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Biorefined proteins from rapeseed

- economic assessment and system analysis

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Abstract

Enhanced biorefining are based on concepts using solvents and enhanced rapeseed extraction and aqueous extraction to separate proteins, refined oil and other by-products from rapeseed. Different protein and oil products from the extraction processes have the potential to substitute a number of well-known market products as well as it provides an opportunity to enter new markets with new product functionalities.

The aim of this study was to assess the cost structure in enhanced extraction and bio-refining and to identify areas of special economic interest in terms of processing costs and end-product functionality. The analysis also focuses on market potentials, price and economic viability of the two production processes.

The proposed production schemes are based on basic research and the products have only been preliminary commercial tested, it is still too early to conclude about the quality of the end-products and about final market opportunities.

[1] Bioraf Denmark Foundation.
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Contents

Preface

Rapeseed is the most important oil seed crop in EU-15. The large majority is mainly extracted into oils for human consumption, non-food purposes and feed meal.

As a measure to improve value added from agricultural production this working paper analyses the economic viability and cost structure of enhanced extraction and green biorefining of rape seed to various high value commodities, such as protein isolates, protein concentrates and rape seed oils.

This report are conducted by Søren Marcus Pedersen and Morten Gylling, Danish Research Institute of Food Economics and Christian L. Bagger, Bioraf Denmark Foundation.

As a subtask in the EU ENHANCE project this project has received financial support from the 5th framework programme: Quality of Life and Management of Living Resources: QLK5 CT 1999 01442. We appreciate the assistance from all the European project partners for providing technical and economic data for the economic system analysis.

Danish Research Institute of Food Economics
Farm Management and Production Systems Division
April 2004

Johannes Christensen

1. Introduction

European crop farmers produce mainly cereals, oil- and protein crops and tubers. A large share of the European crop production is delivered on the bulk market resulting in low market prices and value added to the farmers. In this respect, product and market development has received increasing attention in research projects to establish high value products from agricultural production.

The concept of using bio-refineries is to develop sustainable processing systems for decentralised productions with increased value added. A biorefinery system is tailored to handle and fractionate the agricultural output of the region and to make a full and optimal utilisation of the biomas, in this case oil seed rape. Rapeseed is one of the most cultivated oilseed crops in the world (38 mill tons) after soy (160 mill tons).

Biorefineries can consist of one or several processing lines, which opens up for synergies in relation to investment and labour costs, flexibility in production output and market as well as benefits in relation to transportation of bulky biomass materials.

The overall objective of the ENHANCE-project[3] was to develop and design production systems to extract oilseed rape protein products tailored to meet functional requirements within products such as paper coating, binders in thermal isolating materials, adhesives and cosmetics (Guéguen 2003).

Besides being used for their nutritional benefits, plant proteins (e.g. concentrates and isolates) can be used as functional ingredients to improve texture, viscosity, aroma stability among other things. Until now most functional protein products have originated from soya, wheat proteins (e.g. gluten), milk proteins (casein) and gelatine (Natsch and Wäsche 2003).

This study is based on system analysis and seeks to assess and optimise the production economy in each link of two oil and protein production systems. The system analysis is based on a production facility for each system with an overall capacity of 17,216 tons oil seed rape per year, processed according to the two scenarios developed during the ENHANCE project.

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[3] ENHANCE "Green Chemicals and Biopolymers from Rapeseed Meal with Enhanced End-uses Performance": EU-funded project: Quality of Life and Management of Living Resources: QLK5 CT 1999 01442.

The objective of this subproject has been to assess the economic structure in the process and to identify areas of special economic interest; sales revenue, investments and economic viability.

2. Production flow

The economic model is based on results and developments made during the project lifetime. The model covers four scenarios where scenario 1a (*green biorefining process*) and 2a (*enhanced solvent extraction*) covers two evaluated and developed rapeseed oil extraction methods. Moreover, scenario 2a and 2b covers two adapted methods for extraction of proteins from the resulting oil meals of respectively scenario 1a and 2a. The principal technical production flow process, which forms the basis for the economic models, are shown in figure 1 for both production systems. Appendix A1 gives further details about indicative measures of the variation in protein solubility, protein and oil content, and yields in percent of protein I and II based on oil meal inputs. The variations indicated are generic estimates based on results from different pilot plant processing methods applied on the different rapeseed meals prepared in scenario 1a and 2 a.

Oil seed rape is the primary input in both production processes. The green biorefining process (scenario 1a) is based on cold pressing of de-hulled whole rape seed, whereas the enhanced solvent process (scenario 2a) is based on solvent extraction of whole rape seed, before protein extraction.

Process 1a involves de-hulling, cold pressing and oil refining. The protein content in the oil meal from this process varies between 31-34% with a dry matter yield of 40-45% of the oil meal. The obtained protein solubility at pH 7 by applying this process is 69%. In scenario 1b, the rape seed meal is then further processed by aqueous extraction, precipitation, purification and drying to produce protein concentrates and isolates in which the protein I (20% of dm) and protein II (15% of dm) are extracted from the rape seed meal.

For each protein, their emulsifying properties were analysed at different pH levels, kinetics of creaming was determined and resistance to coalescence was evaluated by conductimetric and centrifugation as described in Schönweitz et. al. (2003).

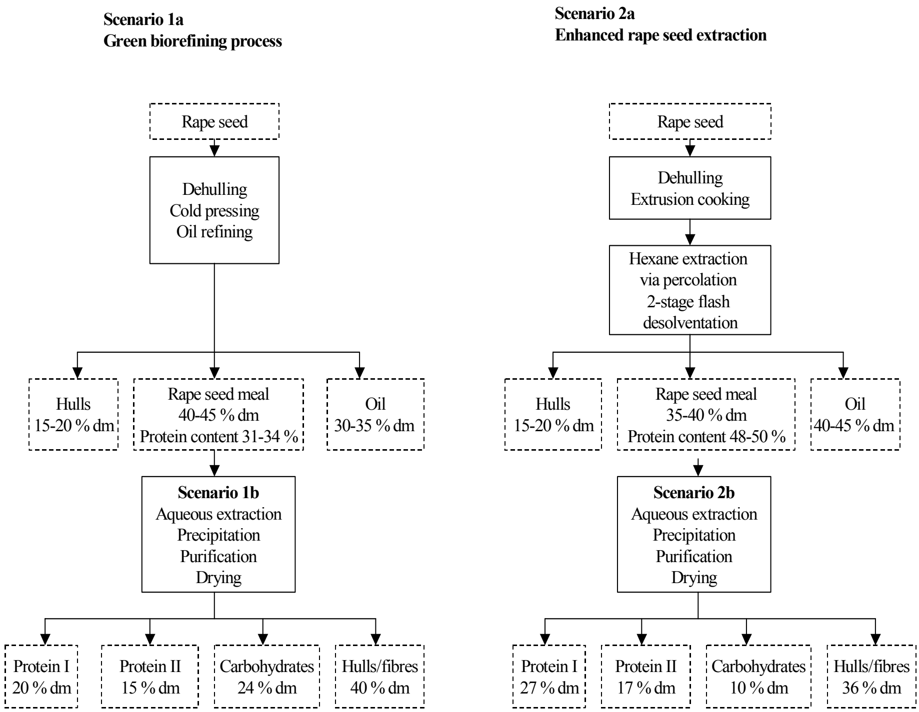
In scenario 2a the rape seed enters a process with extrusion cooking, hexane extraction and mild desolventation.

The rape meal share from this process is about 35-40% dm with a protein content between 48-50%.

Rape seed oil yield is higher in process 2a than 1a but the protein solubility in the rape seed meal is lower in process 2a (55-65%) hence the oil content is lower in the rape seed meal from scenario 2a. The protein content in the rape seed meal from process 2a is between 48 and 50% compared to 31-24% in scenario 1a.

Hereafter in scenario 2b, rape seed meal from process 2a is further treated with aqueous extraction, precipitation and purification as in scenario 1b in order to extract protein concentrates and isolates. The protein content from this process is slightly higher compared with process 1b, but the protein solubility is lower at pH 7.

Figure 1. Production flow diagram for scenario 1: Green biorefining process and scenario 2: Enhanced rape seed extraction



3. Scale of production

The scale of production used in the models, as presented in the production flow diagram, are based on an estimated market of protein II of about 1,000 tons per year. A total production of 1000 tons of protein II, with a protein content between 81 and 96%, corresponds to approximately 17,000 tons of oilseed processed per year. Protein II is regarded as a substitute for casein (milk protein) and a production at this scale accounts for 6-12,5% of the present estimated casein used in EU for adhesive purposes.

The production system is running for about 7,326 hours per year, corresponding to a capacity of 2.4 tons of oilseed per hour and about 1 ton oil meal per hour for preparation of protein concentrates and isolates. Key data are based on pilot scale trials carried out in a scale of 25-100 kg/h resulting in scale up factors of 25-100.

The economic feasibility study, is based on data and recommendations from the technical and biological partners in the EU-financed ENHANCE project. An overall sales revenue and gross margin analysis is conducted for both production scenarios and supplemented with sensitivity analysis regarding changes in investments. In addition, the economic viability at different price levels of proteins has been calculated. The analysis has also focused on the price trends for the various output products in the production process.

4. Product inputs and sales prices

The oil seed protein end-products developed during the ENHANCE-project have the potential to substitute a number of well known oil and protein products and to enter both well known and possibly new markets. The input in the process, however, is based on only one single raw material, oilseed rape.

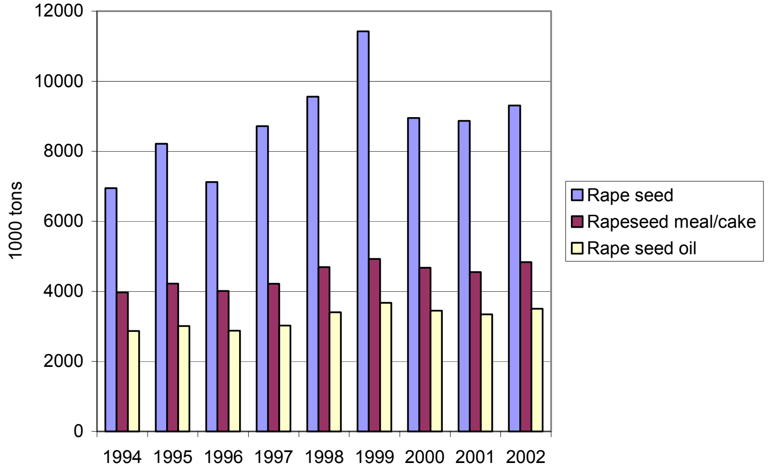
Table 1. Sales prices

Input prices		EUR/tons
Oilseed rape		243
Sales product	**Substitute**	
Grad rest/hulls/fibres	Wheat bran	133
Crude oil	Crude edible oil	700
Refined oil	Refined rape seed oil	800
Oil meal	Rape seed meal	185
Protein I	Fish meal	800
Protein II	Casein	3,300
Carbohydrates	Molasses	140

Source: Danish Statistics and own calculations, 1 EUR = 7.5 DKK.

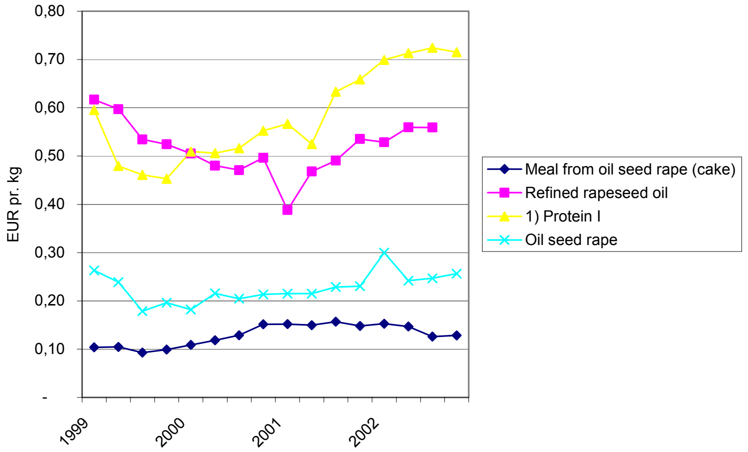
Oilseed rape is the primary input in the production system and covers about 50 percent of the variable costs in both production systems. The future price of rapeseed will depend on the world market price for other oilseed crops such as soy bean and the general subsidies within the Common Agricultural Policy in EU. The current production of rape seed in EU make a total of about 9 mill tons in year 2001/02 and the production of rapeseed oil is about 3.5 mill. tons (FAO, 2003). Germany (3.8 mill tons), France (3.3 mill. tons) and UK (1.5 mill. tons) are the main rape seed producers in Europe. Rape seed is primarily processed to rape seed cake for feed purposes and rape seed oil for human consumption and non-food production (biodiesel). The market regime for rape seed production shifted in 1992/93 from indirect market price support to direct payments per hectare. Currently, rape seed is either grown as a food crop in competition with cereals or as a non-food crop on set-aside land. Since 1999 the hectare subsidy for rapeseed has declined significantly compared to crops like wheat and barley and subsidies are now similar for all crops. In this matter, the gross margins for producing rapeseed has declined since 1998 (Cartrysse and Falise 2003). Slightly increased prices of oil rapeseed has however compensated for income reductions.

Figure 2. Production of rape seed in EU-15



Source: FAO agricultural statistics, www.fao.org.

Figure 3. Price of refined rapeseed oil, meal and pellets from rapeseed and protein[1)]



[1)] The application of protein I is comparable to pellets, meal and powder from fish and shellfish.

Source: Danish Statistics.

The main outputs from the biorefining processes are refined rapeseed oil and proteins.

Prototype proteins have been produced in pilot scale. They have been evaluated and their functional properties have been enhanced during the project.

The ENHANCE proteins consist of two different protein products: Protein I and II.

Protein I and II account for about 20% of the total output in the system and almost 50 percent of the total revenue in the system. In this respect they are vital products in both systems and only small changes in the output price will have a major impact on the overall economy.

Protein I and II
In Europe, more focus has been put on replacing animal proteins with plant proteins. The reason is to reduce further risk of transmission of diseases from animal proteins in light of the complications with BSE in some European countries. A total of 14 mill. tons of "animal waste", not eaten by humans, was processed to meat and bone meals in EU in 1996. These protein bone meals have a monetary value similar to soy bean meal. A total replacement of animal proteins with plant proteins will create an additional demand of 2 mill. tons of plant protein per annum, which may lead to increases in plant protein prices (Milne 1997).

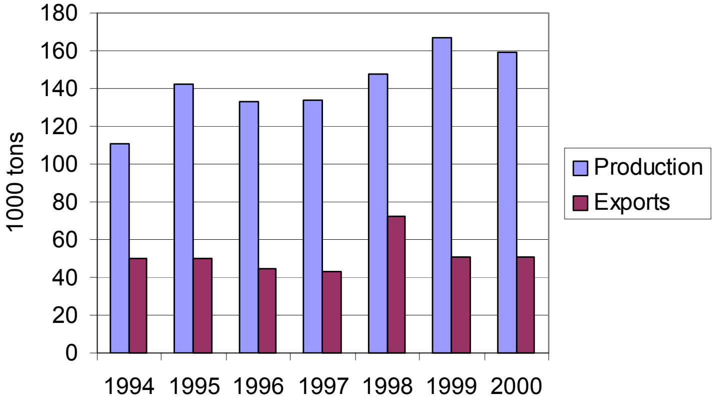
Fish meal can be regarded as a substitute for protein I. The price of fish meal has slightly increased since 1999 and the import price is currently at about 0.7 EUR per kg. Worldwide, the total fish catch is about 130 mill. tons. of which about 1/3 is used for fish meal and fish oil production (Aquamedia 2003). In EU-15 the total fish catch is about 7 mill. tons (FAO, 2003). The availability of fishmeal protein in EU depends on the EU fishery policy and quota system.

The most important sales product in the system is the enhanced protein isolates (protein II). The price of casein[4] has been relatively unstable during recent years – e.i. price variation between 1 EUR in 1999 and 6 EUR in 2001.

Casein is a by-product from the milk and dairy sector and closely linked to the milk production in Europe.

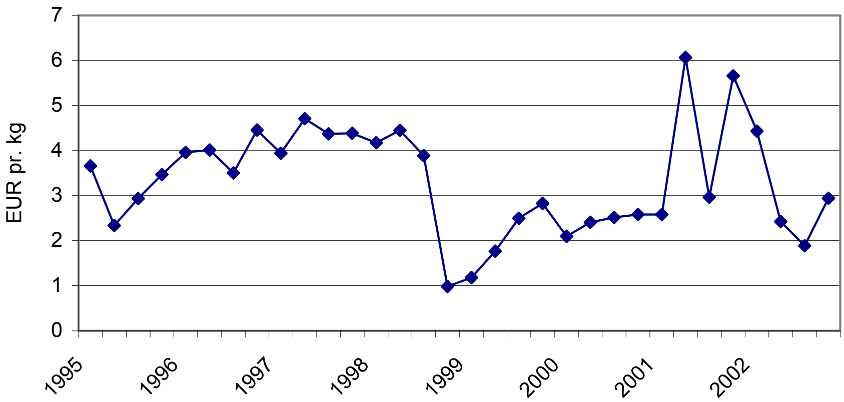
[4] Casein can be regarded as a comparable product to ENHANCE protein II

Figure 4. Casein production and exports in EU-15



Source: European Commission, Directorate General for Agriculture.

Figure 5. Protein II, comparable to casein price



Source: Danish Statistics.

The consumption of casein is very low compared with traditional bulk commodities and probably negotiated by very few buyers. In this respect it is difficult to predict the future price of casein and hence protein II.

The European production of casein has slightly increased in the period between 1994 and 1999 but fell again in 2000. The total production is about 160,000 tons per year (2000) and about 50,000 tons are exported.

Soya protein and wheat gluten are among the most important vegetable protein sources. On the world market is consumed about 185,000 tons of soy isolates (protein content > 90%) and about 220,000 tons of soy concentrates (protein content: 64-90%) for food and non-food purposes. Furthermore, it is assumed that the European consumption (incl. Africa) of soya protein isolates and concentrates is about 85.000 tons per year (Pedersen and Gylling 2001).

The market price of soy isolate is about 18-25 DKK/kg, (2.4-3.3 EUR/kg) whereas the market price of soy concentrate is about 10-16 DKK/kg (1.3-2.1 EUR/kg) (1999).

Wheat gluten is also produced in large amounts as a by-product in the wheat starch industry. In the late eighties and beginning of the nineties the world gluten production increased considerably and was about 475,000 tons per annum in 1996. The gluten price is currently a little less than 1 EUR per kg. In the eighties the price has been about 2 EUR per kg. The current price of gluten has forced the industry to develop new applications of this protein within the food industry (baking, meat products, desserts etc) as well as the non-food industry.

From the green biorefining process and the enhanced rapeseed extraction process it is possible to obtain proteins that are similar to soy isolates/casein and soy concentrates/fish meal). The protein content in protein I is 50% (scenario I) and 70% (scenario II) with a protein solubility ph7 at 48 and 25, respectively. The protein content in protein II is 81% for scenario I, and 96% for scenario II with a protein solubility (ph 7) at 96 and 90 respectively.

Since it is possible to reach relatively concentrated/pure proteins for protein I and II that are about the same protein contents as soy concentrates and isolates it is assumed that an average price of protein I of 0.80 EUR pr. kg and protein II of 3.3 EUR/ pr. kg is a reasonable estimate (see table 1).

Refined rapeseed oil

Refined rapeseed oil is the second most important sales product in the system. The price of refined oil has been relatively stable within the last years. It is assumed that the price of refined oil from both biorefining systems is about 0.8 EUR/kg, which is a little above the average price in recent years.

Carbohydrates

The price of carbohydrates are similar to the price of molasses from sugar production. Molasses is a typical by-product from sugar-beet production and the carbohydrates from the ENHANCE-project is likewise regarded as a by-product. The price is assumed to be 0.14 EUR/kg. Although there have been a slight tendency of a reduced price for this commodity. Carbohydrates are however low value products and therefore less vital in the overall economic system.

Hulls and dietary fibres

Wheat bran is like carbohydrates a low value product. The price is currently about 0.08 EUR/kg.

Other variable costs

A minor share of the variable costs is related to the use of water and pH, chemistry. The energy costs in both processes adds to about 1. mill. EUR for energy, either from electricity, gas or fuel oil. In this respect, significant increases in fuel prices may have some impact on the economic viability for both production systems.

5. Capacity and investments

The processing and investment costs are estimated for each scenario and for the combined system per unit of oilseed rape (tons) in a production set-up with a capacity of about 2,35 ton seed/hour. The running time at the plant is 22 hours per day and 333 days per year, which corresponds to an annual input of 17.216 tons rape seed. Total investments adds up to 11,2 mill. EUR for the *enhanced rapeseed extraction* (incl. stationary machinery, processing equipment and buildings) and total investments for the *green process* are about 7,3 mill. EUR. The period of depreciation is 20 years for buildings and 10 years for machinery. Capital costs are assessed by using the current real interest (5%).

Table 2. Investments

EUR	**Scenario 1 Aqueous extraction (green biorefining process)**	**Scenario 2 Enhanced rapeseed extraction (traditional process)**
	1A	**2A**
Machinery		
storage	200,000	200,000
Dehulling	100,000	100,000
Extrusion		500,000
Pressing	500,000	
Oilprocessing	200,000	
Oilrefining	300,000	
Cold solvent extraction		3,000,000
Hexane distillation		1,350,000
Buildings	1,000,000	1,000,000
	1B	**2B**
Machinery	4,000,000	4,000,000
Buildings	1,000,000	1000,000
Total investments	**7,300,000**	**11,150,000**

6. Economic viability

As previously indicated, this system analysis is based on 2 production scenarios: 1) A green biorefining process and 2) Enhanced mild solvent extraction process.

The overall sales revenue in both systems are about the same since both systems produces nearly the same products. However the yield of refined oil is a little higher in the enhanced mild solvent extraction process although the end product quality is slightly better in the green biorefining process. In this case the price of refined oil is assumed to be slightly higher in the biorefining process. The protein content in protein II is higher from process 2b compared with 1b. The most severe differences between the two systems are related to investment costs, which are significantly lower in the green biorefining process.

An important item in the cost structure is product development and marketing activities. If the production facility should be regarded as an ongoing concern these activities should be included as yearly expenses. An estimate is 10 percent of the revenue, which corresponds to about 1 mill. EUR in both scenarios.

These expenditures cover laboratory facilities, engineers for product development and research, laboratory technician, marketing and salesmen. The cost of marketing and product development is at the same level as similar biotechnological companies. It is however difficult at this stage to estimate the exact expenditures.

Miscellaneous costs covers packing and other expenditures in connection to the production and sales activities.

In this study, expenses related to approval and testing of the end products are not included.

Table 3. Sales revenue and gross margins		
EUR	**Scenario 1 Aqueous extraction (green biorefining process)**	**Scenario 2 Enhanced rapeseed extraction (traditional process)**
Sales revenue		
Grad rest	103,038	103,038
Hulls	309,115	309,115
Refined oil and crude oil	3,718,678	4,338,457
Fibres	372,205	298,154
Protein II	3,463,183	3,493,403
Protein I	1,119,413	1,345,054
Carbohydrates	232,628	82,820
Sales revenue, total	**9,457,179**	**9,964,620**
Variable costs 1		
Oil seed rape	4,183,512	4,183,512
Acid	10,467	4,187
Electricity	312,098	272,159
Energy for steam	706,068	69,.264
Energy fuel and gas	16,786	92,967
Chemistry. Ph	87,912	87,912
Water	14,234	14,077
Total	**5,331,077**	**5,353,077**
Gross margin 1	**4,126,102**	**4,611,543**
Variable costs 2		
Labour and machinery (fixed costs)	1,221,500	1,938,250
Gross margin 2	**2,904,602**	**2,673,293**
Other fixed costs, buildings, insurance, administration and marketing etc.	**1,720,925**	**1,908,849**
Profit (revenue-costs)	**1,183,677**	**764,443**

Note: Real interest rate 5%.
Inflation: 2 percent.
Period of depreciation: Machinery 10 years, Buildings 20 years.

The total sales revenue in the system is about 9.5-10 mill. EUR/year and the overall yearly profit is 1.2 mill. EUR for the biorefing process and 0.8 mill. EUR for the enhanced mild solvent extraction.

The results of the preliminary feasibility study indicate that a combined production can be a viable investment if the assumptions about processing costs, investments, yields and product functionality can be realised on a commercial market.

The calculations in the basic scenario are based on average 2002 prices. A sensitivity analysis has been conducted with respect to a change in the price level.

An initial investment of 7.3 mill EUR for scenario 1 and 11 mill for scenario 2 will then create an *internal rate of return* of 25% and 14% respectively. The pay back time for the investment is 3.8 years and 5.6 years.

The net present value is 13.2 mill EUR for the green biorefining process and 8.1 mill EUR for the enhanced extraction process. In this analysis it is assumed that the NPV is based on yearly profits (before capital costs) over a period of 20 years.

Table 4. Profit, Internal rate of return (IRR) and pay back time

	Scenario 1 **Aqueous extraction (green biorefining process)**	Scenario 2 **Enhanced rapeseed extraction (traditional process)**
Profit (yearly) (income minus costs)	1.2 mill EUR	0.76 mill EUR
Internal rate of return	25%	14%
Net present value (20 years)	13.2 mill EUR	8.1 mill EUR
Pay back time	3.8 years	5.6 years

Note: Real interest rate 5%.

The calculation above shows that the basic economic scenario is viable based on the mass balance mentioned in the appendix, and given that the quality of the end products are accepted by the end users.

It should be stressed that the economic results are based on a going concern hence some unforeseen expenses could have an impact on the economic viability. Furthermore, a basic assumption is that the current market price will not be influenced by the production increase from these processes although the total amount of proteins (about 2,500 tons) may be relatively high on a local scale.

It is a prerequisite that the production process is technical possible. However, as the technical process has not been tested in a continuous flow, it is plausible that some variations in investment and costs for testing and labelling may occur.

7. Sensitivity analysis

Scenario 1

In table 5 and 6 is presented a sensitivity analysis for the green aqueous extraction process. Table 5 shows that a raise in investments of 3 mill. EUR imply a reduction of the internal rate of return (IRR) to 12.5% over a 20 years period. In this case it is economic viable to shift from the aqueous extraction green process to the solvent enhanced extraction process.

Table 5. Green biorefining process: Increased investments (1-3 mill. EUR)

	Basic scenario	--------- Increase in machinery investment ----------		
Total investments, Mill EUR	7.3	8.3	9.3	10.3
Net present value [1)], Mill EUR.	13.2	10.9	8.5	6.2
Internal rate of return, % [2)]	25	20	16	12.5
Pay back time, years	3.8	4.4	5.1	5.9

[1)] Real interest rate 5%.
[2)] 20 years period.

Table 6 indicates the effect on economic viability by raising or reducing the price of protein II, which is the most important product in the process. The table establishes that the green process is the best alternative even with 20% price reductions. As indicated above, the price of casein has fluctuated significantly in previous years.

Table 6. Green biorefining process: Increased protein II prices

	Basic scenario	---- Change in price of protein II ----	
Total investments, Mill EUR	7.3	+ 20%	- 20%
Net present value [1)], Mill EUR.	13.2	20.9	5.4
Internal rate of return, % [2)]	25	35	14.1
Pay back time, years	3.8	2.8	5.7

[1)] Real interest rate 5%.
[2)] 20 years period.

Scenario 2

Table 7 and 8 shows are presented a sensitivity analysis for the *enhanced rapeseed extraction process.*

The basic economic calculations are based on the assumption that the production system is established and running for a period of 20 years. In this respect the system analysis describes a going concern company, which in principal can operate indefinitely and stays in business. However, the company has to raise enough resources to stay in business and to continue after the run-in period. The initial erection costs (including costs of machinery and buildings) may vary according to unforeseen costs and start up costs in the first years. In this case it is relevant to assess the sensitivity of these investment costs. Table 7 shows that a raise in investments of 3 mill. EUR imply a reduction of the internal rate of return (IRR) to 1.1%, which is well below economic viability.

Table 7. Enhanced rapeseed extraction: Increased investments (1-3 mill EUR)

	Basic scenario	--------- Increase in machinery investment ----------		
Total investments, Mill EUR	11.2	12.2	13.2	14.2
Net present value [1], Mill EUR.	8.1	5.8	3.5	1.1
Internal rate of return, % [2]	14	11.1	8.5	6
Pay back time, years	5.6	6.3	7	7.9

[1] Real interest rate 5%.
[2] 20 years period.

Table 8 shows the effect on economic viability by raising or reducing the price of protein II. The table shows that the *enhanced rapeseed extraction process* is just at a breakeven level if the price of protein II is reduced by 20%. The internal rate of return is just above the discount rate.

Table 8. Enhanced rapeseed extraction: Increased protein II prices

	Basic scenario	---- Change in price of protein II ----	
Total investments, Mill EUR	11.2	+ 20%	- 20%
Net present value [1], Mill EUR.	8.1	15.9	0.3
Internal rate of return, % [2]	14	21.3	5.36
Pay back time, years	5.6	4.2	8.3

[1] Real interest rate : 5%.
[2] 20 years period.

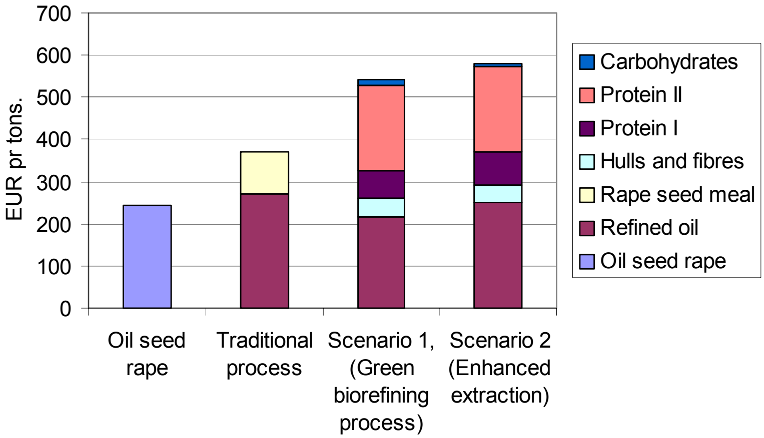
8. Perspectives and conclusions

This study indicates that both ENHANCE production system (i.e. green biorefining process and enhanced extraction) could be economically viable based on the assumptions and technologies presented above. The green biorefining process is the most economic viable system due to lower investment costs. However, for both processes it is vital that the price and demand for proteins are stable in the years to come.

Green biorefining and enhanced mild extraction should enable us to create a potential production of oilseed rape proteins, as a compliment to other plant and animal proteins. Irrespective of the green process or the enhanced extraction process is chosen, it is possible to increase value added with about 150-200 EUR per. tons rapeseed input compared with traditional oil processing.

Figure 6 indicate the change in value added by refining 1 tons of oil seed rape.

Figure 6. Change in sales revenue (value added) from bioerefining, based on a production unit of 17,216 tons oil seed rape



The potential end-products from these processes have the potential to substitute a number of well known products and to enter well known and new markets even though that the process is based on only one single raw material.

This approach could be a model for creation of other new production systems and making a better utilisation of biomass material. The production system may also enable the farmer and agro-industry to increase value added in the whole production chain. However, as the production is based on basic research and pilot scale productions and since it has solely been submitted for preliminary commercial testing it is still too early to conclude about the quality of the end-products and the final market possibilities.

A production facility as described above could be organised as a joint stock company. In this case where the primary input is a standard bulk commodity it is hardly necessary to organise a formal contractual agreement between the farmers and the production unit. Likewise it may not be relevant to establish a co-operative with contractual delivery agreements among farmers. Rapeseed is a conventional crop, which is available from most of the European regions.

In this case it is important that the company can receive a relatively large amounts of long-term external capital and this is probably best done through shares and by establishing a joint stock company.

However, it could be relevant to create a more formalised contractual delivery agreement of seeds if the final trials indicate that special species of rapeseed are a prerequisite for a commercial production of the various end products from these two processes.

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Appendix

Table A1.

OIL EXTRACTION					
Scenario I Dehulling Cold pressing		**Scenario 2** Dehulling Extrusion cooking Hexane extraction via percolation 2-stage Flash desolventisation		**Traditional** Flaking Hot pressing Hexane extraction via percolation Desolventisation live stream	
Oil yield % dm.	30-35	Oil yield % dm.	40-45	Oil yield % dm.	40-45
Hulls etc.	15-20	Hulls etc.	15-20		
Oilmeal yield % dm.	40-45	Oilmeal yield % dm.	35-40	Oilmeal yield % dm.	50-55
Protein solubility pH 7	69	Protein solubility pH 7.4	55-65	Protein solubility pH 7.4	
Protein content	31-34	Protein content	48-50	Protein content	
Oil content	10-15	Oil content	4-5	Oil content	
PROTEIN EXTRACTION					
Scenario 1 b Aqueous extraction Precipitation Purification Drying		**Scenario 2 b** Aqueous extraction Precipitation Purification Drying			
Protein I		**Protein I**			
Protein solubility pH 7	48	Protein solubility pH 7	25		
Protein content	50	Protein content	70		
Oil content	35	Oil content	7		
Yield in % dm. of meal	20	Yield in % dm. of meal	27		
Protein II		**Protein II**			
Protein solubility pH 7	96	Protein solubility pH 7	90		
Protein content	81	Protein content	96		
Oil content	<5	Oil content	<1		
Yield in % dm. of meal	15	Yield in % dm. of meal	17		
Carbohydrates		**Carbohydrates**			
Yield in % dm. of meal	24	Yield in % dm. of meal	10		
Hulls/fibre		**Hulls/fibre**			
Yield in % dm. of meal	40	Yield in % dm. of meal	36		

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