SES6-CT-2003-502705

RENEW – Renewable fuels for advanced powertrains

Integrated Project
Sustainable energy systems

Scientific report
COST ASSESSMENT

Due date of delivery:	
Actual transmission date:	02/2008
Start date of project:	01-01-04
Duration:	48 months

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Under support of ECBREC and LUND

Revision 0 Draft 1

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CONTENT

ABBREVIATIONS

50	50 MW biomass feedstock – direct provision
500	500 MW biomass feedstock – direct provision
500P	500 MW biomass feedstock – pyrolysis (P)
approx.	approximately
BtL	biomass to liquid
CHP	combined heat and power
DH	district heating
d	dry matter
EUC	eucalythus (only relevant for SOUTH)
GP	gathering point
LHV	lower heating value
LR	logging residues
MIS	miscanthus bales
O&M	operation and maintenance
S1	Scenario 1: Maximized bio-fuel production ‘2020
S2	Scenario 2: Self-sufficient bio-fuel production ‘2020
SRC	short rotation coppice chips
Starting Point (SP)	situation for 2000-2004 (base case)
STR	straw bales
SWG	switch grass (only relevant for SOUTH)
WB	wood bundles
WC	wood chips
WCC	whole cereal crop bales

1 INTRODUCTION

For the production of liquid biofuels (BtL) several steps are necessary. The liquid biofuel production and provision chain is shown in Figure 1-1.

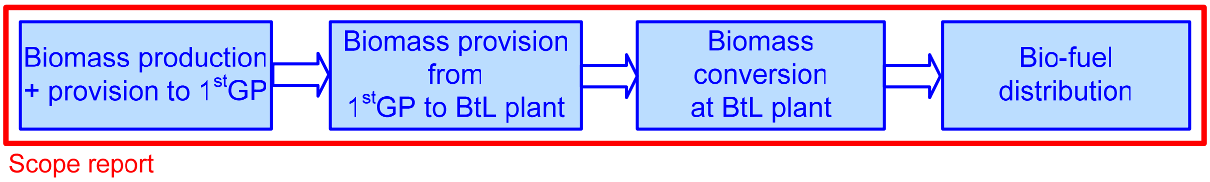

Figure 1-1 Elements of BtL supply chain and scope the report

With regard to the cost assessment of producing BtL fuels the following key questions that were answered are the following:

* What typical costs can be expected for the different segments of the supply chain (i.e. with regard to biomass and the BtL fuel)?
* What are the relevant and main drivers?
* Which concepts for BtL production and locations (EU regions) are the most promising?

In the following within the report a summary of the defined cost calculation approach applied in the RENEW project as well as basic results and exemplary sensitivity analysis are given for each of the elements of the whole BtL supply chain (cf. Figure 1-1). This allows the reader to carry out fundamental estimations for total BtL production costs by him-/herself.

In addition to that a comprehensible description of applied methodological approaches and results of biomass related costs and BtL production costs can be gathered from the deliverables named as follows: D 5.3.3, D 5.3.4, D 5.3.5, D 5.3.6, D 5.3.7.

2 GENERAL APPROACH OF COST CALCULATION

The general approach for the cost calculation within the SP 5 of RENEW project is shown in Figure 2-1. It combines specific data for the defined European regions WEST, EAST, NORTH, ALPINE, SOUTH, UK+IR (represented by reference countries – such as Germany, Poland, Sweden, Switzerland, Greece, Ireland – referring to the SP 5 partners of the RENEW project) and aspects of technical assessment of the defined plant concepts for BtL production and consists of three cost calculation matrixes:

* *Matrix I.* For the production of energy crops and their provision to the first GP, a comprehensive cost calculation for different crop assortments and European regions was elaborated (D 5.3.4). It takes into account e.g. costs for risk and land, plantation establishment, fertilisation, harvesting, field and road transports. The costs for the provision of agricultural and forestry residues have been calculated in (D 5.3.6) based on a calculation tool that includes e.g. baling, bales collecting, forwarding, loading in, transport, loading out and storage. The provision costs to the 1st GP also took into account data and costs of the defined European regions.

* *Matrix II.* Based on the outcome of matrix I (i.e. absolute costs for energy crops and biomass residues at the 1st GP), biomass provision costs from the 1st GP to the BtL plant have been calculated by the IEE for the different biomass assortments, European regions and BtL plant sizes as well as RENEW scenarios. Therefore, a cost calculation model has been developed further that considers regional specific aspects (e.g. infrastructure, means of transport, cargo handling) as well as required transport distances based on region specific biomass potentials (absolute potentials normalised for total land area).
* *Matrix III.* The total biomass provision costs (i.e. accumulated from matrix I and II) are used as biomass costs for the calculation of total BtL production costs, which have been elaborated for the different BtL concepts. Thus, the total BtL production costs at free plant gate represent accumulated costs of the shown cost calculation matrixes or steps respectively along the BtL supply chain (cf. Figure 1-1).

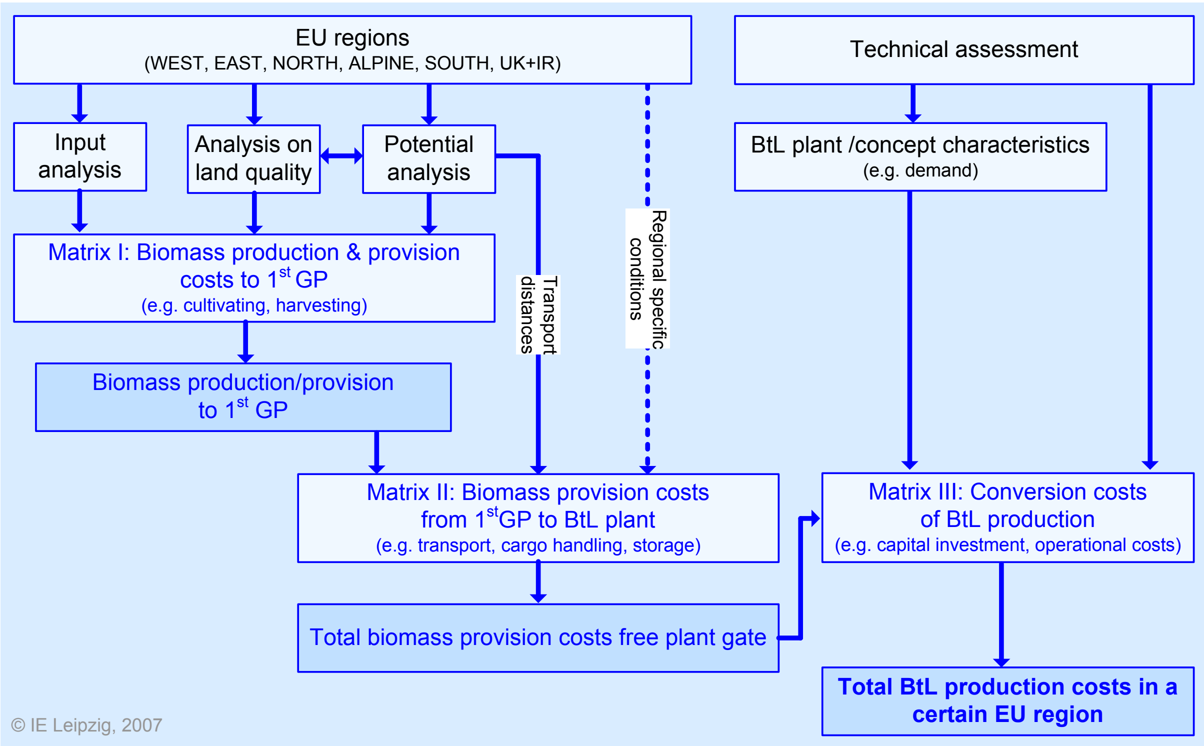

Figure 2-1 General approach of cost calculation within RENEW

The responsibilities of the WP 5.3 partners regarding cost assessment are shown in Figure 2-2. The input of relevant data and specific costs for the calculation of biomass production and provision costs have been provided by the WP 5.3 partners in a comprehensive data and cost inventory.

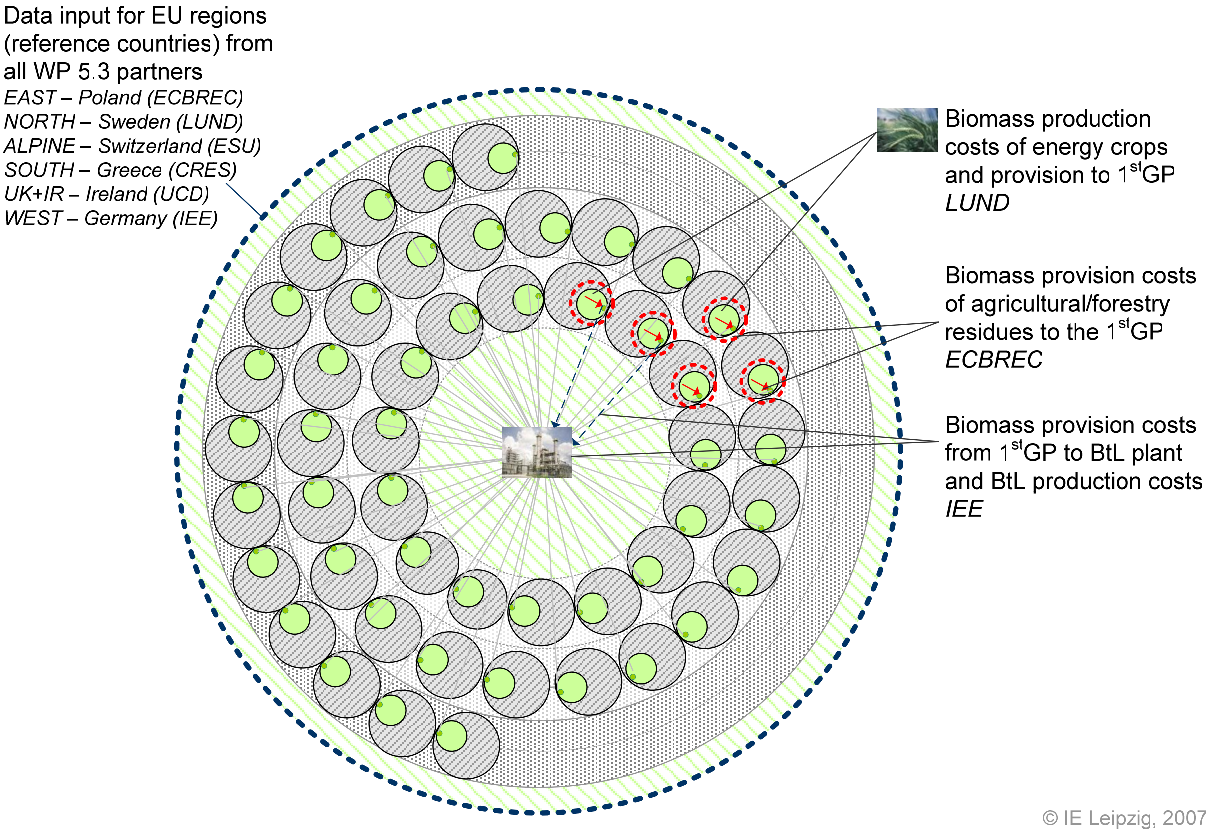

Figure 2-2 Responsibilities of WP 5.3 partners along the BtL supply chain

3 BIOMASS PRODUCTION AND PROVISION COSTS TO THE 1ST GATHERING POINT

Costs aspects concerning biomass production and provision to the 1st GP are discussed within this section. Starting with a brief introduction into the methodology of matrix I the basic results in form of the biomass costs at the 1st GP are shown (cf. Figure 2-1). The aim was to calculate indicative values of biomass provision costs at the 1st GP under defined frame conditions of the biomass provision. Moreover, exemplary sensitivity results are presented. More detailed information as well as explanations on results are given in D 5.3.4 and D 5.3.6.

3.1 Methodology in brief

Biomass costs at the 1st GP include all operations, which have to be performed to supply biomass from production site to a local gathering/storage place (i.e. 1st GP), e.g. biomass production (relevant only for energy crops), harvesting, handling, field transport/ forest terrain haulage, road transport and storage. Considering the RENEW project assumption on BtL plants sizes of 50 MW_{th} and 500 MW_{th}, large amounts of biomass will be required as a raw material. Due to this fact only regions of significant biomass potential are regarded as biomass supply areas for BtL production. In such regions professional and cost effective provision options can be performed by contractors with high-capacity machineries.

For identifying the indicative biomass costs at 1st GP the following cost approaches were applied by LUND (cf. D 5.3.4) and ECBREC (cf. D 5.3.6).

3.1.1 Energy crops

The calculations contain three basic elements: (i) calculating the base case economics of growing different crops, (ii) making the cost assumptions and calculations for different regions in a similar way and (iii) transforming the calculations to large scale cultivation with present conditions and large scale cultivation in 2020.

Crops usually go through different development stages in terms of total crop area, breeding, machinery, knowledge and experience, as well as organisational factors. Input data for different crops and regions were gathered based on the present situation, a hypothetical present situation with large scale crop cultivation, and a possible situation with large scale cultivation in 2020. Cost levels for different regions were determined by identifying important cost indicators, thus avoiding the effort of gathering data at the level of detail used in the base case calculations. Based on these cost levels, and the base case calculation, the production costs for different regions were calculated. For all concepts a road transport of 30 km to the 1st GP is assumed.

Several factors determine the total cost and hence the compensation needed by the farmer to produce energy crops. Three categories of costs can be identified: (i) costs for growing the crop, (ii) costs for land and (iii) costs for compensating the risk of growing a new crop.

3.1.2 Agricultural and forestry residues

Biomass costs at 1st GP were calculated for provision chains defined in Figure 3-1. The cost structure of provision chains is analysed as costs of separate operations in the chain, e.g. baling, collecting, transportation, etc. For each of the operations main cost components were estimated, i.e. investment related costs, labour costs, fuel costs and other O&M costs. Based on this a sensitivity analysis was performed in order to estimate provision costs for future scenarios S1 and S2.

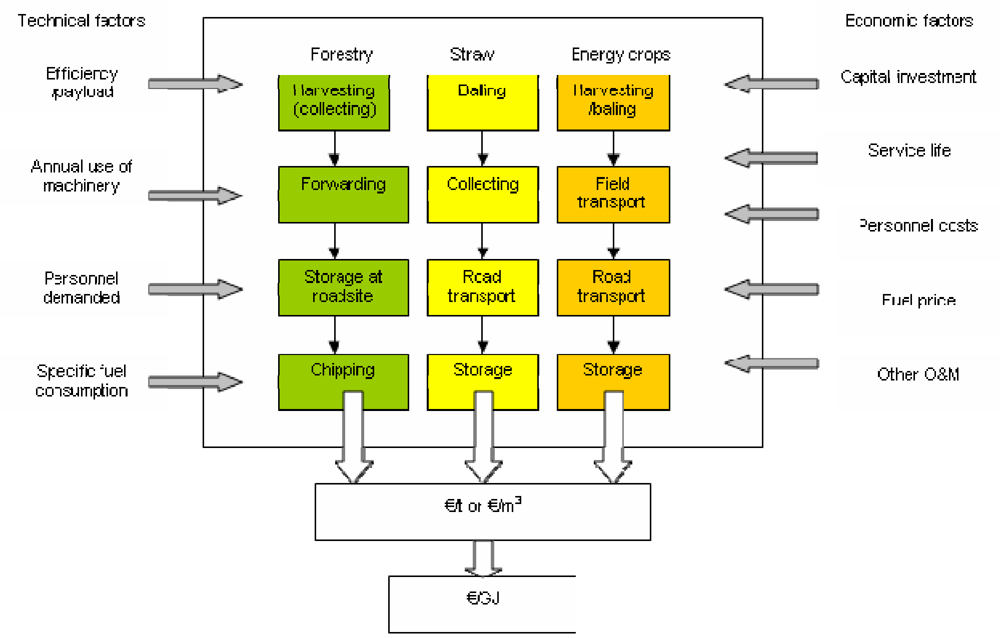

Figure 3-1 Cost calculation approach of the residue biomass provision up to the 1st GP

Cereal straw is harvested in form large rectangular bales, which are collected and delivered by tractors and trailers to the storage at the 1st GP. The road transport distance is 15 km. Storage is organised in a stack on a hard ground and under a portable roof construction and lasts on average six months.

Forestry residues (logging residues and thinning wood) in form of branches, tops of trees and low-diameter stems are collected at the felling site by a harvester or forwarder and transported at a max. distance of 1 km to a roadside storage. The uncomminuted material is stored there for several months. At the time of delivery it is chipped and loaded into truck containers. In NORTH bundling option is also included.

3.2 Basic results for energy crops

For selected energy crops the best cost alternatives for biomass costs at the 1st GP (cf. chapter 3.1.1) are shown in Figure 3-2. The results show that current energy production costs can be reduced significantly in the future scenario with large scale cultivation. The relatively larger cost reductions for woody crops such as willow and eucalyptus compared to herbaceous crops such as miscanthus are explained by high development potential in harvesting and handling cost of woody crops. Straw balling technologies used for herbaceous crops are well developed today and there is little potential for further bales densification.

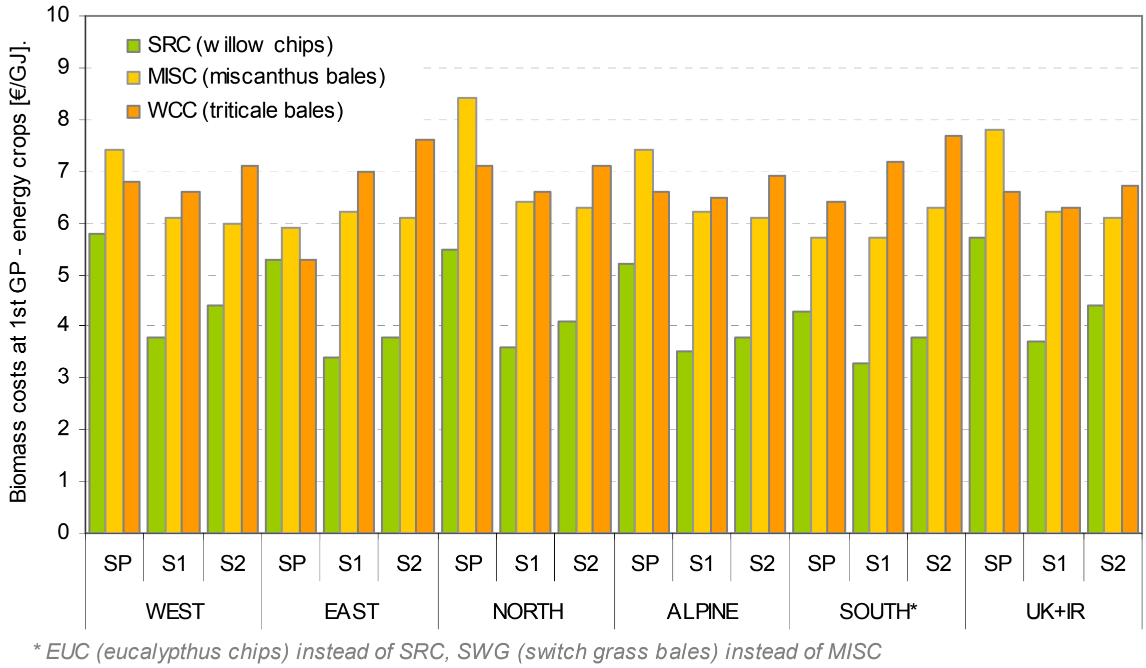

Figure 3-2 Biomass costs at 1st GP for energy crops (diagram IEE, data LUND/ECBREC)

Overall, the results show that annual crops generally have the highest production costs (approx. 6 to 7 €/GJ in the 2020 scenario) due to annual establishment costs, intensive cultivation, and relatively high handling costs. Perennial herbaceous crops have lower costs (approx. 5 to 6 €/GJ) since annualised establishment costs are lower, cultivation is less intensive, but handling costs remain relatively high. This assumes that no major technical developments take place in the densification of herbaceous crops. The lowest production costs are reached for SRC (about 3 to 4 €/GJ in 2020), since costs for establishment and handling costs are relatively low. However, therefore the largest changes at the farm level are required.

The crops with the highest production costs (e.g. WCC) require the smallest changes at the farm level.

3.3 Basic results for agricultural and forestry residues

The basic results for agricultural residues and forestry residues are shown as follows (Figure 3-3 et seqq.). Depending on the scenarios and European region the costs at the 1st GP vary between 2.20 to 3.90 €/GJ_{LHV} for straw, 1.30 to 3.20 €/GJ_{LHV} for logging residues and 2.40 to 7.50 €/GJ_{LHV} for thinning wood. For forestry residues (i.e. thinning wood and logging residues) costs are dominated by the cutting and/or forwarding to road site. The costs for the provision of straw are primarily influenced by the expenditures for fertiliser (NPK value of straw for the soil), balling and storage.

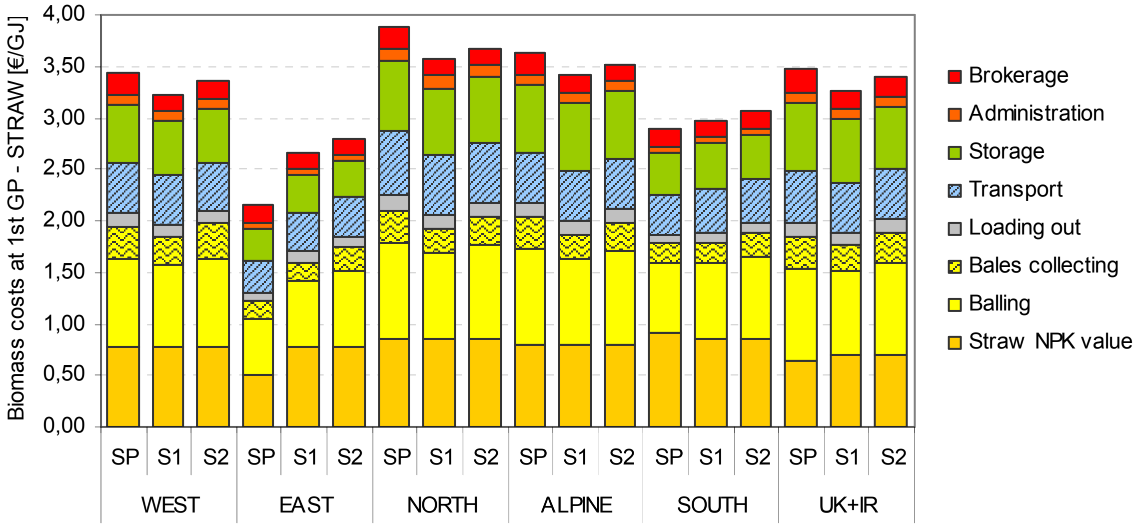

Figure 3-3 Biomass costs at 1st GP for straw bales (diagram IEE, data ECBREC)

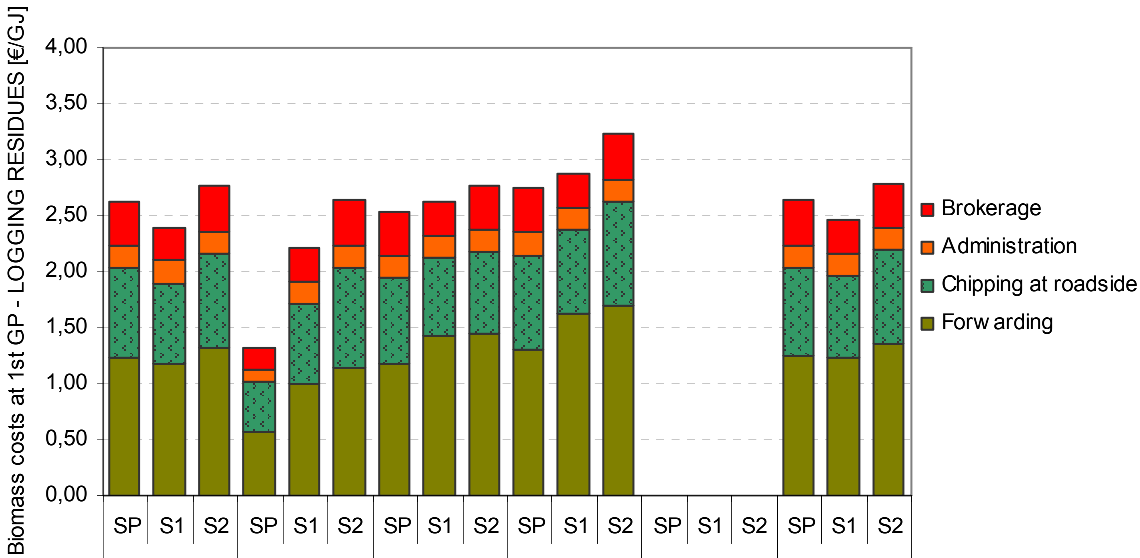

Figure 3-4 Biomass costs at 1st GP for logging residues (diagram IEE, data ECBREC)

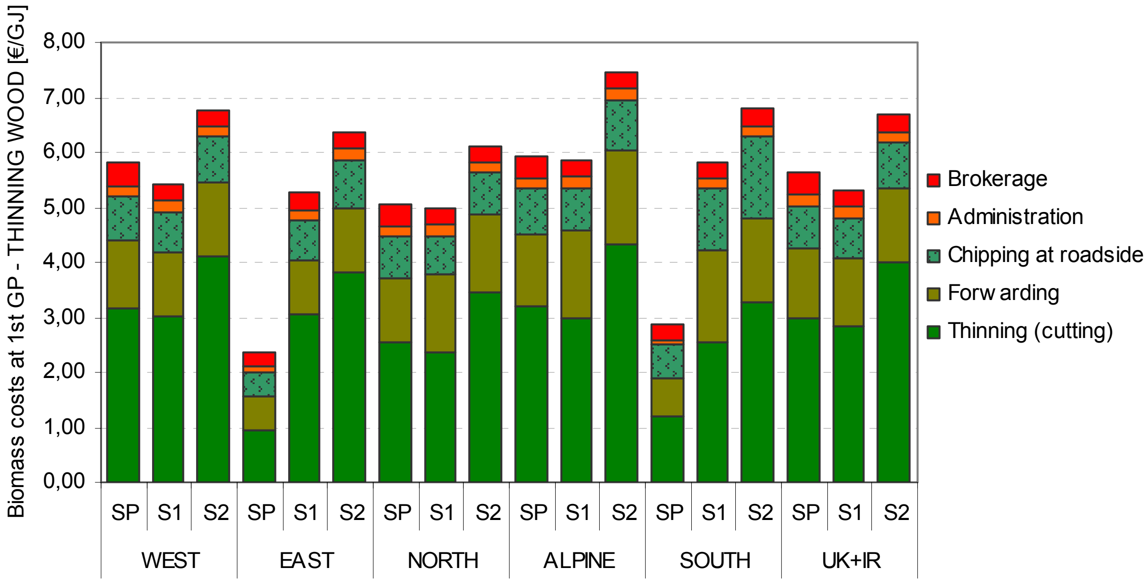

Figure 3-5 Biomass costs at 1st GP for thinning wood (diagram IEE, data ECBREC)

3.4 Exemplary sensitivity analysis

The costs of biomass provision at the 1st GP would be influenced by the region specific potentials. High biomass availability (i.e. high yields, large-scale fields and concentrated biomass production sites) creates opportunities for significant cost reductions with regard to more efficient use of harvesting and handling machinery, reduction in transport distances to the 1st GP as well as more efficient overall organization and administration of the provision chain.

An exemplary sensitivity analysis was performed for straw provision cost to the 1st GP for SP (Figure 3-6). The base case costs are relevant for high straw availability, where machinery can be used efficiently (cf. chapter 3.3). Low biomass availability/low region specific potentials (e.g. fragmented fields and mosaic land use pattern) makes the provision costs higher due to decreased annual usage of machineries and increased distance to the 1st GP. The changes in cost structure for NORTH are presented in Figure 3-7.

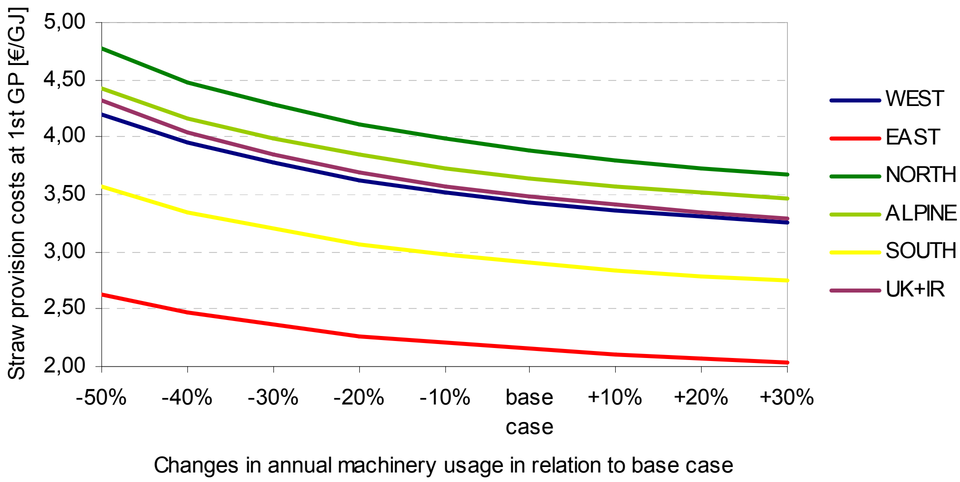

Figure 3-6 Straw provision costs at 1st GP vs different level of annual machinery usage with reference to base case, SP, NORTH

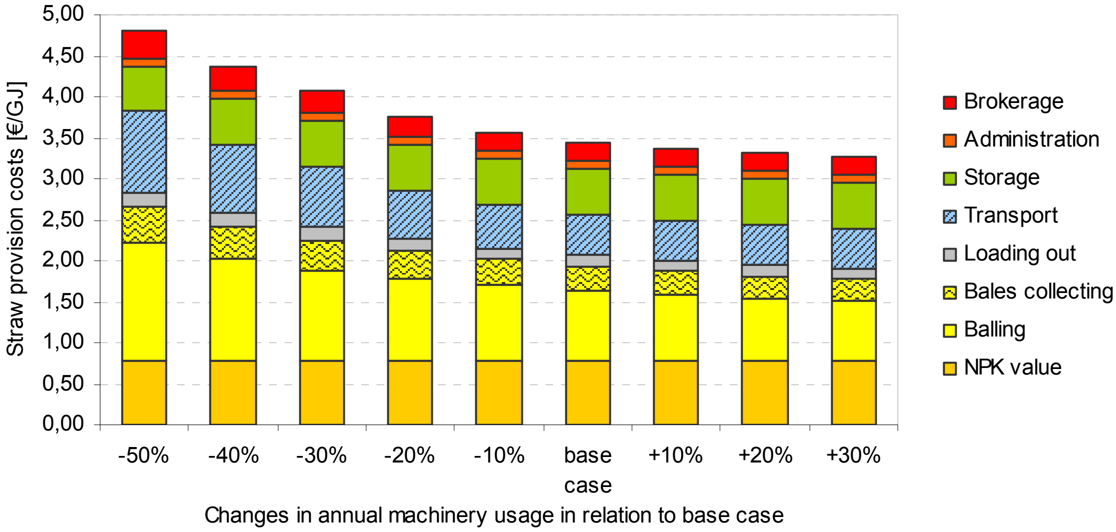

Figure 3-7 Structure of straw provision costs at 1st GP vs. different level of annual machinery usage with reference to base case, SP, NORTH

The cultivation costs of different energy crops vary between the regions depending on the yield and cost level of the region. Table 3-1 shows a cost matrix for willow, including only the cost of cultivation. The cost level of 100 % refers to NORTH. The cost of cultivation generally differs more between regions in comparison to the production cost which also includes the costs of land and of risk. The cost of land equalises the production costs between different regions, assuming it is estimated as the opportunity cost based on e.g. cereal production. When applying this method, regions with low costs of cultivation generally also have high costs of land due to high net gross margins of cereal production.

Table 3-1 Example of cost matrix for willow. Costs are in EUR per GJ today with different cost level and yield level (excluding land cost and risk compensation). The base case for the Northern region is represented by 100% and 9 t_d/ha.

Cost level (%)	Yield level,[t_d / hectare]									
	5	6	7	8	9	10	11	12	13	14
60	3.4	3.0	2.7	2.5	2.4	2.3	2.1	2.1	2.0	1.9
70	4.0	3.6	3.2	3.0	2.8	2.6	2.5	2.4	2.3	2.3
80	4.6	4.1	3.7	3.4	3.2	3.0	2.9	2.8	2.7	2.6
90	5.2	4.6	4.2	3.9	3.6	3.4	3.3	3.1	3.0	2.9
100	5.8	5.2	4.7	4.3	4.1	3.9	3.7	3.5	3.4	3.3
110	6.5	5.7	5.2	4.8	4.5	4.3	4.1	3.9	3.7	3.6
120	7.1	6.3	5.7	5.3	4.9	4.7	4.5	4.3	4.1	4.0
130	7.7	6.9	6.2	5.8	5.4	5.1	4.9	4.7	4.5	4.4

Figure 3-8 shows the breakdown of the production costs of willow and reed canary grass (RCG) for today, assuming small and large areas of production, and for the future. In comparison, willow is dissociated with the higher cost of establishment and hobbits, but lower costs of handling.

The cost of cultivation associated with perennial energy crops is expected to decrease as the production volumes of these crops increase. The cost reductions can be attributed to increased competition between companies involved in perennial energy crops, decreased distances between fields containing these crops and decreased costs of organisation, advising and brokerage. The fixed costs of special machinery will also decrease per hectare due to a higher degree of utilization of the machinery and increased competition between different contractors. In general, larger cost reductions will be possible for SRC crops, such as willow, compared to herbaceous crops, such as RCG, due to the difficulty in achieving further cost reductions in the handling of bales (Figure 3-8).

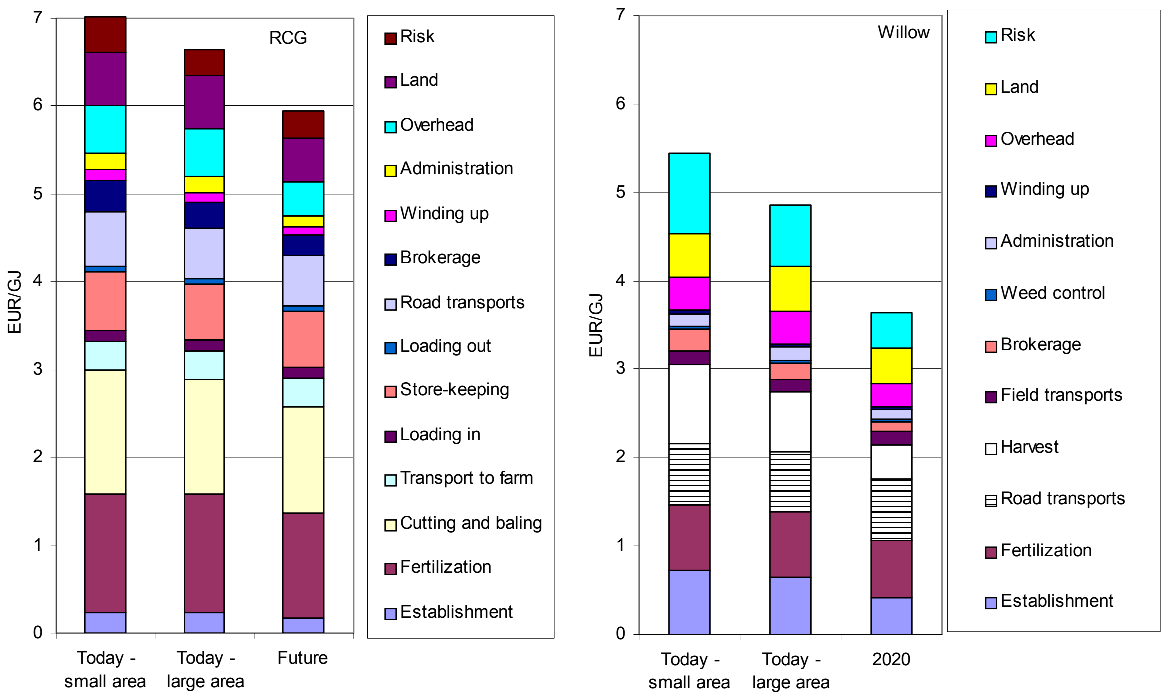

Figure 3-8 *Breakdown of the production costs of Reed Canary grass (RCG) and willow at 1st GP for today (2005), assuming small or large areas of production, and for the future assuming a large area production, NORTH*

4 BIOMASS PROVISION COSTS FROM THE 1ST GATHERING POINT TO THE BTL PLANT AND TOTAL BIOMASS PROVISION COSTS

Within this section the methodology of matrix II is briefly described followed by the presentation of the basic results in form of the total biomass provision costs at BtL plant gate (cf. Figure 2-1). Moreover, for the provision costs from the 1st GP to the BtL plant exemplary sensitivity results are summarised. More detailed information as well as explanations on results can be gathered from D 5.3.6.

4.1 Methology in brief

In the cost calculation model plant specific level are included for the different steps of the biomass provision to BtL production. The main principle of this model is shown in Figure 4-1. Relevant costs of each level are added or summarised respectively to total biomass provision costs (given in €/GJ_{LHV}). The comparison of these total costs of the different reference concepts will be categorised in (i) biomass production and provision to the 1st GP (i.e. biomass costs at 1st GP), (ii) storage, (iii) transport, (iv) cargo handling, (v) pyrolysis, (vi) swap body for bimodal transportation as well as (vii) storage and pre-treatment of the biomass freight at the BtL plant site.

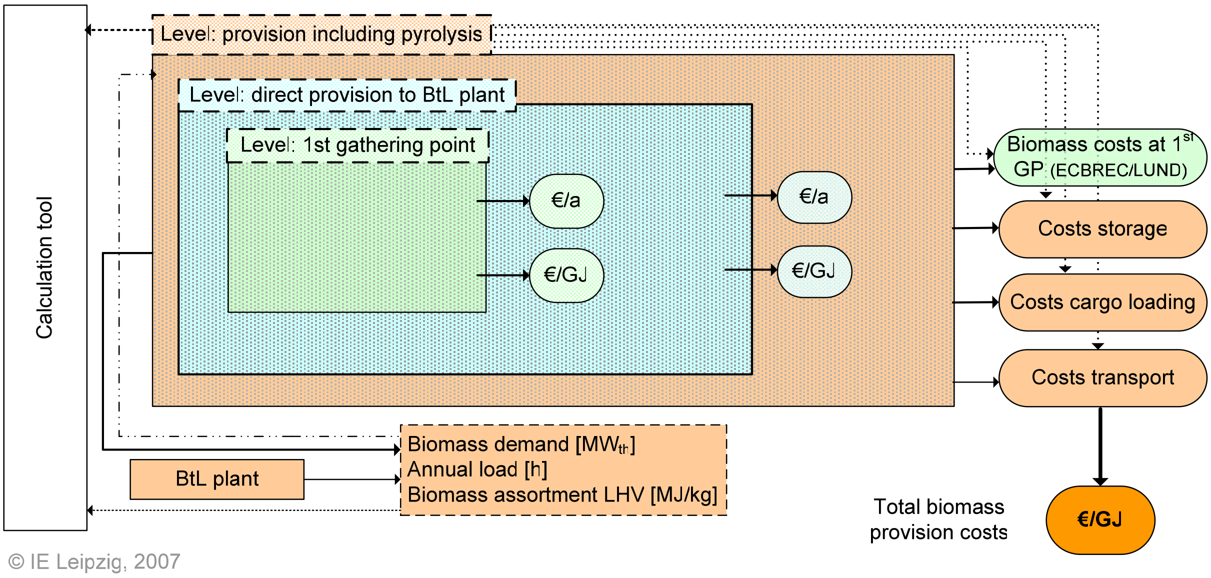

Figure 4-1 Calculation model – biomass provision cost at BtL plant

For the calculation of the provision costs from the 1st GP to BtL plant, basically the following assumptions were made:

* For the calculation of specific transport distances EU region specific biomass potential density were used (approx. 2 to 30 GJ/(ha a) provided by ECBREC at reference country level under the basic frame conditions of the RENEW project; cf. chapter 2). In specific EU provinces, where BtL plants will be favourably installed, these specific biomass potential density can be significantly higher (cf. also D 5.1.3, D 5.1.7).
* Logging residues and thinning wood are provided together in form mixed wood chips in containers (i.e. addition of their biomass potential densities and appropriate sharing of their biomass costs at 1st GP), i.e. forestry wood is chipped at road site (relevant to costs at 1st GP) and loaded to the container. SRC is provided as wood chips, miscanthus, triticale and straw in form of bales.
* Considering the provision paths including pyrolysis, only the costs provision of biomass to the pyrolysis plant and thence the provision of pyrolysis slurry are taken into account. The specific capital investment and O&M costs for the pyrolysis plant are counted among the calculation of the total biomass conversion costs (part of deliverable D 5.3.7).
* The final biomass treatment is done at the BtL plants with regard to the different requirements of the specific concepts (cf. Table 5-2),
* The biomass input to be considered at BtL plant is about 50 MW_{th} biomass input for the TUV/BKG concept, about five pyrolysis plant of 100 MW_{th} biomass input each for pyrolysis (i.e. approx. 432 MW_{th} of pyrolysis slurry at the BtL plant) as well as 500 MW_{th} biomass input for the other BtL plants.

Assumptions for the analysis of the future scenarios S1 and S2 can be summarised as follows (cf. D 5.3.5): For the scenario S1 an overall state of the art is expected in all Member

States; a significant modification of that biomass provision chains are not expected (e.g. a doubling of transportation fuel costs is only of minor influence to the total provision costs and thus to the BtL production costs). For the scenario S2 it is assumed that BtL is used as transportation fuel.

4.2 Basic results for energy crops

Compared to the costs for residues, the total provision costs of energy crops (focus road transport) are significantly higher (6.7 to 46.20 €/GJ_{LHV}) (Figure 4-2). They increase with BtL plant capacity. Depending on the region (area or region specific potentials and infrastructure aspects) the total provision costs are typically dominated by the biomass costs at the 1^{st} GP. These cost parameter increases when pyrolysis is applied and thus – in addition to the storage losses – also losses due to the pyrolysis conversion efficiency have been taken into account. Moreover, primarily due to the increased energy density of pyrolysis slurry (when compared to the direct provision), overall transport costs can be slightly reduced (although the bulk of the costs incur for straw provision free pyrolysis plant) while cargo handling costs increase. As already mentioned, the transport costs are basically caused by the following parameters: (i) means of transport, their load and associated costs and thus the frequency of movements, (ii) area or region specific potentials of the different biomass assortments and thus the typical transport distance between the 1^{st} GP and the BtL plant.

Favourable costs are shown for WEST, EAST and NORTH (approx. 7 to 18 €/GJ_{LHV}). For SOUTH the relevant energy crops are eucalyptus (EUC) and switch grass (SWG) instead of short rotation coppice and miscanthus, provision costs range between 8 to 32 €/GJ_{LHV}. The total provision costs for energy crops in UK+IR are about 12 to 36 €/GJ_{LHV}.

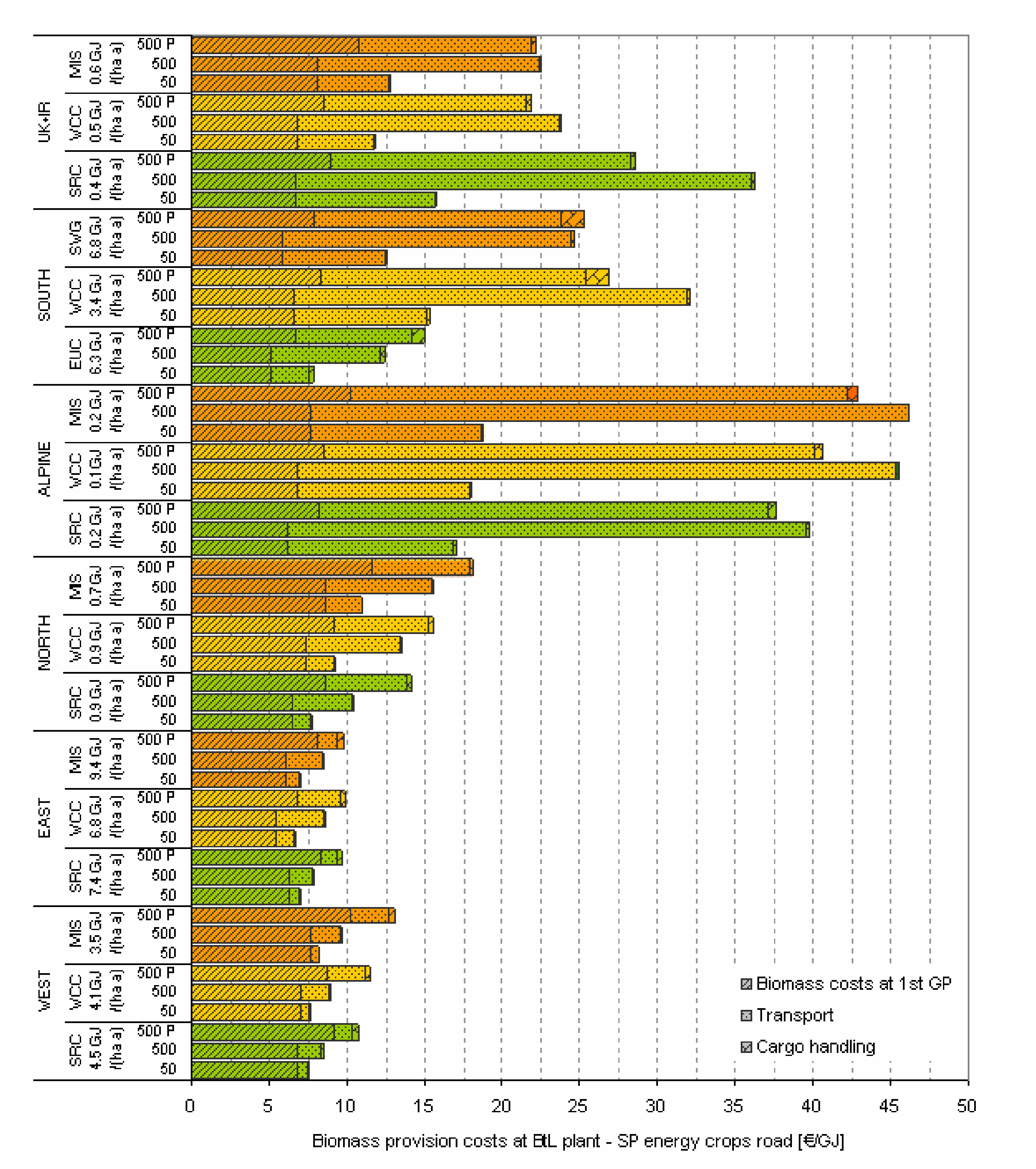

Figure 4-2 Total provision costs at BtL plant (SP) – road transport of energy crops (SRC, MIS, WCC and specific biomass potential densities according RENEW frame conditions) (LHV_{SRC} 18.8 GJ/t_d;LHV_{MIS} 18.4 GJ/t_d; LHV_{WCC} 17.2 GJ/t_d)

The most favourable biomass cost alternatives at BtL plant gate in the EU regions (according to the RENEW frame conditions) are shown in Figure 4-3. However, even in best cases total biomass provision costs for energy crops (basically SRC, in UK+IR also WCC and MISC) of more than 5 €/GJ (approx. 86 to 94 €/t_d) can accumulate.

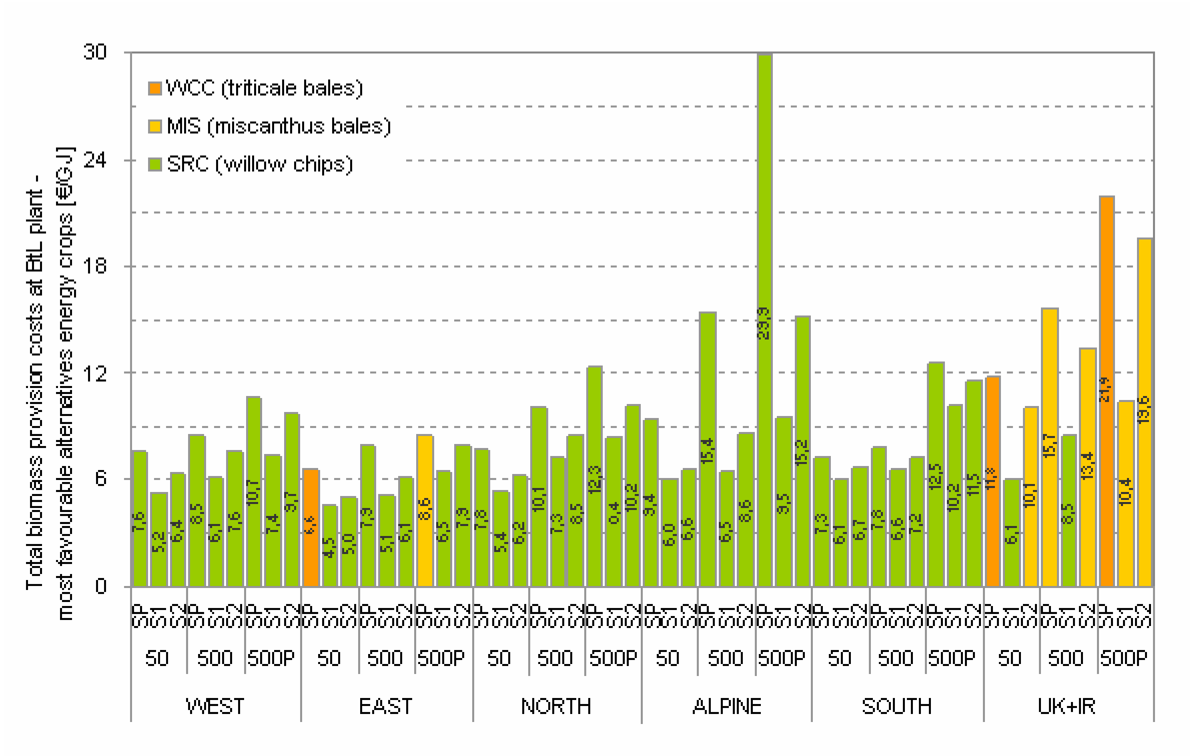

Figure 4-3 *Total provision costs at BtL plant – most favourable cost alternatives (SRC, MIS, WCC) (LHV_{SRC} 18.8 GJ/t_d;LHV_{MIS} 18.4 GJ/t_d; LHV_{WCC} 17.2 GJ/t_d*

4.3 Basic results for agricultural and forestry residues

The variation of total provision costs for agricultural (straw) and forestry residues (wood chips and bundles) is between 3 and 21 €/GJ_{LHV} (Figure 4-4) and thus lower than for energy crops. Basically the same parameter and tendencies are valid for the different regions as already discussed above for the energy crops.

Wood industry-by products market prices in the representative countries are also presented in Del. 5.3.6. The data were delivered by the WP5.3 partners with a comment that commonly the by-products are utilised at the place of origin for material or energy purposes in wood industry. The given values are in a range of 3.0 to 10.3 €/GJ for wood chips and of 1.5 to 2.2 €/GJ for saw dust.

The most favourable biomass cost alternatives at BtL plant gate in the EU regions (according to the RENEW frame conditions) are STR in WEST, EAST and SOUTH as well as WC/WB in NORTH, ALPINE and UK+IR (Figure 4-5). However, even in best cases total biomass provision costs of more than 3 €/GJ (i.e. approx. 52 to 57 €/t_d) have been calculated.

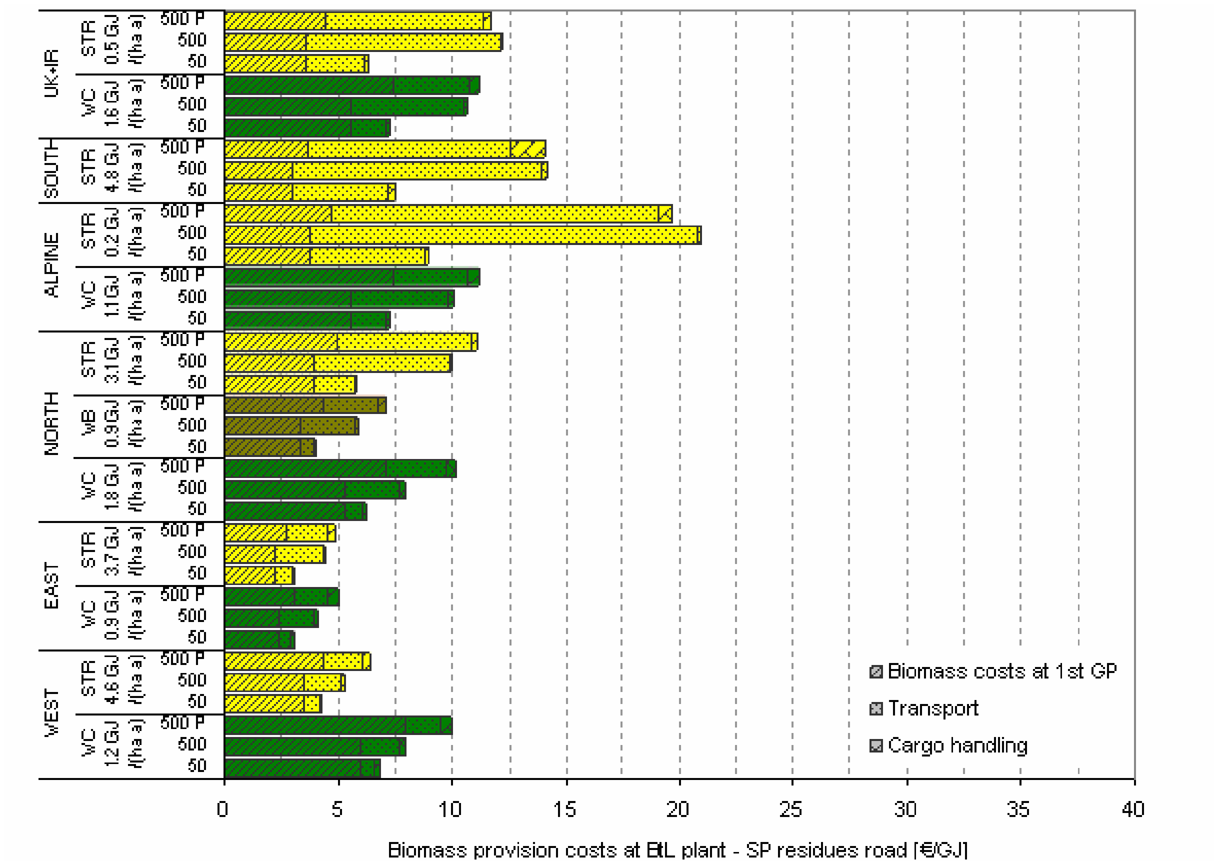

Figure 4-4 *Total provision costs at BtL plant (SP) – road transport of residues (WC/WB, STR and specific biomass potential densities according RENEW frame conditions) ($LHV_{WC/WB}$ 19.0 GJ/t_d; LHV_{STR} 17.2 GJ/t_d)*

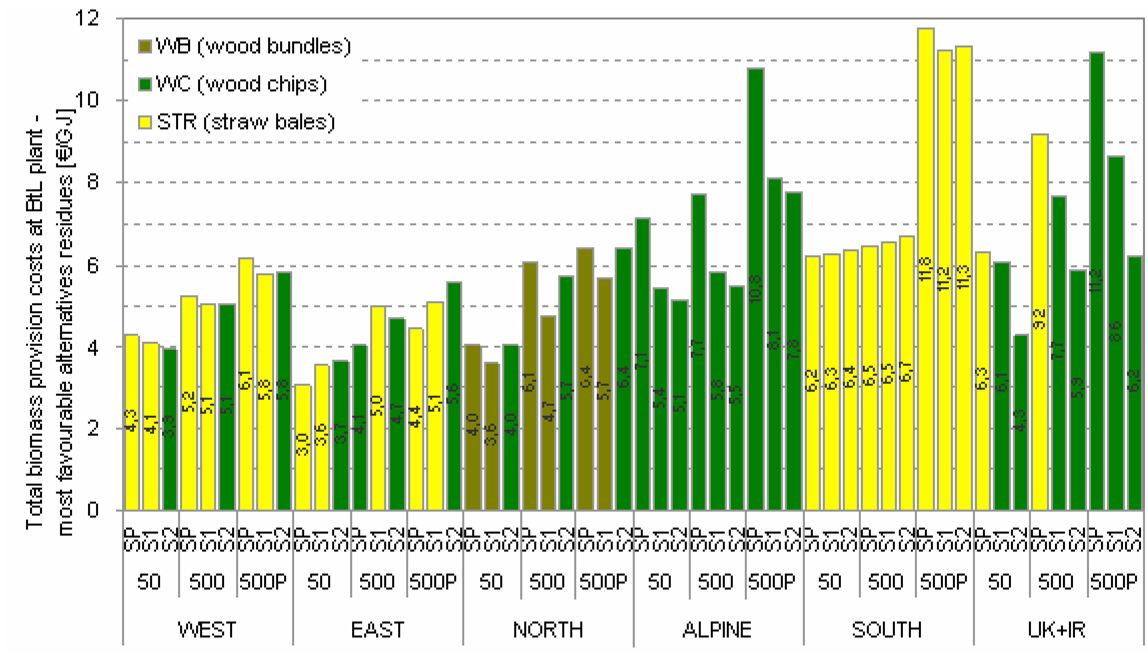

Figure 4-5 *Total provision costs at BtL plant – most favourable cost alternatives (WC/WB, STR) ($LHV_{WC/WB}$ 19.0 GJ/t_d; LHV_{STR} 17.2 GJ/t_d*

4.4 Exemplary sensitivity analysis

Direct biomass provision versus provision including pyrolysis

A comparison of total biomass provision costs for the direct provision (e.g. to a BtL plant that includes centralised pyrolysis such as cEF-D) and the provision including decentralised pyrolysis (e.g. dEF-D, cf. Table 5-2) is exemplary shown for STR and WC (both WEST, SP scenario) for different BtL plant sizes in Table 4-1. It can be seen that – according to the specific assumptions within RENEW – for the WEST region total biomass provision costs increase significantly with increasing plant sizes; however in case of 5,000 MW_{th} costs including decentralised pyrolysis are at a similar level or lower.

Table 4-1 Total biomass provision costs for direct provision vs. provision including pyrolysis (example WEST, SP)

	Total biomass provision costs [€/GJ]			
BtL plant size	500 MW_{th}	1,000 MW_{th}	2,000 MW_{th}	5,000 MW_{th}
Direct provision (road-rail-road)				
STR	5.5	5.7	6.0	6.6
WC	8.5	9.0	9.5	10.6
Provision including pyrolysis (road-pyrolysis-rail-road)				
Slurry from STR	6.2	6.3	6.4	6.7
Slurry from WC	9.9	9.9	10.1	10.2

As one can reveal from the cost increase shown in this Table 4-1 and the basic differences in total biomass provision costs (cf. Figure 4-4) e.g. in ALPINE this cost situation and thus the comparison between direct biomass provision and provision including pyrolysis can differ.

Biomass provision costs from 1st GP to BtL plant versus region specific biomass potentials

With regard to the fact that biomass provision costs from the 1st GP to the BtL decrease with increasing area or regional specific potentials exemplary sensitivity analyses were made. The results are summarised as follows for the future scenario S1 for road transport for a BtL plant of 500 MW_{th}. No significant cost differences emerge for the SP scenario. The graphs (here potential trend lines) allow the reader to estimate the provision costs from the 1st GP to the BtL production plant in different regions or provinces with area or region specific potentials that are different from the base case investigated within the RENEW frame conditions for cost assessment (cf. Final report – WP 5.1), e.g. in some of the provinces frame conditions could be that favourable that the BtL plant can be installed closed to the 1st GP.

According to this, the biomass provision costs from the 1st GP to the BtL plant significantly can be reduced in region of high biomass potentials. This is due to the decreasing transport distance per transported tonne of biomass and thus reduced transport costs (i.e. especially with regard to fuel demand and annual driven km per means of transport). However, the cost reduction is limited since the basic frame conditions (i.e. infrastructure, specific payload per means of transport and thus the number of e.g. semi trailers, cargo handling and storage demand) will be the same independent of the area or region specific biomass potential. Thus, when comparing the different European regions (represented by the defined reference countries, cf. Figure 2-2) the (partly significant) differences in provision costs still remain.

Agricultural residues. The results for straw (as reference for an herbaceous biomass transported in form of rectangle bales) are simplified shown in form of potential trend lines in Figure 4-6 (for more details, e.g. higher costs in SOUTH due to comparably low payload of straw transport vehicles, cf. D 5.3.6) including the value frame according to the basic frame conditions of the RENEW cost assessment (cf. chapter 4.1).

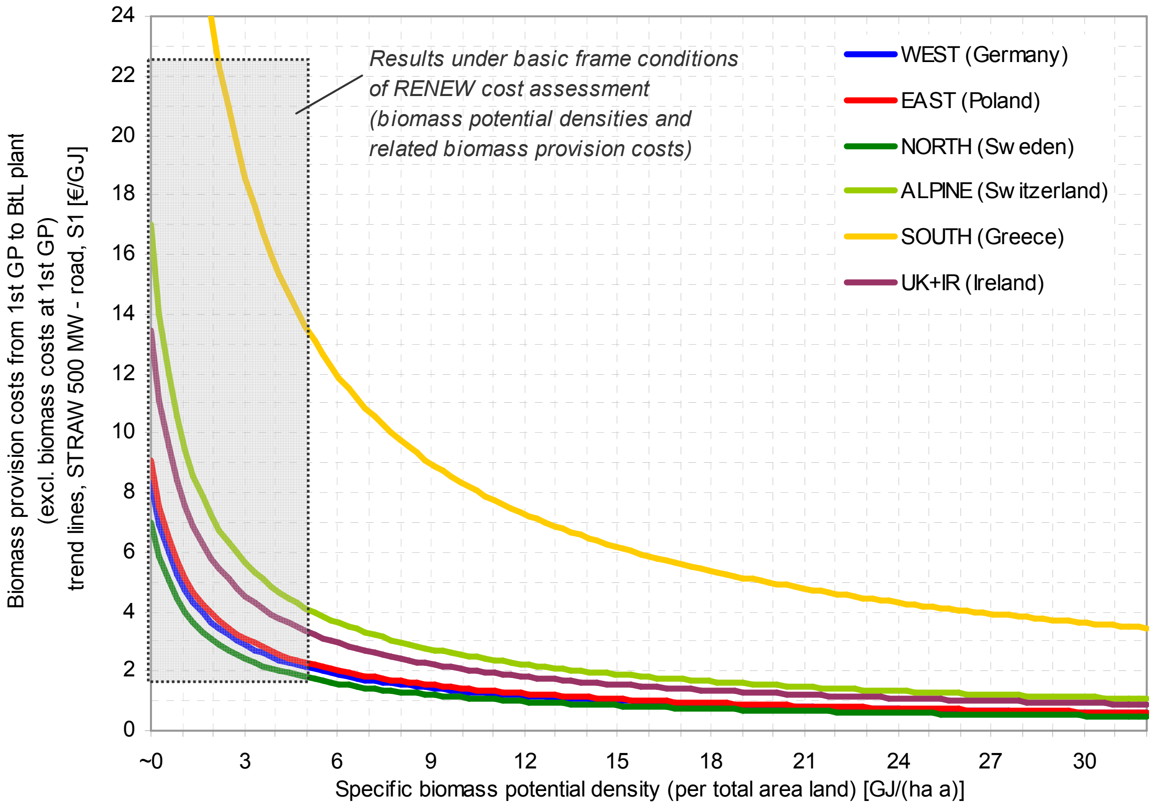

Figure 4-6 *Provision costs vs. area or region specific potentials – straw, road, S1; best specific biomass density of EU provinces > 16 GJ/(ha a)*
(LHV_{STR} 17.2 GJ/t_d)

Energy crops. The results for willow (as reference for a woody biomass transported as wood chips) are simplified shown in form of potential trend lines in Figure 4-7 (for more details cf. D 5.3.6) including the value frame according to the basic frame conditions of the RENEW cost assessment (cf. chapter 4.1).

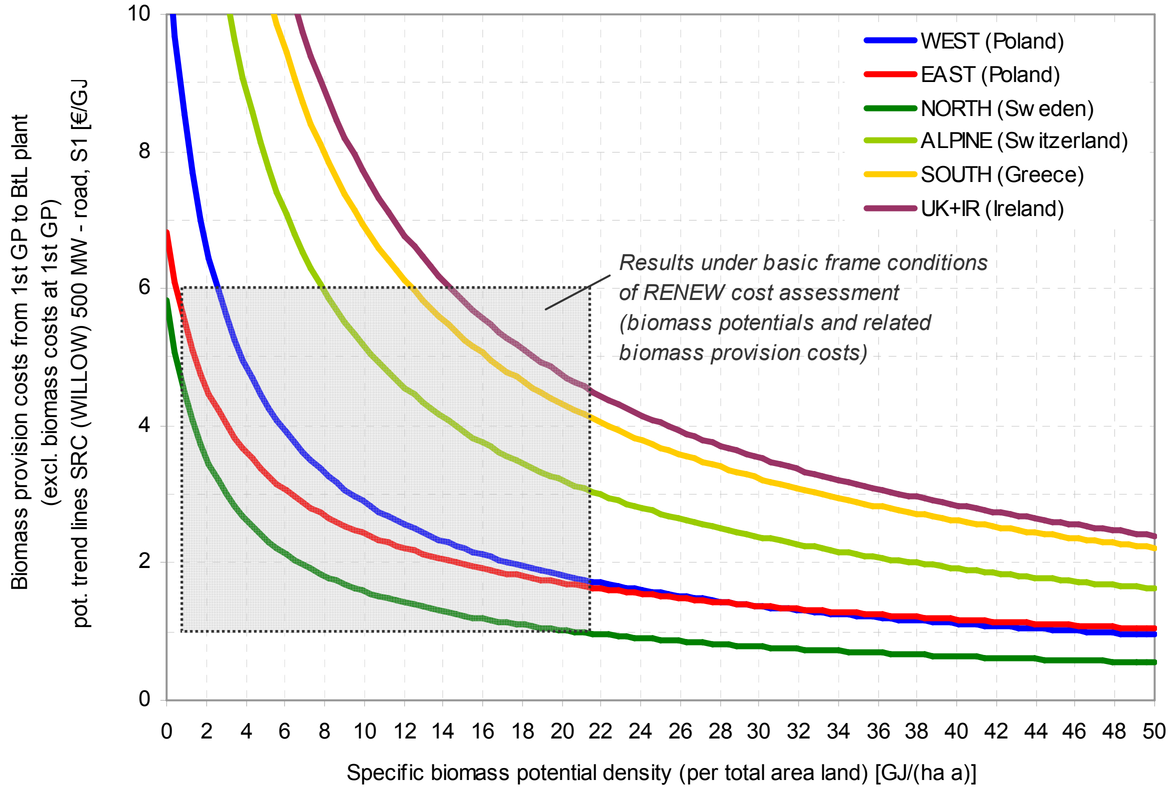

Figure 4-7 *Provision costs vs. area or region specific potentials – willow, road, S1; best specific biomass density of EU provinces > 27 GJ/(ha a)* *(LHV_{SRC} 18.8 GJ/t_d)*

5 BTL PRODUCTION COSTS

Within this section the methodology of matrix III is briefly described followed by the presentation of the basic results in form of the total BtL production costs (cf. Figure 2-1). Moreover, for exemplary sensitivity results are summarised. More detailed information as well as explanations on results can be gathered from D 5.3.7.

5.1 Methodology in brief

5.1.1 Calculation tool

An application oriented calculation model has been developed for the cost assessment. Thereby the calculation sequence follows accepted guidelines VDI 2067 and VDI 6025. Figure 5-1 shows the calculation procedure of this model. For details please see the D 5.3.2.

Based on this costs and revenues the annuities of the different costs and revenues can be determined. With regard to the annual production rate the specific fuel production costs can be calculated. As a result of this calculation an assessment of the different concepts by both economic figures (annuity and fuel production costs) is possible.

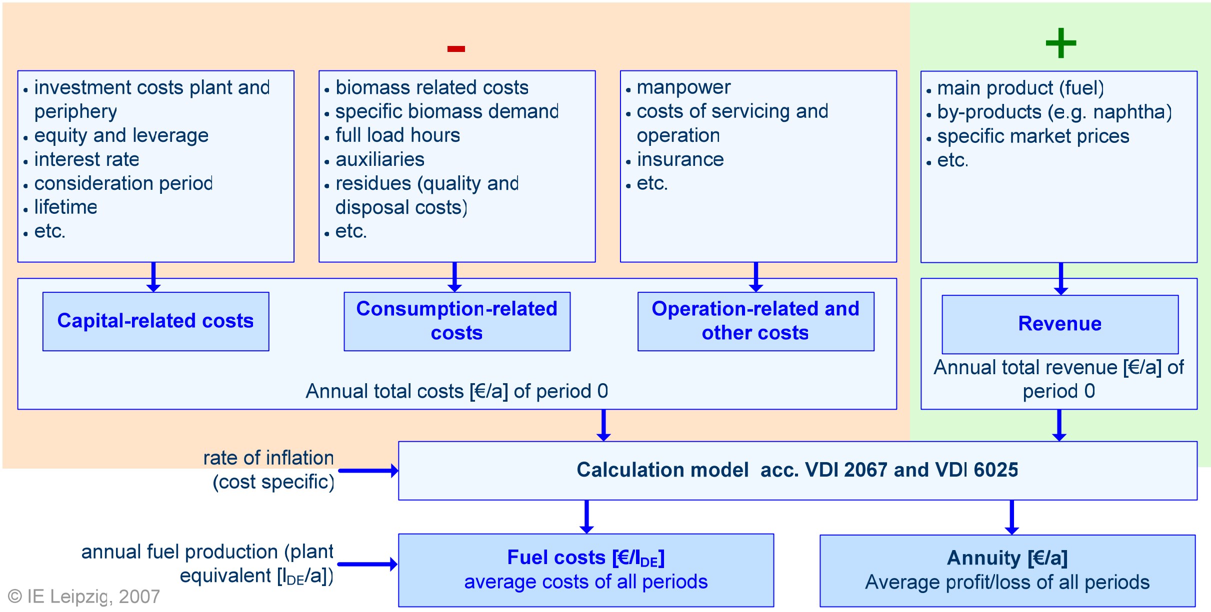

Figure 5-1 Model for cost calculation of BtL production costs

5.1.2 Frame conditions and database

For calculation, the knowledge or assumption of several framework parameters is necessary. Table 5-1 compiles the parameters used for calculation grouped into the different cost categories.

Table 5-1 Overview of framework parameters, listed for various cost categories (TCI – Total Capital Investment)

Cost parameter	Assumption at frame conditions
Capital-related costs	
Investment costs	concept specific (time horizon 2005)
Installation factor (additional costs to install single components = TCI)	1,54 (500 MW_{th}); 1,66 (50 MW_{th})
Maintenance factor	included by servicing cost
Scale factor R (for TCI)	0,7
Consumption-related costs	
Specific biomass costs	According calculation free plant gate (see chapter 4)
Full load hours	8.000 h/a
Natural gas	40 €/MWh
Electrical power	-
Oxygen	0,08 €/m³ i. N.
Operation-related costs	
Average specific personnel costs	50.000 €/a employee
Personnel costs (if no manpower demand given)	0,5 % p. a. (of investment costs)
Costs for service and operation	3 % p. a. (of investment costs)

Cost parameter	Assumption at frame conditions
Other costs	
Insurance	1 % p. a. (of TCI)
Administration	0,5 % p. a. (of TCI)
Contingencies	1 % p. a. (of TCI)
Others	0,75 % p. a. (of TCI)
Revenues for by-products	
Compensation for naphtha	400 €/t
Compensation for electricity	60 €/MWh_{el}
Compensation for heat	(30 €/MWh_{th})

In Table 5-2 the calculated concepts are summarised. They are chosen in a way that gives a representative overview about available BtL technologies, including both different input biomasses and various plant products. For details of the plant technologies please see report on technical assessment.

Table 5-2 BtL concepts – basic characteristics

Concept	cEF-D	dEF-D	BLEF-DME	EF-E	CFB-D	ICFB-D	CFB-E
Scenario	SP MF SS	SP MF SS	SP MF SS	SP MF SS	SP MF SS	SP MF SS	SP MF SS
willow	eq.SP		eq.SP	eq.SP	eq.SP	eq.SS	eq.SP
straw	eq.SP	eq.SP			eq.SP		
miscantus						eq.SS	
Biomass input power [MW]	500					50	500
Pretreatment - mech. / thermal	drying	drying		drying	drying + pelletising	drying	
- thermochemical	carbonisation	pyrolysis	residue: black liquor (pulp mill)*	torrefaction	—		
- location	plant	decentral	plant				
Gasification	EF				CFB		
	chemical quench**	quench			autothermal	allothermal	
Gas cleaning / conditioning	conventional physical absorbtion:				dedicated technologies		conventional physical absorbtion:
	Selexol	Rectisol		Selexol			Selexol
Synthesis	TFBR, Co	SBCR, Co	MeOH, DME	no information	TFBR, Fe	SBCR, Fe	no information
Upgrading	Destillation, Hydrocracking		Destillation	Destillation	external upgrading (refinery)		Destillation
Plant product	FT-Diesel		DME	Ethanol	FT-raw-product		Ethanol
Data provision by	UET	FZK	CHEMREC	ABENGOA	CUTEC	TUV	ABENGOA

LEGEND

General
c central
d decentral
BL Black Liquor

Biomass input
willow
straw
miscantus

Synthesis
TFBR Turbular Fixed Bed Reactor
SBCR Slurry Bubble Column Reactor
MeOH, DME Methanol, DME Reactor
Fe, Co Ferrum - Iron, Cobalt

BtL output
DME Dimethylether
E Ethanol
FT-D / D Fischer-Tropsch Diesel
Fischer-Tropsch raw-product

Scenario
SP starting point
MF maximum biofuel
SS self sufficient
eq. equal

Gasification
EF Entrained Flow
CFB Circulating Fluidized Bed
ICFB Internally CFB

* no explicit thermochemical conversion step: residue of pulp mill
** temperature reduction via injection of char (primarily endothermal gasification reactions)

5.2 Basic results

5.2.1 Investment costs

Total investment costs were assumed according to the method of study estimation (accuracy ± 20 to 30 %) that is based on literature and study survey taken into consideration scaling and installation factors (cf. Table 5-1). The studies costs are related to the time horizon of 2004. In Figure 5-2 the total capital investments (TCI) for the different BtL concepts with SP technology are shown in a relative comparison for the different plant areas, e.g. biomass treatment, gasification or fuel synthesis. Moreover, specific TCI related to the fuel output of the BtL plant are given.

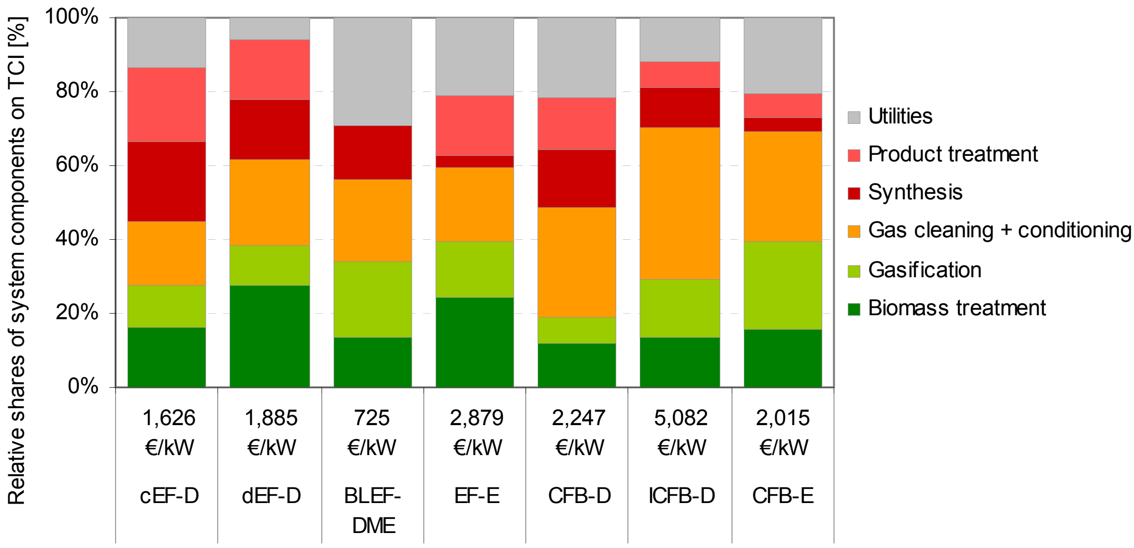

Figure 5-2 Relative shares of system components on total capital investment for the BtL concepts (2004 base)

Based on that, to substitute 4 % of the mineral oil based diesel fuel demand in the EU in 2020 approx. 49 large-scale BtL would be required which demands to a TCI demand of approx. 15 to 21 bn € under the current frame conditions.

5.2.2 Total BtL production costs based on reference biomass assortments

According to the defined concept and scenario specific biomass assortments (cf. SP5-Scenarios, Table 5-2), the relevant biomass costs and the resulting total BtL production costs are summarised in Table 5-3. They were calculated for SP technologies based on the most favourable biomass provision cost in SP and S1 scenario (cf. Figure 4-3, Figure 4-5 and D 5.3.6). Thus, costs are given for specific EU regions (approx. 16 to 63 €/GJ_{BtL}) and not for an explicit plant site in provinces where costs can diverge.

Table 5-3 *Concept specific total BtL production costs (SP-technology, SP and S1-biomass costs for reference biomass assortments)*

	cEF-D	dEF-D	CFB-D	ICFB-D[a]	BLEF-DME	CFB-E	EF-E
SP-SCENARIO							
Biomass costs – most favourable cost alternatives [€/GJ], region							
SRC (willow)	7.8 SOUTH	-	7.8 SOUTH	7.0 EAST	7.8 SOUTH	7.8 SOUTH	7.8 SOUTH
STR (straw)	4.5 EAST	4.4 EAST	4.5 EAST	-	-	-	-
MIS (miscanthus)	-	-	-	7.0 EAST	-	-	-
Total BtL production costs [€/GJ]							
based on SRC	34.0	-	52.4	62.5	21.0	58.5	71.3
based on STR	24.6	39.8	39.3	-	-	-	-
based on MIS	-	-	-	63.2	-	-	-
S1-SCENARIO							
Biomass costs – most favourable cost alternatives [€/GJ], region							
SRC (willow)	5.1 EAST	-	5.1 EAST	4.5 EAST	5.1 EAST	5.1 EAST	5.1 EAST
STR (straw)	5.0 EAST	5.1 EAST	5.0 EAST	-	-	-	-
MIS (miscanthus)	-	-	-	7.0 EAST	-	-	-
Total BtL production costs [€/GJ]							
based on SRC	26.5	-	41.2	30.0	16.1	40.9	45.9
based on STR	26.0	42.3	41.5	-	-	-	-
based on MIS	-	-	-	63.4	-	-	-

[a] plant size 50 MW_{th} (plant size of other concepts 500 MW_{th}, except dEF-D with 500 MW_{th} pyrolysis)

[b] (1 €/l_{DE}= 1 €/l / 0.0357 GJ/l_{DE}=28 €/GJ)

The cost share (biomass costs, operation-related costs, consumption-related costs and capital-related costs) differ between the technical concepts. Figure 5-3 gives a relative comparison of them using the example of SP-technology with S1 biomass costs.

It is incidental that the provision costs of biomass are the main influencing factor. Due to this fact, plant efficiency is mostly important. Furthermore, an influential cost category is also built by the capital-related costs, in this relation full load hours and availability of the plant become relevant.

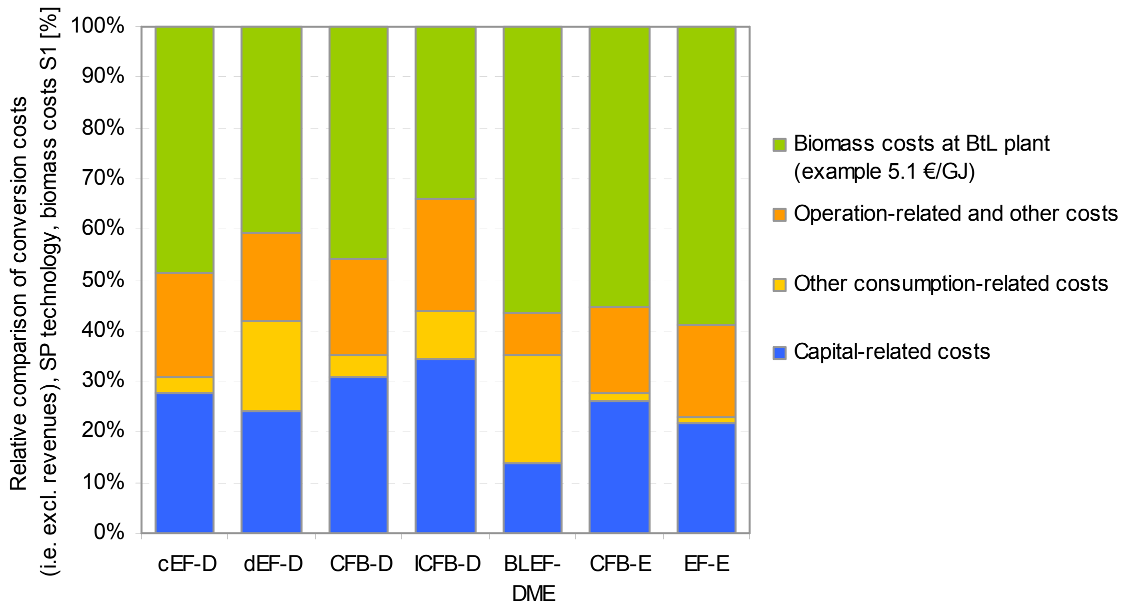

Figure 5-3 Relative comparison of concept specific BtL production costs in region EAST

5.3 Exemplary sensitivity analysis

5.3.1 Biomass costs

As shown in the following (Figure 5-4), BtL concepts with a high biomass conversion efficiency (e.g. BLEF-DME, cEF-D) will be able to produce BtL at favourable costs at a broader level of total biomass provision costs; for example to produce BtL at a cost level of up to approx. 30 €/GJ biomass provision costs for the concept cEF-D can be in a range of up to 6 €/GJ, for the concept CFB-D biomass should not cost more than 3 €/GJ. Regarding that aspects need to be taken into account (cf. D.5.4.2.4), such as that (i) the BLEF-DME concepts offers significant advantage for a specific niche application (e.g. a higher conversion efficiency of the DME synthesis compared to e.g. FT-synthesis and lower TCI for new recovery boiler in the paper mill) and (ii) the EF-E concept are based on a gross data base and thus less efficiency.

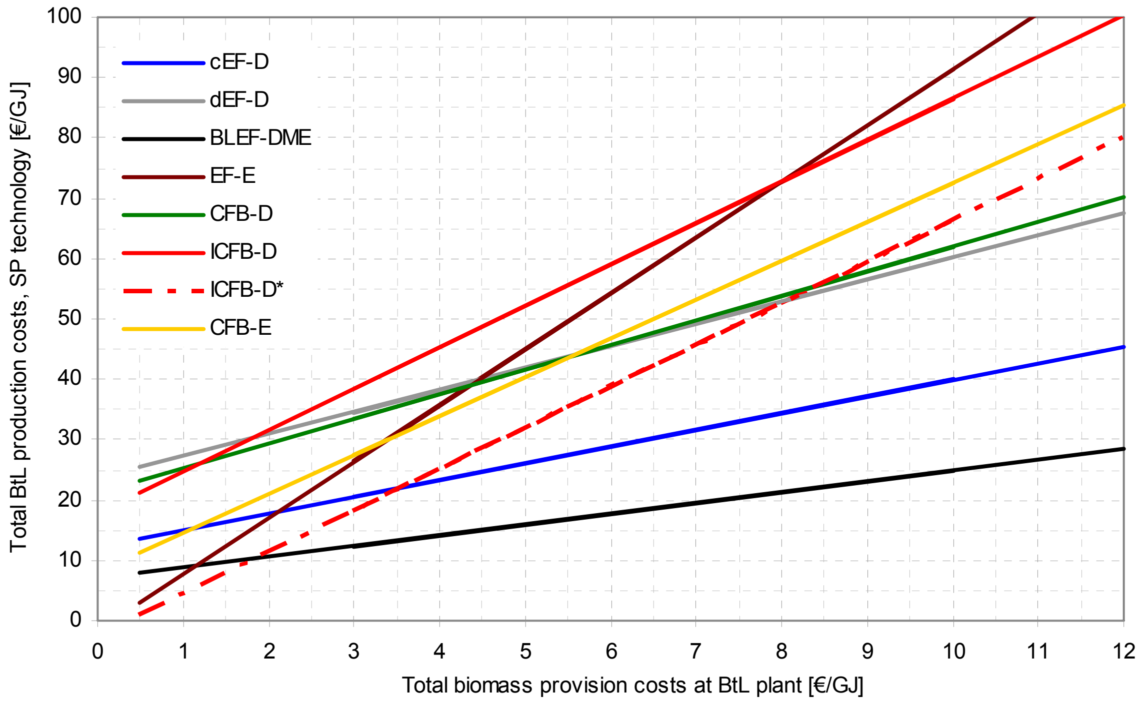

Figure 5-4 Influence of concept specific efficiency and role of biomass costs to the total BtL production costs (1 €/l_{DE}= 1 €/l / 0.0357 GJ/l_{DE}=28 €/GJ); ICFB-D - incl. revenues for surplus electricity 15 €ct/kWh_{el} (for all other concepts 6 €ct/kWh_{el} are assumed)*

If biomass provision costs change, it causes a variation in the structure of the conversion costs. With increasing biomass costs their part in the overall fuel production costs significantly increases. This behaviour is also shown in Figure 5-5.

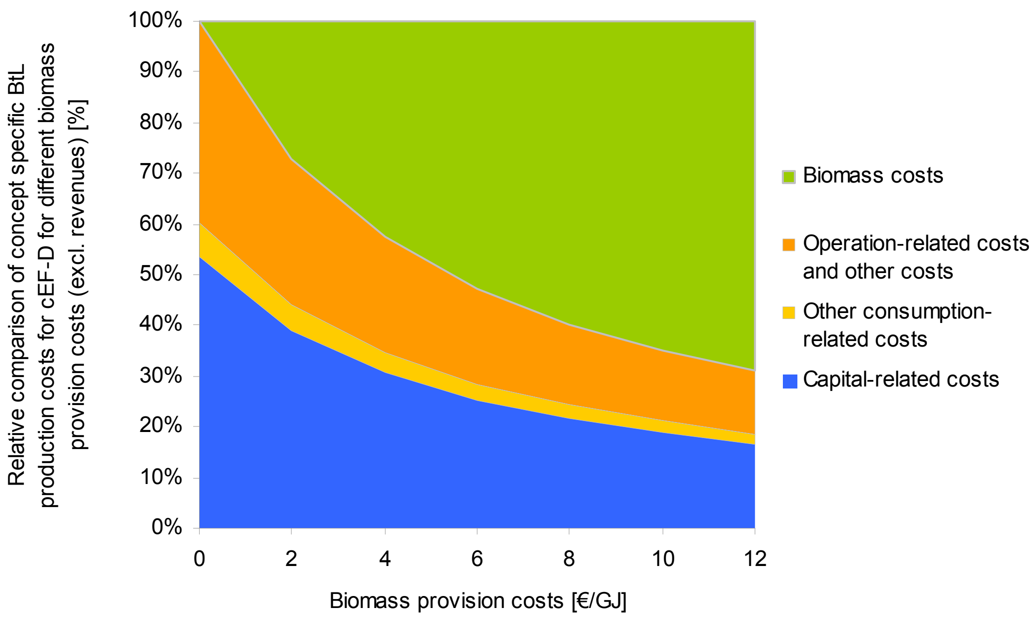

Figure 5-5 Correlation between biomass provision costs and the structure of cost categories (example cEF-D)

5.3.2 Economy of scale

By up-scaling a plant, the BtL production costs can be reduced due to effects of economy of scale. While total biomass provision costs increase with in increasing BtL plant size (cf. Table 4-1), total BtL production costs will decrease. Thus, increasing biomass provision costs can be compensated by the benefits resulting from economy of scale. In Figure 5-6 the production costs of cEF-D and dEF-D concept are exemplary calculated for the biomass assortments given in Table 4-1 for BtL plant sizes from 500 MW_{th} to 2 GW_{th} in WEST. The described correlation is valid both in the SP and S1 scenario.

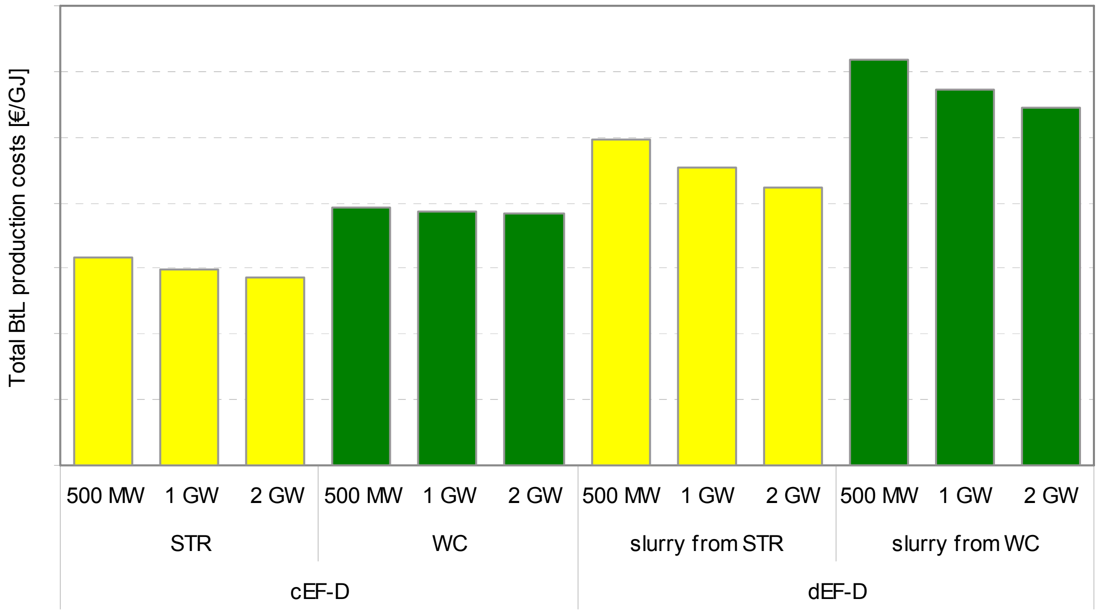

Figure 5-6 Effect of up-scaling – cEF-D versus dEF-D, SP, WEST

As already mentioned in chapter 4.4, depending on biomass availability and biomass provision costs this situation can be different (e.g. in ALPINE).

5.3.3 External hydrogen provision

In case of external hydrogen provision, the price of electricity for hydrogen electrolysis has a significant influence on the BtL production cost. Table 5-4 gives an overview of this correlation, using the cEF-D concept with standard biomass (SRC). Base case stands for cEF-D, SP, WEST.

Table 5-4 Correlation between price of electricity for hydrogen electrolysis and BtL production costs

	Base case [€/GJ]	Price of electricity for hydrogen electrolysis [€ct/kWh_{el}]		
		5	7	12
Increase in total BtL production costs compared to base case	39.4	+ 12,1 %	+ 32,6 %	+ 84,8 %

6 WELL-TO-TANK COSTS

Using the conversion cost calculations described in the paper on hand, typical distribution cost can be added to calculate the costs of biofuel free tank/free filling station. This was done in the scientific report based on typical distribution costs from the biofuel production plant to fuel station provided by the WTW study of EUCAR, CONCAWE & JRC/IES (cf. WTW, 2006). There are figures determined for every type of fuel as shown in Table 6-1. If bandwidths are given, they result out of the consideration of small-scale and large-scale plants respectively. However, when compared to total BtL production costs, specific fuel distribution costs are quite low and thus of less impact to the overall well-to-tank (WTT) costs.

Table 6-1: Typical distribution costs of biofuels [WTW, 2006]

Biofuel	FT-diesel	DME	Ethanol
Distribution costs [€/GJ]	0.4 – 0.7	0.8 – 2.2	1.0

calculation based on an crude oil price of 50 US-$/bbl

For calculating a range of so called WTT costs, for every plant concept the appropriate minimum resp. maximum distribution costs from Table 6-1 were added to the minimum resp. maximum BtL production costs of every plant concept. Thereby all European regions (cf. chapter 2) have been considered. The result is given in Figure 6-1.

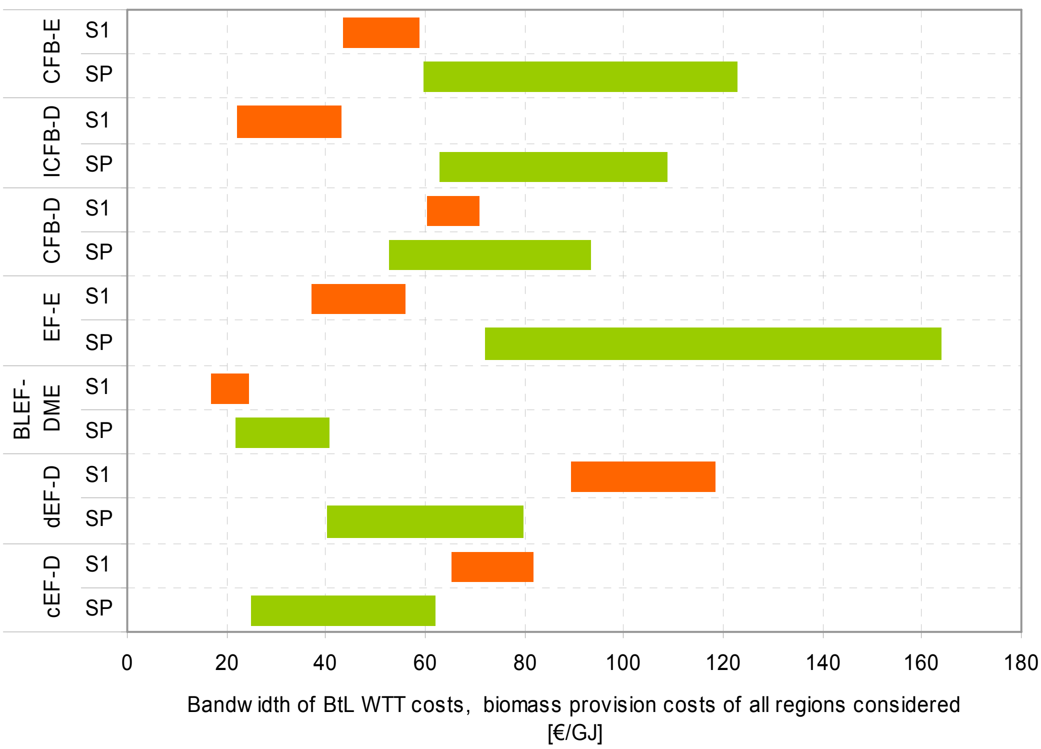

Figure 6-1: Bandwidth of BtL WTT costs over all European regions

7 CONCLUSIONS

Within RENEW project cost assessment is done in a three-stage matrix system along the BtL supply chain, i.e. (i) biomass production and provision costs to the 1st GP, (iii) biomass provision costs from the 1st GP to the BtL plant; (iv) biomass conversion costs. For the cost efficient production of BtL fuels the feedstock costs free BtL plant are one of the most important factors. The results of the different cost analysis have been summarised within this final report. From that the following conclusions can be revealed according to the specific assumptions made within the RENEW cost assessment:

* Energy crops production costs show the perspective to decrease in future.
* Total biomass provision costs (i.e. biomass costs at the 1st GP as well as provision costs from 1st GP to BtL plant) are primarily dominated by the biomass costs at the 1st GP as well as transport costs that depend on the region specific biomass potentials and regional specific infrastructure aspects; thus, high potentials results in lower costs. For the most favourable alternatives according RENEW frame conditions the costs bandwidth is approx. 3 to approximately 30 €/GJ.
* In SP straw is basically the favourable biomass in WEST, EAST, SOUTH and UK+IR; for NORTH and ALPINE the use of wood chips or bundles.
* In the majority of the European regions SRC is the most promising energy crop in terms of total provision costs at BtL plant; in UK+IR also WCC and MIS are relevant.
* For BtL production costs (i.e. accumulated costs, most favourable cost alternatives according RENEW frame conditions approx. 16 to 63 €/GJ) the conversion costs strongly depend on biomass costs and therewith on the concept specific biomass conversion efficiency. Thus, favourable options from economic point of view are plants with high conversion efficiency/process integration (e.g. BLEF-DME) and/or conversion of residues (e.g. cEF-D using straw). In future, significant cost reduction when energy crops are provided on lower cost level.
* Overall BtL costs (i.e. WTT costs) are only slightly higher than total BtL production costs due to comparably low distribution costs of 0.4 to 2.2 €/GJ.

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