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Deliverable 5 Total

Technology deployment plan

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Dissemination level

PU	Public	**X**
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the Consortium (including the Commission Services)	

Table of contents

1. Introduction

In Work package 4, the Consortium described and evaluated different reference and biorefinery cases for the 7 retained industrial sectors. The results obtained so far can be considered as ‘objective’, meaning that they are based on facts and figures gathered amongst sector specialists within and outside the Consortium.

In this work package, the Consortium will analyse the more ‘subjective’ aspects of each biorefinery case. There are three steps in doing so:

a. Technical feasibility analysis: how feasible are the proposed processes?

b. Commercial feasibility analysis: are the commercial considerations (market prices, proposed volumes…) realistic?

c. SWOT analysis: what are the strong and weak points of each case? What are the underlying trends influencing potential success?

Next to the evaluation of the subjective aspects, this work package will also cover the cross-sector analysis. By aggregating all the results of different sectors, the Consortium will also try to draw general conclusions on the addition of biorefinery cases to existing reference processes. This will lead us to a general conclusion for the project, including recommendations for the reader.

2. Methodology

2.1. Technical and commercial feasibility

To assess the technical and commercial feasibility of the different cases, the Consortium chose to work with a questionnaire.

Statements and weight factors
In a first step, a set of criteria influencing the technical and commercial feasibility was edited as statements. These statements were assessed by the Partners of the Consortium (8 respondents) according to their importance. Based on the ranking made by the responding partners, each statement received a weight factor. In both cases, the sum of the weight factors is 50.

The statements influencing the technical feasibility are clustered around the process development (required downstream processing, proof-of-concept, upscalability, safety and waste issues) and the applications development of the selected products issued from the biorefinery cases. The process development statements account for 2/3 of the total weight.

Similarly for the commercial feasibility, the statements are clustered into project characteristics (how many new products/application combinations are proposed), market characteristics, competitive advantages, social & environmental impact and regulatory impact. The competitive advantage and the social & environmental impact are the main issues. This seems logic as a commercial success depends highly on objective benefits (competitive advantage) and the perception of the product by customers/consumers (social & environmental impact).

The lists of criteria with respective weight factor are shown in Table 5.1 and 5.2.

Table 5.1 *Technical feasibility statements and respective weight factors*

Technical feasibility statements	Weight factor
Process development	
The integrated concept does not require significant downstream processing	7
All steps of the integrated concept are well identified	7
Required technologies are already developed for the targeted products	6
Required technologies are proven on industrial scale for the targeted products	6
Process does not require toxic or hazardous auxiliaries	4
The integrated concept does not generate additional waste that has to be treated	4
Application development	
Most of the selected applications are already existing	6
Products can be used in most of the selected applications	3
Products are referenced in most of the selected applications	4
Secondary products are referenced in the applications	3

Table 5.2 *Commercial feasibility statements and respective weight factors*

Commercial feasibility statements	Weight factor
Project characteristics	
The integrated concept is leading to 1 new product	1
The product(s) can be used in several applications/markets	1
Market characteristics	
The integrated project addresses existing product/market combinations	4
The addressed markets are innovative (= open for new products/concepts)	2
The targeted markets are large enough to absorb the foreseen volumes	4
Competitive advantage	
Introduction of the new product(s) will lead to an economical benefit for the user	5
The new product(s) have functional benefits	5
There are specific benefits related to the integrated concept compared to the conventional processes	4
Social & environmental impact	
The new product(s) is an alternative to fossil-based products	3
The integrated concept is not in competition with food supply	2
The integrated concept does not require large quantities of fresh water	2
The integrated concept is leading to additional renewable energy production	3
The integrated concept is ‘LCA positive’	4
The integrated concept improves the European competitive position in a global market	3
Regulatory impact	
There are no regulatory barriers affecting the market introduction of the product(s)	3
There is a supporting EU directive promoting the integrated concept	4

Definitions:

- *'Integrated concept*': one of the concepts described in WP4 (other than the reference case)
- *'Product(s)':* all products made additionally to those in the reference case; includes energy and waste as well
- *'Secondary products':* products generated inevitably by producing main product(s)
- *'Auxiliaries':* processing aids needed to come to the product(s) (like solvents, enzymes, reagents…)
- *'Downstream processing':* all process steps needed to come to the final product(s).
- *'Application':* field of usage of the product(s)
- *'LCA positive':* the concept reduced greenhouse gas emissions, energy consumption, use of hazardous auxiliaries…compared to the reference process (see WP4.3 for more details).

Questionnaire

For each separate case (biorefinery cases as defined in WP4.2) a questionnaire will be filled in.

Each statement can be answered as (= the score):

- I agree with the statement ➔ fill in '**2**'
- I'm neutral to the statement (or 'don't know') ➔ fill in '**1**'
- I disagree with the statement ➔ fill in '**0**'

Point of view: all statements were evaluated from the point of view of the state-of-the art of the technology/market, not from the perspective of a particular producer.

The limited choice between 0, 1 and 2 as possible answer has the advantage that the respondent has to make an 'educated choice'.

Technical and Commercial feasibility calculation

The technical and commercial feasibility (TF and CF) is computed as the sum of the products of the weight factor (WF) and the answer (A) for each statement.

$$\text{TF or CF} = \Sigma(WF_i \times A_i)$$

As mentioned, the sum of the weight factors is 50 and each statement can have a '0, 1 or 2' answer. Hence, the technical and commercial feasibility will vary between 0 (all answers are '0' or 'I disagree with the statement') and 100 (all answers are '2' or 'I agree with the statement'). For an easy understanding, the technical and commercial feasibility will be expressed in %.

Aggregate feasibility

For each biorefinery scheme, a questionnaire has been completed by different partners (see list in Table 5.3). The final feasibility score can be now computed as the average score given by the respondents multiplied by the weight factor.

$$TF_{total} \text{ or } CF_{total} = \Sigma_i(\Sigma_j(WF_{ij} \times A_{ij}) / \text{\# respondents})$$

where i = a particular statement and corresponding weight factor
j = a particular respondent

Depending on the sector, 3 to 6 partners completed a questionnaire.

Table 5.3 *Distribution of questionnaires according to the evaluated sectors*

Sector	Bioethanol	Biodiesel	Pulp & Paper	Oil refinery	Power production	Food	Agro
ECN	1			1	2		1
Abengoa	1						1
U Gent	1	1			1		
Bioro		1					
Innventia			1		1		
VTT			1	1	1		
Ten Kate						1	
VFT	1	1	1			1	1
Cehave	1						
Repsol				1			
AFSG	1	2	1			1	1
Total questionnaires	6	5	4	3	5	3	4

Overall feasibility

By multiplying the technical to the commercial feasibility, we obtain the overall feasibility of each biorefinery case.

Graphical representation

For a visual impression on the feasibility, a graphical representation has been proposed. On 1 chart, the technical feasibility is represented against the commercial feasibility. The chart is divided in 4 quadrants with axis crossing set at the average feasibility for the whole set of projects we are evaluating. The green area covers the zone with overall feasibility above par, the red below par.

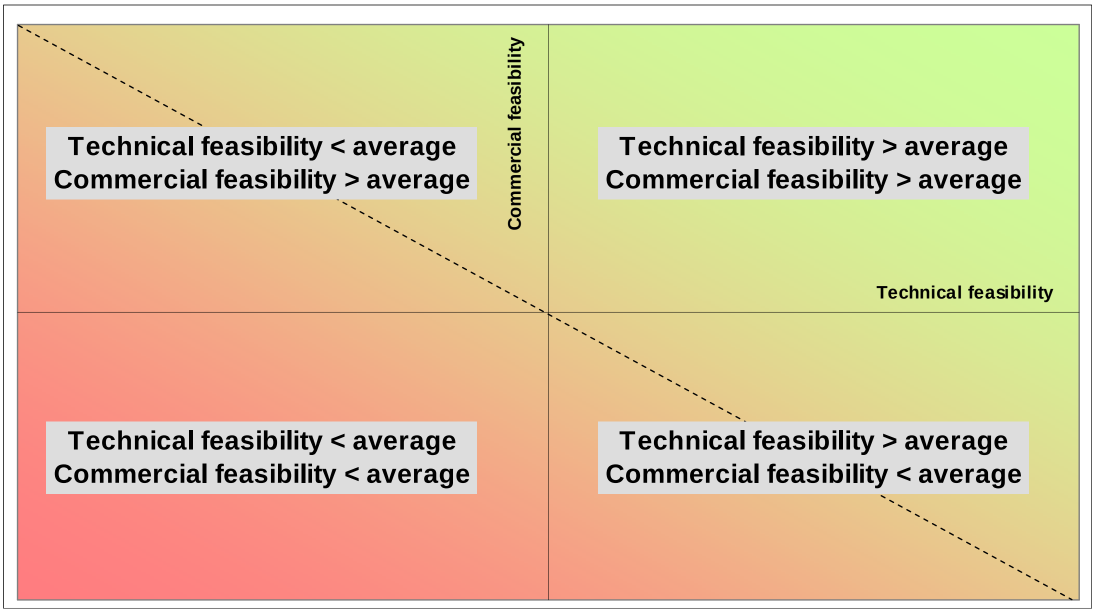

Figure 5.1 *Graphical framework for project feasibility*

2.2. SWOT analysis

Together with the questionnaires on the technical and commercial feasibility, different Partners gave input on the SWOT analysis for each biorefinery scheme.

All the comments have been brought together, clustered and summarized, to come with a comprehensive list of SWOT items. A lot of attention has been given in putting all comments in the proper SWOT category: S & W referring to the differentiating arguments for a biorefinery concept compared to the reference concept; O & T referring to the external trends affecting the biorefinery schemes. Together with the feasibility analysis, this SWOT completes the 'subjective' evaluation of the biorefinery cases.

2.3. Cross-sector analysis

Up to now (WP1, WP4, WP5.1/5.2/5.3) each biorefinery case has been compared to the reference case and possibly other biorefinery cases within the same sector. In order to find out whether more general conclusions could be drawn out of the Bioref-Integ project, it is necessary to also compare the different sectors to each other.

Impact level
In a first step, each biorefinery case has been sorted according to the impact on the reference process:

- Low impact: cases leading to a better use of a co-product
  e.g.: propanediol from glycerol (Biodiesel sector)
- Medium impact: cases leading to an alternative use of the feedstock
  e.g.: AFEX treatment of DDGS (Bioethanol sector)
- High impact: cases affecting the complete production process
  e.g.: decentralised sugar beet plants (Agro sector)

Δ sales price for Internal Rate of Return at 20%
The major difficulty in comparing the different sectors is that the projects can have a totally different dimension. Also, as we didn't consider subsidies in this project (subsidies are indeed highly versatile and different from case to case, from country to country), some projects have a negative IRR (like power production cases). For all these cases, investment analysis doesn't give us elements to compare projects to each other.

In an attempt to 'normalise' the different projects, the Consortium calculated the required sales price and corresponding delta compared to the actual sales price to obtain an IRR of 20%. This has been done for all cases, including the reference cases, and allows us to compare all projects to each other.

Remark: as there was no investment analysis done for the conventional oil refinery sector (biorefinery cases do not require an investment and are always leading to a cost increase; motivation is based on legislative drive to incorporate bio-based feedstock in transportation fuels), the IRR @ 20% analysis has not been done for this sector.

Correlation analysis
With this additional information on all projects, the Consortium made an attempt to look for correlations and trends between the impact levels / required sales price for IRR @ 20% and the technical and commercial feasibility.

3. Technical feasibility of selected biorefinery schemes (D5.1)

For each sector, the technical feasibility of the biorefinery cases will be compared to the project average (= average of all biorefinery schemes considered in the Bioref-Integ project). Main deviations from average will be highlighted (orange for below average; green for above average) and briefly commented.

3.1. Bioethanol sector

Statement	Weight factor	Bioethanol				Project average	
		Lactic		AFEX			
		Score	Weighted	Score	Weighted	Score	Weighted
Process development							
The integrated concept does not require significant downstream	7	0,3	2,3	1,2	8,2	0,8	5,8
All steps of the integrated concept are well identified	7	2,0	14,0	1,5	10,5	1,7	12,0
Required technologies are already developed	6	1,8	11,0	1,2	7,0	1,5	9,1
Required technologies are proven on industrial scale	6	1,7	10,0	0,2	1,0	0,9	5,5
Process does not require toxic or hazardous auxiliaries	4	1,5	6,0	0,8	3,3	1,6	6,2
The integrated concept does not generate additional waste	4	1,3	5,3	1,2	4,7	1,4	5,6
Application development							
Most of the selected applications are already existing	6	2,0	12,0	1,8	11,0	1,8	10,7
Products can be used in most of the selected applications	3	2,0	6,0	1,7	5,0	1,7	5,2
Products are referenced in most of the selected applications	4	1,7	6,7	1,3	5,3	1,6	6,3
Secondary products are referenced in the applications	3	1,5	4,5	1,2	3,5	1,4	4,3
Technical feasibility	50		77,8		59,5		70,7

Bioethanol + lactic acid
This case is considered more feasible than average, mainly due to the proven technologies used in this scheme. Point of attention is the need for a substantial additional downstream processing, meaning extra complexity to manage.

AFEX treatment of DDGS
AFEX treatment of DDGS is more challenging: the AFEX technology is not yet proven on industrial scale and the use of the hazardous NH_3 is also penalising the case.

3.2. Biodiesel sector

Statement	Weight factor	Biodiesel				Project average	
		PDO		ECHi			
		Score	Weighted	Score	Weighted	Score	Weighted
Process development							
The integrated concept does not require significant downstream processing	7	0,4	2,8	1,4	9,8	0,8	5,8
All steps of the integrated concept are well identified	7	1,8	12,6	1,8	12,6	1,7	12,0
Required technologies are already developed	6	1,8	10,8	2,0	12,0	1,5	9,1
Required technologies are proven on industrial scale	6	1,2	7,2	1,8	10,8	0,9	5,5
Process does not require toxic or hazardous auxiliaries	4	2,0	8,0	1,0	4,0	1,6	6,2
The integrated concept does not generate additional waste	4	1,0	4,0	0,8	3,2	1,4	5,6
Application development							
Most of the selected applications are already existing	6	1,8	10,8	2,0	12,0	1,8	10,7
Products can be used in most of the selected applications	3	2,0	6,0	2,0	6,0	1,7	5,2
Products are referenced in most of the selected applications	4	1,8	7,2	2,0	8,0	1,6	6,3
Secondary products are referenced in the applications	3	1,4	4,2	1,6	4,8	1,4	4,3
Technical feasibility	50		73,6		83,2		70,7

Glycerol to 1,3-PDO
Considered as merely an average case. The technology is considered as rather mature and benign. Main penalty comes from the significant downstream processing.

Glycerol to Epichlorohydrin (ECH)
Glycerol to ECH is well above average. This seems logic, as this is already an industrial process. This is clearly reflected in the high scores for the process feasibility. Worries mainly about safety issues (epichlorohydrin is toxic) and waste treatment.

3.3. Pulp & Paper sector

Statement	Weight factor	Pulp & Paper: Lignin Score	Lignin Weighted	DME Score	DME Weighted	Ethanol Score	Ethanol Weighted	Project average Score	Project average Weighted
Process development									
The integrated concept does not require significant downstream	7	0,8	5,3	0,0	0,0	0,3	1,8	0,8	5,8
All steps of the integrated concept are well identified	7	2,0	14,0	2,0	14,0	2,0	14,0	1,7	12,0
Required technologies are already developed	6	2,0	12,0	1,3	7,5	1,3	7,5	1,5	9,1
Required technologies are proven on industrial scale	6	1,0	6,0	0,8	4,5	0,8	4,5	0,9	5,5
Process does not require toxic or hazardous auxiliaries	4	1,5	6,0	1,8	7,0	1,8	7,0	1,6	6,2
The integrated concept does not generate additional waste	4	2,0	8,0	1,8	7,0	1,8	7,0	1,4	5,6
Application development									
Most of the selected applications are already existing	6	2,0	12,0	1,5	9,0	2,0	12,0	1,8	10,7
Products can be used in most of the selected applications	3	2,0	6,0	1,8	5,3	1,8	5,3	1,7	5,2
Products are referenced in most of the selected applications	4	1,5	6,0	1,0	4,0	2,0	8,0	1,6	6,3
Secondary products are referenced in the applications	3	1,5	4,5	1,3	3,8	1,8	5,3	1,4	4,3
Technical feasibility	50		79,8		62,0		72,3		70,7

Lignin extraction
Better than average. This process is already used on industrial scale (LignoBoost), reflected in a good score for the process definition and maturity.

Black liquor gasification to DME
Below average: although well defined, the process is not yet proven. Also the product DME is not yet fully approved in the market. But the main challenge is the significant downstream processing (and change in main process design) required to realise this scheme.

Ethanol co-production
On average. Positive is that the required process is well identified; negative are the challenges linked to lignocellulosic ethanol (second generation) and the required complex downstream processing.

3.4. Refinery sector

Statement	Weight factor	Refinery FCC Score	Refinery FCC Weighted	Refinery HDS Score	Refinery HDS Weighted	Project average Score	Project average Weighted
Process development							
The integrated concept does not require significant downstream	7	2,0	14,0	2,0	14,0	0,8	5,8
All steps of the integrated concept are well identified	7	1,7	11,7	1,7	11,7	1,7	12,0
Required technologies are already developed	6	1,7	10,0	2,0	12,0	1,5	9,1
Required technologies are proven on industrial scale	6	1,0	6,0	1,3	8,0	0,9	5,5
Process does not require toxic or hazardous auxiliaries	4	1,7	6,7	1,7	6,7	1,6	6,2
The integrated concept does not generate additional waste	4	1,3	5,3	1,3	5,3	1,4	5,6
Application development							
Most of the selected applications are already existing	6	2,0	12,0	2,0	12,0	1,8	10,7
Products can be used in most of the selected applications	3	2,0	6,0	2,0	6,0	1,7	5,2
Products are referenced in most of the selected applications	4	2,0	8,0	2,0	8,0	1,6	6,3
Secondary products are referenced in the applications	3	2,0	6,0	1,7	5,0	1,4	4,3
Technical feasibility	50		85,7		88,7		70,7

Vegetable oil in FCC unit
Highly realistic: processes well defined, no major technological challenges and … no need for additional downstream processing. Products are more or less referenced in the targeted (fuel) markets.

Vegetable oil in HDS unit
Highly realistic. Same comments as for the FCC case, with process considered even more feasible.

3.5. Power generation sector

Statement	Weight factor	Power				Project average	
		Pyrol		Chem			
		Score	Weighted	Score	Weighted	Score	Weighted
Process development							
The integrated concept does not require significant downstream	7	1,4	9,8	0,4	2,8	0,8	5,8
All steps of the integrated concept are well identified	7	1,4	9,8	1,4	9,8	1,7	12,0
Required technologies are already developed	6	1,2	7,2	1,2	7,2	1,5	9,1
Required technologies are proven on industrial scale	6	0,8	4,8	0,6	3,6	0,9	5,5
Process does not require toxic or hazardous auxiliaries	4	1,4	5,6	1,0	4,0	1,6	6,2
The integrated concept does not generate additional waste	4	1,4	5,6	1,2	4,8	1,4	5,6
Application development							
Most of the selected applications are already existing	6	1,4	8,4	1,2	7,2	1,8	10,7
Products can be used in most of the selected applications	3	1,6	4,8	1,4	4,2	1,7	5,2
Products are referenced in most of the selected applications	4	1,4	5,6	1,4	5,6	1,6	6,3
Secondary products are referenced in the applications	3	1,0	3,0	1,4	4,2	1,4	4,3
Technical feasibility	50		64,6		53,4		70,7

CHP and pyrolysis integration
Rather challenging case. The additional downstream process is not considered as a major hurdle. What is challenging is the complete design (not yet fully understood) and the proof-of-concept. Also markets for the additional products (pyrolysis oil…) are not yet fully defined.

Result can be explained by the fact that this scheme interferes significantly with the reference process.

Biomass gasification with extraction of chemicals
This is the less feasible scheme. The whole process is considered highly challenging, with a heavy downstream processing required. Also the markets for the products (mixed alcohols, tar…) are not yet understood.

This scheme is a total disruption from the reference case, explaining the poor technical feasibility score.

3.6. Food sector

Statement	Weight factor	Food Lactic Score	Food Lactic Weighted	Project average Score	Project average Weighted
Process development					
The integrated concept does not require significant downstream	7	0,0	0,0	0,8	5,8
All steps of the integrated concept are well identified	7	1,3	9,3	1,7	12,0
Required technologies are already developed	6	1,3	8,0	1,5	9,1
Required technologies are proven on industrial scale	6	0,7	4,0	0,9	5,5
Process does not require toxic or hazardous auxiliaries	4	2,0	8,0	1,6	6,2
The integrated concept does not generate additional waste	4	1,3	5,3	1,4	5,6
Application development					
Most of the selected applications are already existing	6	1,7	10,0	1,8	10,7
Products can be used in most of the selected applications	3	1,7	5,0	1,7	5,2
Products are referenced in most of the selected applications	4	1,3	5,3	1,6	6,3
Secondary products are referenced in the applications	3	1,7	5,0	1,4	4,3
Technical feasibility	50		60,0		70,7

Lactic acid production from whey
The result is below average. The significant downstream process (lactic acid fermentation and extraction plant) is a major penalty, together with the definition of the process design. Also the proof-of-concept is slightly below average.

This seems *rather surprising*, as lactic acid fermentation from lactose is a typical reaction in yoghurt. However, despite some attempts in USA and NL, there is still no industrial production of lactic acid from lactose.

3.7. Agro sector

Statement	Weight factor	Agro				Project average	
		Beet		Grass			
		Score	Weighted	Score	Weighted	Score	Weighted
Process development							
The integrated concept does not require significant downstream	7	0,8	5,3	0,8	5,3	0,8	5,8
All steps of the integrated concept are well identified	7	1,8	12,3	1,8	12,3	1,7	12,0
Required technologies are already developed	6	1,5	9,0	1,0	6,0	1,5	9,1
Required technologies are proven on industrial scale	6	1,0	6,0	0,0	0,0	0,9	5,5
Process does not require toxic or hazardous auxiliaries	4	2,0	8,0	1,8	7,0	1,6	6,2
The integrated concept does not generate additional waste	4	1,5	6,0	1,8	7,0	1,4	5,6
Application development							
Most of the selected applications are already existing	6	2,0	12,0	1,5	9,0	1,8	10,7
Products can be used in most of the selected applications	3	1,8	5,3	0,8	2,3	1,7	5,2
Products are referenced in most of the selected applications	4	1,8	7,0	0,8	3,0	1,6	6,3
Secondary products are referenced in the applications	3	1,3	3,8	1,0	3,0	1,4	4,3
Technical feasibility	50		74,5		54,8		70,7

Decentralised beet processing plants
Average case. There were no major hurdles identified, although this scheme is a significant change compared to the reference case. Basically, it is a combination of existing technologies. Some steps were abandoned, others outsourced. This explains the rather positive evaluation.

Grass biorefinery
Very challenging case, almost the most one of al projects investigated. There are two weak points: the proof-of-concept is very week and the generated products are all but referenced in the potential markets. The combination of these 2 are leading to a very low technical feasibility. As the process is in an early stage of development, more research might help to overcome some of the apparent weaknesses (proof of concept).

3.8. Overall comments

When looking at the different biorefinery schemes next to each other, it appears clearly that major deviations from the average are dealing with the process, rather than the application. Exceptions are the application challenges in the grass biorefinery case and DME case.

Within the process development, the need (or not) for significant downstream processing is determining, as well as the proof-of-concept and scalability. Safety and waste issues as well as process design are leading to fewer deviations from average.

Interestingly, for schemes including an additional fermentation step, it is the need for a complex downstream processing that is challenging, not the fermentation process itself.

Finally, the 3 biomass-to-electricity schemes (Agro (Grass refinery); Power Generation) are all poorly quoted. This could be a hint to a ‘keep it simple’ advice in this field.

4. Commercial feasibility of selected biorefinery schemes (D5.2)

For each sector, the commercial feasibility of the biorefinery cases will be compared to the project average (= average of all biorefinery schemes considered in the Bioref-Integ project). Main deviations from average will be highlighted (orange for below average; green for above average) and briefly commented.

4.1. Bioethanol sector

Statement	Weight factor	Bioethanol Lactic Score	Bioethanol Lactic Weighted	Bioethanol AFEX Score	Bioethanol AFEX Weighted	Project average Score	Project average Weighted
Project characteristics							
The integrated concept is leading to 1 new product	1	1,8	1,8	1,0	1,0	1,6	1,6
The product(s) can be used in several applications/markets	1	2,0	2,0	1,3	1,3	1,6	1,6
Market characteristics							
The integrated project addresses existing product/market combinations	4	2,0	8,0	1,7	6,7	1,8	7,3
The addressed markets are innovative (= open for new products/concepts)	2	1,5	3,0	1,2	2,3	1,4	2,7
The targeted markets are large enough to absorb the foreseen volumes	4	1,0	4,0	1,8	7,3	1,8	7,2
Competitive advantage							
Introduction of the new product(s) will lead to an economical benefit for the user	5	1,0	5,0	1,5	7,5	1,3	6,3
The new product(s) have functional benefits	5	1,0	5,0	1,5	7,5	1,1	5,4
There are specific benefits related to the integrated concept	4	1,0	4,0	1,5	6,0	1,2	4,7
Social & environmental impact							
The new product(s) is an alternative to fossil-based products	3	1,5	4,5	1,7	5,0	1,7	5,1
The integrated concept is not in competition with food supply	2	0,8	1,7	1,0	2,0	1,6	3,1
The integrated concept does not require large quantities of fresh water	2	1,0	2,0	1,5	3,0	1,5	3,1
The integrated concept is leading to additional renewable energy production	3	0,3	1,0	1,3	4,0	1,1	3,2
The integrated concept is 'LCA positive'	4	1,0	4,0	0,7	2,7	1,4	5,7
The integrated concept improves the European competitive position in a global market	3	1,3	4,0	1,5	4,5	1,6	4,8
Regulatory impact							
There are no regulatory barriers affecting the market introduction of the product(s)	3	1,5	4,5	1,0	3,0	1,4	4,1
There is a supporting EU directive promoting the integrated concept	4	0,3	1,3	1,3	5,3	1,3	5,0
Commercial feasibility	50		55,8		69,2		71,0

Bioethanol + lactic acid
Below average. Main worries are that the lactic market is not elastic enough to absorb the targeted volumes without price erosion, the lack of economical benefit (not perceived as a cheaper process) and the poor social & environmental score.

AFEX treatment of DDGS
Average scheme. The perceived competitive advantages are outbalanced by the concerns on social (food crop) & environmental impact (NH_3 issue).

4.2. Biodiesel sector

Statement	Weight factor	Biodiesel PDO Score	Biodiesel PDO Weighted	Biodiesel ECH Score	Biodiesel ECH Weighted	Project average Score	Project average Weighted
Project characteristics							
The integrated concept is leading to 1 new product	1	1,6	1,6	2,0	2,0	1,6	1,6
The product(s) can be used in several applications/markets	1	1,4	1,4	2,0	2,0	1,6	1,6
Market characteristics							
The integrated project addresses existing product/market combinations	4	2,0	8,0	2,0	8,0	1,8	7,3
The addressed markets are innovative (= open for new products/concepts)	2	1,4	2,8	1,0	2,0	1,4	2,7
The targeted markets are large enough to absorb the foreseen volumes	4	2,0	8,0	2,0	8,0	1,8	7,2
Competitive advantage							
Introduction of the new product(s) will lead to an economical benefit for the user	5	1,4	7,0	1,2	6,0	1,3	6,3
The new product(s) have functional benefits	5	1,6	8,0	1,0	5,0	1,1	5,4
There are specific benefits related to the integrated concept	4	1,8	7,2	1,6	6,4	1,2	4,7
Social & environmental impact							
The new product(s) is an alternative to fossil-based products	3	2,0	6,0	2,0	6,0	1,7	5,1
The integrated concept is not in competition with food supply	2	2,0	4,0	2,0	4,0	1,6	3,1
The integrated concept does not require large quantities of fresh water	2	1,0	2,0	2,0	4,0	1,5	3,1
The integrated concept is leading to additional renewable energy production	3	0,4	1,2	0,4	1,2	1,1	3,2
The integrated concept is 'LCA positive'	4	1,6	6,4	1,6	6,4	1,4	5,7
The integrated concept improves the European competitive position in a global market	3	1,6	4,8	1,6	4,8	1,6	4,8
Regulatory impact							
There are no regulatory barriers affecting the market introduction of the product(s)	3	1,8	5,4	1,6	4,8	1,4	4,1
There is a supporting EU directive promoting the integrated concept	4	1,2	4,8	1,2	4,8	1,3	5,0
Commercial feasibility	50		78,6		75,4		71,0

Glycerol to 1,3-PDO
Commercially attractive project, especially regarding integration benefits and functional attributes (functionality of PDO-based polyesters). Some concerns related to water needs and no benefit of production of renewable energy (missing possible subsidies!).

Glycerol to Epichlorohydrin
Slightly above average, driven by integration benefits and slightly better score on other statements.

4.3. Pulp & Paper sector

Statement	Weight factor	Pulp & Paper: Lignin Score	Lignin Weighted	DME Score	DME Weighted	Ethanol Score	Ethanol Weighted	Project average: Score	Weighted
Project characteristics									
The integrated concept is leading to 1 new product	1	2,0	2,0	2,0	2,0	1,8	1,8	1,6	1,6
The product(s) can be used in several applications/markets	1	1,5	1,5	1,8	1,8	1,5	1,5	1,6	1,6
Market characteristics									
The integrated project addresses existing product/market combinations	4	2,0	8,0	1,8	7,0	2,0	8,0	1,8	7,3
The addressed markets are innovative (= open for new products/concepts)	2	1,8	3,5	1,0	2,0	1,3	2,5	1,4	2,7
The targeted markets are large enough to absorb the foreseen volumes	4	2,0	8,0	2,0	8,0	2,0	8,0	1,8	7,2
Competitive advantage									
Introduction of the new product(s) will lead to an economical benefit for the user	5	1,8	8,8	1,5	7,5	1,3	6,3	1,3	6,3
The new product(s) have functional benefits	5	1,0	5,0	1,5	7,5	1,0	5,0	1,1	5,4
There are specific benefits related to the integrated concept	4	1,5	6,0	1,5	6,0	0,5	2,0	1,2	4,7
Social & environmental impact									
The new product(s) is an alternative to fossil-based products	3	2,0	6,0	2,0	6,0	2,0	6,0	1,7	5,1
The integrated concept is not in competition with food supply	2	2,0	4,0	2,0	4,0	2,0	4,0	1,6	3,1
The integrated concept does not require large quantities of fresh water	2	1,5	3,0	1,5	3,0	1,3	2,5	1,5	3,1
The integrated concept is leading to additional renewable energy production	3	1,5	4,5	1,5	4,5	1,0	3,0	1,1	3,2
The integrated concept is 'LCA positive'	4	1,5	6,0	1,5	6,0	1,3	5,0	1,4	5,7
The integrated concept improves the European competitive position in a global market	3	2,0	6,0	2,0	6,0	1,5	4,5	1,6	4,8
Regulatory impact									
There are no regulatory barriers affecting the market introduction of the product(s)	3	2,0	6,0	1,5	4,5	2,0	6,0	1,4	4,1
There is a supporting EU directive promoting the integrated concept	4	1,3	5,0	1,8	7,0	2,0	8,0	1,3	5,0
Commercial feasibility	50		83,3		82,8		74,0		71,0

Lignin extraction
Highly attractive project. No weak points from commercial feasibility point of view. Strong points are found on the 2 main commercial drivers: tangible competitive advantages and a positive image: renewable energy (solid fuel) without competition with food.

Black liquor gasification to DME
Highly attractive project. No weak points from commercial feasibility point of view. Strong points are found on the 2 main commercial drivers: tangible competitive advantages (attractive liquid fuel with technological benefits over bioethanol and biodiesel) and a positive image: renewable energy (liquid fuel) without competition with food. This case is also supported by EU legislation on biofuel usage.

Ethanol co-production
Rather neutral case. Positive legislative impact, but no real benefit on the main issues: competitive advantage and Social & Environmental (= perception) impact.

Question remains whether it is interesting to produce ethanol instead of pulp, seen the lower market price of ethanol. This is reflected in the weak score for 'integration benefits'.

4.4. Refinery sector

Statement	Weight factor	Refinery FCC Score	Refinery FCC Weighted	Refinery HDS Score	Refinery HDS Weighted	Project average Score	Project average Weighted
Project characteristics							
The integrated concept is leading to 1 new product	1	1,3	1,3	1,3	1,3	1,6	1,6
The product(s) can be used in several applications/markets	1	2,0	2,0	2,0	2,0	1,6	1,6
Market characteristics							
The integrated project addresses existing product/market combinations	4	2,0	8,0	2,0	8,0	1,8	7,3
The addressed markets are innovative (= open for new products/concepts)	2	1,0	2,0	1,3	2,7	1,4	2,7
The targeted markets are large enough to absorb the foreseen volumes	4	2,0	8,0	2,0	8,0	1,8	7,2
Competitive advantage							
Introduction of the new product(s) will lead to an economical benefit for the user	5	0,7	3,3	0,7	3,3	1,3	6,3
The new product(s) have functional benefits	5	0,7	3,3	0,7	3,3	1,1	5,4
There are specific benefits related to the integrated concept	4	0,0	0,0	0,0	0,0	1,2	4,7
Social & environmental impact							
The new product(s) is an alternative to fossil-based products	3	2,0	6,0	2,0	6,0	1,7	5,1
The integrated concept is not in competition with food supply	2	0,7	1,3	0,7	1,3	1,6	3,1
The integrated concept does not require large quantities of fresh water	2	1,7	3,3	1,7	3,3	1,5	3,1
The integrated concept is leading to additional renewable energy production	3	1,7	5,0	1,7	5,0	1,1	3,2
The integrated concept is 'LCA positive'	4	1,3	5,3	1,3	5,3	1,4	5,7
The integrated concept improves the European competitive position in a global market	3	1,7	5,0	1,7	5,0	1,6	4,8
Regulatory impact							
There are no regulatory barriers affecting the market introduction of the product(s)	3	1,0	3,0	1,0	3,0	1,4	4,1
There is a supporting EU directive promoting the integrated concept	4	1,7	6,7	1,7	6,7	1,3	5,0
Commercial feasibility	50		63,7		64,3		71,0

Vegetable oil in FCC unit
Commercial feasibility below par. Incorporation of vegetable oil in a conventional refinery is leading to a more expensive product. There is absolutely no integration benefit and there may be concerns about using food grade oil for fuel.

Although not fully appreciated by all respondents, there are some technical benefits in this scheme. The most important advantage is that biofuels produced from vegetable oil have improved qualities compared with the fossil ones: higher octane for "green gasoline" produced in FCC / higher cetane and lower density for "green diesel" produced in HDS. This fact could also result in an economic benefit (could result in a "premium" for quality for the biofuels produced). Although this quality premium will not compensate in any case the loss of margin in the unit.

The main drivers are the supportive legislation (blending in biofuels) and the production of renewable energy.

Vegetable oil in HDS unit
Same comments as above.

4.5. Power generation sector

Statement	Weight factor	Power: Pyrol Score	Power: Pyrol Weighted	Power: Chem Score	Power: Chem Weighted	Project average Score	Project average Weighted
Project characteristics							
The integrated concept is leading to 1 new product	1	1,6	1,6	1,2	1,2	1,6	1,6
The product(s) can be used in several applications/markets	1	1,0	1,0	1,2	1,2	1,6	1,6
Market characteristics							
The integrated project addresses existing product/market combinations	4	1,0	4,0	1,4	5,6	1,8	7,3
The addressed markets are innovative (= open for new products/concepts)	2	1,6	3,2	1,6	3,2	1,4	2,7
The targeted markets are large enough to absorb the foreseen volumes	4	1,6	6,4	1,6	6,4	1,8	7,2
Competitive advantage							
Introduction of the new product(s) will lead to an economical benefit for the user	5	0,8	4,0	0,8	4,0	1,3	6,3
The new product(s) have functional benefits	5	1,4	7,0	1,2	6,0	1,1	5,4
There are specific benefits related to the integrated concept	4	0,4	1,6	1,0	4,0	1,2	4,7
Social & environmental impact							
The new product(s) is an alternative to fossil-based products	3	1,4	4,2	1,6	4,8	1,7	5,1
The integrated concept is not in competition with food supply	2	2,0	4,0	2,0	4,0	1,6	3,1
The integrated concept does not require large quantities of fresh water	2	2,0	4,0	2,0	4,0	1,5	3,1
The integrated concept is leading to additional renewable energy production	3	1,6	4,8	1,2	3,6	1,1	3,2
The integrated concept is 'LCA positive'	4	2,0	8,0	1,8	7,2	1,4	5,7
The integrated concept improves the European competitive position in a global market	3	1,4	4,2	1,6	4,8	1,6	4,8
Regulatory impact							
There are no regulatory barriers affecting the market introduction of the product(s)	3	1,0	3,0	1,2	3,6	1,4	4,1
There is a supporting EU directive promoting the integrated concept	4	1,2	4,8	1,2	4,8	1,3	5,0
Commercial feasibility	50		65,8		68,4		71,0

CHP and pyrolysis integration
Slightly below average. This scheme is perceived as being 'LCA positive', is leading to extra renewable energy (without competition with food) and products with interesting properties (pyrolysis oil). However, this same pyrolysis oil is new to the market, and the whole case does not have a positive economical impact (see WP4.4).

Biomass gasification with extraction of chemicals
Almost perfectly neutral project. Main deviation from average is due to a negative economical impact (see WP4.4).

4.6. Food sector

Statement	Weight factor	Food Lactic Score	Food Lactic Weighted	Project average Score	Project average Weighted
Project characteristics					
The integrated concept is leading to 1 new product	1	1,3	1,3	1,6	1,6
The product(s) can be used in several applications/markets	1	2,0	2,0	1,6	1,6
Market characteristics					
The integrated project addresses existing product/market combinations	4	2,0	8,0	1,8	7,3
The addressed markets are innovative (= open for new products/concepts)	2	1,7	3,3	1,4	2,7
The targeted markets are large enough to absorb the foreseen volumes	4	1,7	6,7	1,8	7,2
Competitive advantage					
Introduction of the new product(s) will lead to an economical benefit for the user	5	1,7	8,3	1,3	6,3
The new product(s) have functional benefits	5	1,0	5,0	1,1	5,4
There are specific benefits related to the integrated concept	4	2,0	8,0	1,2	4,7
Social & environmental impact					
The new product(s) is an alternative to fossil-based products	3	1,0	3,0	1,7	5,1
The integrated concept is not in competition with food supply	2	1,3	2,7	1,6	3,1
The integrated concept does not require large quantities of fresh water	2	1,3	2,7	1,5	3,1
The integrated concept is leading to additional renewable energy production	3	0,0	0,0	1,1	3,2
The integrated concept is 'LCA positive'	4	1,3	5,3	1,4	5,7
The integrated concept improves the European competitive position in a global market	3	1,3	4,0	1,6	4,8
Regulatory impact					
There are no regulatory barriers affecting the market introduction of the product(s)	3	1,0	3,0	1,4	4,1
There is a supporting EU directive promoting the integrated concept	4	0,3	1,3	1,3	5,0
Commercial feasibility	50		64,7		71,0

Lactic acid production from whey

Slightly below average. The positive competitive advantages (this scheme has a positive effect on the cost and profitability of the main product, WP4.4) are counterbalanced by mainly legislative issues: novel food concerns for lactic acid from whey and no specific supportive legislation. Not mentioned here: the integrated case is saving on energy, as the evaporators are (partially) replaced by reverse osmosis.

Anyway, this is a rather surprising result, as lactic acid is an existing product, available in large quantities and referenced in several markets.

4.7. Agro sector

Statement	Weight factor	Agro – Beet Score	Agro – Beet Weighted	Agro – Grass Score	Agro – Grass Weighted	Project average Score	Project average Weighted
Project characteristics							
The integrated concept is leading to 1 new product	1	1,5	1,5	1,5	1,5	1,6	1,6
The product(s) can be used in several applications/markets	1	1,5	1,5	1,5	1,5	1,6	1,6
Market characteristics							
The integrated project addresses existing product/market combinations	4	2,0	8,0	1,8	7,0	1,8	7,3
The addressed markets are innovative (= open for new products/concepts)	2	1,5	3,0	1,3	2,5	1,4	2,7
The targeted markets are large enough to absorb the foreseen volumes	4	1,8	7,0	1,8	7,0	1,8	7,2
Competitive advantage							
Introduction of the new product(s) will lead to an economical benefit for the user	5	1,8	8,8	1,8	8,8	1,3	6,3
The new product(s) have functional benefits	5	0,5	2,5	1,0	5,0	1,1	5,4
There are specific benefits related to the integrated concept	4	2,0	8,0	1,8	7,0	1,2	4,7
Social & environmental impact							
The new product(s) is an alternative to fossil-based products	3	1,8	5,3	1,0	3,0	1,7	5,1
The integrated concept is not in competition with food supply	2	1,3	2,5	2,0	4,0	1,6	3,1
The integrated concept does not require large quantities of fresh water	2	1,5	3,0	1,8	3,5	1,5	3,1
The integrated concept is leading to additional renewable energy production	3	1,5	4,5	1,0	3,0	1,1	3,2
The integrated concept is 'LCA positive'	4	1,5	6,0	1,5	6,0	1,4	5,7
The integrated concept improves the European competitive position in a global market	3	2,0	6,0	1,3	3,8	1,6	4,8
Regulatory impact							
There are no regulatory barriers affecting the market introduction of the product(s)	3	1,3	3,8	1,3	3,8	1,4	4,1
There is a supporting EU directive promoting the integrated concept	4	2,0	8,0	0,5	2,0	1,3	5,0
Commercial feasibility	50		79,3		69,3		71,0

Decentralised beet processing plants
Above average project. Strong competitive benefits identified (cost impact, integration benefits), but no functional benefits; positive impact of extra renewable energy.

Grass biorefinery
Average project. Mainly positive impact related to a better cost for electricity due to the refinery case. The lower amount of renewable energy and lack of supportive legislation for this concept is compensating this.

4.8. Overall comments

As first general comment, the Consortium didn’t consider the project characteristics (# products / applications) and market characteristics (market size / elasticity, innovative character) as discriminative. All projects are scoring average on this (and the average is high, ranging from 1.4 to 1.8). This is partially also explained by the fact that no project is actually leading to substantial volumes of new products, potentially disruptive market equilibrium.

In all sectors the Consortium identified strong drivers on competitive advantage, except for the energy cases (power generation and refinery sector). For these, there seems to be a competitive *dis*advantage. Overall, the score related to competitive advantage are rather ‘neutral’ (1.3/1.1/1.2).

The ‘perception-related’ statements (Social & Environmental impact) are on average (for all projects) scoring high (1.4-1.7) except for the statement on ‘renewable energy’. This statement scores 1.1, almost neutral. This seems logic, as some projects are leading to additional renewable energy (score close to 2) and other reduce the amount of renewable energy (score close to 0) and some are neutral (score close to 1). So, this statement is highly dependent on the project type and levels out on average.

Legislation penalises a project when new regulatory approvals are needed for entering the market and are supporting a project when enforcing the use of biorefinery products. All over the project, the impact of legislation on the projects is considered as mildly positive (1.3 – 1.4 score).

5. Overall feasibility

Figure 5.2 shows the technical vs. commercial feasibility for all biorefinery schemes studied in Bioref-Integ. As explained in §2.1, the top right quadrant groups the projects with both technical and commercial feasibility above average, the bottom left those below average. Above the diagonal are those projects with overall feasibility (technical x commercial feasibility) above average; close to the diagonal the 'average' projects.

The axes are set at average throughout all projects, being 71%, both for technical as commercial feasibility.

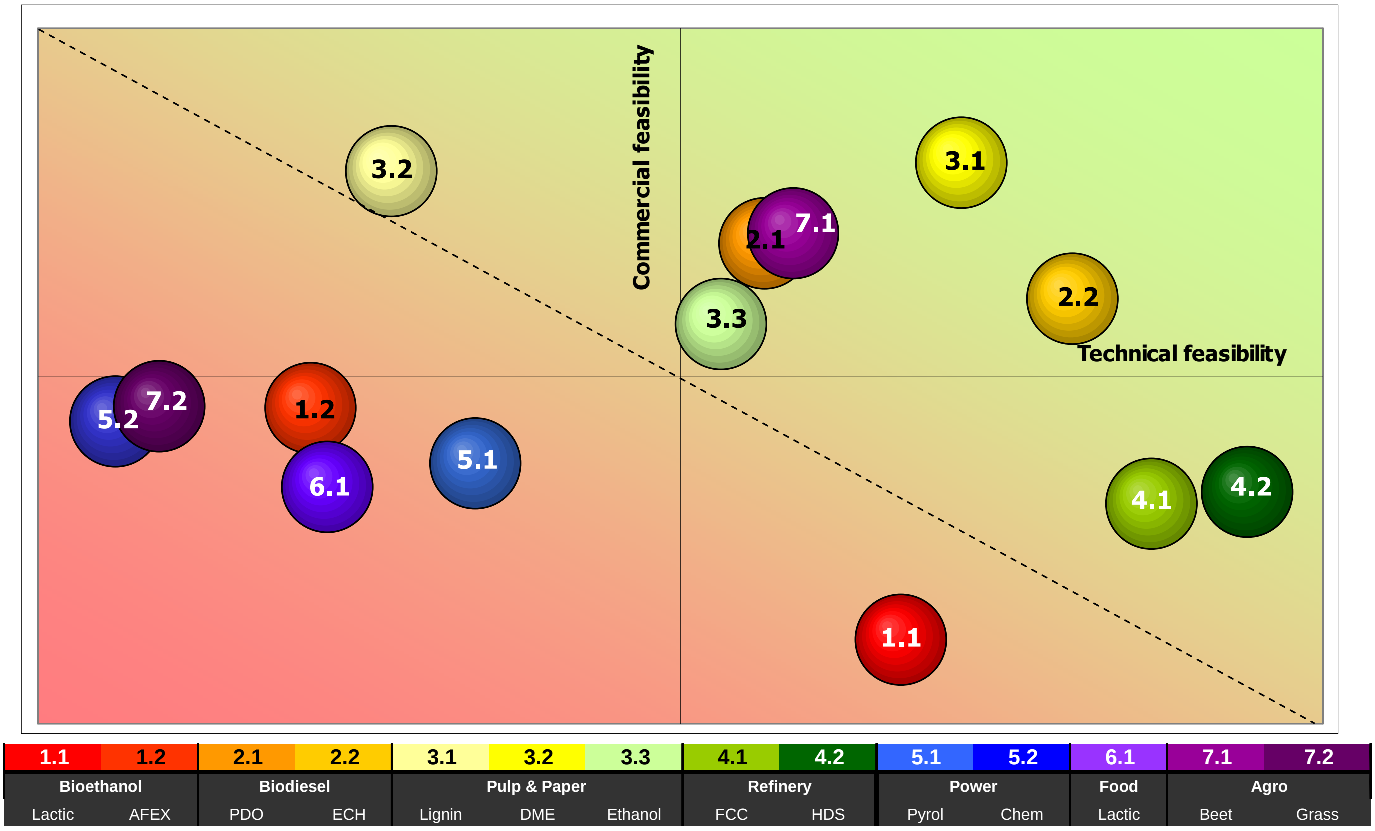

Figure 5.2 *Graphical representation of the technical, commercial and overall feasibility*

Out of this graph, we can conclude per sector:

- **Bioethanol:** both retained cases are overall below average feasibility
- **Biodiesel:** the 2 cases are in the top right quadrant of high feasibility
- **Pulp & Paper:** 3 cases from neutral to above average
- **Conventional oil refinery:** both cases technically well feasible, but commercially borderline
- **Power generation:** both cases are underperforming regarding both technical and commercial feasibility
- **Food:** the retained biorefinery case is well below average on both feasibilities
- **Agro:** this is the only sector with a positive (decentralised beet plant) and negative (grass biorefinery) case

In chapter 7, we will look at the same graph from another perspective, looking for cross-sector trends.

6. SWOT analysis of selected biorefinery schemes (D5.3)

6.1. Bioethanol sector

Ethanol + Lactic

Strength: internal; what features are improving the competitive position of the operator (compared to operators sticking to reference case)?

- Economical value:
  - More added value driven out of feedstock
- Strategic value
  - Less dependent on EU directives
  - Possibility of product flexibility in response to market conditions i.e. to vary the relative amounts of lactic acid and ethanol produced
- Lower production cost of ethanol by co-producing lactic acid.

Weaknesses: internal; what features are threatening the competitive position of the operator (compared to operators sticking to reference case)?

- Technological challenge
  - Has the use of unrefined sugars for lactic acid production already been done at industrial scale? (normally refined sugars are used)
  - Utilities (e.g. waste water treatment) may be more complex with 2 products, process integration less obvious
  - More complexity
- Cost structure
  - Costs are potentially higher for a plant with 2 different fermentation sections and corresponding downstream processing sections
  - Increased operating cost of the integrated case in comparison with the reference case
  - Increased capital investment as well.

Opportunities: external; general trends affecting the integrated concept positively

- Increasing market for lactic acid, mainly driven by bioplastics
- Lactic acid market is not dependent on EU directives (it is a ‘natural’ market)
- On the other hand, a “Bioplastic directive” could boost lactic acid demand
- Possibility to extend technology to lignocellulosic feedstocks
- Lower sensitivity to world oil market prices
- Attractive concept for investors.

Threats: external; general trends affecting the integrated concept negatively

- Novel food directive (new process)
- Market growth for lactic acid mainly driven by bioplastic: still speculative
- Higher ethanol prices will increase profitability of competitors more than profitability of integrated refinery owners
- Underestimation of capital costs
- Traces of hazardous chemicals involved in lactic acid downstream processing might cause DDGS to be a waste instead of a product.

AFEX DDGS

Strength: internal; what features are improving the competitive position of the operator (compared to operators sticking to reference case)?

- More value out of the feedstock material: more ethanol and higher DDGS price
- Contribution to meeting EU targets on biofuel consumption with less feedstock (less competition with food)
- Platform for other 2nd generation fermentations.

Weaknesses: internal; what features are threatening the competitive position of the operator (compared to operators sticking to reference case)?

- Technical feasibility
  - AFEX treatment not at industrial scale yet
  - Ethanol fermentation on other sugars than glucose, sucrose not yet developed on industrial scale
  - Safety issues with high pressure ammonia handling
- Expensive process
  - Potential high energy use and costs (for AFEX)
  - High investment.

Opportunities: external; general trends affecting the integrated concept positively

- Less competition with food supply
- Bio-ethanol from DDGS is 2nd generation ethanol which is much supported by EU
- EU Directive on biofuels
- Lower value for normal DDGS due to market saturation (this will be a problem for the competitor and to a lesser extent to the biorefinery owner, so it will increase competitiveness)
- New markets for higher quality DDGS in animal feed, possibly human food.

Threats: external; general trends affecting the integrated concept negatively

- Dependence on biofuel legislation
- AFEX DDGS not yet accepted in feed industry
- Underestimation of capital costs.

6.2. Biodiesel sector

1,3-PDO

Strength: internal; what features are improving the competitive position of the operator (compared to operators sticking to reference case)?

- High added value product out of glycerol leading to more competitive biodiesel operation
- New fermentation platform from glycerol.

Weaknesses: internal; what features are threatening the competitive position of the operator (compared to operators sticking to reference case)?

- Technical issues:
  - Fermentation based on glycerol not proven at industrial scale yet
  - Technical challenge to use crude glycerol
  - Lot of downstream processing
  - Lot of ‘waste’ / co-products
- Economical issues:
  - Investment cost: scale needs to be large enough to be economical advantageous
  - Market for 1,3-PDO is limited and depends on textile fibre development
- Strategic issues:
  - Application of PDO depends on Dupont (controls the fibre production)
  - Currently only 1 significant customer.

Opportunities: external; general trends affecting the integrated concept positively

- Low glycerol price (due to overproduction)
- Future product diversification possible (e.g. fatty acid esters of 1,3-PDO → lubricants)
- Replacing fossil-based chemicals by bio-based chemicals
- Second supplier of PDO.

Threats: external; general trends affecting the integrated concept negatively

- Dependence of Dupont patent restrictions
- Sustainability issues seed oils/palm oil
- Competition with advanced biofuels may reduce biodiesel production, hence glycerol availability
- Competition with PDO from sugars
- Success depends on acceptability of new fibre: non established target market).

Glycerol to epichlorohydrin

Strength: internal; what features are improving the competitive position of the operator (compared to operators sticking to reference case)?

- High added value product out of glycerol leading to more competitive biodiesel operation
- Stable outlet (price-wise) for glycerol towards ‘bulk’ chemical.

Weaknesses: internal; what features are threatening the competitive position of the operator (compared to operators sticking to reference case)?

- Epichlorohydrin is a toxic product
- Investment cost: large scale needed ideally
- Small scale epichlorohydrin production when integrated in (even a large) biodiesel plant
- Chemical process to implement (hazardous).

Opportunities: external; general trends affecting the integrated concept positively

- Replacing fossil-based chemicals by bio-based chemicals
- Low glycerol price (due to overproduction)
- Chemical modification of glycerol platform: further conversion potential to other products (glycidol, propylene oxide, 1,2-PG).

Threats: external; general trends affecting the integrated concept negatively

- Sustainability issues seed oils/palm oil
- Competition with advanced biofuels may reduce biodiesel production, hence glycerol availability
- Technology controlled by Solvay and Dow and operated at much larger scale.

6.3. Pulp & paper sector

Lignin

Strength: internal; what features are improving the competitive position of the operator (compared to operators sticking to reference case)?

- Technology:
    - Production of lignin in demonstration plant and end use experiments
    - Technology used is not very complicated
- Economy:
    - The economics for lignin production are promising
    - The investment costs are small
    - Pulp capacity may be increased with up to 25% by debottlenecking of the recovery boiler
- Strategy:
    - Reduction of heavy fuel oil consumption in pulp mills, where heavy oil is used. Lignin produced can be used as a lime kiln fuel.
    - The operator can export a solid biofuel (that can be stored and used when electricity price is high) or a raw material that may in the future be used for carbon fibres and chemicals.

Weaknesses: internal; what features are threatening the competitive position of the operator (compared to operators sticking to reference case)?

- Some technical risks possible in industrial production of lignin
- Less electricity export per tonne produced pulp (but balanced by solid fuel)
- Increased chemical costs
- Extra downstream processing.

Opportunities: external; general trends affecting the integrated concept positively

- Increasing oil price
- Trend towards bio-based energy
- This integrated concept does not compete with food resource
- Lignin may be used in other applications (carbon fibres or chemicals) which may increase the lignin price very much.

Threats: external; general trends affecting the integrated concept negatively

- Economical viability of the concept depends on the relative evolution of the price of electricity (as seller, incl. subsidies or as buyer), crude oil and solid fuel
- Pulp demand is decreasing which makes the capacity increase less relevant.

DME

Strength: internal; what features are improving the competitive position of the operator (compared to operators sticking to reference case)?

- Technology:
  - Gasification stage demonstrated in pilot scale (20 t/d BLG) and DME demonstration plant (500 t/d BLG) planned within a few years
  - DME is a better product than ethanol as alternative to fossil fuel
- Economy:
  - Economics of integrated concept is promising
  - Pulp capacity may be increased with up to 25% by debottlenecking of the recovery boiler
- Strategy:
  - Production of transportation fuel, and higher added value chemicals in pulp mills possible instead of only pulp and power.

Weaknesses: internal; what features are threatening the competitive position of the operator (compared to operators sticking to reference case)?

- Complex technology: more complicated process than lignin precipitation process and technical risks in industrial scale operation possible
- Large investment costs required and it may be even higher in the future
- Higher operating and maintenance costs
- Dependence on support from fuel industry.

Opportunities: external; general trends affecting the integrated concept positively

- Increasing oil price
- Trend towards bio-based energy
- This integrated concept does not compete with food resources
- Acceptance of DME by EU countries as biofuel (in addition to biodiesel and bioethanol).

Threats: external; general trends affecting the integrated concept negatively

- Economical viability of the concept depends on the relative evolution of the price of electricity (as seller, incl. subsidies or as buyer), crude oil and transport fuel
- Change in legislation on biofuels
- Hard to get someone to invest in the first plant due to the high investment cost
- Large amounts of biomass (bark) needs to be imported to keep the electricity balance, a high biomass price affects the concept’s economic outcome
- No acceptance of DME by EU countries as biofuel (in addition to biodiesel and bioethanol).

Wood ethanol

Strength: internal; what features are improving the competitive position of the operator (compared to operators sticking to reference case)?

- Technology:
    - A pilot plant is operated by SEKAB. The plan is to build a demonstration plant within 3 years that will produce 60 000 m^3 ethanol per year.
- Economy:
    - Economics of integrated concept is promising
- Strategy:
    - Production of transportation fuel in pulp mills possible instead of only pulp and power.
    - Platform for 2nd generation fermentation
    - This concept can be applied to old pulp mills.

Weaknesses: internal; what features are threatening the competitive position of the operator (compared to operators sticking to reference case)?

- Economics of production is not very promising (yield pulp-to-ethanol; value of ethanol…)
- Dependence on support from oil industry
- Less efficient process, more by-products to take care of (CO_2, organic residues).

Opportunities: external; general trends affecting the integrated concept positively

- Increasing oil price
- Trend towards bio-based energy (EU directive on biofuels)
- This integrated concept does not compete with food resources
- Pulp demand is decreasing and instead of closing a mill down, this is a good option since the investment cost will be very low and much of the equipment from the pulp mill can be used in the ethanol plant.

Threats: external; general trends affecting the integrated concept negatively

- Economical viability of the concept depends on the relative evolution of the price of electricity (as seller, incl. subsidies or as buyer), crude oil and transport fuel.
- Change in biofuel legislation
- Enzymes to hydrolyse wood to sugars still are not commercially available
- Alternative routes to biofuels from wood: C5 fermentation of black liquor, gasification/FT of wood, DME from wood via gasification.

6.4. Refinery sector

Vegetable oil in FCC

Strength:

- This route facilitates the refinery to comply with EU directives on mandatory incorporation of biofuels (2003/30/EC) and on reduction of greenhouse gases by 10% (Fuel Quality Directive)
- The existing unit operations can be used for renewable vegetable oil.
- The technical feasibility has been demonstrated on industrial scale
- Biofuels generated by the route proposed are more similar to conventional fossil fuels than the currently used biofuels (bioethanol and biodiesel).
- Some of the properties (quality) of the biofuels are improved compared to conventional fossil fuels (higher cetane and lower density for diesel and higher octane for gasoline)
- The use of the biofuels produced by co-processing does not require any modification in the current gasoline and diesel motors, even at high percentage. The automotive sector is favourable to the use of this kind of biofuels.

Weaknesses:

- Production cost is higher:
  - The price of feedstock (vegetable oil) is generally higher than fossil fuel feedstock. Only if residual feedstock (animal fat or used cooking oil) is used, the price of the feedstock could be lower
  - The cost in auxiliaries is slightly higher when vegetable oil is co-processed, compared to the processing of conventional fossil feedstock
  - There can be unpredictable costs in long term operation in commercial unit (catalyst life etc).
- Oxygen compounds introduced in a refinery process which can be input in other processes and products where they can lead to problems
- Biofuels are introduced in products where they have no commercial benefit yet.

Opportunities:

- There is a supporting EU directive (Directive 2003/30/EC) promoting the mandatory incorporation of a certain amount of biofuels in road transport fuels (5,75% in energetic value in 2010)
- There is a supporting EU directive (Fuel Quality Directive) that obliges refiners to reduce by 10% the emission of greenhouse gases (GHG) between 2011 and 2020 (compared to the emission levels of 2010).
- Europe has an important energetic dependence. The biorefinery process proposed will allow European refiners to substitute part of the fossil feedstock by a renewable feedstock. In this way, dependence of external crude oil is reduced (which is highly appreciated and promoted). The exposure to highly volatile prices of crude oil would also be reduced in this way.
- In 2020 the EU aims to increase the share of biofuels in transport fuels from 5,75% to 10% (on energetic base). Due to differences in properties of bio-ethanol and FAME biodiesel compared to fossil fuels, this 10% incorporation level will be difficult to reach. The proposed concept, however, has no technical limitations in the incorporation level.

Threats:

- There is no mechanism to compensate the higher production costs due to the use of renewable vegetable oils to the oil refinery.
- Second generation biofuels may become cheaper and more competitive than blending in oil in a conventional refinery.

Vegetable oil in HDS

Strength:

- This route facilitates the refinery to comply with EU directives on mandatory incorporation of biofuels (2003/30/EC) and on reduction of greenhouse gases by 10% (Fuel Quality Directive)
- The existing unit operations can be used for renewable vegetable oil.
- The technical feasibility has been demonstrated on industrial scale
- Biofuels generated by the route proposed are more similar to conventional fossil fuels than the currently used biofuels (bioethanol and biodiesel).
- Some of the properties (quality) of the biofuels are improved compared to conventional fossil fuels (higher cetane and lower density for diesel and higher octane for gasoline)
- The use of the biofuels produced by co-processing does not require any modification in the current gasoline and diesel motors, even at high percentage. The automotive sector is favourable to the use of this kind of biofuels.

Weaknesses:

- Production cost is higher:
  - The price of feedstock (vegetable oil) is generally higher than fossil fuel feedstock. Only if residual feedstock (animal fat or used cooking oil) is used, the price of the feedstock could be lower
  - The cost in auxiliaries is slightly higher when vegetable oil is co-processed, compared to the processing of conventional fossil feedstock
  - There can be unpredictable costs in long term operation in commercial unit (catalyst life etc.)
  - The production costs a lot of expensive hydrogen. The product may have a problem of being more expensive compared to FAME bio-diesel
- Oxygen compounds introduced in a refinery process which can be input in other processes and products where they can lead to problems
- Cold properties of “green diesel” are worse compared with fossil diesel
- Biofuels are introduced in products where they have no commercial benefit yet.

Opportunities:

- There is a supporting EU directive (Directive 2003/30/EC) promoting the mandatory incorporation of a certain amount of biofuels in road transport fuels (5,75% in energetic value in 2010)
- There is a supporting EU directive (Fuel Quality Directive) that obliges refiners to reduce by 10% the emission of greenhouse gases (GHG) between 2011 and 2020 (compared to the emission levels of 2010).
- Europe has an important energetic dependence. The biorefinery process proposed will allow European refiners to substitute part of the fossil feedstock by a renewable feedstock. In this way, dependence of external crude oil is reduced (which is highly appreciated and promoted). The exposure to highly volatile prices of crude oil would also be reduced in this way.
- In 2020 the EU aims to increase the share of biofuels in transport fuels from 5,75% to 10% (on energetic base). Due to differences in properties of bio-ethanol and FAME biodiesel compared to fossil fuels, this 10% incorporation level will be difficult to reach. The proposed concept, however, has no technical limitations in the incorporation level.

Threats:

- There is no mechanism to compensate the higher production costs due to the use of renewable vegetable oils to the oil refinery.
- Second generation of biofuels may become cheaper and more competitive than blending in oil in a conventional refinery.

6.5. Power generation sector

Fast pyrolysis

Strength: internal; what features are improving the competitive position of the operator (compared to operators sticking to reference case)?

- Remarkably smaller investment than for example in application producing Fischer-Tropsch products.
- Better product mix: liquid fuel (pyrolysis oil) in addition to heat and electricity
- Pyrolysis oil is a way to store heat and electricity (“storable heat” as invented by Vølund in the Harboøre plant) and follow the market demand in heat and electricity while maintaining full capacity
- Improved energy efficiency: flue gas and char from pyrolysis can be valorised
- Lower emissions from bio-oil compared to direct wood use in smaller-scale applications.
- Pyrolysis oil may be used as a raw material to a wide range of products with potentially high market value.

Weaknesses: internal; what features are threatening the competitive position of the operator (compared to operators sticking to reference case)?

- Upscaled process and long-term usage still to demonstrate: industrial-scale pyrolysis, use of bio-oil in fossil fuel boiler...
- More complex process
- Much higher CAPEX
- Less “green” electricity produced (but balanced by “stored energy”)
- Production of instable pyrolysis oil
- The varying quality of pyrolysis oil produced is an important bottleneck to the development of applications
- Ash is a waste stream as it is not fully converted.

Opportunities: external; general trends affecting the integrated concept positively

- Increasing oil price
- Trend towards bio-based energy
- This integrated concept does not compete with food resource
- Can be used as second generation biofuel after refining (supported by EU).

Threats: external; general trends affecting the integrated concept negatively

- The demand for green electricity may increase in the future, while this concept produces less green electricity
- Competition with other bio-oil products, for example with rapeseed oil, palm oil or their derivatives
- Competition of alternative processes such as indirect gasification and combustion
- Pyrolysis oil is unstable and can be mutagenic and carcinogenic.

Chemical recovery

Strength: internal; what features are improving the competitive position of the operator (compared to operators sticking to reference case)?

- Increased return because of production of high added value chemicals
- Production of (bio-based) chemicals with already existing high market value
- Scalability
- Possibility to follow the market demand in heat and electricity while maintaining full capacity.

Weaknesses: internal; what features are threatening the competitive position of the operator (compared to operators sticking to reference case)?

- Unproven technology:
    - Combination of numerous individually proven, though integrated not yet proven, technologies
    - Combination of low pressure processes upstream and high pressure processes downstream
    - Many separation units needed
    - Even the reference case is not commercially proven technology. No demonstration of the whole process.
- Expensive infrastructure
- Chemical extraction at low yield and low volumes
- Complex concept: many products to manage, many processes to integrate.

Opportunities: external; general trends affecting the integrated concept positively

- Increasing oil price
- Trend towards bio-based energy and products/chemicals
- This integrated concept does not compete with food resource
- The mixed alcohols can be used as 2nd generation biofuels (supported by EU)
- Possibility for integration with existing chemical industries
- Development of pressurised gasification systems.

Threats: external; general trends affecting the integrated concept negatively

- The demand for green electricity may increase in the future, while this concept produce less green electricity
- Quality control of the chemicals
- Alternative processes: production of (fine) chemicals via biochemical biorefineries
- Possible issue with REACH.

6.6. Food sector

Lactic acid from whey

Strength: internal; what features are improving the competitive position of the operator (compared to operators sticking to reference case)?

- Mainly economical benefits: high value potential for lactose and whey proteins
- Products supplied to existing markets
- Lower non renewable heat demand.

Weaknesses: internal; what features are threatening the competitive position of the operator (compared to operators sticking to reference case)?

- High CAPEX
- Complex downstream processing
- Technical risks: membrane processes will suffer from fouling problems. The degree of fouling is not yet known.

Opportunities: external; general trends affecting the integrated concept positively

- EU directive on renewable materials can drive demand for bioplastics / PLA / lactic acid
- Cheaper production of lactic acid?
- Worldwide shortage on phosphates ($CaHPO_4$).

Threats: external; general trends affecting the integrated concept negatively

- High fluctuation in whey market
- Developments of world market on lactic acid
- Collapse of renewable material market due to scepticism of consumer
- Regulatory status? New process may lead to Novel Food application.

6.7. Agro sector

Decentralised beet refinery

Strength: internal; what features are improving the competitive position of the operator (compared to operators sticking to reference case)?

- Value maximisation, both in the plant as on the land
- Product diversification = risk spreading
- Additional 2nd generation feedstock supply; especially favourable for farming cooperatives operating beet sugar plants / refineries
- Process-related benefits:
  - Better utilisation of installations compared to only sugar beet processing leads to lower production costs/higher revenues
  - Less transport costs
  - Less downstream processing
  - Less waste.

Weaknesses: internal; what features are threatening the competitive position of the operator (compared to operators sticking to reference case)?

- Technology:
  - Complex scheme, that has to be balanced
  - Ethanol production of sugars from beet pulp (pectin, hemicellulose…) is under development and has not been proven
  - Fractionation technology probably not proven at industrial scale yet; need further R&D
  - Increased operating cost
- Strategy:
  - Outsourcing of ethanol production and anaerobic digestion may form a commercial risk i.e. price to be paid for pulp, molasses may fluctuate
  - Less added value at the sugar plant, more added value at farm
  - Some current installations will be abandoned (very fast depreciation of equipment needed)
- Specification of protein meal and position in market not yet known
- Dependence on environmental conditions during cultivation.

Opportunities: external; general trends affecting the integrated concept positively

- Bio-energy, biofuels demand
- Ethanol from beet pulp may be considered as 2nd generation?
- Increasing demand for ‘green’ products
- Concept open to new application of products, especially proteins.

Threats: external; general trends affecting the integrated concept negatively

- Whole operation highly depending on legislation that can change
- Current outlet of beet pulp as animal feed product is reasonably good
- To some extent competition with food and/or feed production
- Farmers might become independent of central processing facility (intermediate products are more easily transported to alternative factories)
- Competition with conventional heat and power production
- Enough volume to enter the market?

Grass refinery

Strength: internal; what features are improving the competitive position of the operator (compared to operators sticking to reference case)?

- Economical factors:
  - Cheap feedstock
  - High added value potential
  - Plant might be profitable even without subsidies (whereas anaerobic digestion reference case will never be profitable)
- Strategic factors:
  - Platform towards non-energetic products (business development).

Weaknesses: internal; what features are threatening the competitive position of the operator (compared to operators sticking to reference case)?

- Technology and operation:
  - Technology not yet proven
  - Extraction plant idle 75% of the time
- Economy and market:
  - Logistic cost (supply of grass to the biorefinery)
  - Reduction of electricity per volume of anaerobic digester
  - Fibre prices are currently low
  - No established market for products protein meal and especially for fibres (the lack of outlet for fibres has proved to be critical in previous grass biorefinery commercialization efforts e.g. by AVEBE)
- Regulatory:
  - Proteins need to be approved
  - Specification of protein meal and position in market not yet known
- Dependence on environmental conditions during cultivation and harvesting.

Opportunities: external; general trends affecting the integrated concept positively

- Cheap 2^{nd} generation feedstock, no direct interference with food production
- Simple, sustainable concept that could be highly appealing to the general public
- Good environmental profile expected
- High future phosphate prices might increase profitability of further refinery
- Allowance for digestate instead of nitrogen/phosphate fertilizer would increase value of digestate
- Possibilities for purification of minerals from grass, thus decreasing mineral load on agricultural area.

Threats: external; general trends affecting the integrated concept negatively

- Cut down of subsidies
- Quality control of final product (proteins)
- Volume large enough to enter the market? (Electricity).

7. Cross-sector analysis

The methodology used in this chapter is described in § 2.3.

7.1. Impact level

Depending on the impact of the biorefinery case on the overall reference process, all biorefinery cases were clustered into three categories.

Low impact cases:
- Bioethanol, coproduction of lactic acid
- Biodiesel, glycerol to 1,3-PDO
- Biodiesel, glycerol to epichlorohydrin
- Pulp & Paper, lignin extraction
- Food, lactic acid from whey.

Basically, most of these cases are dealing with a better use of a co-product of the reference case. Any problem occurring in running these projects has no impact on the production of the main product.

Medium impact cases:
- Bioethanol, AFEX treatment of DDGS
- Pulp & Paper, DME production
- Pulp & Paper, ethanol co-production.

These cases have some impact on the reference process, by changing the mass balances of the main feedstock-to-main product route or the reference co-product treatment. Problems in running these cases have some impact on the main product production.

High impact cases:
- Refinery, vegetable oil in FCC and HDS
- Power generation, combined CHP and pyrolyser
- Power generation, biomass gasification and chemical extraction
- Agro, decentralised beet refineries
- Agro, grass biorefinery.

These cases profoundly modify the reference case. Problems in operating these processes will have a huge to dramatic impact on the whole plant, possibly leading to production stop.

7.2. IRR = 20%

In WP4.4, the IRR and payback time of the different projects (reference cases and biorefinery cases have been computed. Several cases had a negative IRR, with payback time exceeding 12 years, which made it difficult to discriminate such projects from each other.

Targeted investment analysis
In order to normalise the different projects to each other, the minimal sales price to reach a 20% IRR has been computed within WP5. This 20% IRR corresponds to an acceptable return on investment and a +/- 5 years payback time.

The required sales price can be considered as a target for sales teams or as a combination of the market price and possible subsidies (subsidies have been discarded in this project due to their regional specificity).

Table 5.4 *Calculation of required sales price for IRR = 20%*

IRR 20% analysis	Current market price	Required sales price increase	New target sales price	% change vs market price	Main product cost (WP4,2)
Bioethanol: reference	€800/T	-€25/T	€775/T	**-3%**	**€628/T**
Bioethanol: lactic	€800/T	-€255/T	€545/T	**-32%**	**€368/T**
Bioethanol AFEX 80	€800/T	-€90/T	€710/T	**-11%**	**€577/T**
Biodiesel: reference	€700/T	€65/T	€765/T	**9%**	**€726/T**
Biodiesel: PDO	€700/T	€115/T	€815/T	**16%**	**€732/T**
Biodiesel: ECH	€700/T	€35/T	€735/T	**5%**	**€668/T**
Pulp & Paper: reference	€500/T	€130/T	€630/T	**26%**	**€398/T**
Pulp & Paper: lignin	€500/T	€50/T	€550/T	**10%**	**€347/T**
Pulp & Paper: DME	€500/T	€210/T	€710/T	**42%**	**€367/T**
Pulp & Paper: ethanol	€500/T	€490/T	€990/T	**98%**	**€586/T**
Refinery: reference FCC	n.a.	n.a.	n.a.	**n.a.**	**330**
Refinery: veg. oil in FCC	n.a.	n.a.	n.a.	**n.a.**	**370**
Refinery: reference HDS	n.a.	n.a.	n.a.	**n.a.**	**380**
Refinery: veg. oil in HDS	n.a.	n.a.	n.a.	**n.a.**	**415**
Power: reference CHP	€50/MWh	€100/MWh	€150/MWh	**200%**	**€60/MWh**
Power: CHP/pyrolyse	€50/MWh	€135/MWh	€185/MWh	**270%**	**€88/MWh**
Power: reference gasification	€50/MWh	€60/MWh	€110/MWh	**120%**	**€74/MWh**
Power: gasification/chemicals	€50/MWh	€150/MWh	€200/MWh	**300%**	**€48/MWh**
Food: reference	€2.250/T	€0/T	€2.250/T	**0%**	**€1.916/T**
Food: lactic	€2.250/T	-€205/T	€2.045/T	**-9%**	**€1.441/T**
Agro: reference beet	€400/T	€30/T	€430/T	**8%**	**€329/T**
Agro: decentralised beet	€400/T	-€15/T	€385/T	**-4%**	**€252/T**
Agro: reference grass	€50/MWh	€230/MWh	€280/MWh	**460%**	**€177/MWh**
Agro: grass biorefinery	€50/MWh	€280/MWh	€330/MWh	**560%**	**€171/MWh**

Looking at the projects from this perspective gives a slightly different view than the product cost analysis as done in WP4 (right column in table 5.4).

For a good understanding, colour codes used in table 5.4 are:

- **Black** for reference cases
- **Green** for improvement compared to reference
- **Red** for worse compared to reference.

As mentioned earlier, IRR analysis could not be done for the refinery cases, as no extra investment was needed and the operating cost in all cases was higher than reference.

As first remark, and as validation of the whole calculation, it appears that the required additional price for electricity cases (Power generation / Agro, grass refinery) is quite in line with the subsidies granted for green electricity in the Netherlands.

Bioethanol:
Both bioethanol cases are an improvement compared to the reference case. This can give an edge to bioethanol producers, to preserve a sustainable profitability in case of fluctuations in feedstock price and crude oil benchmark.

Biodiesel:
For biodiesel, the cases are only dealing with a better –integrated- valorisation of glycerol. Depending on the case, this can improve the overall profitability of a biodiesel plant.

Pulp & Paper:
Here we have a first discrepancy between a simple cost calculation and a targeted investment analysis: the DME case reduces the pulp cost, but the profitability –with the current assumptions (see WP4.1/4.2)- is worse than the reference case. Probably that mixed solutions, including a recovery boiler and a gasifier, resulting in a debottlenecking of the pulp mill, with capacity increase as consequence (see lignin case) can improve the DME case.

Power generation:
None of the proposed biorefinery cases are improving the profitability of the reference cases. The targeted investment analysis revealed that even in the gasification/chemicals case, a lower product cost compared to reference case is not sufficient for a profitable process.

The message for thermal treatment of biomass seems to be double:

- Next to electricity, it is recommended to have a valuable outlet for heat
- Keep it simple! Making the downstream complex does not improve the profitability.

Food:
Simple case, in correlation with the cost analysis.

Agro:
Especially for the grass biorefinery, we want to refer to the recommendations of the Power sector: simplicity is the message. Alternatively, increasing the amount of products extracted from grass at the expense of electricity can also improve the picture.

7.3. Correlation analysis

Finally, bringing all data together, both objective data as subjective ones (feasibility, SWOT), will complete the evaluation of the biorefinery cases and will allow for a 'cross sector' analysis.

Table 5.5 is giving a complete overview of the discriminating criteria for each reference and corresponding biorefinery cases.

Colour code: Subjective criteria; **Green**: above average
Orange: average
Red: below average
Objective criteria: **Black**: reference cases
Green: improvement compared to reference
Red: worse compared to reference.

Table 5.5 *Subjective and objective criteria*

	Subjective criteria			Objective criteria	
	Impact level	Technical feasibility	Commercial feasibility	New target sales price (for IRR 20%)	% change vs market price (for IRR 20%)
Bioethanol: reference				€775/T ethanol	**-3%**
Bioethanol: lactic	Low	**78%**	**56%**	€545/T ethanol	**-32%**
Bioethanol AFEX 80	Medium	**60%**	**69%**	€710/T ethanol	**-11%**
Biodiesel: reference				€765/T biodiesel	**9%**
Biodiesel: PDO	Low	**74%**	**79%**	€815/T biodiesel	**16%**
Biodiesel: ECH	Low	**83%**	**75%**	€735/T biodiesel	**5%**
Pulp & Paper: reference				€630/T pulp	**26%**
Pulp & Paper: lignin	Low	**80%**	**83%**	€550/T pulp	**10%**
Pulp & Paper: DME	Medium	**62%**	**83%**	€710/T pulp	**42%**
Pulp & Paper: ethanol	Medium	**72%**	**74%**	€990/T pulp	**98%**
Refinery: reference FCC				n.a.	**n.a.**
Refinery: veg. oil in FCC	High	**86%**	**64%**	n.a.	**n.a.**
Refinery: reference HDS				n.a.	**n.a.**
Refinery: veg. oil in HDS	High	**89%**	**64%**	n.a.	**n.a.**
Power: reference CHP				€150/MWh	**200%**
Power: CHP/pyrolyse	High	**65%**	**66%**	€185/MWh	**270%**
Power: reference gasification				€110/MWh	**120%**
Power: gasification/chemicals	High	**53%**	**68%**	€200/MWh	**300%**
Food: reference				€2.250/T cheese	**0%**
Food: lactic	Low	**60%**	**65%**	€2.050/T cheese	**-9%**
Agro: reference beet				€430/T sugar	**8%**
Agro: decentralised beet	High	**75%**	**79%**	€385/T sugar	**-4%**
Agro: reference grass				€280/MWh	**460%**
Agro: grass biorefinery	High	**55%**	**69%**	€330/MWh	**560%**

Impact level and objective criteria
In 10 out of 12 cases, there is some concordance between the impact level and the targeted investment analysis: a low impact project tends to be more profitable. Figure 5.3 plots the trend line between the impact level and the economical value (computed as % change in market price for reaching an IRR of 20% for the purpose of the graph).

Major exception to the trend is the decentralised beet case (highlighted). This is a high impact project, with positive economical value.

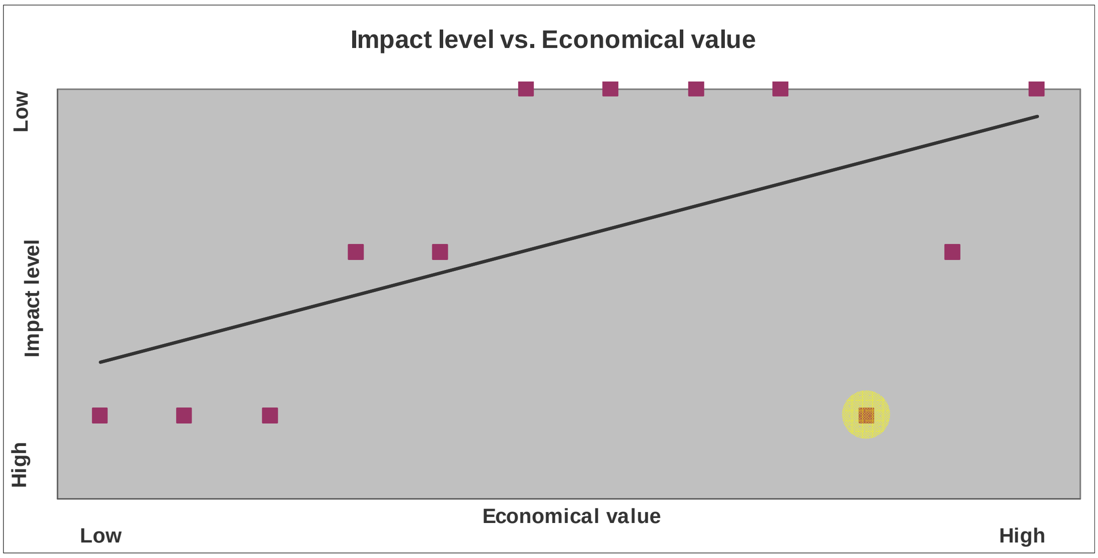

Figure 5.3 *Correlation between impact level and objective criteria*

Technical feasibility and objective criteria
Similarly, we found a reasonable correlation between the technical feasibility and the economical value, as shown in figure 5.4. The main deviation here is the Food case (highlighted): the feasibility is considered rather low (60%) while the economical value is definitively positive.

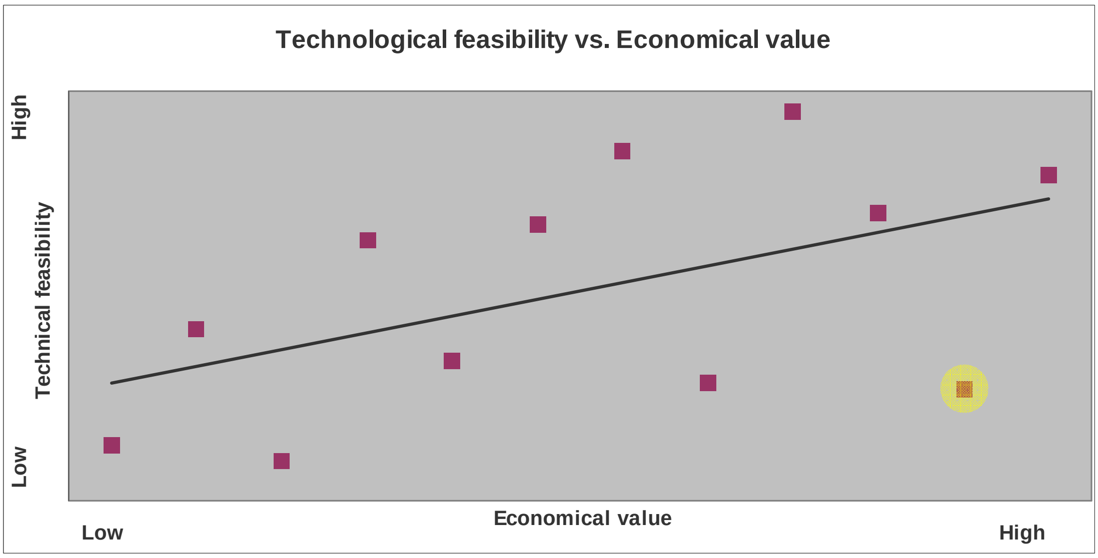

Figure 5.4 *Correlation between technological feasibility and objective criteria*

Commercial feasibility and objective criteria
As opposed to the more technical subjective factors, there is surprisingly no correlation between the commercial feasibility and the economical value.

How to understand this? Seemingly, the Consortium believes that economically attractive projects are not necessarily commercially feasible. Data may look attractive, but the challenge may be big. This tends to prove the added value to incorporate such a feasibility analysis to more conventional objective return on investment analysis.

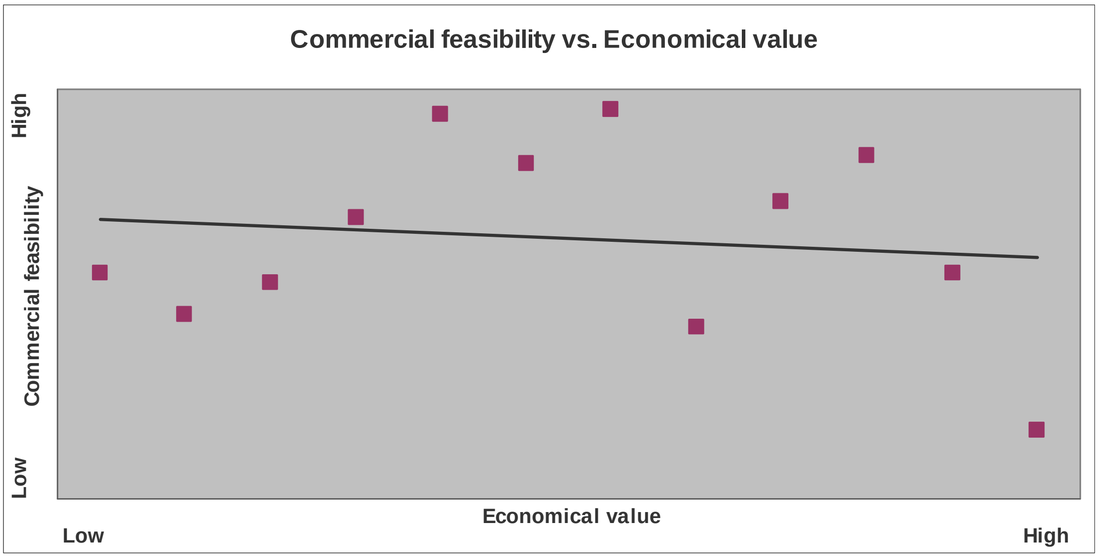

Figure 5.5 *Correlation between commercial feasibility and objective criteria*

Finally, some projects were clustered and compared to each other according to other attributes. These projects are selected out of all sectors.

Power generation projects
As a red wire throughout WP5, 3 biorefinery cases –Power, gasification / Power, CHP / Agro, grass-, respectively large, medium and small scale electricity production projects do show a similar trend:

- High impact projects
- Below average technical feasibility
- Average commercial feasibility
- Very poor return on investment (one order of magnitude worse than other biorefinery cases), even for reference cases.

This explains why subsidies are needed to support such projects and highlights the complexity to define suitable biorefinery cases to improve the overall performance. As mentioned earlier, all efforts need to be oriented to a maximal valorisation of heat (co-product) and keeping a simple design.

Co-product valorisation projects
Projects focused on getting a better value for existing co-products have the best chances of success. These are typically the 'Low impact' projects.

Table 5.6 *Co-product valorisation projects*

	Subjective criteria			Objective criteria	
	Impact level	Technical feasibility	Commercial feasibility	New target sales price (for IRR 20%)	% change vs market price (for IRR 20%)
Biodiesel: PDO	Low	74%	79%	€815/T biodiesel	16%
Biodiesel: ECH	Low	83%	75%	€735/T biodiesel	5%
Pulp & Paper: lignin	Low	80%	83%	€550/T pulp	10%
Food: lactic	Low	60%	65%	€2.050/T cheese	-9%

All these projects are either considered as highly feasible, and/or have a good economical value.

Co-production projects
These are the projects where part of the main product of the reference case is replaced by (an)other product(s). There are 3 projects in this category.

Table 5.7 *Co-production projects*

	Subjective criteria			Objective criteria	
	Impact level	Technical feasibility	Commercial feasibility	New target sales price (for IRR 20%)	% change vs market price (for IRR 20%)
Bioethanol: lactic	Low	78%	56%	€545/T ethanol	-32%
Pulp & Paper: ethanol	Medium	72%	74%	€990/T pulp	98%
Agro: decentralised beet	High	75%	79%	€385/T sugar	-4%

These projects are considered as technically feasible and tend to be economically attractive.

Fermentation projects
These are the projects where the biorefinery cases include an additional fermentation step.

Table 5.8 *Fermentation projects*

	Impact level	Technical feasibility	Commercial feasibility	New target sales price (for IRR 20%)	% change vs market price (for IRR 20%)
Bioethanol: lactic	Low	78%	56%	€545/T ethanol	-32%
Bioethanol AFEX 80	Medium	60%	69%	€710/T ethanol	-11%
Biodiesel: PDO	Low	74%	79%	€815/T biodiesel	16%
Pulp & Paper: ethanol	Medium	72%	74%	€990/T pulp	98%
Food: lactic	Low	60%	65%	€2.050/T cheese	-9%
Agro: decentralised beet	High	75%	79%	€385/T sugar	-4%

Fermentation projects tend to improve the reference case, except for the co-production of ethanol in a pulp mill. The Glycerol to PDO is also negative in economical value, but this can probably be improved by increasing the yield / productivity of the fermentation step. On the contrary to the other projects, all leading to ethanol or lactic acid, fermentation of glycerol to 1,3-PDO is not yet a mature technology, neither is PDO as a product.

Thermal treatment of biomass
This category is covering projects involving a thermal treatment of the incoming biomass.

Table 5.9 *Thermal treatment of biomass projects*

	Subjective criteria			Objective criteria	
	Impact level	Technical feasibility	Commercial feasibility	New target sales price (for IRR 20%)	% change vs market price (for IRR 20%)
Pulp & Paper: DME	Medium	62%	83%	€710/T pulp	42%
Power: reference CHP				€150/MWh	200%
Power: CHP/pyrolyse	High	65%	66%	€185/MWh	270%
Power: reference gasification				€110/MWh	120%
Power: gasification/chemicals	High	53%	68%	€200/MWh	300%

We exceptionally included 2 reference projects in this group, to better illustrate the comments. Seemingly, thermal treatment of biomass is still not a viable industrial option. Neither the reference cases nor the biorefinery cases are leading to a positive economical activity.

With the exception of the high commercial feasibility of DME (DME is indeed an interesting product with functional benefits, supplied in a demanding and regulatory supported market), all feasibility parameters are below average.

Legislation-driven projects
The final category is covering projects strongly supported by legislation.

Table 5.10 *Legislation-driven projects*

	Subjective criteria			Objective criteria	
	Impact level	Technical feasibility	Commercial feasibility	New target sales price (for IRR 20%)	% change vs market price (for IRR 20%)
Refinery: veg. oil in FCC	High	86%	64%	n.a.	n.a.
Refinery: veg. oil in HDS	High	89%	64%	n.a.	n.a.

Both selected projects have a high technical feasibility. Commercial feasibility however is below par, fully explained by the higher cost and the lack of technical benefits (as perceived by some respondents) compared to the respective reference cases.

This score has to be put into the right perspective: our model gives a lower weight to legislative support compared to price and technical benefits. Seen the directive character of the legislative support for these projects, this should be opposite.

8. Alternative improvement options

As explained in §7.2, sales price of the main product will have to increase substantially for several cases studied in this project in order to have a decent return on investment. This can be achieved by focussing on niches with potentially higher market price or by a subsidy mechanism (such as existing for green electricity).

Another option could be to reduce the processing cost or to further increase the value of the co-products. Some ideas (a.o. derived from WP3 and WP4.5) are mentioned here.

Bioethanol sector

Feedstock and steam are the most important cost factors in the bioethanol production, accounting resp. for 60% and 10% (excluding return on co-products). 2nd generation feedstocks (lignocellulosics) are obvious choices to reduce the feedstock cost, in combination with a higher conversion yield. This can be obtained in the '100% Bioethanol concept' in which part of the biomass is steam exploded, lignin extracted (used as solid fuel) and the remaining C5 and C6 fraction converted into ethanol. The rest of the biomass is gasified and transformed into ethanol by catalytic synthesis. The energy released in the gasification process is used to reduce the energy bill of the fermentation process.

This concept is focused on reducing the main cost drivers but is still immature (technological risk) and carries a high capex. This is an option for the future and a nice research challenge.

Biodiesel sector

Use of waste oil / fats as feedstock reduces the feedstock cost by 50%, only partially offset by a higher auxiliary and utility cost and extra investment cost. All in all, the production cost can be reduced by 20-25%, making a biodiesel production highly profitable (IRR of 40% at current sales price of €700/T).

Drawback is the limited availability of waste oil and fats and possibly technical problems on the long run due to accumulation of impurities and variability of incoming feedstock quality.

Pulp & Paper sector

As indicated in WP4, extracting lignin from the black liquor can significantly improve the profitability of pulp mills, mainly by debottlenecking the pulp mill. The hemicellulose fraction however remains in the liquor and is combusted.

A very attractive option is to consider a total valorisation of the incoming wood: cellulose to pulp, lignin to solid fuel and hemicellulose to ethanol and furfural. But this means that less energy will be available for operating the pulp mill. The solution is proposed by the AVAP^{tm} technology. Pulping is done by using ethanol (from hemicellulose) and sulphur dioxide in a closed system. In parallel, forest residues (and possibly lignin) are gasified supplying enough energy for the whole plant.

Another alternative process combines integrated cases studied in this project. Lignin removal debottlenecks the recovery boiler, allowing for a 25% capacity increase. This additional cellulose can be saccharified (as pulp market is rather saturated) and used as feedstock for fermentation (ethanol, lactic acid …).

Food sector

In the integrated case, lactose is converted into lactic acid by fermentation. A recent technology describes the fermentation of lactose to vitamin C (a.o. US patent 4259443). Vitamin C sells at €6/kg, compared to €0.8/kg for lactic acid. Assuming a 40-50% yield (realistic target) on lactose, this would reduce the production cost of cheese by 50%. The required sales price for cheese now drops to €1.620 for an IRR=20%, well below the cheese market price.

This example illustrates that a proper choice of the target product for co-product valorisation has a huge impact on the overall profitability.

Agro sector
In our grass biorefinery case, proteins are extracted from grass and sold as animal feed at €150/T dry. This concept is not profitable, as shown in table 5.4 and subsequent discussion on Agro sector.

Seen the low volumes involved in such a grass biorefinery (<600 T dry proteins/a), it may be possible to further process these proteins into higher added value niche products such as hydrolysed vegetable proteins used as flavouring agents (sales price around €1,500/T, 10 times the feed value).

The effect on the cost for electricity (main product in this case) is spectacular, and makes such a grass refinery closer to reality.

This illustrates that the production of electricity out of biomass (in this case grass), can be profitable, providing a high value side stream. Basically, energy outlets can be considered as a co-product of the hydrolysed protein production.

9. Conclusions

- In Work package 5, the Consortium tried to analyse the different biorefinery cases according to both **objective** (profitability measurement) and **subjective** (technical and commercial feasibility; SWOT analysis) criteria. For all criteria, new data were generated, as complementary to data generated in WP4.
- The technical and commercial feasibility, as well as the SWOT analysis were measured by a **questionnaire** filled in by experts within the Consortium.
- Regarding Technical Feasibility, major deviation from the average are related to **process development** (proof-of-concept, scalability…). Application development (=referencing new products in the market) are mostly considered as less critical.
- Concerning the Commercial Feasibility, not surprising, the **tangible competitive advantages** (cost, price, technical benefits) are key success factors. The other key determinant, the perception of the products, processes… by the consumers is generally speaking scoring rather high for all projects. A good point for ‘bio-based economy’ projects as studied in Bioref-Integ! But this makes the perception criteria less discriminative for the different projects.
- The objective criteria used are related to investment analysis. In WP5 we proposed a **‘targeted investment analysis’**. In a similar IRR calculation model as used in WP4, we computed the required sales price for the main product to reach an IRR = 20%. This gives a better perspective to compare the different projects to each other.
- Another new parameter is the **‘impact level’**: how deep will a biorefinery concept affect the reference process. We clustered the biorefinery projects in 3 groups: low, medium and high impact.
- Out of our study, there is a **positive correlation between the technical feasibility and the economical value** (measured as targeted sales price for IRR=20%). Low impact projects are also leading to a higher economical value.
- The **commercial feasibility has no correlation with the economical value**. It should be considered together with financial analysis to make an educated decision on biorefinery schemes.
- Projects involving **thermal treatment of biomass** (CHP, pyrolysis, gasification) are clearly still **immature** and not yet industrially feasible. This appears clearly in a low technical feasibility and a negative economic value.
- **Power generation** (electricity from biomass) projects also have a **negative evaluation** (subsidies were not taken into account!). This is of course in line with the comments on thermal treatment, as frequently the same technology is used. The message to electricity-from-biomass projects is: find a value application for heat and … keep it simple or … change focus and produce products from biomass.
- Biorefinery projects that have the **potential to improve the economics of reference cases** are **low impact projects** (no significant impact on the reference process), **fermentation projects** and **co-product valorisation projects**. These projects frequently also have an above average technical and commercial feasibility score.
- Finally, **legislation** is an important factor, driving the use of bio-based feedstock (see biofuel directive) or supporting directly biorefineries by several subsidy incentives.