Title	Strategic Innovation Programme (SIP) "**Biorefinery for raw material availability and flexibility**"
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1. Introduction

Abstract & Challenge

The key issues that need to be addressed for a successful transition from a fossil-resources based society towards a sustainable, biomass-based society are the availability of sufficient raw materials and the flexibility that can be realized in their sourcing and application. The food sector needs to guarantee the availability of safe and healthy food for a growing global population with increasing welfare standards. Projections show that the problem of food insecurity will escalate due to the increasing food demand (up to 70% more by 2050) on the one hand, and climate change combined with a decrease in energy and water availability on the other. Next to this, the upcoming bio-economy will put an increasing claim on the available biomass for non-food applications like chemicals, materials and energy. To tackle these important future challenges a collaborative programme "Biorefinery for raw material availability and flexibility" is proposed.

The programme will be founded on the ambition to provide the technology and value chain integration to:

- Guarantee the sustainable supply of raw materials and the flexibility in their application to realize food security
- Supply biomass-derived raw materials in sufficient quality and quantity to enable the sustainable development of other sectors of the bio-economy (chemistry, materials, energy)

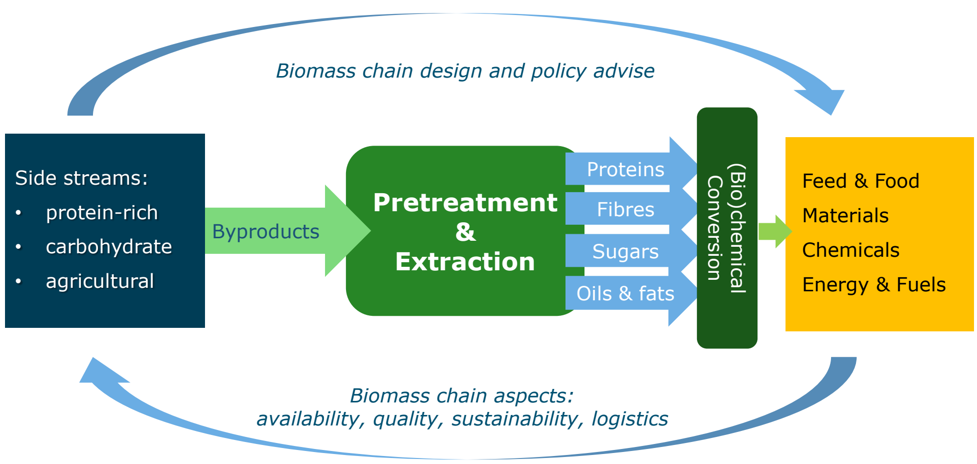
With respect to the availability of raw materials the programme focusses on the technology development to:

- Make better use of existing resources, with a special focus on carbohydrate and protein-rich side streams
- Enable the use of raw materials for higher-value applications, e.g. proteins from feed to food
- Explore new sources for the sustainable supply of raw materials for food and non-food applications

With respect to raw material flexibility, two research lines will be explored:

- Exploration of the boundaries between food and non-food applications
- Development of application-dedicated food and non-food ingredients with specifications related to their functional (including nutritional) properties, rather than specifications that focus on safety and purity alone.

The approach of co-production of food and non-food intermediates/final products is visualised in the figure below, showing the value chain integration with respect to availability, quality, sustainability and logistics.



The knowledge generated in this programme will facilitate the development of integrated value chains, in which a broad range of available raw materials can be, interchangeably, applied for a spectrum of final products. This programme thereby significantly contributes to strengthening of the links between the Agro&Food and the Chemicals & Materials domains. This also implies that a broad range of stakeholders representing all relevant industrial sectors needs to be involved for further scoping of this programme into concrete research activities (Work Packages). Industrial back-up will be leading in the budget allocation over the various Work Packages. An indication of the intended budget division is given within this programme description.

Adjacent to this programme an accompanying SIP will be developed that strategically links this programme with food applications (SIP "Customized Processed Food for Quality and Health").

2. State of the art and proposed knowledge development

Proposed knowledge development

The increasing demand for food as well as renewable raw materials requires a transition towards new agro-production systems that focus on complete and sustainable valorisation of biomass. Current production chains will be redesigned into fully integrated value chains that deliver intermediates and final products to all sectors of the bio-economy. Integrated biorefinery concepts, i.e., the sustainable processing of biomass into a spectrum of bio-based products/intermediates (food, feed, chemicals, materials) and bioenergy (biofuels, power and/or heat), are a key enabler for this transition. The objective of biorefining is to disclose and unravel all available components of vegetable or animal origin in an ecological and economical way while preserving their intrinsic functional properties. These components (e.g. proteins, minerals, oils, fats, carbohydrates and minor miscellaneous compounds) can be used in a range of new applications, with a cascading value ranging from pharmaceutical use to food, feed, chemicals, materials or energy.

In an ideal scenario all available biomass will be processed according to a fully integrated biorefinery concept as shown in Figure 2. In this scheme, fermentation can be replaced by other carbohydrate conversion technologies, e.g. polymer modifications or chemo-catalytic conversion of carbohydrates into building blocks.

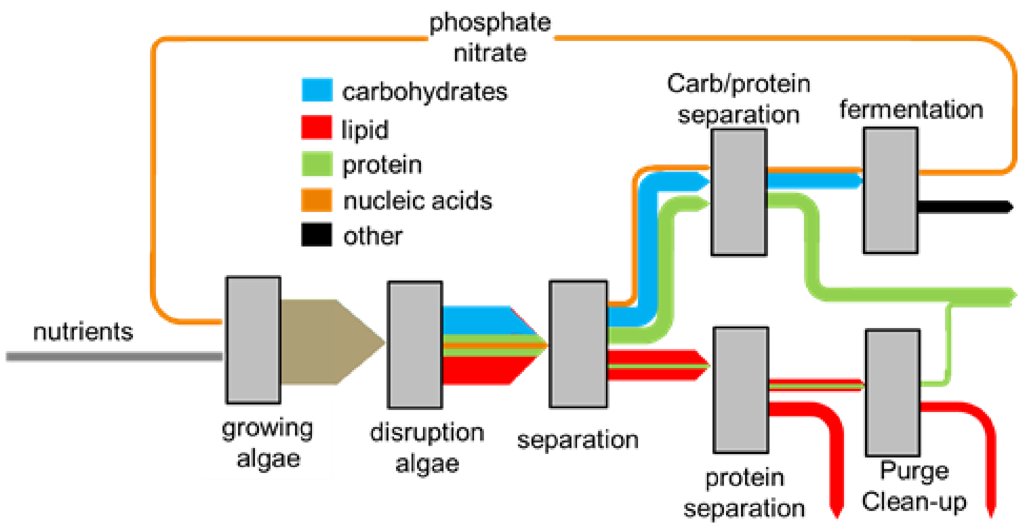


Figure 2. An ideal biorefinery concept (in this case: algae).

The proposed knowledge development focusses on 3 major pillars in the programme:

1. Raw materials: Development of strategies to generate raw materials of sufficient quality and quantity as input for the next steps in the process. This includes:
    - Improved valorisation of currently available side streams and process residues, e.g., wheat middlings, DDGS, maize protein and potato protamylasse
    - Integrated use of domestic Dutch crops, e.g., sugar beet pulp, stalks and foliage
    - Improved valorisation of imported biomass, e.g., rapeseed meal
    - Exploration of future raw materials, e.g. insects
    - Strategies to avoid functionality-loss of raw materials, e.g., oil oxidation and pressure/heat protein unfolding (rapeseed valorisation) or enzymatic degradation and/or microbiological destabilization in processing of fresh biomass (grass, leaves, pulp, etc.)
    - Strategies to remove components that have no value in subsequent process steps, e.g., water, undesired minerals
    - Local cycle closure, e.g., related to minerals

2. Separation and conversion technologies: development of new technologies for application in biorefinery concepts to add new economic value to different biomass streams. This includes:
    - Mild disruption and separation technologies
    - Fractionation of proteins and carbohydrates
    - Conversion of the proteins and carbohydrates into building blocks /fractions suitable to serve as chemicals in the biobased economy

3. Applications: strategies to extend the range of applications of biobased (including food/feed) intermediates and final products:
    - Value-shift towards higher-end applications including identification of key opportunities for food applications from currently under-exploited biomass sources
    - Exploration of boundaries between food and non-food applications
    - Development of intermediates with application-dedicated functionality

Activities in the Work Packages will integrate the research questions over these 3 pillars, either starting from the raw materials (availability) or focussed on the applications (flexibility). Chapter 5 will further elaborate on the foreseen Work Packages in this programme.

State of the art – pillar 1: raw materials

Proteins and carbohydrates play a pivotal role in this programme for several reasons:

- The predicted shortage of proteins for food and feed applications
- The potential of carbohydrate rich side streams as replacement for crude oil based polymers
- The potential of proteins and carbohydrates for application as building block for chemicals and materials
- The valorisation potential of currently under-utilised protein and/or carbohydrate containing side streams

Several side streams in the agro-industry contain proteins and carbohydrates. Protein residues and carbohydrate rich residues are frequently used as animal feed, but their application is often limited by the presence of anti-nutritional factors or the limited economic value. A major cause for the latter is that processing has a negative effect on the technical functionality of proteins.

One possible way to characterize the side streams is on the basis of their protein and carbohydrate content (see Table 1). The group with a high protein content, such as oil press cake, are already used as animal feed. The second group with a protein content of 25-45% finds less application as animal feed. Its economic value depends on the protein content and quality, but also on the amount of sugars and/or the presence of anti-nutritional components. The group with a content of 10-20% is generally seen as a material with a low value and is often left on the field. In addition to protein rich side streams, carbohydrate rich side streams like sugar beet pulp, wheat bran, or corn stover, can be classified using the same approach. With respect to carbohydrates it should be mentioned that the development of new second generation bio-ethanol production technologies and the likes, will put a large claim on carbohydrate rich side streams. In most cases, side streams need to be produced with a higher valorization potential than the corresponding caloric value. This aspect shall also be studied.

Table 1. Protein containing (side)streams

Classification	Side streams
Group 1: Protein content >50%	Soy flour, rapeseed flour, insects
Group 2: Protein content 25–40%	Oil cake rapeseed, sunflower, soy and olive. Sunflower flour, side streams from meat industry, DDGS
Group 3: Protein content 15 %	Rapeseed membranes, pods, soybean, beet leaves
Group 4: Protein content 5 %	Grass, rapeseed straw and soy straw, corn stover, sunflower membranes

Group 2, with a relatively high protein content of 25-40%, currently has limited economic value. It is expected that the use of these fractions as commodity in the food and non-food sector will increase the economic value. Thus, the cooperation between TNO and DLO will focus on this class of materials, and more specifically on side streams from the potato and sugar industry, and the food industry in general. Valorisation of these proteins will be achieved through various methods that facilitate their application in the non-food and/or food sector. This concerns both larger polymers and small fragments that can be used as building block for the development of new polymers.

State of the art – pillar 2: separation and conversion technologies

Mild processing technologies for application in biorefinery concepts are still in their infancy and require further development before providing new economic value to different biomass streams. Traditional processing does not obey the natural ordering, protection and preservation of components in plant materials. This results in a number of undesired effects, such as loss in quality and/or more difficult separations of components afterwards. Examples of such inefficiencies include:

- Standard edible oil extraction. The natural preservatives and protective membranes are destroyed by seed expression and subsequent hexane extraction. Later in the process, anti-oxidants need to be added to prevent natural unsaturated oils from going rancid. Furthermore, protein functionality is greatly diminished.
- Prevention of enzymatic degradation (lipoxygenases in seeds or polyphenol-oxidases/peroxidases and glycosidase). During standard processing, high temperatures are applied to inactivate or degrade these enzymes, resulting in lower yields, lower quality and non-enzymatic browning.

- Side streams from the biodiesel or –ethanol production in which the protein has lost most of its functionality.

To overcome the abovementioned inefficiencies, mild fractionation processes for dry and concentrated/viscous systems need to be developed, which require less heat or diluted conditions and make optimal use of the intrinsic driving forces for separation that are present within the plant material.

To create a broad field for application of proteins and carbohydrates mentioned above, it is important to keep biopolymers solubilized and in their native state, which requires fractionation and isolation on the basis of molecular weight, hydrophobicity and charge density. An alternative and more preferred method is when insoluble proteins and carbohydrates as such can be brought into solution. In the past, TNO has performed research on soybean meal by incubating the meal in a strongly alkaline solution and subsequently cross linking the solubilized proteins into a gel. This gel can be applied as water binder for irrigation purposes. The gel will be slowly digested and thereby act as a nitrogen source. The water-binding capacity of these gels is lower than that of commercial products that are now being used (polyacrylates) in flower boxes, but the use of these products is undesirable in the food chain. There are also opportunities for blending the proteins with water-binding carbohydrates such as pectin, which can also be extracted from side streams. With respect to carbohydrates, knowledge related to chemical and enzymatic modification will be used to develop specific building blocks, both polymeric and oligomeric.

In the past at TNO and DLO knowledge has been acquired to obtain soluble proteins from side streams rich in insoluble proteins. In almost all cases this was achieved by enzymatic or chemical hydrolysis. In projects the focus was on residues such as chicken feathers, soybean meal, brewers grain and residues from the meat and fish industry, as well as on straw, potato peels, and potato pulp with respect to carbohydrates. The technology works well but can have the disadvantage that small peptides are produced. As building blocks for the synthesis of polymers that is the desired effect, but for larger structures such as gels or polymers, or coatings a high degree of hydrolysis is undesirable.

State of the art – pillar 3: applications

This programme aims to extend the range of applications of biobased (including food/feed) intermediates and final products, e.g., through a value-shift towards higher-end applications including application in food products. Non-food products could be modified carbohydrates or proteins to be used in applications like coatings, adhesives, cosmetic or papermaking, but also biobased building blocks that can be used in the production of plastics for packaging of e.g. food products. Economic values of such products typically vary between 1200- 5000 Euro/tonne

A special focus will be on the interconnection of separation and conversion technologies on the one hand, and application on the other hand. This interconnection will be investigated through further development of the concept of *application-dedicated functional fractions*. The highly refined ingredients that are currently applied in modern food products have a high sustainability impact (water, energy, side-streams), while the intensive processing conditions reduce their nutritional and/or functional quality. For many applications, functionality of ingredients is more important than their molecular purity. In addition, modern diets are short in components such as dietary fibres and various micro-nutrients. Scientific publications provide evidence that micronutrients are more effective in the original plant matrix than in isolated form. Plant derived fractions processed under mild conditions into functional, application-dedicated, fractions may thus provide advantages in both quality and sustainability compared to the current highly refined ingredients.

3. Objectives and knowledge questions

The programme will be founded on the ambition to provide the technology and value chain integration to:

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- Supply biomass-derived raw materials in sufficient quality and quantity to enable the sustainable development of other sectors of the bio-economy (chemistry, materials, energy)

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With respect to raw material flexibility, the focus will be on the:

- Exploration of the boundaries between food and non-food applications
- Development of application-dedicated food and non-food ingredients with specifications related to their functional (including nutritional) properties, rather than specifications that focus on safety and purity alone.

Specific research questions that will be addressed are:

- How to improve the availability of applicable proteins, oils, carbohydrates and minerals with tune-able functionality from sustainable resources?
- How to increase the value of agro side streams into higher value streams for feed, chemicals, materials, and/or energy?
- What are the options to avoid loss of functionality perishable biomass due to enzymatic and/or microbiological degradation?
- What are potentially new driving forces for fractionation understanding the structure of highly concentrated plant materials?
- Which mild disclosure, separation and conversion technologies qualify for inclusion into integrated biorefinery concepts, and what is their technology readiness level (TRL)?
- Which side streams would benefit from the (in-situ) removal of anti-nutritional factors and/or unwanted by products (e.g., Maillard-related compounds) that currently prevent food applications in biorefinery concepts?
- What methods can be used to solubilize proteins and carbohydrates from insoluble residuals?
- Is it possible to improve the solubility by pre-treatment of the side stream?
- What methods qualify to fractionate specific proteins or carbohydrates?
- What is an optimal process from the sustainability perspective (People, Planet, Profit).
- What are the options to reduce carbon and ecological footprints of upstream processing of food proteins/carbohydrates?
- What is the application window for maximum flexibility in usage of different ingredient sources?
- What are the options to reduce processing aids to become clean label and implement sustainable processing techniques, saving water and energy for high quality food products?

- Is it possible to define an optimal process from a sustainability perspective (People, Planet, Profit)?
- What non-food applications are possible with the isolated proteins or protein fragments or carbohydrate fragments or modified carbohydrates?
- Which technologies are available for the chemical or physical modifications of proteins and carbohydrates into building blocks /fractions suitable to serve as chemicals in the biobased economy, or other biobased applications?

4. Impact

The Top Sectors Agri&Food, Chemistry, Water, Horticulture and Energy have expressed their joint ambition to become frontrunner in the development of the biobased economy, which will create new economic opportunities for all relevant sectors of the Dutch industry: agriculture, food, chemistry, materials, energy and logistics (SER, 2010). The strong agro/food- and chemical sectors, logistic position and the strong knowledge infrastructure provides the Netherlands a very good starting position for the transition from a fossil-based to a biobased economy. Projection show that this transition may be accomplished by 2050, and will be achieved through a number of steps which are already more (stage 1 and 2) or less (stage 3 and 4) visible:

- Stage 1: Increased efficiency in the use of fossil and mineral resources
- Stage 2: Replacement of (molecular) building blocks in fossil resources by (molecular) building blocks from biomass
- Stage 3: Development of new enabling processing routes for (intermediate) products through the generation of new (fundamental) knowledge in the field of catalysis, enzymes, fermentation and down-stream processing
- Stage 4: Agricultural production of biomass for food, feed, fuels and the entire spectrum of functional materials (including new functionalities); fully developed biorefinery utilizing the available complexity in nature (including dedicated crops)

The available amount of biomass is a critical factor in this transition and asks for an integrated, cross-sectorial approach. The Innovation Contract Biobased Economy (Werkgroep Businessplan BBE, 2011) describes a first action plan for this approach based on 2 major design principles: maximum valorization of biomass and sustainability from the start. This collaborative research programme of DLO and TNO provides the required scientific building blocks for this approach with respect to biomass sourcing, refinery and conversion technology as well as application in intermediates and final products (replacement and new products). It helps tackling sustainability challenges for the agro-food system, and contributes to the diminishment of the potential shortage (and concomitant price volatility) of essential constituents for both the food and non-food industry.

The programme is expected to have impact on all relevant sectors of the Dutch industry. New and more sustainable processing technologies will be developed that will help the industry to decrease their ecological footprint through savings in water, raw materials and/or energy. Mild separation and conversion technologies reduce the (eco-) costs of processing as well as the inefficiencies related to side stream generation. The production of less pure, application-dedicated, fractions results in a reduction of the volume of side streams that are currently produced. The latter can be illustrated by the example of wheat starch processing: with an annual production of about 1 million ton of dry wheat starch, about 200,000 ton wheat starch by-product is generated. This side stream is in practice used for feed, but could (at least partly) be made available for food applications by applying integrated biorefinery approaches. In a recent study (Bos et al., 2012) the impact of 10 similar examples of integrated biorefinery on the Dutch economy was estimated to be: more efficient land use (4 million hectare), reduced energy consumption (5.000 TJ) and phosphate use (60 ton) as well as the generation of 9.000 highly qualified jobs (mainly at SME's).

Integrated biorefinery concepts will also improve the availability of nutrients for livestock animals. An additional advantage of fractionating feed materials is that components with little or even negative nutritional value for animals (anti-nutritional factors; bulk) are extracted and become available for other applications within the bio-based economy. With the annually available amount of biomass for feed applications (on dry matter basis over 35 Mt[1]), the Netherlands has a huge potential for the further development of the bio-based economy.

Valorisation of side streams also provides a huge potential for the development of non-food products. On the short term, development of these biobased products is aimed at replacing the current oil-based products on the market. For the long term, the unique (plant-based) functionalities should be utilized to develop completely new functional products that currently can't be made. Carbohydrate or protein rich side streams like sugar beet pulp, wheat bran, rape seed meal, corn stover or potato pulp are available in the Netherlands and Europe at million tonnes/year scale. Given the limited value when applied as animal feed (50-200 Euro/tonne), there is a big interest to develop non-food products based on these agricultural side streams. Such non-food products could be modified carbohydrates or proteins to be used in applications like coatings, adhesives, cosmetic or papermaking, but also biobased building blocks that can be used in the production of plastics for packaging of e.g. food products. Economic values of such products typically vary between 1200- 5000 Euro/tonne. Big brand owners like Pepsico, Coca-Cola, Danone and Unilever have already indicated their desire to have access to biobased products originating from the non-edible part of biomass (thereby avoiding competition between food and non-food use).

5. Programme description

The programme will be built around the pillars raw materials, processing/technology and applications, which are closely interconnected within the concept of integrated biorefinery. During the writing process of this version of the SIP (July 2014) a first scoping of research activities has been done, based on the foreseen research needs of the industrial partners and the complementary skill base of TNO and DLO. This first scoping has resulted in 5 Work Packages, each with a specific research focus and placement over the pillars (see Figure 3). Further scoping of the research programme will take place in the 2nd half of 2014 in close consultation with the network of industrial partners and other stakeholders.

[1] This includes the transit feed materials: about $10x10^9$ kg of raw materials for the compound feed industries in Germany and other hinterland countries are shipped through Rotterdam each year.

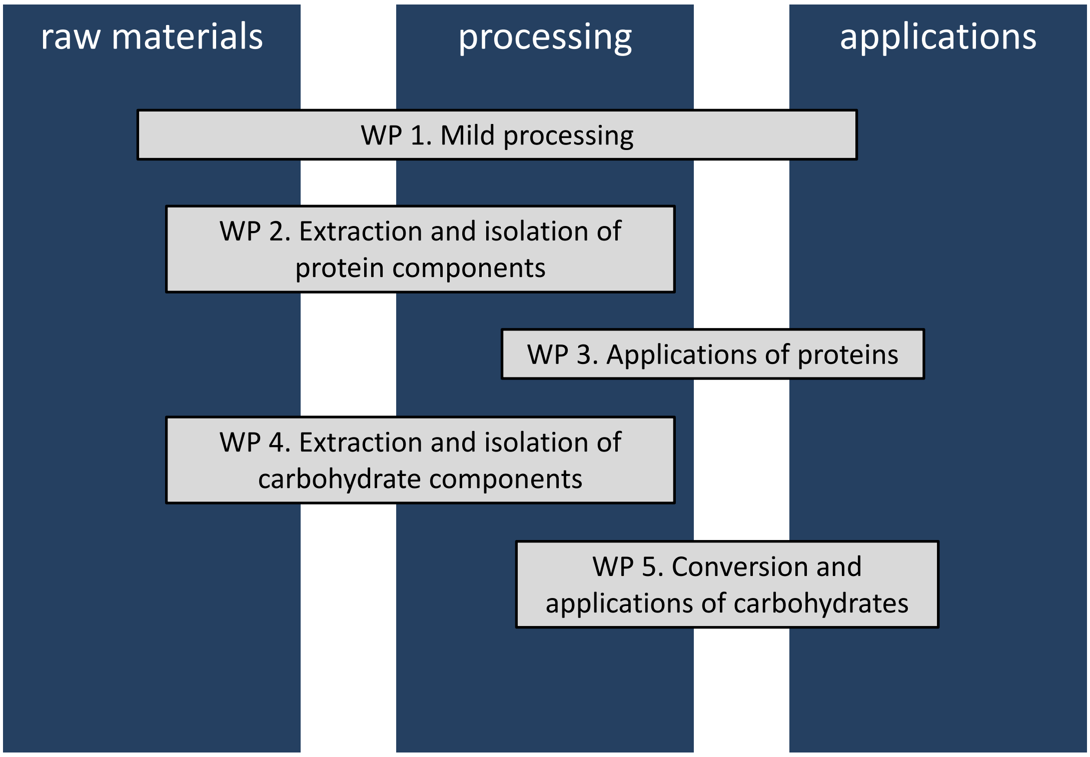

Figure 3: The foreseen Work Packages in the Biorefinery SIP (NB.: this is the result of the first scoping phase; further scoping will be done in close consultation with the network of industrial partners and other stakeholders)

A more detailed description of the foreseen Work Packages is given below.

Work Package 1: Mild processing technologies

Innovative bio refining concepts, mild separation methods and other methods are necessary for optimal utilisation of biomass, including side streams. The understanding of the intrinsic quality of plant fractions will be used to define the process conditions in which disentanglement of the components can be achieved, without the necessity of using extreme process conditions. Innovative separation techniques will be developed and applied for specific cases to extract valuable components from side streams. Special emphasis will be on the use of mild technologies for preservation/stabilization to avoid functionality loss of native ingredients due to enzymatic and/or microbiological degradation. The concept of *application-dedicated functional fractions* will be applied to interlink fraction functionality and process technology: less components have to be removed when more components from a starting material are functional in an application. As a first step in this approach, combinations of biomaterials and suitable food application products will be selected. The preferred route is to maintain all components that could be functional or are acceptable in the food product. If the result appears unsatisfactory, step by step more components can be removed.

Mild Separation Technologies

The successful application of biorefining for food, animal feed or bio based products depends on the possibilities to separate the available biomass into various functional components. Hydrolysis, fractionation and separation technologies are the most vital aspects herein. DLO and TNO develop new technologies that reduce the consumption of water, energy and chemicals on the one hand,

and preserve the natural structure of the components on the other hand. This approach will be applied to develop new functional ingredients.

The main separation technologies to be used are:

- Pervaporation: Pervaporation can be used for recovery of volatiles having a molecular weight less than about 300Da. It opens a broad range of novel flavour products, where quality and authenticity are the ultimate goals.
- Membrane filtration: Membranes can be used for selective removal of components from a product stream. Selection of the membrane largely determine the components to be extracted.
- Air classification: Air classification is a dry separation technology based on the aerodynamic behaviour of (small) particles. On one hand the rotational speed results in an outward centrifugal force. On the other hand an airflow results in an inward drag force. Due to different particle sizes there is an imbalance between the drag force and the centrifugal force.
- Electrostatic separation: Electrostatic Separation uses the difference in chargeability as driving force for the separation of the different components. The technology saves a lot of energy compared to wet separation processes. Moreover, starch and protein remain in their native state, which increases the quality and value of the separated fractions.
- Novel extraction technologies: high pressure, pulsed electric fields and enzymatic techniques can be applied for mild extraction of components. These technologies can be used for permeabilisation of the cell membrane, resulting in an increased extraction of components from the cell wall.
- Simulated moving bed chromatography: A variant of HPLC that uses a specific valve-and-column set up to lengthen the stationary phase indefinitely, thereby enabling the separation of particles and/or chemical compounds.
- In situ product recovery: Separation processes combined with continuous conversion or fermentation processes aimed at increased process output and/or easier recovery of the target product.

Mild Preservation Technologies

For successful biorefinery, especially for side streams of the food industry, stabilization of these side streams is essential. As (microbial) spoiled side streams can’t be used for high value applications, mild preservation of the side streams enables a more economic biorefinery process. The focus will be on existing technologies (e.g. acidification and heat treatments) and novel mild preservation processes:

- High pressure processing: Pressures up to 700 MPa can be applied for food preservation and preparation. High pressure is used in industry for pasteurisation of food products at room temperature and is also potentially interesting for sterilisation.
- Pulsed electric field processing: Preservation of bulk products by electrical impulses can be applied homogeneously through the product for pasteurisation of liquid foods at reduced temperatures.
- Cold plasma treatment: Cold plasma gas is suitable for decontamination of surfaces without affecting the quality of the product or packaging. Produced by electric discharges in inert gases that carry exited molecules, cold plasma gas offers the potential to inactivate micro-organisms on surfaces at temperatures below 40 °C.
- Radio frequency heating: water immersed radio frequency heating is used for fast and homogeneous heating of packed product to achieve pasteurisation or sterilisation with improved quality compared to conventional processing.
- Acidification: the enzymatic and microbiological activity can be reduced by lowering the pH.
- Superheated steam technology: can be applied for the combination of stabilization and disclosure of biomass.

Work Package 2: Small scale biorefinery of proteins

Centralisation and the increase in scale have led to drastic cost reductions for processing of agro-raw materials over the last decades. Recent societal changes, like the increasing costs of transport, the desire for forward-integration, cycle-closure for minerals and the necessity for integral use of all process streams have led to changing insights around 'the economy of scale'. Small-scale biorefinery is a promising concept that can contribute significantly to a smarter use of scarce resources. Small scale processing offers opportunities for local cycle-closure (e.g. water, minerals, side products) without extra costs for transport or refining. The relatively low investment costs stimulate the implementation of small scale facilities based on best available technologies.

Next to the concept of small scale, this Work Package includes the following topics:

Pretreatment of side streams

The pre-treatment and opening up the side stream matrix may enhance the extractability of insoluble proteins. For this different routes will be studied:

- Enhance the solubility of protein by reactions in the matrix with (reducing) carbohydrates.
- Mechanical pretreatment to open up the matrix (e.g. ball mill, homogenizer).
- Use of cell wall degrading enzymes in (mechanical) for treatments

Solubilizing of proteins

With different methods (both processing and using various extractants) the yield is studied of solubilizing protein from selected side streams. This is done by bringing the protein mildly in solution by adding a detergent or by a combination of a detergent with a mild alkaline treatment. In order to prevent that the dissolved protein precipitates immediately after removing the extractants it must be examined which options there are to keep the protein in solution

Extrusion-extraction technology

DLO has had a patent on the oil extraction from materials by using an extruder. In this concept two dynamic plugs are created both at the start and at the end of the extruder. The configuration can be adapted for the mild extraction of proteins from biomass (mild acid or base conditions).

Protein extraction

For the use of proteins in non-food applications, it is often important to use well defined building blocks. This is among other things necessary for the reproducibility of the various processes that are involved in an end-use application. For the production of protein fragments that vary for instance in molecular weight, anionic character, the following techniques are set-up:

- Anion chromatography
- Gel permeation chromatography
- Various filtration techniques

Work Package 3: Non-food applications of proteins

This Work Package focusses on the application of proteins in the non-food sector, such as:

Biopolymers with high molecular weight (bioplastic, binders, coatings)

The use of proteins as a biopolymer is still possible. Here, the comparison with starch-based bioplastics can be made. For many years these plastics are used in certain niche markets. It is to be expected that this market will be there and possibly expand. However, to facilitate the substitution of high-quality petroleum-based polymers by products from biobased monomers (eg lactic acid for PLA), DLO has developed a set of protocols that can be used to assess the suitability of the isolated protein (fragments).

Surface active compounds (emulsifier, detergents etc).
Peptides are an interesting feedstock for the preparation of surfactants. The surfactant market is very large and very diverse. In many (polymer) systems, surface active substances are used to create emulsions or to improve the adhesion of coatings/paints Surfactants based on protein structures are already used in cosmetic products such as creams and shampoos. Products on the basis of, for example, gelatin hydrolysates which are modified with fatty acids are produced on a commercial scale. In addition peptides based surfactants possibly can be used as a tool for protecting all kinds of crops (adjuvants) or as bio-flocculant.

Chemical building blocks
In the coating industry, large quantities of polymers are used as a binder. Research is being performed to use various renewable resources (Dutch Polymer Institute -DPI). Protein fragments possess many functional groups that can be used for a variety of chemical reactions. As a result, there are many possibilities for the use of proteins in this filed, whether or not in combination with traditional binders, such as alkyd resins or polyurethanes

Chemical modifications
The properties of proteins are dependent on both the protein source (amino acid composition) and the structural parameters (globular etc). The properties of proteins can be adjusted by enzymatic and chemical modification. Because of the wide variety of reactive groups in proteins (which is in sharp contrast to for example starch), there are many opportunities and tools for chemical reactions. Examples are:

- Hydrophilation: incorporation polar groups (such as -COOH, -NH2, -OH, -PO22-, -SO32-)
- Hydrophobation : incorporation non-polar groups (such as alkyl or aromatic groups)
- Cross-linking: covalent coupling of protein molecules

For a number of end-use applications the use of chemical modifications is important. For example, the development of surfactants on the basis of peptides is in general the covalent coupling of fatty acid moieties to the peptide chain. Also more hydrophilic units such as sugar units can be coupled to a protein.

Dissolved proteins can form a structure by modification or may be modified such that properties (hydrophobicity, temperature stability, etc.) are changed. In addition the possibilities will be studied to get low-cost methods for cross-linking to obtain gels or water-insoluble coatings.

Process development
Laboratory results need to materialize in industrial processes. This translation is not obvious and requires attention. The optimum process can be developed from the sustainability approach (People, Profit, Planet). Software is developed to quantify the sustainability of products and processes on the three dimensions: People, Planet, and Profit. The challenge lies among others in taking into account product quality.

Work Package 4: Biorefinery to add economic value to carbohydrate riche side streams

Carbohydrate rich side streams, like sugar beet pulp, wheat bran, potato fibre pulp, corn stover or bagasse, usually consist of a number of different carbohydrates. The most common carbohydrate polymers in these side streams are cellulose, hemi-cellulose, starch and pectin. Besides these more common polymers also carbohydrates such as cell wall fragments are present in lower amounts in these side streams. Each of these carbohydrates carries unique properties which can be used, e.g., for separation of the different polymers. In order to separate these carbohydrate polymers various strategies will be used and studied on their applicability such as:

- Chemical treatment aiming at selective isolation of specific carbohydrate fractions or sugar monomers
- Enzymatic treatment for selective removal of certain polymers or to modify a polymer to facilitate easier separation
- Thermal treatment: Especially the use of Super-Heated Steam (SHS) will be pursued in the treatment of carbohydrate rich side streams.

4a. Extraction and isolation of carbohydrates

Extraction and isolation of interesting carbohydrate fractions is the first step in exploring new applications for these side streams. In literature several strategies have been published such as treatment with acid or base in water using elevated temperature or steam explosion and the like. In this project a new promising technique using Super-Heated-Steam will be developed further. First experiments using SHS have shown that e.g. lignocellulose containing side streams, treated with SHS are easily separated. The technology is founded on minute scale treatment of the respective side stream. TNO has experience with this technology, has a pilot plant for experiments, and already has filed several patents in this area. After the SHS treatment the side streams are ready for further processing. Besides SHS also other already published treatments can be applied in order to compare the pros and cons of SHS. In addition the project will capitalize on DLO experience with regard to biomass pretreatment under mild basic as well as mild acidic conditions. This will result in solubilized hemicellulose (and optionally depending on feedstock) lignin fragments and non-soluble cellulose fibres. The technology will be further adapted to be able to derive pure hemicellulose or hemicellulose derived sugars.

4b.Sugar crude

Fermentation processes use in most cases carbohydrate monomers such as C6- and C5-monosaccharides as a starting building block for the production of complex components such as alcohols and specific organic acids. Preferably carbohydrate side streams containing glucose, fructose, and xylose are chosen for this purpose. By choosing the proper treatment it will be possible to obtain the proper carbohydrate monomer at high dry weight concentration, which subsequently can be applied in fermentation processes.

Processes creating building blocks and chemical intermediates using biotechnological fermentation techniques will surely contribute to a further establishment of the biobased economy. But, in addition to this it is paramount that also chemocatalytic conversion processes will be needed to create a more biobased economy. Chemocatalytic conversions compliment the biotechnological processes and enable to perform conversions that cannot be done using biotechnology. Within this programme special emphasis will be given to the chemical conversions of the C5 and C6 sugars resulting from agricultural side streams. The use of these C5 and C6 sugars does not compete with potential food uses, while these sugars are excellent starting materials for the production of intermediates for bulk chemicals and specialty chemicals. Subsequent chemical conversion will (in)tolerate other impurities than comparable biotechnological techniques. Within the scope of this Work Package the optimal sugar crude will be generated for subsequent chemical conversion.

Work Package 5: Conversion of sugar crude and polymeric carbohydrates

Activities in this Work Package will be subdivided into 2 research lines:

5a.Conversion of the sugar crude into intermediates for bulk and specialty chemicals

The C5 and C6 sugars will be converted into furan containing intermediates that subsequently can be used in the production of bulk-and specialty chemicals like building blocks for resins, polymers, pharmaceutical intermediates, but also flavors and fragrances for the agri-food industry. Furan intermediates will be converted into the targeted product using Diels Alder chemistry. Here aspects such as the influence of the purity of the sugars on the subsequent conversion to furan like molecules will be explored. Also here the use of the Superheated steam technology offers potential as well as methods like conversion in biphasic systems or in alcoholic solution to suppress by product formation. Next to batch conversions, use can also be made of continuous reaction set ups.

5b. Chemical modification of polymeric carbohydrates

Next to hydrolysis of carbohydrate polymers into monomers, also the polymer as such can be used for the development of new applications. Especially through chemical modifications properties can be introduced and tuned. In this project the following modification routes are foreseen:

- Oxidation. Via oxidation charge is introduced on the polymer through the formation of carboxylic acids. Several oxidation techniques will be used. Typical applications of these type of compounds are alternatives for poly acrylates, substitutes for super absorbents, co-builders in laundry formulations, and binder systems for paints.
- Etherification. These type of chemical modifications can be used for several purposes, namely charge can be added (e.g. carboxymethylation) of the polymer can be linked with hydrophobic groups. Each of these modifications will alter the properties. Typical applications are similar to products from oxidation in the case of carboxymethylation or coatings, emulsifiers etc. in the case hydrophobic groups are linked to the carbohydrate polymers. The research will focus on modification strategies using so-called “dry” modifications implying that the modifications will be carried out without solvents such as water. SHS will play a major role in these strategies.
- Esterification. Esterification is another way of modifying carbohydrate polymers. For example it will be possible to alter the glass transition (usually lower the transition) resulting in applications such as hot melts, adhesives, and the like are within reach. Also alternatives for poly-vinyl-acetate will be a part of this research.
- Crosslinking. Crosslinking of (modified) polymers create structures whereby polymers are linked to each other. These cross-linked product will find applications in delivery systems and hydrogels. By using various polymer blends specific properties of hydrogels can be achieved. Applications for hydrogels are many e.g. retaining water or absorbing water, applications in agriculture, and soil remediation.

Upscaling

Lab scale experiments need to be up scaled in order to produce larger batches for application purposes. These up scaling experiments can be performed at DLO and TNO but the preference is to conduct these up scaling experiments together with industrial partners. Therefore during the progress of the project collaboration with industrial partners will actively be pursued.

6. SIP organisation

Programme management

Proper governance of such a large programme with a portfolio of mixed-funded projects is needed to secure high quality output, monitoring of deliverables, objective and transparent process of initiating and granting projects within the programme, etc. We have sufficient experience from previous and running PPP’s to develop a governance model this year. Minimally needed are:

- a programme director
- a governing board
- a scientific advisory board
- work package / theme leaders
- support (HRM, F, legal, PR)
- an objective and transparent monitoring and control system to fund, review, and finalize projects
- a knowledge management tool

Collaboration TNO-DLO

This programme will be built on 4 technology portfolio’s within TNO and DLO. We see the possibility to strengthen the interaction between DLO and TNO significantly from the start of this project on the following areas of expertise:

- Separation, conversion and processing technology (TNO/DLO)
- Sustainable biomass chains (DLO)
- Ingredient (modification) technology (TNO)
- Biorefinery and biobased products (DLO/TNO)

Planning

A detailed planning for the coming years will be written after a consultation phase with industry. Please refer to the document “Plan van aanpak Strategische Innovatie Programma TNO-DLO 2014-2016” for further details on planning and governance.

Finance

This strategic collaboration serves as a catalyst for joint programming and joint R&D&I in the period 2014-2016, ultimately leading to a solid portfolio of mixed-funded projects with industrial clients, set against the societal challenges mentioned above. This portfolio is built on topsector capacity TNO-DLO, EU, NWO, regional funds, etc. Furthermore, strong links are foreseen with regional initiatives on biomass valorisation such as Bioeconomy Innovation Cluster Oost Nederland (BIC-ON) and “Zuid-West Nederland”.

Intended budget breakdown per Work Package (to be further detailed in consultation with the intended industrial partners)

Work Package	**Year**	**Budget DLO (in K€)**	**Budget TNO (in K€)**
1. Mild processing	2015	175	175
	2016	175	175
2. Extraction and isolation of protein components	2015	175	175
	2016	175	175
3. Non-food applications of proteins	2015	175	175
	2016	175	175
4. Biorefinery to add value to carbohydrate rich side streams	2015	237,5	237,5
	2016	237,5	237,5
5. Conversion and application of carbohydrates	2015	237,5	237,5
	2016	237,5	237,5
Total		**2,000**	**2,000**
(industry cash contribution)		1,000	1,000
(EZ transitiemiddelen bijdrage)		1,000	1,000