing phase 4 with a report	5/7/2004	23/7/2004	20.00
5.1305	HAZOP and F&EI analysis	Process safety and analysis	20/7/2004	28/7/2004	8.00
5.1306	CFB and syngas cooler de	Equipment details en design	20/7/2004	28/7/2004	10.00
5.1308	Heat integration	Plant wide integration	20/7/2004	28/7/2004	24.00
5.1401	Writing whole report	Finising the final design for BOD report	20/7/2004	30/7/2004	760.00
5.2701	Final presentation	Present the final BOD to clients, instruc	6/8/2004	6/8/2004	40.00

Appendix 12.3 Overview of results of creativity processes

Table A.12.3.1: Overview of group and creativity processes used and results

Method used	Date	"Direct" result
Visual expression	During some meetings and brainstorm sessions	Better structure and overview of alternatives or results
Group discussion	During daily meetings, e.g. 11/5/2004	Mutual involvement, generation of indicators
Group rules	e.g. 7/5/2004	Cake!
Brainstorming	26/4, 28/4 and 4/5/2004	Generation of process alternatives
Alert notation	Only during Phase 1 of DDM	Generation of many possible biomass feed stocks
Deadlines	e.g. end of each phase of the DDM; 23/4, 29/4, 14/5/2004	Assurance of progress
Socializing	e.g. 5/5/2004	No burnouts yet!
Variation of work	Every week	Chairman/secretary changing every week, giving opportunities to improve one's weak points
Team meetings	Every day	Better communication, better organisation, better overview
Creativity coach present at brainstorm sessions	26/4, 28/4 and 4/5/2004	Objective view helps to structure the session, helps to clear "bottlenecks" during the session
Involvement of survey in design process		Objective view on social aspects of designs
Involvement of discussion with environmental group in design process		Useful tips regarding several environmental issues that influence the sustainability of the design
Involvement of plant visit and extra lecture in design process		Creative solutions after observe the current practice, some valuable information about process details, economics and regulations.

Appendix 12.4 Belbin results

Initial Code
AK: Andy Kurniawan
BV: Berend Vreugdenhil
EH: Emile Herben
LD: Lissa Djatmiko
WH: Wilma Hensen

Colour code
1st best (red)
2nd best (magenta)
3rd best (cyan)

Table A.12.4.1: Belbin group role assessment, PHASE 0

	CH	SH	PL	CW	CW (company worker)	RI	TW	CF
AK	12	12	4	11	11	8	4	12
BV	15	11	5	4	11	0	14	10
EH	7.5	17.5	2.5	9	24	7.5	2	0
LD	12	9	6	5	13	10	10	5
WH	6	20	0	5	25	0	0	11

Table A.12.4.2: Belbin group role assessment, PHASE 4

	CH	SH	PL	CW	CW (company worker)	RI	TW	CF
AK	12	12	2	9	13	4	10	8
BV	7.5	10	5	12.5	5	7.5	15	7.5
EH	6.5	9	0	11	31	7.5	5	0
LD	7	12	10	2	10	11	8	10
WH	6	15	5	1	18	4	2	9

Table A.12.4.3: Belbin group role assessment, PHASE 7

	CH	SH	PL	CW	CW (company worker)	RI	TW	CF
AK	10	11	2	13	14	3	7	8
BV	4	12	4	18	15	0	14	3
EH	2.5	18.5	3	14.5	16.5	5	10	0
LD	4	12	11	2	14	16	9	4
WH	11	12	5	0	23	4	3	11

Appendix 12.5 Summary of the meeting with the environmental group

First of all let me say that it was an interesting evening/night. The people we met really thing different about the same subject, probably because of their background. This resulted in a list of comments/critical notes and new ideas, which I will list below.
The people we met are all Environmental Science students. Carolien continued to do biology just because she liked it. She finished Environmental Science with a thesis on durable construction. Richard has worked on all sorts of projects from legislation, modeling to advising. He is now also involved in European projects. Dirk is working in consultancy, concerning air-conditioning, water and communications. At the moment he is working on an energy savings plan.

Critical notes/comments

- A mixture of biomass would lead to a much more robust process and it would make the company less vulnerable if for a reason Sweden decides to make use of the wood residues for a biomass process of their own. Over dimensioning, is a good method to reduce the dependency on biomass sources.
- Using ships for transportation and around a ship per day, it will become very crowded near the entrance of the tweede Maasvlakte. First of all is it possible that so many ships be integrated in an existing infrastructure and a second issue is the noise that will be generated by these ships. Since in the vicinity of the tweede Maasvlakte also a residential area is planned, can this lead to problems.
- Isn't there a conflict with durability if the fuel produced in the Netherlands originates in the Baltic States and Sweden? Since the Netherlands contributes to a reduction of fuel from crude oil with biomass from the BS and Sweden. Another issue is the wood area, which is still declining worldwide. When wood is removed from the woods carbon is added to the carbon cycle and the net result is not zero.
- The purchase of hydrogen and the LCA are supposed combined, because LCA also takes side streams into account. Sometimes it seems that we are diverting our responsibilities by selling our waste to "responsible" companies
- The way looked at process design nowadays is mostly financial, but the better question is, is it energetic also feasible. How much energy is used to produce one m^3 of synthesis gas and what is the energy content of the gas.
- A good idea to take into account in the report phase is the question if something is a financial or a profitability consideration.
- We looked at the social side of the problem but the noise, horizon, emissions of process related companies and personal issues when it comes to legislation. These can become important when the plant is going to be built.
- Isn't there a problem with torrefaction and milling, because the char produced is hot and it can easily ignite when a shear force is presented onto the char?
- A good side of the project is the locality, since the biomass is imported from European countries.
- It could be interesting to include an environmentally good option and an

economically good option.
- Try to keep the report transparent and report everything.
- Purification in fewer steps is always a plus for the process.

New ideas

- Transportation of biomass with a conveyer belt, similar as it is done with transportation of coal.
- Hydrogen producing bacteria/tree, but it has genetic modification ethical issue.
- Genetically altered (manipulated) trees, which convert themselves into bio-diesel or methane, it has also ethical issue.
- Direct diesel production instead of this elaborate process.

Interesting people we could include:
- Han Brezet IDEMAT at IO
- Pieter Bots at TBM. He is making models with regard to durability

Interesting sites:
- www.nieuwekaart.nl
- www.atlasvannederland.nl

Others
- EZ
- NOVEM
- CENTER
- VROM
- Diok de ecologische stad