Opportunities for Dutch Biorefineries

Editors: Wageningen UR (E. Annevelink, J. Broeze and R. van Ree)
and ECN (J.H. Reith and H. den Uil)

Report 1022

WAGENINGEN UR
For quality of life

ECN
Energy research Centre of the Netherlands

Colophon

Title	Opportunities for Dutch Roadmap Biorefineries
Author(s)	Wageningen UR (E. Annevelink, J. Broeze & R. van Ree, editors) & ECN (J.H. Reith & H. den Uil, editors)
AFSG number	1022
ISBN-number	978-90-8585-407-4
Date of publication	September 2009
Confidentiality	No
OPD code	6222035600
Approved by	Rene van Ree

Agrotechnology and Food Sciences Group
P.O. Box 17
NL-6700 AA Wageningen
Tel: +31 (0)317 480 084
E-mail: info.afsg@wur.nl
Internet: www.afsg.wur.nl

Preface

This Dutch Roadmap Biorefinery has been commissioned by the Dutch Ministry of Agriculture, Nature and Food Quality. It forms the framework and knowledge basis for Research, Development and Demonstration (RD&D) activities, covering both technical and non-technical issues, necessary to develop biorefinery-based value chains to such an extend that large-scale market implementation as part of the future Bio-based Economy will become a reality.

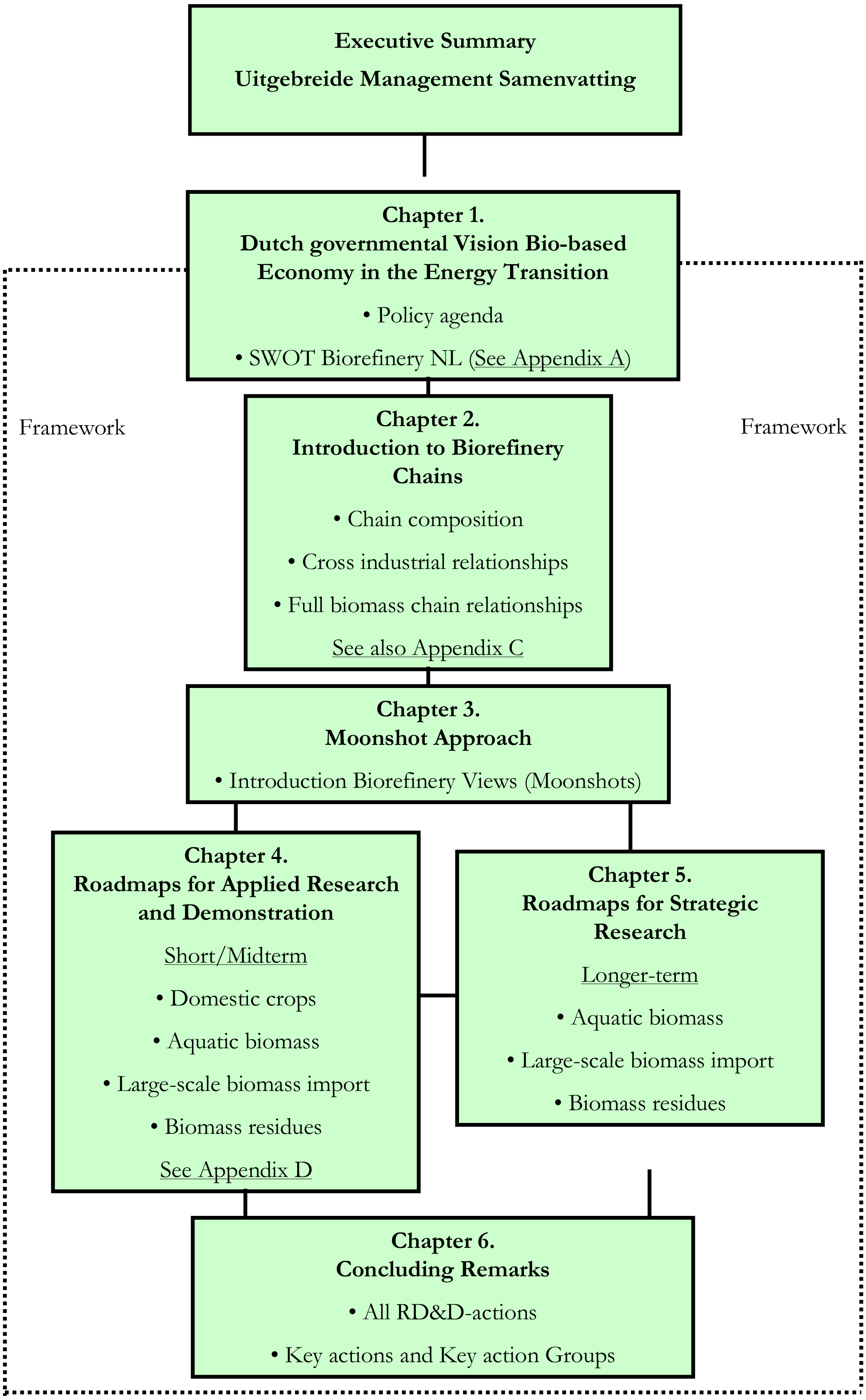
The Roadmap describes the broad landscape of biorefinery options in The Netherlands. The descriptions of possible initiatives within the so called Moonshots (general biorefinery strategies containing more specific biorefinery-based value chains that will become fully operational at industrial scale in the short and midterm to facilitate the transition to a Bio-based Economy in the longer-term) deliberately do not contain the names of parties that might be involved. However, many of the current initiatives have been described in another document, the 'Status Report Biorefinery 2007' (Van Ree & Annevelink, 2007). Also the exact economics of possible initiatives have not been specified yet. These will become clearer when proposals will be submitted by consortia of the stakeholders involved.

Roadmapping Process

The Roadmap has been drawn in close cooperation with all stakeholders involved (industry, governmental organisations, NGOs, research institutes and universities). During a kick-off workshop on the 14th of October 2008 many stakeholders commented on the general biorefinery strategies (Moonshots). Detailed generic biorefinery-related strategic research aspects were identified and specified by a representative group of senior experts from mainly the knowledge infrastructure and some major industrial representatives during a second workshop on the 29th of October 2008. Detailed demonstration case descriptions fitting in these Moonshots were further elaborated with a representative group of stakeholders during a third workshop on the 29th of October. Both the strategic research aspects and the demonstration case descriptions, including applied research issues, were then finished by the project team taking into account feedback given by the stakeholders. Finally, the project team drafted a list with key actions in November 2008, which were sent to some key stakeholders for final comments in January 2009. A complete list of the stakeholders involved in the different phases of the Roadmap preparation process can be found in the acknowledgements.

The specific demonstration cases that have been described as part of the various Moonshots in this Roadmap are merely examples and not some sort of (pre)selection. For robust development of the Bio-based Economy a market-pull approach for the establishment of biorefinery initiatives in The Netherlands will be needed. Companies should be strongly involved in the developments. Therefore, the question if The Netherlands will be able to obtain a leading role in the biorefinery market depends on the initiatives and choices made by industry.

Report Set-up



Content

Preface 3

Report Set-up 4

Executive Summary 7

Uitgebreide Management Samenvatting 19

1 Introduction 45

1.1 Dutch governmental Vision on the Bio-based Economy in the Energy Transition 45
1.2 Sustainable bio-based products and bioenergy: biorefinery 46
1.3 Potential of biorefinery to meet the targets set by the Platform Bio-based Raw Materials (PGG) 49
1.4 Targets Dutch working programme Clean and Efficient ("Schoon en zuinig") 51
1.5 International developments urge The Netherlands to take action 52
1.6 SWOT analysis on biorefinery in The Netherlands 53

2 The biorefinery chain 55

2.1 Introduction 55
2.2 Feedstock 57
2.3 Pre-treatment and primary refinery 57
2.4 Secondary refinery and conversion, and final processing 58
2.5 Market/Output 58
2.6 Challenges for transition to a Bio-based Economy 60

3 Moonshot approach 63

3.1 Moonshots 63
3.2 General description of Moonshots 66
3.3 Stakeholders view on the Moonshots 69

4 Roadmaps for applied research and demonstrations 73

4.1 Short-term Demonstrations: Connection to the future Bio-based Economy 73
4.2 Demonstrations Moonshot 1: Domestic Crops 75
4.3 Demonstrations Moonshot 2: Aquatic Biomass 81
4.4 Demonstrations Moonshot 3: Large-scale Biomass Import 90
4.5 Demonstrations Moonshot 4: Biomass Residues 96
4.6 Concluding remarks 99

5 Roadmaps for strategic research 101

5.1 Introduction 101
5.2 Strategic research drivers 101
5.3 High quality use of raw materials and low CO_2 emissions including low capital costs 102
5.4 Low raw material cost 104

5.5 Social values, how to cope with growing competitive claims 106
5.6 Some other strategic research issues 107

6 Integrated Research, Development and Demonstration (RD&D) agenda for the transition to a Bio-based Economy 109
6.1 Individual key actions 109
6.2 Key Actions Groups 111

References 117

Acknowledgements 119

Appendix A. SWOT analysis Biorefinery from a Dutch point-of-view 125

Appendix B. Constituent components of lignocellulosic crops 126

Appendix C. Transition towards cross-industrial connections 128

Appendix D. Targets, barriers & actions of demonstration cases 134

Executive Summary

In October 2007 the 'Dutch governmental Vision on a Bio-based Economy in the Energy Transition' was presented (LNV, 2007). The Bio-based Economy should play a major role in the sustainable development of The Netherlands. Replacing fossil resources by renewable resources like biomass will contribute to the reduction of greenhouse gas emissions. Building a Bio-based Economy – an economy in which companies will produce a portfolio of non-food products (chemicals, materials, fuels, power and heat) from biomass – will create new economic opportunities for the Dutch industry.

The government identified chances for the Dutch industry, specifically within the field of the production of (high) added-value products from biomass. Based on this, and on the fact that the required biomass has to be produced in a sustainable way, the Dutch government set-up a policy agenda. One of the focus points of policy agenda is improving the efficiency of biomass utilization, with biorefinery as key concept/ technology.

Development of a Bio-based Economy is crucial for reducing CO_2 emissions and dependency on fossil resources. Because of its unique strengths (logistic position, strong agri and chemical sectors, strong knowledge base both at national and European level) The Netherlands is very suitable for further developing and exploiting a Bio-based Economy. Biorefinery is a central strategy within the Bio-based Economy: converting biomass into a cascade of products (from high added-value chemicals to energy), maximizing the potential value and impact of biomass use.

The Innovation Agenda Energy (EZ, 2009) gives concrete targets for 2020 in the field of energy transition. The scope of the Innovation Agenda Energy is the period 2008-2012. The agenda is aimed primarily at the start-up of the necessary developments within several innovation themes. One of these themes is Bio-based Raw Materials ('Groene Grondstoffen'). This concerns among others sustainable production and development of biomass, and co-production of transportation fuels, chemicals, electricity and heat. An important activity in this cabinet period within the theme Bio-based Raw Materials is drawing up a (technology) roadmap biorefinery. Therefore, the Dutch Ministry of Agriculture, Nature and Food Quality (LNV) in 2008 commissioned the development of a Dutch Roadmap on Biorefinery, which is needed as first step in a powerful and integrated approach towards the establishment of biorefineries, as part of a Bio-based Economy, in The Netherlands. This Roadmap will show the road from the current mainly Fossil-fuel based Economy to a future Bio-based Economy, emphasizing the role of biorefinery processes within this transition process. Specific attention in this Roadmap is given to the short-term (< 2015) actions (a.o. pilot/demo plant support, support of both technical and non-technical applied and strategic research, stakeholder analysis) necessary to pave the road for the transition to a fully

implemented Bio-based Economy in the longer-term. The results of the roadmapping process are presented in this report.

<u>Definition Biorefinery</u>

Biorefinery is the sustainable processing of biomass into a spectrum of marketable products and energy (IEA Bioenergy Task 42 on Biorefineries)

This definition includes the key words:

- *Biorefinery*: concepts, facilities, processes, cluster of industries
- *Sustainable*: maximising economics, minimising environmental aspects, fossil fuel replacement, socio-economic aspects taken into account
- *Processing*: upstream processing, transformation, fractionation, thermo-chemical and/or biochemical conversion, extraction, separation, downstream processing
- *Biomass*: crops, organic residues, agro-residues, forest residues, wood, aquatic biomass
- *Spectrum*: more than one
- *Marketable*: a market (acceptable volumes & prices) already exists or is expected to be developed in the near future
- *Products*: both intermediates and final products, i.e. food, feed, materials, and chemicals
- *Energy*: fuels, power, heat

Biorefinery is not a completely new concept. In agriculture and food industries, usually agricultural crops and materials are converted into various products, each with different applications (food and feed). The dairy, potato and soy sectors are very good examples of the biorefinery concept. However, to fulfil the needs and potential of a Bio-based Economy (production of a large part of the needs of food and feed as well as chemicals, fuels, energy and heat from biomass) at low cost, broadening of this approach, and more optimal use of the raw materials including minerals is necessary. To fully exploit the potential of this approach large research efforts, combined with industrial pilots and demonstrations, will be needed.

This Roadmap describes a number of routes, including both short and midterm opportunities and more strategic actions for the longer-term, towards the development of a Bio-based Economy in The Netherlands. Most promising innovation directions pursue on opportunities that are a good fit to strengths and can cope with weaknesses within the specific Dutch framework. Based on a SWOT analysis (see Table S1, and Appendix A), the following promising directions for biorefinery in The Netherlands have been identified:

- Biorefinery based on domestic Dutch crops, using synergy of existing agro and chemical sectors, including the Dutch plant breeding sector.
- Biorefinery of aquatic biomass, using Dutch microbiology, plant breeding and processing knowledge.

- Biorefinery of bulk imported biomass and biomass-derived intermediates, using existing logistic and petrochemical infrastructure.
- Biorefinery of residues, based on co-operation in production chains and networks, relatively small transport distances and business competences of Dutch entrepreneurs.

Table S1 Short-list SWOT-analysis Biorefinery in the NL (long-list in Appendix A).

Strengths (internal)	**Weaknesses (internal)**
• Strong agrocluster, chemical sector and energy sector available, situated relatively close to each other • Advantageous geographical position in European market and logistical infrastructure (a.o. harbours in/export) • Good Knowledge Infra Structure (KIS, universities and institutes) • Food industry is already experienced with biorefinery processes	• Insufficient co-operation between stakeholders of agro, chemical and energy sectors • Studying instead of implementing • Investment capital for pilot and demo initiatives difficult to find • Key technologies partly still in R&D-phase • Full chains often not yet market competitive due to relatively cheap fossil fuels
Opportunities (external)	**Threats (external)**
• Strengthening of the economic position of the agro, chemical and energy sectors • Co-operation between stakeholders can boost the development and implementation of biorefinery concepts • Development of multi-purpose biorefineries in a framework of scarce raw materials and energy • Challenging national and European policy goals for bioenergy (fuels, energy) lead to high demand and trade of biomass	• Fluctuating (long-term) governmental policies delay company investments • Focus on single products (biofuels and electricity) only (no chemicals yet), and not on multiple products • High initial investment costs for pilots and demos • Discussion food/feed/fuels and biomass sustainability • Existing industrial infrastructure is not depreciated yet

Together with the most relevant stakeholders four Moonshots were elaborated as envisaged biorefinery strategies, with high potential for the Dutch economy, which will be fully operational far before 2030, and that are ready for small-scale demonstration of parts of the biorefinery concept before 2015:

- Moonshot 1: Biorefinery of specific Dutch crops
- Moonshot 2: Biorefinery of aquatic biomass
- Moonshot 3: Biorefinery of imported biomass at Dutch harbour sites
- Moonshot 4: Biorefinery based on the valorisation of waste and residue streams

White biotechnology is an integral part of these biorefinery strategies, and therefore is not defined as a separate Moonshot.

The identified Moonshots reflect promising feedstock sources (BIOPOL, 2009):

1. Specific Dutch crops with high biomass productivity (beet, maize, grass). Large-scale biorefinery of such crops will result in different demands to the raw materials than current chains do. Hence, alternative systems may be needed for agricultural production and harvesting.
2. Aquatic biomass (micro-algae and seaweeds) is an interesting new feedstock for biorefinery, characterized by high productivity per area unit, and a high content of valuable components, including: oils, proteins, polysaccharides and specific biomolecules. Due to the varied composition, micro-algae and seaweed biomass are highly suited for biorefinery with end-products ranging from fuels and bulk chemicals to specialty chemicals and food and feed ingredients. This Moonshot requires the development of production and conversion technologies, and the formation of logistic chains.
3. Imported biomass at Dutch harbour and port sites (energy densified lignocellulosic raw materials and biomass-derived intermediates). Large-scale biomass import is common for food/feed and for energy (think of wood chips) already. For this Moonshot feedstock can be retrieved from (existing) commodity markets, with connected advantages (independent from variations in local agricultural production, reduced seasonal dependency).
4. Biomass residues and waste streams (multi-industrial intersectoral approach). A substantial fraction of the residues from food industries is used for feed (although the mineral contents mostly is far from optimal). A part of the organic residues is used for biogas production. New technologies and chain arrangements are needed for better use of these biomass streams.

The chosen Moonshots are mainly identified on the basis of differences in feedstock, in line with the promising directions mentioned above. A strategy for further development of a Bio-based Economy demands for large-scale implementation of these biorefinery strategies in the forthcoming decade. Industrial developments are urgently needed. Therefore, starting demonstrations on the short-term is essential.

In interactive workshops with a broad range of stakeholders (representatives from industries, governments, research institutes and universities) a number of suggestions for biorefinery demonstrations have been identified per Moonshot.

Table S2 Suggestions Biorefinery Demonstrations.

Moonshot	Examples for Biorefinery demonstrations
1. domestic crops	• whole crop sugar beet • grass
2. aquatic biomass	• micro-algae • sea weeds
3. large scale biomass import	• syngas production • integral valorisation of biomass for biofuels, feed and chemicals
4. biomass residues	• food residues (undefined streams) • residues of food production (defined streams)

Through the preliminary search for potential demonstrations, industry as well as researchers are mobilised and stimulated to participate. It forms a basis for a demand-driven formulation of priorities for applied research, which – in return – can stimulate rapid development of the industrial demos. The above list of potential demonstrations should not be considered a pre-selection; it is only indicative for potential demonstrations, and has been used to derive the general actions required.

Some of the biorefinery-related implementation barriers (especially the longer-term questions) are of a more generic character. These generic – often strategic – biorefinery barriers should be dealt with in an integrated approach. During a brainstorm meeting with people from industry, knowledge institutes, universities and government, a large number of technologies were identified that might contribute to the Bio-based Economy following biorefining approaches.

In order to (1) stimulate industrial demonstrations (which still face various technical and non-technical barriers), (2) keep on track with the full development of a Bio-based Economy, and (3) control societal sustainability of the developments, large efforts will be needed, connected to the following aspects of biorefinery development:

- Feedstocks (availability and suitability)
- Biomass pre-treatment processes
- Secondary refinery and final processing
- Market development and market-oriented biorefinery chain development
- Chain development and overcoming chain-wide challenges
- Societal and environmental assessment of biorefinery developments

Table S3 summarizes Key Actions based on the actions and R&D priorities (connecting the R&D priorities to the Moonshots and demonstrations, formulated in close interaction with stakeholders from industry, government, research institutes and universities). Both short, medium and long-term Key Actions are specified. Technical as well as non-technical issues are addressed. The individual Key Actions in Table S3 are grouped under Key Action Groups (Figure S1).

Table S3 Individual Key Actions Dutch Roadmap Biorefinery for different aspects of biorefinery development.

Aspects of biorefinery development	*Demonstration*	*Applied research and piloting*	*Strategic Research*
Feedstocks (availability and suitability)	• optimise logistics for collection • selection and screening of species and crops	• dedicated test facilities • standardisation + property certification of feedstock • on-site sustainable nutrients management • algae harvesting	• increase storage life • search other feedstocks for use in same process • increase productivity of crops • increase contents and accessibility of valuable ingredients in crop
Biomass pre-treatment and primary refinery processes	• scalability • demonstrate feasibility & reliability	• dedicated test facilities • proven long-duration operation • feedstock-tolerant technologies • on-site sustainable water management • optimisation of functionality of new ingredients in relation to processes applied and purity	• local pre-treatment • low-cost technologies • exploit potency of existing technologies • increase storage life feedstock • cost reduction • reduction energy use • determination of functionality of new (modified) ingredients
Secondary refinery and final processing	• demonstrate technologies for multiple-products • demonstrate feasibility & reliability	• dedicated test facilities • extraction of minerals • mild extraction / separation processes (low temp & low energy) • sustainable water management solutions	• low-cost separation • multiple feedstocks for year-round use of facilities • ensure high-purity end-products • develop design tool
Market development and market-oriented biorefinery chain development	• technology as export products • proof of product quality	• standardisation of products • integral valorisation of biorefinery products	• solve 1-1 dependency new supplier & customer biobased product • market-oriented product development: high-value chemicals and bulk materials
Chain development and overcoming chain-wide challenges	• financing options (e.g. financing fund) • optimal chain formation: scales & logistics & modular concepts • co-operation between sectors agro – chemistry – energy • found a knowledge centre • interface with other national programs (b-basic, catch-bio, ccc, dsti, process intensification)	• combine and integrate different technologies • use international available facilities • integrate existing knowledge agro & chemical sectors • integrate existing infrastructure agro & chemical sectors	• dissemination & education • international networking/ knowledge import • coupling withCO_2 capturing

	All three Phases		
Societal and environmental assessment of biorefinery developments	• approved demo locations north sea with nutrients supply at sea (aquatic biomass) • public acceptation • nutrients supply at sea • exploit international GMO context • solving legal label "waste" • rural development • integrated approach for food-feed-fuel production • adding value through regional production	• integrated approach for food-feed-fuel production • optimal use of residues • consumer acceptance • search for markets (new and existing, in price and volume) • cross-sector integration • risk management • chain formation/ consortium building	• implementation questions Cramer criteria (boundary condition) • environmental and spatial permits • nutrient cycles • transition to biobased system • guarantee sustainability and transparency of biorefinery chains, respecting food-feed-fuel demand • reward external benefits (GHG reduction, fossil input displacement

For a more detailed description of the specific demonstration-based targets, barriers and actions see Appendix D.

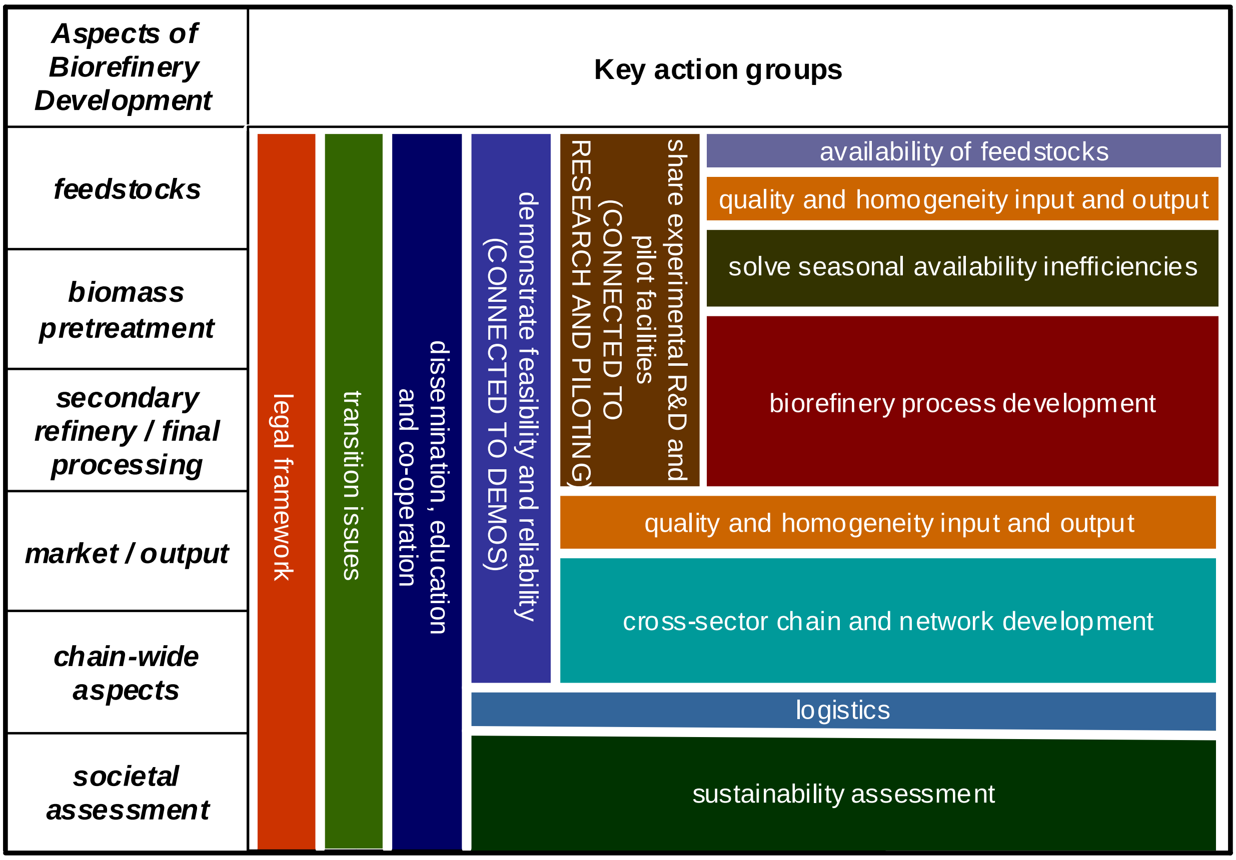


Figure S1 Overview of Key Action Groups related to the above mentioned aspects of biorefinery development.

For the Key Action Groups, the following questions have to be addressed:

- **Sustainability assessment**
  To guarantee sustainable and societal-desirable development, an evaluation framework is needed (think of ecological food-print analysis and Cramer criteria). Sustainability evaluation will address local as well as global effects, people and planet aspects, including nutrient cycles, water management and food-feed-fuel-competition. Furthermore, sustainability comparisons of bio-based and fossil-based products, and comparisons of bio-based routes, are essential. Also potential coupling with CO_2 capturing will be relevant. This key theme is relevant for social acceptance of biorefineries, for consumer acceptance of the products, and for consciously-oriented incentives by the government.

- **Cross-sector chain and network development**
  Biorefinery leads to the arrival of new companies and sectors. Existing companies will want to both work together and compete with each other. Furthermore, new relationships between new and existing sectors will develop: the agricultural world will step into the non-food world and vice versa. Several typical issues are:
    - How and where does pricing take place, and what types of contracts are used with regard to different flows of biomass and intermediate products?
    - How are the different links in the chain organised (degree of organisation)?
    - What are their specific interests and rules of the game?
    - What power of negotiation do they have with respect to suppliers and customers?
    - What influence do they have in public arenas?
    - Opportunities for cluster forming (national/regional) versus international sourcing and supply.
    - Needs and knowledge/experience gap analysis: promoting links and collaboration between two previously separate industries does not allow top-down management.
    - What do the firms in the agrifood sector and the chemical industry see as barriers, and uncertainties, when considering opportunities, collaborations and activities?

- **Logistics**
  This connects distributed (relatively small-scale) primary production to the end-product: from harvesting to standardised end-products, taking into account the full biomass value chain. Relevant issues are:
    - Harvesting and on-site pre-treatment methods oriented at the intended use and at acceptable collection logistics.
    - Storage/quality preservation of the feedstock, intermediate and end products within the chain.
    - Scalability of chain actors.

  - Standardisation of the products.
  - Increase energy density for long distance transport.

- **Biorefinery processes development**
  From pre-treatment through various refinery processes until the output product, with focus on:
  - Production efficiency of the processes.
  - Optimisation of functionality of products in relation to processes applied and purity of the products.
  - Cost reductions.
  - Reduction of energy use.
  - Improvement of product quality.
  - New refinery/product development.
  - Sustainability of the whole chain.
  - Cost efficiency optimisation of the whole production chain for the various products.

  The required technology development involves both physico-chemical or thermochemical processes, and biotechnological processes often in combination, depending on the type of feedstock and the desired biobased products.

  In addition to technical process development, knowledge sharing and process modelling will facilitate deliberating about new biorefinery processes and chains. New concepts usually consist of new combinations of existing and potentially new technologies applied to existing biomass streams.

- **Availability of feedstocks**
  Sustainability and feasibility of biorefinery largely depends on availability of feedstock. Developing a biorefinery will affect the market for the feedstock material; therefore strategic analysis is required. Typical questions are:
  - What is the current and future availability?
  - What is the elasticity of price and availability?
  - What will the effect be of using the feedstock for biorefinery on cost price development?
  - What will be the effect on food and feed price?
  - What price fluctuation is expected, and how could this be influenced?
  - Build technologies that lead to several high volume standardized intermediate products.

  With regard to this issue there is a strong link with the intended *Sustainable Biomass Production Programme*. This aims at ensuring the optimal quality of biomass feedstocks.

- **Quality and homogeneity of input and output**
  What input quality is available, and how could this be improved (e.g. increasing contents and accessibility of valuable ingredients in the crop through crop and cultivar choice, improved primary production and through plant breeding)? What quality does the intended market (food, feed, pharma, chemistry, energy) demand? One of the typical properties of agricultural products is "biological variation". Products used for biorefinery will also have large variations, especially residue streams. Biorefinery processes should be able to handle large variations of input quality, and produce sufficiently homogeneous outputs. What standardisation is possible?

- **Solve seasonable availability inefficiencies**
  Agricultural crops are produced seasonably. Seasonal processing in biorefinery chains results in inefficient use of the equipment and discontinuous supply of outputs to the market. Search for:
    - Ways to increase storage life (of feedstocks or half-products).
    - Multiple feedstocks for year-round use of facilities (e.g. storage in the field).
    - Miscanthus, winter beet, combining import with domestic production, storability.
    - Other solutions.

- **Demonstrate feasibility and reliability**
  Prove technical feasibility and reliability of the processes and products through long-during industrial demonstrations. This question is crucial to convince industries to further develop biorefinery.

- **Share experimental R&D and pilot facilities**
  There is a broad range of biorefinery processes; a large variety of experimental facilities is needed. Setting up a complete set of facilities is not feasible (neither for industry nor for one research organisation). Sharing existing infrastructure and co-operative setup of new facilities (agro and chemical sectors) is needed, preferably in co-operation with international partners.

- **Legal framework**
  Existing legislation is not optimal for biorefinery development. For example, the use of the label "waste" hinders a broad range op potential biorefinery initiatives. Furthermore, local environmental and spatial permits are limiting possibilities (also think of marine or off-shore algae production). Questions are oriented at how to facilitate biorefinery developments without unwanted societal harm.

- **Transition issues**

  Development of the Bio-based Economy and biorefinery is a major challenge, requiring involvement of government, non-governmental organisations, firms and centres of knowledge. Interaction between those four major players (which measure, at what time, by whom?) is needed to develop the biorefinery from a niche-market to a well-developed new economy. One of the goals of demonstrations is to learn about the transition process of this development towards the Bio-based Economy and biorefinery (from a perspective of entrepreneurs as well as society). Assessment of the demonstrations and other results will speed-up further development of the Bio-based Economy. For a detailed description of especially these issues see Appendix C.

- **Dissemination, co-operation and education**
    - "Import" international state-of-the-art knowledge and make this available for stakeholders in The Netherlands.
    - International networking/ knowledge import.
    - Integrate existing knowledge agro & chemical sectors.
    - Build new academic and professional education programmes.

Further recommendations

- The development of a bio-based economy requires the large-scale implementation of biorefinery strategies.
- Short-term pilots and demonstrations of (parts of) biorefinery chains are required to arrive at large-scale implementation in the future.
- There is a large number possibilities for biorefining of biomass. Since the objective is to contribute to the development of a bio-based economy, it is industry who has to pull the developments in this area.
- Support of pilots, demonstrations and accompanying (strategic) research is required to accelerate the development of a bio-based economy.

Uitgebreide Management Samenvatting

De Bio-based Economy dient een hoofdrol te vervullen in de Duurzame Ontwikkeling van Nederland, zoals aangegeven in de 'Overheidsvisie op de Bio-based Economy in de Energietransitie' (LNV, oktober 2007). Substitutie van fossiele brand- en grondstoffen door duurzame alternatieven op basis van biomassa levert potentieel een significante bijdrage aan de reductie van de broeikasgasemissies in Nederland. Verder zal de realisatie van een Bio-based Economy – een economie waarin een scala aan non-food Bio-based Producten (chemicaliën, materialen, brandstoffen, elektriciteit en warmte) wordt geproduceerd – nieuwe economische mogelijkheden scheppen voor de Nederlandse industrie. Binnen dit kader heeft de overheid kansen voor het Nederlandse bedrijfsleven geïdentificeerd, met name op het gebied van de productie van (hoge) toegevoegde marktwaarde producten uit biomassa. Op grond hiervan – en het feit dat de vereiste biomassa op een duurzame wijze dient te worden geproduceerd – heeft de Nederlandse overheid een beleidsagenda opgesteld. Eén van de speerpunten van deze beleidsagenda is het verhogen van de efficiëntie van het biomassagebruik, met bioraffinage als sleutelconcept/-technologie.

Ontwikkeling van een Bio-based Economy is essentieel voor de reductie van enerzijds de nationale CO_2-emissies en anderzijds de afhankelijkheid van het gebruik van fossiele brand- en grondstoffen. Vanwege haar unieke specifieke sterkten op het gebied van o.a. de logistiek (havens), de agro- en chemische sectoren en de aanwezige kennisinfrastructuur (instituten en universiteiten) is Nederland uitermate geschikt voor de verdere ontwikkeling en exploitatie van een Bio-based Economy. Bioraffinage is een specifieke strategie welke onderdeel is van de Bio-based Economy. In deze strategie wordt biomassa benut voor de productie van een cascade van Bio-based Producten – van hoge toegevoegde marktwaarde chemicaliën tot energie – waardoor de economische verwaarding van de biomassa binnen een ecologisch verantwoord kader wordt gemaximaliseerd.

De Innovatieagenda energie (EZ, juli 2008) schetst concrete doelen voor 2020 op het gebied van de energietransitie. De scope van de Innovatieagenda energie is de periode 2008-2012. De agenda richt zich primair op het in gang zetten van noodzakelijke ontwikkelingen binnen verschillende innovatiethema's. Eén van die thema's is Groene Grondstoffen. Dit betreft o.a. duurzame productie en ontwikkeling van biomassa, en co-productie van transportbrandstoffen, chemicaliën, elektriciteit en warmte door middel van bioraffinage. Een belangrijke activiteit binnen het thema Groene Grondstoffen in deze kabinetsperiode is het opstellen van een (technologische) roadmap bioraffinage. Vandaar dat het Ministerie van Landbouw Natuur en Voedselkwaliteit (LNV) in augustus 2008 een opdracht heeft verleend voor de uitwerking een Nederlandse Roadmap Bioraffinage. De opzet van een Roadmap Bioraffinage vormt een 1^e^-stap van een integrale aanpak om de implementatie van op bioraffinage-gebaseerde biomassa-waardeketens – als hart van de Bio-based Economy – te bevorderen. De Roadmap laat een aantal mogelijke routes zien van de huidige vooral op fossiele brand-/grondstof gebaseerde economie naar een toekomstige Bio-based Economy, waarbij de rol van Bioraffinage in het transitieproces wordt benadrukt. Het resultaat van de LNV-opdracht is onderliggend rapport. Dit rapport is tot stand gekomen door een gezamenlijke inspanning van een groot aantal nationale stakeholders (industrie, overheid, milieuorganisaties, kennisinstellingen, universiteiten) onder aanvoering van genoemd consortium (WUR, ECN, RB).

Definitie Bioraffinage

Bioraffinage is de duurzame verwerking van biomassa in een spectrum van vermarktbare producten en energie (IEA Bioenergy Task 42 on Biorefineries)

Deze definitie bevat de volgende sleutelwoorden:

- Bioraffinage: concepten, faciliteiten, processen, cluster van industrieën
- Duurzaam: maximaal economisch rendement, minimale milieubelasting, sociaal acceptabel
- Verwerking: voorbehandeling en primaire raffinage, transformatie, fractionering, thermo-chemische en (bio)chemische conversie, extractie, productscheiding, product opwerking
- Biomassa: gewassen, hout, organische/agro/bosbouwresiduen, aquatische biomassa (algen)
- Spectrum: meer dan één
- Vermarktbaar: er bestaat reeds een markt (zowel qua marktvolume als prijsstelling) voor de afzet van de producten of er wordt verwacht dat er op de korte termijn een markt zal ontstaan
- Producten: voedsel, veevoer, chemicaliën, materialen; finale- en tussenproducten
- Energie: brandstoffen, elektriciteit en warmte

Bioraffinage is niet nieuw. In zowel de agro- als de voedings-/genotmiddelenindustrie worden landbouwgewassen omgezet in een scala aan producten voor verschillende toepassingen. De zuivel-, aardappel- en soja-industrie zijn goede voorbeelden van reeds geïmplementeerde bioraffinageconcepten. Om echter invulling te kunnen geven aan de vormgeving van een toekomstige Bio-based Economy, waarin het overgrote aandeel van het menselijke voedsel, het veevoer, de chemicaliën, de materialen, de brandstoffen en de elektriciteit en/of warmte uit biomassa moet worden geproduceerd, dient de bioraffinagestrategie verder te worden ontwikkeld en toegepast. Alvorens de bioraffinagestrategie grootschalig kan worden geïmplementeerd is een aanzienlijke toegepaste en strategische Onderzoek- & Ontwikkeling (O&O) inspanning, inclusief industriële demonstratie, vereist. Derhalve is het noodzakelijk om zo spoedig mogelijk serieus aan de slag te gaan.

Deze Roadmap Bioraffinage beschrijft een aantal mogelijke routes naar de ontwikkeling en implementatie van een bioraffinage-gerelateerde Bio-based Economy in Nederland. De Roadmap combineert korte- en middellange termijn mogelijkheden (commerciële implementatie, demonstratie plants, pilot plants en gerelateerd toegepast onderzoek) met strategisch onderzoek voor de langere termijn.

De meest veelbelovende bioraffinage-gerelateerde innovatierichtingen zijn gebaseerd op mogelijkheden resulterend uit een uitgevoerde SWOT-analyse, zie tabel S1.

Tabel S1 Short-list SWOT-analyse Bioraffinage in Nederland (long-list, Appendix A).

Sterktes (intern) • Agro-, chemische- en energiesectoren relatief dicht bij elkaar gepositioneerd. • Geografische positie in Europees kader, incl. de beschikbare logistieke infrastructuur (havens) • Kennisinfrastructuur op het gebied van de BbE (instituten en universiteiten) • Voedingsindustrie is reeds bekend met bioraffinage processen	**Zwaktes (intern)** • Onvoldoende tot geen samenwerking actoren agro-, chemische-, energiesectoren • Studeren i.p.v. implementeren • Investeringskapitaal voor pilot en demo initiatieven moeilijk te vinden • Sleuteltechnologieën deels nog in O&O-fase • Volledige biomassawaardeketens veelal niet markt competitief door relatief goedkope fossiele brand-/grondstoffen
Mogelijkheden (extern) • Versterken van de economische positie van de agro-/chemische- en energiesectoren • Samenwerking tussen actoren binnen biomassa-waardeketens en uit verschillende marktsectoren kan de tijd tot grootschalige marktimplementatie van bioraffinageprocessen als onderdeel van de BbE aanzienlijk verkorten • Ontwikkeling van flexibele bioraffinage processen in een toekomstig kader van schaarser wordende (duurdere) grondstoffen en energie • Uitdagende nationale en Europese beleidsdoelstellingen voor bioenergie (brandstoffen, energie) resulteren in een toenemende vraag en handel in biomassa	**Bedreigingen (extern)** • Veranderende (lange-termijn) overheids-doelstellingen vertragen investerings-beslissingen door de industrie • Fiscale stimulering productie van biobrandstoffen en bioenergie en niet van toegevoegde waarde producten als chemicaliën/materialen, laat staat van optimale co-productiesystemen (bioraffinaderijen) • Hoge noodzakelijke investeringskosten voor pilot en demonstratie faciliteiten • Voeding/veevoer/brandstof discussie en discussie m.b.t. duurzaamheidsaspecten • Bestaande industriële infrastructuur gebaseerd op fossiele brand-/grondstoffen is nog niet afgeschreven

Samen met de meest relevante stakeholders zijn vier z.g. Moonshots uitgewerkt, als voorziene bioraffinagestrategieën met een grote potentie voor de Nederlandse economie. Deze Moonshots (samenstellende biomassawaardeketens) zullen naar verwachting volledig operationeel zijn voor 2030 en gedeeltelijk gereed voor demonstratie voor 2015. De gedefinieerde Moonshots zijn:

- Bioraffinage van specifieke Nederlandse gewassen (Moonshot 1.)

- Bioraffinage van aquatische biomassa (Moonshot 2.)
- Bioraffinage van geïmporteerde biomassa in het Nederlandse havengebied (Moonshot 3.)
- Bioraffinage gebaseerd op de verwaarding van reststromen en bijproducten (Moonshot 4.)

Witte biotechnologie is een integraal onderdeel van genoemde bioraffinagestrategieën en derhalve niet opgenomen als separate Moonshot.
De Moonshots hebben betrekking op veelbelovende grondstoffen (BIOPOL, 2009), te weten:

1. Specifieke Nederlandse gewassen met een hoge biomassaproductiviteit, zoals: bieten, maïs en gras. Grootschalige raffinage van deze gewassen zal resulteren in andere eisen aan de geproduceerde biomassa t.o.v. de huidige conventionele inzet. Alternatieve productiesystemen en oogsttechnieken zullen noodzakelijk zijn. Bij deze Moonshot wordt gebruik gemaakt van intensieve productiemethoden, een klassieke sterkte van de Nederlandse agro-food sector.
2. Aquatische biomassa (microalgen en zeewieren) is een veelbelovende nieuwe biomassa-grondstof voor raffinagedoeleinden met enerzijds een hoge productiviteit per hectare en anderzijds een hoge concentratie aan waardevolle inhoudsstoffen, zoals; oliën, eiwitten, koolwaterstoffen en specifieke biomoleculen. Vanwege de grote verscheidenheid aan verschijningsvormen met een grote variatie in samenstelling is aquatische biomassa uitermate geschikt voor bioraffinagedoeleinden voor de productie van eindproducten die kunnen worden afgezet in zowel de voeding-/veevoersectoren, de chemische sector en de energiesector. Deze bioraffinage strategie vereist de ontwikkeling van productie- en conversietechnieken, alsmede de realisatie van logistieke ketens. Bij deze Moonshot wordt ingespeeld op de in Nederland geschikte condities voor ontwikkeling en commercialisatie van micro-algen en zeewieren teelt (Reith, 2004 & 2005). Voor micro-algen teelt zijn de klimatologische condities relatief gunstig gezien de relatief lange lichtperiode per dag en de beperkte temperatuurwisselingen over het etmaal. Voor zeewierenteelt is in het door Nederland beheerde deel van de Noordzee in principe een groot, aanvullend areaal beschikbaar, mogelijk in combinatie met windturbineparken en andere vorm van aquacultuur zoals mosselenteelt.
3. Geïmporteerde biomassa in Nederlandse havengebieden (energie verdichte lignocellulose biomassa grondstoffen en gerelateerde intermediairen). Grootschalige import van biomassa voor voeding en veevoer, alsmede voor energiedoeleinden, is reeds een gemeen goed. Voor deze Moonshot kan de benodigde biomassa worden betrokken vanuit (bestaande) internationale markten. Dit heeft als potentieel voordeel de onafhankelijkheid van variaties in lokaal biomassa-aanbod t.g.v. seizoensinvloeden. Bij deze Moonshot wordt gestreefd naar vergroting van de toegevoegde waarde van aangevoerde biomassa en naar integrale benutting.
4. Biomassareststromen en bijproducten (multi-industriële en intersectoriële aanpak). Nieuwe technologieën en ketensamenstellingen zijn noodzakelijk voor betere verwaarding van deze biomassastromen en bijproducten. Deze Moonshot (no-regret optie) maakt gebruik

van bestaande biomassastromen, maar vergt logistieke en technologische innovaties en veranderingen van randvoorwaarden m.b.t. gebruik.

Een strategie voor de verdere ontwikkeling en realisatie van een Bio-based Economy vraagt om de grootschalige implementatie van genoemde bioraffinagestrategieën (Moonshots) op de middellange termijn. Hiertoe is realisatie van industriële demonstraties op de korte-termijn met hieraan gekoppeld een toegepast onderzoeksprogramma een absolute noodzaak.

Middels de organisatie van een aantal interactieve vraaggestuurde workshops met vertegenwoordigers vanuit de industrie, de overheid, onderzoeksinstellingen en universiteiten is een aantal suggesties voor bioraffinage demonstratieprojecten – twee per Moonshot – gedaan.

Tabel S2 Suggesties bioraffinage demonstratieprojecten.

Moonshot	Voorbeelden bioraffinage demonstratieprojecten
Bioraffinage specifieke Nederlandse gewassen	• Suikerbietenraffinage (volledig gewas) • Grasraffinage
Bioraffinage aquatische biomassa	• Raffinage van micro-algen • Raffinage van zeewieren (macro-algen)
Bioraffinage van geïmporteerde biomassa in Nederlandse havengebieden	• Thermo-chemische raffinage – synthesegas productie • Integrale valorisatie van biomassa voor biobrandstoffen, veevoer en chemicaliën
Bioraffinage gebaseerd op de verwaarding van reststromen en bijproducten	• Raffinage residuen uit de voedingsmiddelen-industrie (ongedefinieerde stromen) • Raffinage van residuen uit de voedselproductie-keten (gedefinieerde stromen)

Bovengenoemde lijst met potentiële bioraffinage demonstratieprojecten dient slechts als eerste suggestie en is derhalve geenszins een (voor)selectie en is gebruikt om de specifieke acties te identificeren die noodzakelijk zijn om de Moonshots tot ontwikkeling te brengen.

Onderstaand volgt per Moonshot een overzicht van de noodzakelijke korte- en middellange termijn onderzoeksinspanningen, inclusief de potentiële realisatie van benodigde pilot- en demonstratie faciliteiten.

Moonshot 1. Bioraffinage van specifieke Nederlandse gewassen
In Nederland geteelde gewassen kunnen gedeeltelijk bijdragen aan de vraag naar biomassa vanuit de Bio-based Economy. Door een optimale benutting van het gehele gewas (inclusief huidige primaire reststromen) wordt de concurrentie met voedsel beperkt. Biomassa van Nederlandse gewassen wordt momenteel verwerkt in bestaande agroketens. Een effectieve benutting van het gehele gewas vraagt oplossingen op het vlak van productiviteit van gewas en teeltsysteem, logistiek, (scheidings)technologie, productontwikkeling en wet- en regelgeving.

Typering
Het kenmerk van deze Moonshot is dat alle componenten van een geteeld gewas optimaal worden verwaard. In de huidige agroketens wordt vaak de nadruk gelegd op het verwaarden van een beperkt aantal componenten van het gewas, zoals bieten, knollen of zaden. Bij deze Moonshot wordt het gehele gewas geoogst en verwerkt. Beoogde toepassingen/functionaliteiten zijn: voedsel, veevoer, materialen, chemicaliën, transportbrandstoffen, elektriciteit en warmte.

Bij deze Moonshot gaat het om een breed scala aan biomassa gewassen met een hoge productiviteit zoals suiker- en voederbieten, tarwe, maïs, hennep, nieuwe eiwitgewassen (zoals lupine en bonen) en gras. Deze Moonshot kan ook vragen om de ontwikkeling van specifieke gewassen (b.v. Crambe) en om aangepaste agrarische teelt- en oogstsystemen.

Praktische mogelijkheden worden mede bepaald door de schaal van de toepassing. De keuze van de juiste schaalgrootte is erg belangrijk. Grootschalige bioraffinage zal grote hoeveelheden biomassa vragen, wat logistieke vragen oproept. Kleinschalige bioraffinage kan in sommige situaties een goed alternatief bieden.

Voorbeelden van beoogde ontwikkelingen:
- Benutting van het gehele gewas, b.v. niet alleen bieten, maar ook loof; niet alleen graan maar ook stro
- Ontwikkeling van regionale bioraffinageketens
- Jaarrond benutting van bioraffinagesystemen
- Leveren van een breder pallet aan eindproducten
- Voorkomen van reststromen

State-of-the-art
De state-of-the-art m.b.t. bioraffinage verschilt per keten. In de traditionele suikerketen heeft men b.v. al veel kennis over extractie, het zuiveren van sappen, drogen, verdampen, kristalliseren en energie- en waterbeheer. In nieuwe ketens, zoals bij grasraffinage, moet kennis gedeeltelijk nog worden ontwikkeld of overgenomen uit andere sectoren.

Pilots en praktijktoepassingen
Twee mogelijke voorbeelden van bioraffinage demonstratieprojecten zijn verder in detail uitgewerkt in de deze Nederlandse Roadmap Bioraffinage, n.l. suikerbietenraffinage (geheel gewas) en raffinage van gras. Er zijn echter nog veel meer voorbeelden denkbaar, gebaseerd op andere gewassen. Een belangrijk doel voor het opzetten van bioraffinage pilots en demo's is het onderzoeken van de praktische haalbaarheid en mogelijkheden om operationele kosten goed te beheersen.

Onderzoeksfocus

- Verbeterde gewassen met meer nuttige inhoudstoffen (b.v. suikers en eiwitten) per geoogste ton biomassa
- Nieuwe teeltsystemen die leiden tot meer biomassa per ha
- Nieuwe oogst- en opslagsystemen
- Optimale logistieke keteninrichting
- Nieuwe scheidingstechnologie (o.a. adsorptie, fractioneren, filtreren)
- Case-specifiek optimale schaalgrootte bepalen
- Nieuwe producten voor meer toegevoegde waarde per ton biomassa
- Aangepaste wet- en regelgeving

Randvoorwaarden

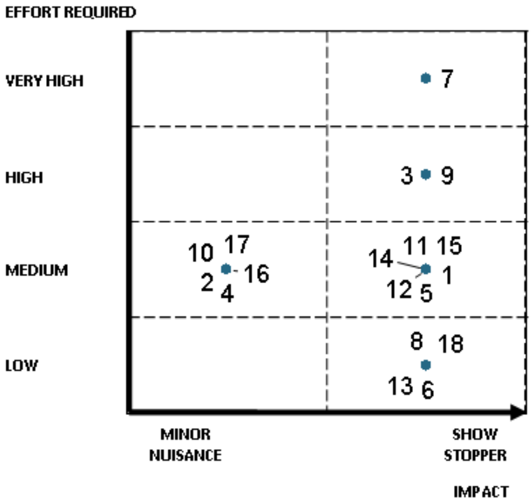
De ontwikkelde kennis en technologie moeten op adequate wijze worden beschikbaar gesteld aan het Nederlandse bedrijfsleven (zowel agro als chemie). Dit houdt wel in dat eigendomsrechten goed moeten worden vastgelegd.

Stakeholder visie

Reacties van actoren uit het bedrijfsleven, de overheid, kennisinstellingen en universiteiten (verzameld tijdens verschillende werksessies) worden weergegeven in navolgende schema's.

Processed barriers

Barriers – Technologies, legislation and logistics

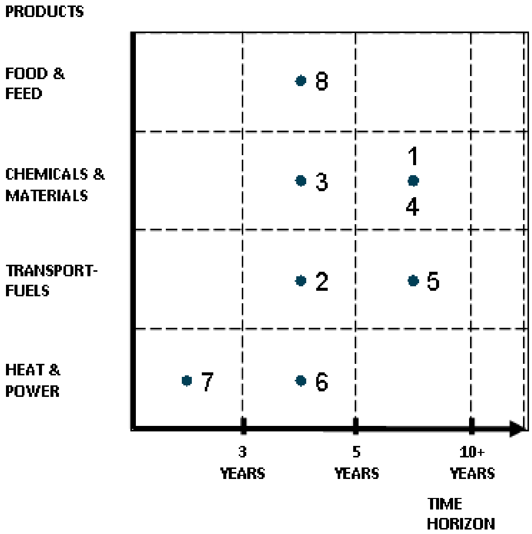


Explanation

1 TECH Separation & fractionation technologies (costs/scale issues)
2 TECH Conversion technology
3 TECH Multidisciplinairy approach
4 TECH Multi-purpose biorefinery (food, feed, chemicals, fuel & energy)
5 TECH Choice of crops crucial
6 TECH GMO technology
7 TECH Metabolic engineering of Dutch crops to acchieve low input/ high output
8 LEG Improve fiscal regulations for biofuels
9 LEG Permit GMO technologies in Europe
10 LEG Permit use of minerals from biorefinery processes as fertilizer
11 LEG Change and relax regulations in field of the treatment & logistics of waste & residue streams
12 LEG Land use issues (competing claims)
13 LOG Limited number of crops available that can be grown on a large scale
14 LOG Large volumes low dry solids for chemical production
15 LOG Process 'wet' crops locally/regionally & move 'dry' crops over larger distances (biocommodities)
16 LOG Supply & demand security are necessary for investments
17 LOG Year-round availability of biomass
18 LOG Change of culture in agricultural sector needed when supplying to chemical sector

Processed opportunities

Opportunities



Explanation

1. Arable production of platform chemicals
2. Horticultural production of specialty chemicals
3. Lactic acid, succinic acid, propanediol
4. Perannual crops for biochemicals, fibres & materials
5. Closing CO2-cycles regionally
6. Small-scale CHP with local fuel or biogas production
7. Consortia of farmers & SME's for regional development
8. Breed new cultivars that have a) high concentrations of ingredients directly in plants & b) allow easy recovery by downstream processing

Moonshot 2. Bioraffinage van aquatische biomassa

Aquatische biomassa (micro-algen en zeewieren) is een interessante nieuwe grondstof voor bioraffinage en een belangrijke aanvulling op het bestaande biomassa aanbod. De kweek van micro-algen vindt plaats in open bassins of gesloten bioreactoren; de grootschalige teelt van zeewieren in open zee. Concurrentie met land voor voedselteelt wordt hierdoor voorkomen. De teelt van aquatische biomassa wordt gekenmerkt door een hoge productiviteit per eenheid oppervlak en kan worden gecombineerd met andere functies zoals waterzuivering en CO_2-vastlegging (micro-algen) resp. off-shore wind parken, vis- en schelpdierenteelt (zeewieren). Aquatische biomassa heeft een unieke samenstelling met een scala aan waardevolle componenten o.a. oliën, vetzuren, eiwitten en polysacchariden en leent zich hierdoor bij uitstek voor bioraffinage. De benutting van dit potentieel vereist ontwikkeling op het gebied van productie- en conversietechnologie en logistieke ketens.

Typering

Het kenmerk van deze Moonshot is dat ketens worden ontwikkeld voor grootschalige productie van biobrandstoffen en industriële (bio)chemicaliën uit micro-algen en zeewieren. Het accent ligt hierbij op de ontwikkeling van logistieke ketens en van processen voor biomassa oogst, voorbewerking, fractionering en de zuivering en opwerking van geëxtraheerde fracties tot eindproducten. Ten opzichte van de huidige technieken dienen de kosten en het gebruik van energie en hulpstoffen sterk te worden gereduceerd. Daarnaast dienen processen ontwikkeld te worden om restfracties in energiedragers om te zetten.

State-of-the-art

Wereldwijd wordt op dit ogenblik ca. 15.000 ton algen en ca. 2 miljoen ton zeewieren per jaar geproduceerd. Beide vormen van aquatische biomassa worden voornamelijk ingezet voor hoogwaardige toepassingen, zoals voedingssupplementen en aquacultuur. Sinds enkele jaren is er sterk groeiende activiteit op het gebied van biobrandstof productie uit micro-algenolie.

Pilots en praktijktoepassingen

Voor aquatische biomassa wordt gestreefd naar de ontwikkeling en demonstratie van commerciële concepten voor de productie van:

- Biobrandstoffen en nevenproducten
- Voer voor aquacultuur, inclusief de recycling van nutriënten
- Productie van ingrediënten voor voeding en nevenproducten

Onderzoeksfocus

- Selectie van strains/soorten en ontwikkeling van productoptimalisatieprocedures en tools
- Verbeteren van oogst- en ontwateringsmethoden
- Ontwikkeling van logistieke concepten
- Ontwikkeling van milde en efficiënte technologie voor fractionering van de aquatische biomassa
- Technologie ontwikkeling voor raffinage van oligosacchariden, lipiden/olie, eiwitten e.d.
- Productontwikkeling in samenwerking met bedrijven incl. toelating van producten
- Vergroten van draagvlak en product acceptatie bij de consument

Randvoorwaarden

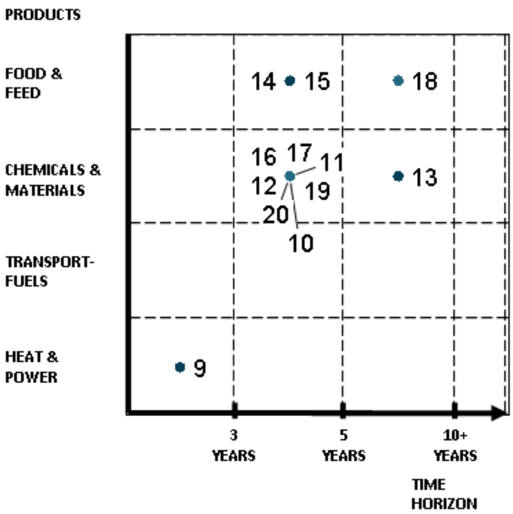
Voor zeewieren teelt is de ecologische inpasbaarheid van grootschalige biomassateelt op zee een kritische succesfactor. De regelgeving is tevens van belang voor de toelating van producten.

Tenslotte zijn voor de ontwikkeling van aquatische biomassa maatschappelijk draagvlak en betrokkenheid van stakeholders bij de ontwikkeling cruciaal.

Stakeholder visie
Reacties van actoren uit het bedrijfsleven, de overheid, kennisinstellingen en universiteiten (verzameld tijdens verschillende werksessies) worden weergegeven in navolgende schema's.

Processed opportunities

Opportunities

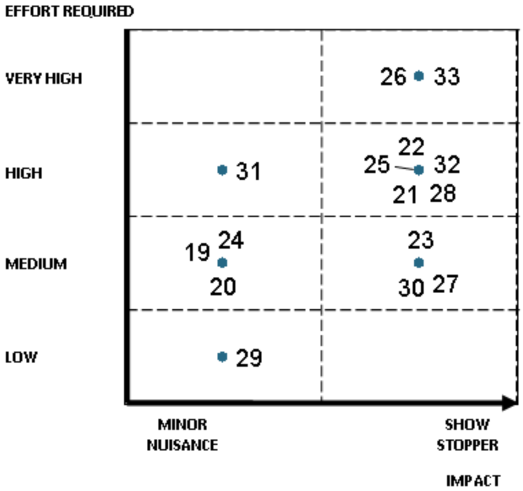


Explanation

9	fuels production by direct processing wet biomass via HTU, fermentation to ethanol, biogas
10	Major source of (combinations of) bulk and fine chemicals, materials, fuels via biorefinery
11	Major source for high value oils, fatty acids, proteins
12	Major source for cellulose for paper or for sugars for the fermentation industry
13	GMO algae for high value chemicals production
14	food & feed ingredients / structured protein fibres
15	Alternative application in aquaculture
16	Alternative application in water purification
17	Alternative application in flue gas cleaning (CO2 and NOx removal)
18	seaweed cultivation systems as nursery for fish
19	cultivation system with waste heat, CO2, NOX, nutrients at zero cost e.g. co-located at a paper or sugar factory
20	Monomeric carbohydrates for chemicals

Processed barriers

Barriers – Technologies, legislation and logistics



Explanation

19	TECH	Micro-algae cultivation on locations where nutrient residues are available
20	TECH	Optimize selection of local adapted algal strains
21	TECH	Optimize energy balance cultivation + harvesting
22	TECH	Harvesting and Down Stream Processing
23	TECH	Development of multi separation/purification technologies (DSTI)
24	TECH	Food-grade technology for extraction of high value minor components from diluted streams
25	TECH	Closing the nutrients balance
26	TECH	Cost reduction esp. CAPEX for biofuels production
27	LEG	Regulations related to spatial arrangement in rural areas and for the use of GMO are needed at the national level
28	LEG	Issues with regard to HACCP sensitivities for open pond systems (esp. feed and food) should be addressed at the EU level
29	LOG	Identify optimal locations for algae farms (in relation to space and availability of resources) and transport of nutrients and residues.
30	LOG	Removal of water and efficient harvesting are seen as potential show-stopper in scale up.
31	LOG	Investment needed in scale-up and demonstration facilities esp. for high tech SME's.
32	LOG	Application of algae reaches multiple sectors. To couple this in integrated systems is a major challenge.
33	LOG	Locations outside the Netherlands may be more suitable in terms of inputs (light, climate) and output quality

Moonshot 3. Bioraffinage van geïmporteerde biomassa in Nederlandse havengebieden

Import van biomassa levert nu al een belangrijke bijdrage aan de huidige Bio-based Economy. In de toekomst zal zowel de relatieve bijdrage van biomassa-import als de absolute omvang van de biomassa-import door de groei van de Bio-based Economy verder stijgen. Door de uitgebreide aanwezige infrastructuur in Nederland (havens, raffinaderijen, chemische en voedingsindustrie) biedt dit unieke kansen voor de Nederlandse economie, nu en in de toekomst.

Typering

Het kenmerk van deze Moonshot is dat duurzame en betrouwbare bioraffinage-ketens worden ontwikkeld voor de omzetting van geïmporteerde biomassa in een breed scala van producten: voedsel, veevoer, materialen, chemicaliën en energiedragers. Zowel aan de voorkant van de keten, de typen biomassa, als aan de achterkant van de keten, de producten die worden gemaakt, is een groot aantal opties mogelijk. De concurrentie tussen inzet van biomassa voor producten laag in de waardeketen (energiedragers) met producten hoog in de waardeketen (voedsel) dient hierbij geminimaliseerd worden. Belangrijk is dat op de korte-termijn al ketens ontwikkeld worden, ook als ze suboptimaal zijn, om voor deelaspecten van de keten ervaring op te bouwen voor de toekomst en om een basis te bieden voor een verdere geleidelijke ontwikkeling van de bioraffinage industrie. In deze Moonshot zullen typisch grootschalige bioraffinaderijen ontwikkeld worden.

State-of-the-art

Voor de verschillende toepassingen van biomassa (voedsel, veevoer, materialen, chemicaliën en energiedragers) worden op dit moment al grote hoeveelheden biomassa geïmporteerd. Op dit moment is de interactie tussen de verschillende sectoren nog slechts beperkt aanwezig en wordt, afhankelijk van de sector, slechts beperkt van geavanceerde geïntegreerde processen gebruik gemaakt om de biomassa uit het oogpunt van economie en duurzaamheid optimaal in te zetten.

Pilots en praktijktoepassingen

De toepassing van nieuwe processen en ketens voor het gebruik van biomassa op pilot en demo-schaal is van belang om ervaring op te doen op aspecten (zowel technische als niet-technische) die voor implementatie van belang zijn. Door de pilots/demo's dient bewezen te worden dat de nieuwe opties langdurig betrouwbaar bedreven kunnen worden. De pilots/demo's kunnen zowel op de korte-termijn als de lange-termijn gericht zijn, waarbij idealiter een relatief eenvoudige toepassingsoptie voor de korte-termijn beschikbaar is met de optie om voor de toekomst meer gecompliceerde bioraffinage-configuraties te ontwikkelen. Pilots en demo's bieden een uitstekende mogelijkheid om samenwerking tussen verschillende sectoren die biomassa gebruiken tot stand te brengen.

Onderzoeksfocus

- Ontwikkeling van internationaal geaccepteerde criteria en monitoring tools om de duurzaamheid van geïmporteerde biomassa aan te tonen
- Ontwikkelen van de logistiek van biomassa import
- Verhogen energiedichtheid geïmporteerde biomassa door voorbehandeling
- Ontwikkeling van scheidingsprocessen om biomassa in functionele fracties te scheiden
- Ontwikkeling van betrouwbare conversieprocessen die biomassaresiduen kunnen verwerken en variaties in biomassa samenstelling aan kunnen
- Ontwikkeling van biomassaraffinageconcepten om biomassa uit het oogpunt van economische waarde en duurzaamheid maximaal in te zetten
- Terugwinnen van mineralen en nutriënten om hergebruik bij biomassateelt mogelijk te maken
- De invloed van biomassateelt en -import op micro- en macro-economisch niveau

Randvoorwaarden

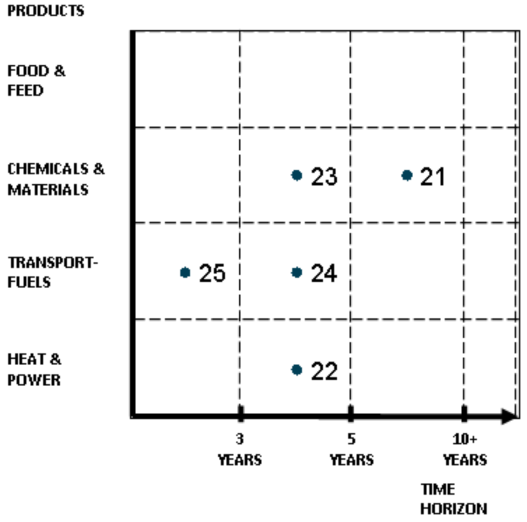
Voor een aantal sectoren is de inzet van biomassa (nog) niet concurrerend met de huidige alternatieven. Gedeeltelijk komt dit door de prijs van de alternatieven en gedeeltelijk door de onvolwassenheid van de benodigde conversietechnologie. Ondersteuning door de overheid is nodig om het (tijdelijke) prijsverschil te overbruggen. Daarnaast dient de (inter)nationale overheid te faciliteren bij het certificeren van de duurzaamheid van de keten.

Stakeholder visie

Reacties van actoren uit het bedrijfsleven, de overheid, kennisinstellingen en universiteiten (verzameld tijdens verschillende werksessies) worden weergegeven in navolgende schema's.

Processed opportunities

Opportunities

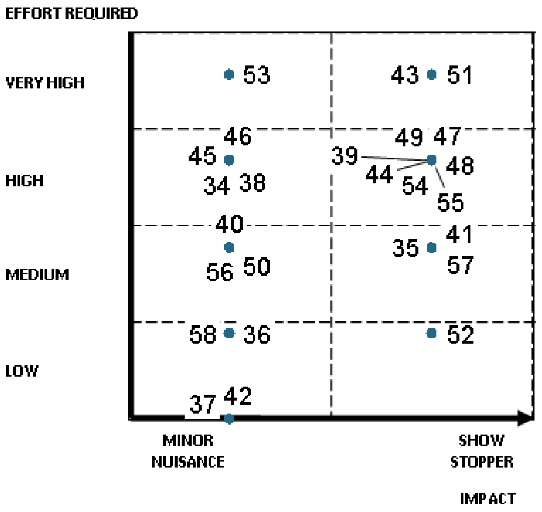


Explanation

21 Flexible bio-based products and bioenergy production depending on market request
22 High-value bio-based products and/or bioenergy from process residues
23 Production bulk chemicals by (advanced) fermentation
24 Demonstration advanced biofuels based biorefineries
25 Integration into conventional petrochemical complex

Processed barriers

Barriers – Technologies, legislation and logistics



Explanation

34	TECH	Large-scale pretreatment for secondary biorefinery
35	TECH	Cost-effective and sustainable primary biorefinery processes: pretreatment/hydrolysis, torrefaction, pyrolysis, HTU, ...
36	TECH	Cost-effective and sustainable secondary biorefinery processes: fermentation, gasification, ...
37	TECH	Oleochemistry instead of petrochemistry
38	TECH	Product separation processes: membranes, ...
39	TECH	Lignin valorization technologies: ... ..
40	TECH	Conversion wet biomass streams: HTU, supercritical gasification, digestion, ...
41	TECH	Mineral valorization technologies
42	TECH	Short-term success stories (demos, applied research) as drivers for long-term developments (basic research)
43	LEG	CO2 credits
44	LEG	Policy making on EU level
45	LEG	GMO legislation
46	LEG	Availability raw materials dependence on import tarrifs – security of supply
47	LEG	Full sustainable chain approach (production – conversion – use)
48	LEG	Raw material and product sustainability criteria in international level
49	LEG	Certification required
50	LEG	Government as launching customer
51	LOG	Biomass densification for transport
52	LOG	Primary biorefinery at place of biomass production -> energy densification + minerals back to the field
53	LOG	Import densified biomass, intermediates or final products?
54	LOG	Feedstock types and place of birth?
55	LOG	Combination with regional concepts
56	LOG	Co-operation chain composing stakeholders necessary – which is the leading party?
57	LOG	Feedstock supply on large scale
58	LOG	Using existing infrastructure

Moonshot 4. Bioraffinage gebaseerd op de valorisatie van reststromen en bijproducten
Bestaande biomassastromen kunnen substantieel bijdragen aan de vraag vanuit de Bio-based Economy. Door betere benutting van bijproducten en reststromen wordt concurrentie met voedsel beperkt. Grote hoeveelheden zijn beschikbaar in bestaande ketens. Reststromen van de agro-food industrie zijn vaak vrij uniforme productstromen, maar verderop in de ketens gaat het vaak om mengstromen (voedselresten in GFT). Effectieve benutting van reststromen en bijproducten vraagt oplossingen op het vlak van logistiek, (scheidings)technieken en veiligheid.

Typering
Kenmerk van deze Moonshot is de ontwikkeling van productieprocessen en ketens waardoor biomassa die momenteel niet of beperkt functioneel wordt gebruikt beter wordt benut in de Bio-based Economy. Hierbij gaat het om een breed scala aan biomassastromen:

- Resten van voedselverwerkingsprocessen, zoals pulp, schroot van oliehoudende vruchten en zaden, schillen, snijresten, afkeur, etc.
- Voedselresten
- GFT afval
- Biomassa uit openbaar groen en natuurgebieden
- Mest

Hoewel veel van deze producten wel nuttig worden aangewend (in o.a. diervoeders en voor bemesting) zijn de huidige ketens vanuit het perspectief van biomassabenutting vaak niet optimaal. Beoogde toepassingen/functionaliteit zijn: energieproductie, materialen en chemicaliën (naast gangbare toepassingen zoals veevoeders). Praktische mogelijkheden worden bepaald door de mate van zuiverheid van het materiaal en logistieke en procestechnische mogelijkheden.

Voorbeelden van beoogde ontwikkelingen zijn:

- Winnen van overmatige mineralen uit huidige veevoedergrondstoffen
- Hoogwaardige toepassingen uit bermgras
- Productie van chemicaliën uit bijproducten van voedselverwerkingsprocessen
- Hoogwaardige toepassingen (mogelijk in combinatie met biogas) uit voedselresten
- Verwerking van mest en digestaat tot waardevolle kunstmestvervangers

State-of-the-art
Een groot deel van de reststromen wordt als afval behandeld en heeft een negatieve waarde. Meest gebruikelijk is composteren; afzet van de compost is problematisch. In toenemende mate wordt met behulp van het organische afval biogas geproduceerd waarna het residu alsnog gecomposteerd wordt. Afgelopen jaren zijn inzamelsystemen ontwikkeld voor voedselresten uit restaurants en grootkeukens; dit vormt een basis voor biogasproductie en evt. andere verwaardingsprocessen. Veel producten uit de voedingsmiddelenindustrie worden aangewend als veevoeder. Bewerkingsstappen in de ketens worden tot het minimum beperkt.

Pilots en praktijktoepassingen
Werken aan praktische innovaties wordt vaak belemmerd door technische en juridische hindernissen, door onbekendheid over de mogelijkheden en het ontbreken van de juiste samenwerkingsverbanden. Enkele voorbeelden uit het recente verleden laten zien dat in de praktijk substantiële stappen gezet kunnen worden, zowel op pilot, demo als op praktijkschaal. Dat is mogelijk voor alle hierboven genoemde voorbeelden van beoogde ontwikkelingen.

Onderzoeksfocus

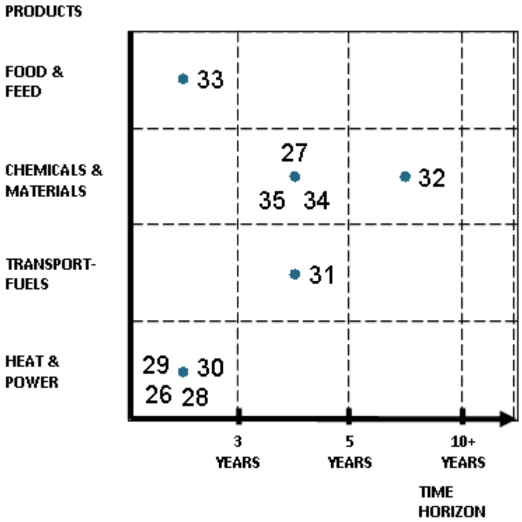
- Kwaliteitsbeheersing van de materialen
- Kwaliteit- en risicomanagement in de keten
- Voorbewerkingen/bioraffinageprocessen (o.a. scheidings- en droogprocessen)
- Logistieke kwesties: oplossingen voor verspreide bronnen
- Sectoroverschrijdende ketenontwikkeling
- Omgaan met juridische beperkingen

Randvoorwaarden
De wetgeving heeft een grote invloed op de praktische mogelijkheden voor reststromen.

Stakeholder visie
Reacties van actoren uit het bedrijfsleven, de overheid, kennisinstellingen en universiteiten (verzameld tijdens verschillende werksessies) worden weergegeven in navolgende schema's.

Processed opportunities

Opportunities

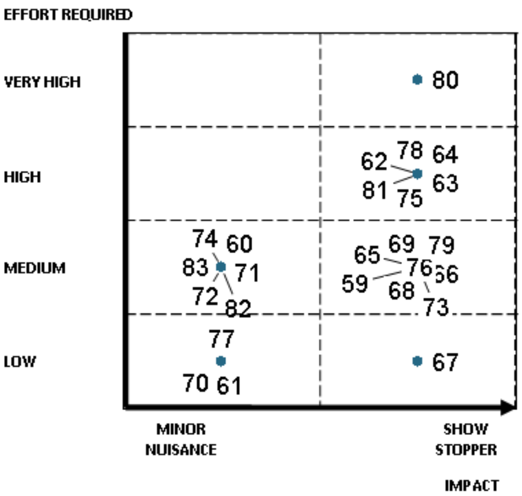


Explanation

26 Materials: manure, food waste, slaughter waste, plant waste, waste water, etc.
27 Mono streams: low economic value of products demands for inexpensive processing
28 Mixed residues (food waste, manure, ...):
29 currently mostly with negative economic value
30 little selective processes like biogas fermentation
31 biogas is potential input for Green gas, Bio LNG, etc.
32 create value through fractionation technologies
33 limited purity of half-products
34 Secondary refinery: increasing added value
35 Residues: potential for recycling minerals

Processed barriers

Barriers – Technologies, legislation and logistics



Explanation

59	TECH	Upstream: measures for increasing residuals quality/homogeneity
60	TECH	Downstream: homogenizing
61	TECH	Downstream: biogas fermentation
62	TECH	Downstream: thermal conversion
63	TECH	Downstream: separation/fractionation processes
64	TECH	Downstream: purpose-oriented purification
65	TECH	Quality/safety management
66	TECH	Downscaling technology (at scale size of local residual stream)
67	LEG	Beware of label "waste"
68	LEG	Manure legislation: limit possibilities
69	LEG	Using food residuals and animal by-products for food or feed is troublesome
70	LEG	Local permissions: forbid other activities locally
71	LEG	Individuals can prevent local new permissions
72	LEG	Variations in regulative behaviour by local government
73	LEG	"Unreliable government": continuity of policy
74	LOG	"Closing mineral cycles" at local/regional/national/global scale
75	LOG	High volumes, expensive (collection) logistics
76	LOG	Residues have low economic value (often negative)
77	LOG	Low priority for quality
78	LOG	Need for continuity of supply/buyers
79	LOG	Need for matching demand and supply in place and time
80	LOG	Residuals-based commodities as bulk materials
81	LOG	Multi-industrial multi-sectorial clustering for valorization each others residues
82	LOG	New collection logistics methods, aimed at product quality
83	LOG	"Biomass yard": one-stop delivery point for biomass residues that combines biomass collection and various biorefinery processes

Naast genoemde Moonshot-gerelateerde korte- en middellange-termijn onderzoeksinspanningen, inclusief de potentiële realisatie van benodigde pilot- en demonstratie faciliteiten, zijn sommige bioraffinage implementatiebarrières, m.n. de lange-termijn vragen, van generiek karakter. Deze generieke – vaak strategische – bioraffinagebarrières dienen integraal te worden opgepakt. Tijdens een brainstormsessie met vertegenwoordigers vanuit de kennis-infrastructuur (instituten en universiteiten), de industrie en de overheid is een groot aantal technologische en niet-technologische aspecten geïdentificeerd die mogelijk kunnen bijdragen aan de grootschalige implementatie van bioraffinageprocessen in de toekomstige Bio-based Economy. Deze aspecten hebben betrekking op:

- Grondstoffen (beschikbaarheid en toepasbaarheid)
- Biomassa voorbehandeling- en primaire raffinageprocessen
- Secundaire raffinageprocessen en finale verwerking
- Marktontwikkeling en marktgeoriënteerde bioraffinageketenontwikkeling
- Integrale ketenontwikkeling en het beslechten van integrale ketenuitdagingen
- Sociale en milieutechnische aspecten van bioraffinageontwikkelingen

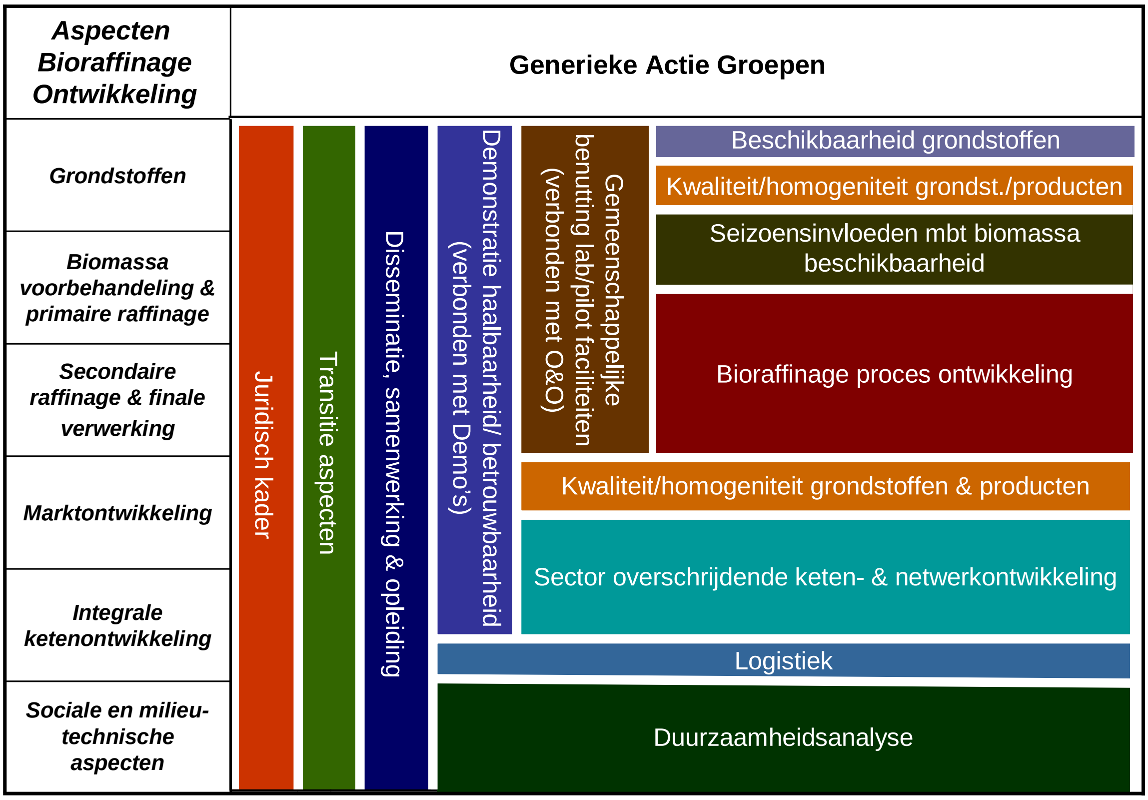
In tabel S3 wordt een overzicht gegeven van individuele acties die noodzakelijk zijn om de implementatie van bioraffinageprocessen in de Nederlandse samenleving te ondersteunen en derhalve de realisatie van een Bio-based Economy te versnellen. De acties zijn geformuleerd in nauwe samenwerking met actoren uit de industrie, de overheid en de kennisinfrastructuur (instituten en universiteiten). Het betreft zowel korte- en middellange-termijn acties gekoppeld aan de Moonshots als meer strategische acties noodzakelijk voor de grootschalige implementatie van bioraffinage processen op de langere termijn.

Tabel S3 Individuele Acties Nederlandse Roadmap Bioraffinage.

Implementatie aspecten bioraffinage ontwikkeling	Demonstratie *Korte-/Middellange-termijn*	Toegepast onderzoek, incl. pilot-plants *Korte-/Middellange-termijn*	Strategisch onderzoek *Lange-termijn*
Grondstoffen (beschikbaarheid en toepasbaarheid)	• Optimalisatie logistiek inzameling • Selectie en screening gewassen	• Toegesneden test faciliteiten • Standaardisatie en certificering grondstoffen • On-site duurzaam nutriënten management • Algen oogst	• Vergroten opslagduur • Alternatief grondstof gebruik • Vergroten productiviteit gewassen • Vergroten concentratie en toegankelijkheid waardevolle inhoudsstoffen
Biomassa voorbehandeling- en primaire raffinage processen	• Op-/afschaalbaarheid • Haalbaarheid en betrouwbaarheid	• Toegesneden test-faciliteiten • Bewezen lange-duur bedrijf • Grondstof flexibele technologieën • On-site duurzaam water management • Optimalisatie functionaliteit nieuwe bestanddelen in relatie tot processen en zuiverheid	• Lokale voorbehandeling • Goedkope technologieën • Verkennen potentieel bestaande technologieën • Vergroten opslagduur grondstoffen • Kostenreductie • Reductie energiegebruik • Bepalen functionaliteit nieuwe gemodificeerde inhoudsstoffen
Secundaire raffinageprocessen en finale verwerking	• Multi-grondstof technologieën • Haalbaarheid en betrouwbaarheid	• Toegesneden test-faciliteiten • Extractie van mineralen • Milde extractie en scheidingsprocessen • Duurzaam water management	• Goedkope scheidings-processen • Grondstof flexibiliteit voor jaarrond gebruik faciliteiten • Zuivere eindproducten • Ontwikkeling ontwerp-gereedschap
Marktontwikkeling en marktgeoriënteerde bioraffinage ketenontwikkeling	• Technologie als export product • Bewijs van product kwaliteit	• Product standaardisatie • Integrale verwaarding bioraffinageproducten	• Oplossen 1 op 1 afhankelijkheid nieuwe leverancier/klant Bio-based Producten • Markt-georienteerde productontwikkeling: hoge toegevoegde waarde chemicaliën en materialen

Implementatie aspecten bioraffinage ontwikkeling	Demonstratie *Korte-/Middellange-termijn*	Toegepast onderzoek, incl. pilot-plants *Korte-/Middellange-termijn*	Strategisch onderzoek *Lange-termijn*
Integrale ketenontwikkeling en integrale keten-uitdagingen	• Financieringskader (investeringsfonds) • Optimaal ketenontwerp: schaal, logistiek, modulaire concepten • Intersectoriële samen-werking agro – chemie – energie • Kennis Centrum opzetten • Interface met andere nationale/internationale programma's (Bbasic, Catchbio, DSTI, procesintensificatie)	• Combinatie en integratie technologieën • Gebruik faciliteiten in internationaal kader • Integratie bestaande kennis in agro- en chemische sector • Integratie bestaande infrastructuur in agro- en chemische sector	• Kennis disseminatie en opleiding • Internationale netwerking en kennis-import • Integreren met CO_2-afvangst en opslag
	Alle drie fasen		
Sociale en milieutechnische aspecten bioraffinage-ontwikkelingen	• Toegestane locaties op de Noordzee met nutriënten toevoer op zee (zeewieren) • Publieke acceptatie • Internationale GMO kader • Oplossen juridisch label "afval" • Landelijke ontwikkeling • Integrale aanpak voeding – veevoer – brandstof discussie • Toevoegen waarde door regionale productie	• Integrale aanpak voeding – veevoer – brandstof discussie • Optimaal gebruik residuen • Consumenten acceptatie • Marktanalyse – nieuw en bestaand (prijzen en volumes) • Sectoroverstijgende integratie • Risico management • Keten formatie en consortium opbouw	• Implementatie Cramer criteria • Milieu en ruimtelijke vergunningen • Nutriënten cycli • Transitie naar een Bio-based Economy • Garanderen duurzaamheid en transparantie bioraffinage ketens • Belonen externe voordelen (CO_2-emissiereductie, fossiele grondstofbesparing, ...)

Figuur S1 toont een schematisch overzicht van de individuele acties gegroepeerd in meer generieke actie groepen.



Figuur S1 Generieke Actie Groepen Nederlandse Roadmap Bioraffinage.

Voor de Generieke Actie Groepen dienen de volgende vragen te worden geadresseerd:

Duurzaamheidsanalyse

Een goede analyse van de duurzaamheidsaspecten van Bio-based Producten en Ketens (bijv. ecologische voetafdruk analyse of Cramer criteria) en de onderlinge vergelijking met de fossiele alternatieven is noodzaak om grootschalige implementatie van bioraffinage processen duurzaam en sociaal acceptabel te laten plaatsvinden. Een duurzaamheidsanalyse adresseert zowel lokale als globale effecten als people- and planetaspecten, incl. nutriëntencycli, watermanagement, de voedsel/veevoer/brandstof competitie en koppeling aan een CO_2-reductiepotentieel. M.n. het punt van de CO_2-emissiereductie is zeer relevant voor de maatschappelijke acceptatie van bioraffinageprocessen, voor de consumentenacceptatie van Bio-based Producten en om in aanmerking te komen voor diverse stimuleringsmaatregelen van de Nederlandse overheid.

Sector overschrijdende keten- en netwerkontwikkeling
Grootschalige implementatie van bioraffinage strategieën resulteert in de nieuwe bedrijvigheid. Bestaande bedrijven zullen proberen samen te werken, dan wel met elkaar in concurrentie gaan. Nieuwe samenwerkingsverbanden tussen nieuwe en bestaande sectoren zullen ontstaan. De landbouwsector zal bijv. de wereld van de Non-Food Bio-based Producten instappen; terwijl de chemische sector zich mogelijk ook zal gaan bezighouden met de teelt van gewassen met specifiek gewenste inhoudsstoffen. Enkele specifieke vragen ter beantwoording zijn:

- Waar en op welke manier zal de prijsstelling van de grondstoffen en intermediairen plaatsvinden en op welke wijze zullen deze worden gecontracteerd?
- Hoe zijn de verschillende schakels in de biomassawaardeketen gekoppeld (mate van organisatie)?
- Wat zijn de belangen van de diverse stakeholders in de biomassawaardeketen en wat zijn de regels van het spel?
- Wat is de onderhandelingskracht van bepaalde stakeholders naar toeleveranciers en consumenten en hoe opereren ze in de maatschappelijke arena?
- Wat zijn de mogelijkheden voor de realisatie van nationale/regionale samenwerkingsverbanden versus internationale aanbesteding?
- Op welke wijze resulteert de samenwerking tussen voorheen separaat opererende bedrijven in eenduidig top-down management?
- Wat zijn volgens stakeholders uit de agrofood, chemische en energiesector de belangrijkste knelpunten en onzekerheden m.b.t. het aangaan van samenwerkingsverbanden en gezamenlijke activiteiten?

Logistiek
De logistieke keten koppelt verspreide relatieve kleine primaire biomassaproductiefaciliteiten via decentrale en centrale conversieprocessen aan de productie en het gebruik van biomassa-gerelateerde eindproducten, waarbij de volledige biomassawaardeketen in ogenschouw wordt genomen. Relevante aandachtsgebieden zijn:

- Oogst- en on-site voorbehandelingstechnieken
- Opslag kwaliteit handhaving van de grondstof, intermediairen en finale producten
- Op-/afschaalbaarheid logistieke keten samenstellende technieken en grootte diverse participerende stakeholders
- Product standaardisatie
- Energieverdichting grondstoffen voor lange afstand transport

Bioraffinage proces-/ketenontwikkeling
Relevante aandachtspunten in de keten van grondstof voorbehandeling t/m de levering van het Bio-based Product zijn:

- Productie efficiëntie keten samenstellende deelprocessen
- Optimalisatie van de product functionaliteit in relatie tot toegepaste processen en de gewenste productzuiverheid
- Kostenreductie, incl. optimalisatie volledige biomassawaardeketen voor productie meerdere Bio-based Producten en Energie
- Reductie energiegebruik
- Verbetering productkwaliteit
- Ontwikkeling nieuwe raffinage deelprocessen en/of nieuwe Bio-based Producten
- Duurzaamheid volledige biomassawaardeketen

Benodigde deeltechnologieontwikkelingen hebben betrekking op fysisch/chemische, thermo-chemische en biotechnologische processen, veelal in combinatie, o.a. afhankelijk van de gebruikte grondstof en de gewenste producten.

Naast (deel)technologieontwikkeling zijn proces- en ketenmodellering en kennisdisseminatie uitermate belangrijke activiteiten bij de ontwikkeling van nieuwe bioraffinage waardeketens. Deze nieuwe waardeketen bestaan meestal uit nieuwe combinaties van bestaande en nieuwe technologieën toegepast op veelal bestaande biomassagrondstoffen.

Beschikbaarheid grondstoffen
De milieu-technische en financieel-economische haalbaarheid van bioraffinage waardeketens wordt voor een groot deel bepaald door de beschikbaarheid en contracteerbaarheid van grondstoffen. Implementatie van bioraffinageketens beïnvloedt de grondstofmarkt. Enkele specifieke vragen ter beantwoording zijn:

- Wat is de huidige en toekomstige beschikbaarheid/contracteerbaarheid van de grondstoffen?
- Wat is de elasticiteit in prijsstelling?
- Welke invloed heeft grootschalige bioraffinage op de kosten van de grondstof?
- Wat is het prijseffect op voedsel en veevoer?
- Zo mogelijk zouden technologieën kunnen worden geïmplementeerd die grootschalig enkele gestandaardiseerde Bio-based tussenproducten uit het scala aan grondstoffen kunnen maken?

Kwaliteit en homogeniteit grondstoffen

De kwaliteit en homogeniteit van de grondstoffen is essentieel voor een goed bedrijf van een bioraffinage installatie. Enkele specifieke vragen ter beantwoording zijn:

- Welke grondstofkwaliteit en homogeniteit is voorhanden en op welke wijze is deze te verbeteren (verhogen concentratie en/of vergemakkelijken bereikbaarheid waardevolle gewas inhoudsstoffen, gewasveredeling)?
- Hoe om te gaan met biologische gewasvariaties?

Seizoensinvloeden m.b.t. biomassa beschikbaarheid

De productie van landbouwgewassen is seizoensgebonden. Seizoensgebonden verwerking van deze gewassen in bioraffinaderijen resulteert in suboptimale benutting van aanwezige infrastructuur en een discontinue product levering naar de markt. Aandachtspunten zijn derhalve:

- Methoden om de opslag van grondstoffen, intermediairen en eindproducten te verbeteren
- Multi-grondstof gebruik van bioraffinaderijen om zodoende jaarrond bedrijf mogelijk te maken
- Gebruik van bijv. olifantsgras en winterbieten, m.a.w. combineren van import met binnenlandse productie

Kwaliteit en homogeniteit producten

De productkwaliteit/-homogeniteit centraal staat voor de klanten. Enkele specifieke vragen ter beantwoording zijn:

- Welke kwaliteitseisen worden er door de afnemers aan de producten gesteld?
- Welke product standaardisaties zijn er mogelijk?
- Hoe integrale verwaarding bioraffinageproducten?

Demonstratie haalbaarheid en betrouwbaarheid

Voor de ontwikkeling en verdere implementatie van bioraffinage processen door de industrie is van essentieel belang dat deze processen behalve technisch en economisch haalbaar tevens zeer betrouwbaar zijn waardoor een continue bedrijfsvoering kan worden gegarandeerd.

Gemeenschappelijke benutting lab- en pilot-schaal faciliteiten

Daar er een grote variëteit aan bioraffinage concepten wordt ontwikkeld, is er behoefte aan een grote diversiteit aan lab- en pilot-schaal faciliteiten. De realisatie van faciliteiten die de gehele biomassawaardeketen omvatten door één stakeholder uit de industrie of de kennisinfrastructuur is financieel-technisch niet haalbaar. Gezamenlijk bedrijf van de bestaande deelinfrastructuren en gezamenlijke (agro/chemische/energiesector) opbouw van nieuwe onderzoeksinfrastructuur is noodzaak, zo mogelijk zelfs in internationaal kader.

Juridisch kader
Bestaande regelgeving is suboptimaal voor de ontwikkeling en implementatie van bioraffinaderijen. Bijv. het etiket "afval" voorkomt de benutting hiervan in een breed scala aan raffinagetoepassingen; lokale milieu- en landschapsvergunningen limiteren implementatie-mogelijkheden (bijv. teelt/raffinage zeewieren).

Transitie aspecten
De ontwikkeling en implementatie van de Bio-based Economy – en van de hiervan onderdeel uitmakende bioraffinage waardeketens in het bijzonder – is een grote uitdaging, waarbij de directe betrokkenheid van een groot aantal actoren (industrie, overheid, NGO's, instituten, universiteiten) uit diverse sectoren is vereist. Optimale interactie tussen genoemde actoren is essentieel voor de ontwikkeling van bioraffinage van een niche-markt naar een goed ontwikkelde Bio-based Economy. Eén van de doelen van voorgestelde pilot-/demonstratieprojecten is om lering te trekken m.b.t. genoemd transitieproces vanuit het oogpunt van zowel de ondernemers als het meer generieke publiek. De pilot-/demonstratieprojecten faciliteren derhalve het transitieproces. Een nadere meer gedetailleerde beschrijving van de Transitie Aspecten is opgenomen in Appendix D.

Disseminatie, samenwerking en opleiding
Kennisdisseminatie, samenwerking tussen verschillende nationale en internationale stakeholders en het opleiden van de nieuwe experts voor de nabije toekomst zijn essentiële aandachtspunten in de transitie naar de Bio-based Economy. Aandachtspunten zijn:

- Import van internationale state-of-the-art kennis/kunde en die beschikbaar maken voor Nederlandse stakeholders
- Internationaal netwerken
- Uitwisselen van bestaande kennis in de agro/chemische/energie sectoren
- Opzet van nieuwe academische en professionele opleidingsprogramma's

Overige (beleids)aanbevelingen

- Voor de ontwikkeling van de bio-based economy is de grootschalige implementatie van bioraffinagestrategiën noodzakelijk.
- Op de korte termijn zijn pilot and demonstratie projecten van (delen van de) bioraffinageketens noodzakelijk om op de lange termijn grootschalige implementatie te bereiken.
- Er bestaat een grote verscheidenheid aan mogelijke bioraffinageketens. Omdat de doelstelling is een bio-based economie te ontwikkelen dient de industrie een leidende rol te nemen bij de ontwikkeling van bioraffinageketens.
- Om de ontwikkelingen van de bio-based economie te versnellen is ondersteuning noodzakelijk bij pilot en demonstratieprojecten en het bijbehorende (strategisch) onderzoek en ontwikkeling.

1 Introduction

1.1 Dutch governmental Vision on the Bio-based Economy in the Energy Transition

In October 2007 the 'Dutch governmental Vision on a Bio-based Economy in the Energy Transition' was presented (LNV, 2007). The Bio-based Economy should play a major role in the sustainable development of The Netherlands. Replacing fossil resources by renewable resources like biomass will contribute to the reduction of greenhouse gasses. Building a Bio-based Economy – an economy in which companies will produce a portfolio of non-food products (chemicals, materials, fuels, power and heat) from biomass – will create new economic opportunities for the Dutch industry.

For the sustainable development of a Bio-based Economy, taking into account both economic, environmental and social aspects (both chances and risks), the Dutch government uses the following framework:

- The Bio-based Economy should contribute to the national greenhouse gas emission reduction policy goals through the Dutch working programme ("Schoon en Zuinig").
- The Bio-based Economy should be linked to the economic strengths of the Netherlands (i.e. the chemical sector, logistical sector (harbours), agro sector, food sector, and the knowledge infrastructure).
- Active contribution to international co-operation in this field, with specific attention to the position of developing countries.

The government identified chances for the Dutch business, specifically within the field of the production of (high) added-value products from biomass. Based on this, and on the fact that the required biomass has to be produced in a sustainable way, the Dutch government linked a policy agenda consisting of four parts:

1. Efficient use of biomass, with biorefinery as key concept/technology.
2. Global sustainable biomass production, with the development of sustainable biomass-to-product chains as main goal.
3. Stimulation of the production of green gas and renewable electricity.
4. Market development, with the government as launching customer for bio-based products.

Ad 1.) Optimal valorisation of green raw materials: How can we co-produce different non-food products from biomass (both crops and agro residues)? To answer this question both research, technology development and stakeholder involvement is required.
Ad 2.) Availability of sustainably produced and cost-effective feedstock of desired quality. A growing biomass demand for non-food applications should not cause a decrease in biodiversity on both national and international level. Therefore, both imported and domestically produced biomass has to be produced in a sustainable way. Competition with food production is

undesirable. The Bio-based Economy therefore particularly aims at non-food applications of biomass, taking into account the food, feed and non-food chains interactions.

So one of the focus points of policy agenda is improving the efficiency of biomass utilization. Biorefinery is a key concept/technology to achieve the optimal valorisation op biomass into a spectrum of products and energy. White biotechnology is a second key technology, using living cells and enzymes to co-produce chemicals, fuels and energy from biomass, with decreased waste production and energy use. The Dutch government is ready to support the development and implementation of 1) biorefinery concepts/technologies and 2) technologies based on white biotechnology.

The Innovation Agenda Energy (EZ, 2009) gives concrete targets for 2020 in the field of energy transition. The scope of the Innovation Agenda Energy is the period 2008-2012. The agenda is aimed primarily at the start-up of the necessary developments within several innovation themes. One of these themes is Bio-based Raw Materials ('Groene Grondstoffen'). This concerns among others sustainable production and development of biomass, and co-production of transportation fuels, chemicals, electricity and heat. An important activity within the theme Bio-based Raw Materials in this cabinet period is drawing up a (technology) roadmap biorefinery. Therefore, the Dutch Ministry of Agriculture, Nature and Food Quality (LNV) in 2008 commissioned the development of a Dutch Roadmap on Biorefinery, which is needed as first step in a powerful and integrated approach towards the establishment of biorefineries, as part of a Bio-based Economy, in The Netherlands. This Roadmap will show a number of possible routes from the current mainly Fossil-fuel based Economy to a future Bio-based Economy, emphasizing the role of biorefinery processes within this transition process. Specific attention in this Roadmap is given to the short-term (< 2015) actions (a.o. pilot/demo plant support, support of both technical and non-technical applied and strategic research, stakeholder analysis) necessary to pave the road for the transition to a fully implemented Bio-based Economy in the longer-term. The results of the roadmapping process are presented in this report.

1.2 Sustainable bio-based products and bioenergy: biorefinery

The current intensive use of crude oil for the production of chemicals and energy is unsustainable. Deficiencies of crude oil are expected for the coming decades. Furthermore, the use of crude oil leads to emission of CO_2 and other greenhouse gasses, and adds to the dependence on other countries. Recent developments have shown that the price level of crude oil can fluctuate significantly, which results in economic instabilities that limit investments from industry in further developments. Solving these problems demands for development of a Bio-based Economy (BbE). Biomass is foreseen to become one of the major renewable resources for the production of food, feed, materials, chemicals, fuels, power and heat.

For instance, for the petrochemical industry, biomass is very promising because crops contain many components which are nowadays produced from crude oil. Other materials can be made out of biomass by functionalizing the basic materials by adding e.g. O, H, Cl or N atoms. Henceforth, biomass can replace crude oil as feedstock for the chemical industry to a large extent. Use of biomass for non-food/feed applications like fuels, power and heat, however, is controversial, because it (partially) competes with the use of biomass for food and feed. New routes that do not rely on using food or feed-grade sources have to be developed.

For a sustainable BbE, a combination of the following developments are needed:

- Drastic increase of agricultural production (doubling is needed according to FAO (2008)) to feed the growing world population (average of 1.14 percent per year) with increasing consumption of meat in countries like China and India. Since the acreage of agricultural land is limited, the doubling of agricultural production needs to be achieved by increasing the productivity (yield per ha) through improved agronomy and plant breeding.
- More efficient use of the raw materials: reducing waste production and more integral valorisation of the biomass through biorefinery. Biorefinery makes different functional ingredients of a biomass stream available for separate applications.

Definition Biorefinery

Biorefinery is the sustainable processing of biomass into a spectrum of marketable products and energy (IEA Bioenergy Task 42 on Biorefineries)

This definition includes the key words:

- *Biorefinery*: concepts, facilities, processes, cluster of industries
- *Sustainable*: maximising economics, minimising environmental aspects, fossil fuel replacement, socio-economic aspects taken into account
- *Processing*: upstream processing, transformation, fractionation, thermo-chemical and/or biochemical conversion, extraction, separation, downstream processing
- *Biomass*: crops, organic residues, agro-residues, forest residues, wood, aquatic biomass
- *Spectrum*: more than one
- *Marketable*: a market (acceptable volumes & prices) already exists or is expected to be developed in the near future
- *Products*: both intermediates and final products, i.e. food, feed, materials, and chemicals
- *Energy*: fuels, power, heat

Both product-driven biorefineries and energy-driven biorefineries can be distinguished. In product-driven biorefineries the biomass is fractionised into a portfolio of bio-based products with maximal added-value and minimal ecological impact, after which the process residues are used for power and/or heat production, both for internal use and for selling of the surplus to national grids. In energy-driven biorefineries the biomass is primarily used for the production of secondary energy carriers (biofuels, power and/or heat). Process residues are sold as feed (current situation), or even better are upgraded to added-value bio-based products, to optimize economics and ecological impact of the full biomass supply chain. Other biorefinery concepts that are mentioned in literature are: Green Biorefineries, Whole Crop Biorefineries, Lignocellulosic Feedstock Biorefineries (Thermo-chemical Biorefinery/Syngas-Platform, Bio-chemical Biorefinery/Sugar-Platform, Two Platform Concept Biorefinery, Forest-based Biorefinery), Marine Biorefineries (Micro Algae Biorefinery, Seaweeds (macro algae) Biorefinery).

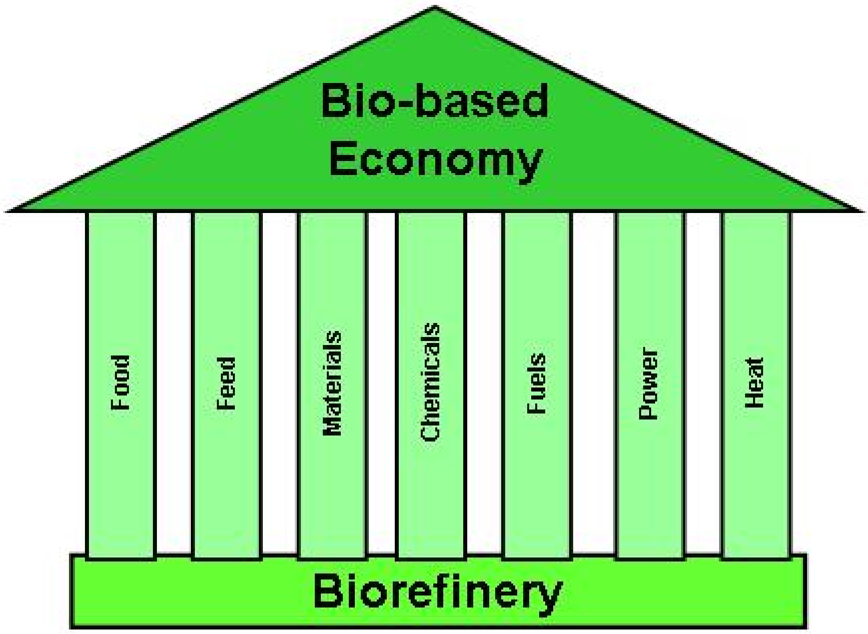


Figure 1 Biorefinery as foundation for the development and implementation of sustainable biomass value chains for Bio-based Products and Bio-energy to feed the Dutch and European Bio-based Economy (WUR, 2009).

Transition to a Bio-based Economy will take a long time. Large investments are required. New biorefinery processes will be integrated with current processes (e.g. improving valorisation of residuals or by-products), and those processes will be gradually adapted towards more optimal situations (feeding long-term ambitions with short-term successes). Other innovations require completely new processes; these are more realistic after depreciation of existing processes and industrial infrastructures.

Because the transition and realisation of a Bio-based Economy will require large investments, convincing evidence about its technical, economic, environmental and social feasibility is needed.

Through new biorefinery approaches, valuable plant compounds like proteins and polysaccharides could be isolated for (novel) food/feed uses, prior to a further conversion of the plant material for non-food/feed (chemicals, materials, fuels, energy) uses. At an input of 40-50,000 kcal/day (half biomass - half fossil, Wirsenius, 2000) for our daily meal of 2,250 kcal digestible energy, significant efficiency improvements within our food chain are possible by application of the biorefinery processes.

1.3 Potential of biorefinery to meet the targets set by the Platform Bio-based Raw Materials (PGG)

According to the Long-Term Vision of the Platform Bio-based Raw Materials (in Dutch: Platform Groene Grondstoffen (PGG)) – an advisory committee to the Dutch government – 30% of the fossil resources used as both raw materials and fuels (see Table 1) should be replaced by bio-based alternatives in 2030 (PGG, 2006a).

Table 1 The 30% LT Vision substitution goal specified over Dutch market sectors (PGG, 2006a).

Application	Envisaged fossil fuel substitution per application [% of use]	Fossil fuel substitution $[PJ_{th,\ affu}]$[1]	CO_2-emission reduction [Mt/a]
Chemicals and Materials	25	140	11
Fuels for transport	60	324	24
Power	25[2]	203	14
Heat	17[3]	185	10
	Sum	852	59

An important constraint of this LT Vision is that the overall energy consumption in 2030 should not exceed that of the year 2000, viz. 3000 PJ_{th}. To realise the 2030 LT Vision a combined package of measures is necessary, a.o. an increase in overall energy efficiency, reduced energy consumption, and offering a framework to enable the large-scale transition towards a Bio-based Economy. The substitution of about 850 $PJ_{th,\ affu}$ of fossil fuels will require about 1200 PJ_{th} raw biomass materials, corresponding to about 80 Mt dry base per year.

[1] *affu = avoided fossil fuel use*
[2] *Full plant substitution necessary*
[3] *Mainly Synthetic Natural Gas (SNG)*

Part of this biomass need can be filled in with biomass available in The Netherlands. According to Rabou et al. (2006) the Gross Dutch biomass production ((import-export) + production) amounted 42.3 Mt or about 742 PJ_{th} in the year 2000. Only a small part of this biomass was available for non-food applications. The projection of the Dutch biomass availability for non-food applications in 2030 is:

- 6 Mt dry base primary by-products/residues (100 PJ_{th});
- 12 Mt dry base secondary by-products/residues (200 PJ_{th}), and;
- 0 to 9 Mt dry base energy crops (0 – 150 PJ_{th}).

Totally: 18 – 27 Mt dry base or 300 -450 PJ_{th}. From these data, Rabou et al. (2006) conclude that 60 -80% of the biomass required to meet the 2030 LT Vision will have to be imported from outside The Netherlands. This import need can be reduced through use of aquatic biomass crops.

A second study by PGG (2006b), which underpins the PGG conclusions as given in Table 1, concludes that imports of biomass can be reduced if the Dutch biomass potential is more efficiently exploited . This can be achieved by several transition paths:

i. Improving the efficiency of using existing biomass, including Dutch biomass that is not being used yet.
ii. Sustainable production of biomass and improving the yield and quality of biomass crops.
iii. Producing aquatic biomass.

Another transition path proposed by PGG (2006b) relies on import. The biomass potential per transition path in 2030 is given in Table 2. However, also in this study imported biomass (option iv and part of the options i and ii) is still necessary, amounting to about 55% of the total required biomass.

Table 2 Biomass potential in 2030 per transition path (PGG, 2006b).

Avoided fossil use PJ	P/H/S 1)	Ethanol	Oil	Chemistry	Total	Import (%)
i) improving efficiency	261	70	10	70	411	50
ii) development of crops	69	78	57	36	240	75
iii) aquatic biomass	114	24	37	81	256	0
iv) imports of residues, half- and end products	73	44	112	0	229	100
Total	517	216	216	187	1136	55
Ambition PGG	388 2)	324		140	852	

1) P = power, H = heat, S = Synthetic Natural Gas (SNG)
2) 203 PJ power + 185 PJ heat

Both studies confirm that full exploitation of the combined transition routes are not sufficient to fulfil the needs of the Bio-based Economy. In addition, more effective use of biomass through biorefinery is an absolute necessity to meet the 2030 LT Vision goals. Note that both studies only consider the needs of The Netherlands. However, because of the specific geographic position of The Netherlands, combined with the excellent logistical and industrial infrastructures in its harbour areas, the biorefinery processes will not only produce Bio-based Products and Bioenergy for the Dutch market, but also for export to external (European) markets. This adds to the envisaged scale size of biorefinery in The Netherlands. This will also contribute to maximise local value addition ("The Netherlands as BioHub for Europe").

1.4 Targets Dutch working programme Clean and Efficient ("Schoon en zuinig")

Biorefinery developments should also substantially contribute to the Dutch working programme *Clean and Efficient* ("Schoon en zuinig", targeted at 2020). In Table 3 the key figures are summarized.

Table 3 Key targets Clean and Efficient.

Item	Target (PJ)
Biomass contribution in 2006	60
Biomass in 2020 according to *Clean and Efficient*	195 – 275
Biomass potential (including current usage) in 2020 according to the Option Document	230
Platform potential 2020	750
Platform ambition 2030	850

The national contribution of biomass to the energy supply is growing considerably. In 1995 this was 20 PJ and in 2006 it was threefold. However, to reach the target of "Schoon en Zuinig" an additional, substantially higher growth rate is required. A fourfold increase in the period 2006 – 2020 is needed. This increase is to be realised by the transition routes mentioned in the previous section. This biorefinery innovation program wants to provide an important contribution to realize this necessary increase in feedstock availability by improving conversion technology, decreasing costs, and enabling faster growth rates. The programme Clean and Efficient (Table 3) is only directed to energy. However, even more important is that biorefinery will also lead to building blocks for the chemical industry (fine chemicals, materials). This innovation programme will strengthen the specific position of The Netherlands and Dutch companies in the biomass market. The combination of highly developed agronomics, competitive biomass supply chains, and strong conversion technology development, makes The Netherlands key player in the international arena.

1.5 International developments urge The Netherlands to take action

Competition for energy will become more and more important. The use of sustainable energy sources, and better and more efficient use of biomass as feedstock for chemical industry, is needed. The Netherlands is well positioned to further develop a Knowledge-based Bio-based Economy by its strong chemical industry, agribusiness cluster, energy cluster, plant breeding industry, logistical infrastructure, and last but not least its strong knowledge base. Dutch research institutes and companies are involved in, and coordinate, many EU projects in the field of Biorefinery. The Netherlands has the potential to take the lead in Europe in this emerging area to establish a competitive advantage. The biorefinery concept will be beneficial for the competitiveness of the Dutch and European industry (chemical sector, energy sector, agribusiness, machinery industry), and for the further transition of the harbour of Rotterdam to a major BioHub.

A large number of biorefinery initiatives is being developed in the EU as well as elsewhere (Van Ree & Annevelink, 2007). A short-list with recent initiatives of international biorefinery pilots and demos outside of The Netherlands is:

- Biohub (France): development of a portfolio of platform chemicals out of 1.3 million tonnes of corn. Total programme costs M€ 90.
- BioGasol (Denmark, island Bornholm): a second-generation bioethanol demonstration plant, also producing solid biofuels and biogas.
- Six Lignocellulosic Biorefinery Initiatives (USA): total reward by the US Department of Energy (DOE) M$ 385.
- Ghent Bio-energy Valley.
- Green Biorefinery Austria (Utzenaich).
- Green Biorefinery Plant (Brandenburg, Germany).
- Lignocellulosic Feedstock Biorefinery (Mývatn, Iceland).
- NExBTL (Finland): production of second generation biodiesel (170,000 tonnes/y), integrated with a conventional oil refinery.

In order to tie-up with the international developments and to capitalize our strong potential with respect to biorefinery, setting up a number of initiatives in The Netherlands is essential. Most international initiatives mentioned above are connected to local large-scale agricultural production. The context for development of the Bio-based Economy, incl. Biorefinery in The Netherlands, is very different; therefore alternative developments are needed (see next section).

1.6 SWOT analysis on biorefinery in The Netherlands

In 2007 a SWOT-analysis was performed on the biorefinery area from a Dutch point-of-view. The results (see Appendix A for the long-list) give an overview of the Strengths, Weaknesses, Opportunities and Threats of the application potential of biorefineries in The Netherlands. The sources for this SWOT were among others the National Governmental Vision on the Bio-based Economy, the results of two stakeholder workshops that were organised in 2006 by the Dutch Knowledge Network on Biorefineries (Biorefinery.nl), and a brainstorm with experts of Wageningen UR and ECN. The outcome is comparable to the SWOT analysis for the industry letter (De Vaan et al., 2004), and can also be found in the Innovation Agenda Energy (2008). In December 2007 this SWOT analysis was evaluated during a workshop with representatives from industry, knowledge institutes, universities and policy makers. The prioritized factors (i.e. that received the highest scores) are presented in Table 4.

Table 4 Most important factors of the long-list SWOT matrix (long-list in Appendix A).

Strengths (internal)	**Weaknesses (internal)**
• Strong agrocluster, chemical sector and energy sector available, situated relatively close to each other • Advantageous geographical position in European market and logistical infrastructure (a.o. harbours in/export) • Good Knowledge Infra Structure (KIS, universities and institutes) • Food industry is already experienced with biorefinery processes	• Insufficient co-operation between stakeholders of agro, chemical and energy sectors • Studying instead of implementing • Investment capital for pilot and demo initiatives difficult to find • Key technologies partly still in R&D-phase • Full chains often not yet market competitive due to relatively cheap fossil fuels
Opportunities (external)	**Threats (external)**
• Strengthening of the economic position of the agro, chemical and energy sectors • Co-operation between stakeholders can boost the development and implementation of biorefinery concepts • Development of multi-purpose biorefineries in a framework of scarce raw materials and energy • Challenging national and European policy goals for bioenergy (fuels, energy) lead to high demand and trade of biomass	• Fluctuating (long-term) governmental policies delay company investments • Focus on single products (biofuels and electricity) only (no chemicals yet), and not on multiple products • High initial investment costs for pilots and demos • Discussion food/feed/fuels and biomass sustainability • Existing industrial infrastructure is not depreciated yet

Table 5 gives a confrontation matrix based on the SWOT table. The confrontation matrix helps to determine both the existing fit between Dutch biorefinery and its environment, and also to devise effective strategies in response to issues in the business environment; in brief, the matrix explicates what options suit the key issues?

Table 5 Confrontation of SWOT-factors to find suitable strategic options.

Internal External	Strengths	Weaknesses
Opportunities	**Options (ideal match)** • Strengthening the economic position of the Dutch agrocluster, chemical sector and energy sector, by realising the synergies between these closely situated sectors. It should help to get from study to action. • Import, process, and trade imported biomass using our advantageous geographical position in the Europe with its logistical infrastructure (a.o. harbours in/export) to satisfy challenging national and European policy goals for bioenergy.	**Options (optimize)** • Boost the development and implementation of multi-purpose biorefinery concepts, by using optimally the existing experience to increase co-operation between stakeholders in different industries.
Threats	**Options (defend)** • Invest in on- and offshore pilots and demos building upon strong Dutch KIS on plant breeding, water technologies and processing	**Options (divest or combine)**

The following promising strategies for biorefinery in The Netherlands are identified:

- Biorefinery based on domestic Dutch crops, using synergy of existing agro and chemical sectors, including the Dutch plant breeding sector.
- Biorefinery of aquatic biomass, using Dutch microbiology, plant breeding, and processing knowledge.
- Biorefinery of bulk imported biomass and biomass-derived intermediates, using existing logistic and chemical infrastructures.
- Biorefinery of residues, based on co-operation in production chains and networks, relatively small transport distances, and business instinct of Dutch entrepreneurs.

Technologies based on white biotechnology – the second type of key technologies that will be supported by the Dutch government within the Bio-based Economy framework (see section 1.1) – will be an integral part of the four strategies mentioned, and therefore is not presented as separate stand-alone strategy.

2 The biorefinery chain

2.1 Introduction

A biorefinery chain consists of a multitude of steps (Figure 2). The efficiency of each step is crucial for the success of the full biorefinery chain. Hence, in the development of any biorefinery process, a multitude of aspects has to be concerned, all of which are essential to the final success of the development.

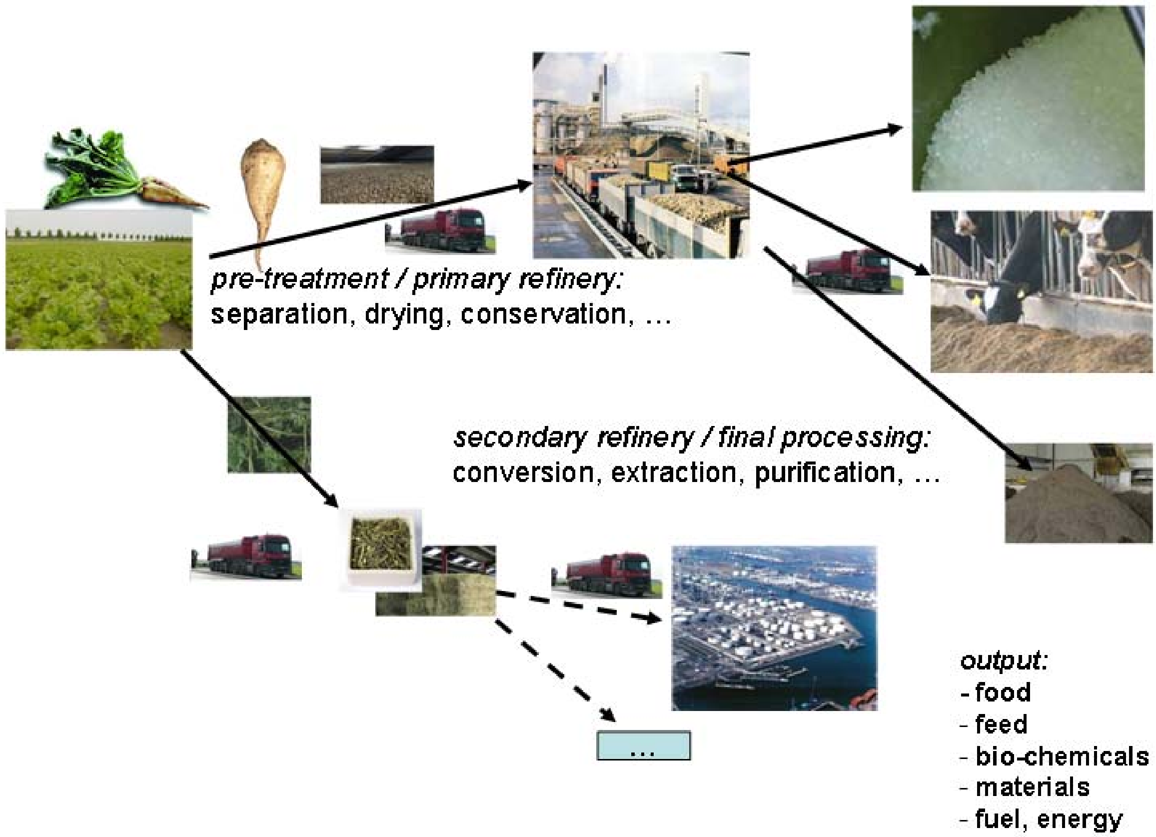


Figure 2 Schematic overview of an example of a biorefinery chain.

Table 6 gives a brief overview of the technical steps of the biorefinery chain, and related issues. Underlying problems and opportunities will be briefly described in the next sections.

Table 6 Technological and other issues in biorefinery chains.

Steps in biorefinery chain	Elaboration: technological and other issues
Feedstock	harvesting (e.g. whole crop), storage (year-round), conservation, logistics, mobile systems, on-line analysis of raw materials, nutrient management, change characteristics of feedstock
Pre-treatment and primary refinery	dewatering, homogenisation, conservation processes, densification (pyrolysis, pelletising, torrefaction), mild separation, hydrolysis, chemical/enzymatic fractionation, combined multi-product pre-treatment, feeding, enzymes
Secondary refinery and conversion	biochemical: lignin valorisation, advanced oleochemistry based processes, new bio-catalytic processes, fermentation processes (ethanol, butanol, H_2, chemicals, biogas), engineering of carbohydrates thermochemical: staged catalytic thermo-chemical processes, gasification, syngas synthesis processes, sub/supercritical/ hydrothermal conversion processes, hydro-thermal upgrading, lignin valorisation, catalytic conversion of biomass fractions and synthesis gas
Final processing	production processes for platform and functionalised chemicals, downstream processes for intermediate product upgrading (e.g. proteins/amino acids upgrading, oligo- and polysaccharides), separation, purification, drying, deoxygenation processes
Market/Output	market development for bio-based materials and intermediate products, development of bio-based commodities, availability, standardisation, legislation
Chain wide issues	cross-sector chain development, process development/ design/integration/optimisation, chain management, traceability and sustainability of used biomass
Transition/Social acceptance	stakeholder involvement, sustainability assessment, transition processes

2.2 Feedstock

Biomass is a broad category of materials with varying:

- productivity per hectare
- functional components
- components contents ratio
- accessibility of the functional components
- quality
- homogeneity
- water contents

Next to these intrinsic attributes, also the place and state of origin plays an import role in the potential use in biorefinery chains:

- bulk availability on one location or diffuse availability
- continuity of availability over the seasons
- freshness
- certified quality
- safety of origin
- plant, animal or mixed origin
- possibly with label "waste"
- predictability and controllability of quality and/or amount

2.3 Pre-treatment and primary refinery

As a first step of the biorefinery process, the raw biomass is subjected to pre-treatment and potentially separation into various streams. Primary refinery processes are usually designed for a specific feedstock. Crude biomass pre-treatment can be accomplished via different technological approaches:

- thermal (e.g. pyrolysis or torrefaction)
- physical (e.g. homogenizing, dewatering, extracting valuable components)
- thermo-chemical (e.g. acid hydrolysis, alkaline hydrolysis, solvent extraction)
- enzymatic (e.g. enzymatic hydrolysis)
- micro-biological (e.g. by excreted enzymes)

Beyond a large number of existing food/feed applications, industrial development of these processes is generally limited to pilot-scale.

2.4 Secondary refinery and conversion, and final processing

Intermediate products are further processed, and possibly decomposed into valuable compounds and building blocks (e.g. for the chemical industry). Generally, a secondary refinery process is output-product specific, and can use half-products from various pre-processed feedstocks. For illustration, conversion routes for constituent components of lignocellulosic crops are listed in Appendix B.

To add maximum value to the biorefinery process as a whole, the production of high-value compounds, polymers and other chemicals, next to food, feed, fuels and energy is essential. In this respect, high-value polysaccharides and protein polymers for medical purposes are examples of the numerous possibilities envisaged. Existing secondary refineries are best developed for pharmaceuticals and food. Even for feed products the use of secondary refinery is very limited (e.g. surplus of minerals in soy cake is not removed, although these are not functional in feed and contribute to manure problems).

2.5 Market/Output

When the crude biomass has been refined into separate components, these can be transformed into a wide array of bio-based products. These can be grouped into a limited number of generic products:

- food (potentially ingredients)
- feed ingredients
- biofuels
- heat and power
- chemicals
- materials

The last two groups of generic bio-based products represent a wide number of products which can be categorised as follows:

- Materials: fibres, wood, which can be used as such.
- Substances: starch, oils, proteins, waxes. These products are crop components that can be isolated from the biomass resource. The products can be used as such, or after (slight) (bio)chemical or physical modification. The plant is used as a factory to produce the desired molecules and substances. This is the most common route within the current agrifood industry.
- Building blocks: lactic acid, ethanol, furanics, glucose, HMF, amino acids, organic acids, fatty acids, syngas. These are produced by breaking down biomass components into small molecules.

These molecules can then be used as chemical feedstock to produce:

- building blocks for organic industries (e.g. furandicarboxylic acid, succinic acid, ethylene glycol, levoglucosan, furfural)
- polymers (e.g. polyesters, polyamides, polyurethanes, polyolefins)
- fine chemicals (e.g. surfactants, agrochemicals, plasticisers)

The syngas route logically can be coupled to the existing use of syngas, and thus replaces syngas from coal or natural gas. The other building blocks can tap into the chemical industry at various places in the production chain, and are more likely to replace mineral oil based chemicals. The same holds for the substances routes.

The present use of biomass according to these routes for non-food products is already substantial (see Table 7).

Table 7 Overview of Bio-based production in 2005 for EU25 according to Eurostat (Nowicki et al., 2007).

Production type	Total value for EU25 (billions €)	Actual bio-based value (billions €)	Potential bio-based value (billions €)
Biomass separated to materials	250.6	187.7	211.6
Biomass separated to substances	47.9	23.1	38.6
Biomass fragmented into building blocks	155.2	34.5	81.6
Totals	453.7	245.3	331.8

The total value of Bio-based production of 245 billion Euros in the EU25 in 2005, according to Nowicki et al. (2007), is an underestimation, since most of the information required for the Eurostat database is confidential and thus not included. This share can grow rapidly to 332 billion Euros. The largest growth (compared to present market size) is expected in the building blocks route. As stated in the previous chapter, this route also is expected to give the highest added value.

2.6 Challenges for transition to a Bio-based Economy

- **Development of a Bio-based Economy demands for a vast amount and standardized quality of biomass feedstocks**. As stated in the previous chapter, this demands for more optimal valorisation of existing and new sources, including largely increasing agricultural production, use of forest and nature products, and use of organic residues. For the required increase of agricultural production numerous measures have to be taken, both on short and long term. Expansion of current agricultural areas, for examples into areas with marginal soils or otherwise suboptimal growth conditions, improved productivity (ton biomass/ha), and higher added value (€/tonne biomass) are needed. New crops have to be developed with much higher productivity, and much better tolerance to drought, and low nitrogen and phosphate availability. Genetically modified crops could play an important role if they provide added value in terms of yield, quality and environmental sustainability. However, their development is still under debate. Also systems for marine biomass production (micro-algae and seaweeds) have to be developed, which allow concurrent production of biomass for food, feed, energy and materials production, and recycling of nutrients. Offshore production of sea weeds, which act as a filter for excess nutrients supplied by rivers, would combine biomass production with sustainable water management. Imported biomass will be necessary to meet the energy goals of the Dutch society. Also the imported biomass should match the sustainability criteria in term of nutrients and greenhouse gas emissions, and protection of natural diversity. The development of sustainable crops and agro production systems, for growth outside Europe, will provide opportunities for Dutch breeding industries and knowledge centres, allowing the development of Intellectual Property (IP) and breeders right for crops grown outside Europe, and imported for biorefining in The Netherlands. To realise optimal production on a global scale, for each target crop a plethora of varieties need to be developed, which are optimally adapted to different growth. Large amounts of biomass residues can be made available at short-term already. Residues from food industries are relatively well-defined materials. Current use (often feed) is far from optimal since only part of the component is functional in feed. More optimal valorisation of these biomass residues in the first place demands for development of biorefinery technologies. Food waste and "vegetable, fruit and garden waste" (GFT) has highly varying composition ("undefined"), and largely varying quality. Furthermore, intensive collection logistics are needed for these streams. Adequate systems should be collected for valorisation of these products.

- **Existing conversion/biorefinery processes have to be improved, and new ones have to be developed, in order to make the conversion of biomass more effective and efficient.** Pre-treatment of biomass is necessary in order to achieve higher functional material/energy density. Improved technologies are necessary for separation, fractionation, fermentation, distillation, gasification, enzymatic washing, catalysis, pyrolysis, torrefaction, electro-dialysis, and extraction.

- **Products from biorefinery processes will replace traditional input materials. Biorefinery chain development not only stands for the connection of feedstock supply and various processing steps, but also for the connection to the end-users.** This means that sector-exceeding (cross-sectoral) relationships will have to be developed (with e.g. chemical industries, energy industries; see Appendix C for a more detailed description of this issue). What new organisations do fit the best? Contracts or joint ventures? Under what conditions is what organisation the most suitable? Furthermore, what incentives have to be organised in the chain in order to produce the products required? Another issue is risk management within the chains. These questions have different answers for different chains: according to scale, to feedstock, to end user. Large-scale processing is suitable for bulk products but takes place under other conditions than small-scale production, which is more suitable for the production of functionalized bulk chemicals (0.5 – 25 M tonnes/year). Products like syngas, ethanol, butanol, methane, sugars, and fibres can be produced in bulk. Products like functionalized chemicals, pharmaceuticals, food ingredients, vitamins, and proteins can only be produced on small scale.

- **Various societal issues have to be resolved**, such as:
    - Social acceptance of the new business. One has to be aware of the fact that new businesses, new technologies require full social acceptance in order to minimize economic risks of (new) investments.
    - (Organisation of) Certification of biomass and products to guarantee sustainability of the developments.
    - Measures have to be taken by government (e.g. legislation), non-government and firms in order to develop the new Bio-based Economy.
    - Environmental and social-economic sustainability assessments.

Furthermore, the process of developing a full-scale Bio-based industry comprises several types of development:

- **Strategic research (research institutes and universities)**: exploring the potential of new technologies for enabling/improving biorefinery processes, assessing sustainability, bringing together complementary partners in networks, and monitoring of the (transition) process. Outcome of this work will stimulate industries and other stakeholders to start biorefinery initiatives.

- **Applied technical development and chain exploration (research institutes in close co-operation with industry)**: demand-driven research on practical applicability and efficiency of biorefinery processes. Demand will come from:
    - Suppliers of biomass (looking for added value for their products, looking for customers).
    - Potential users of the biorefinery end-products (looking for alternative sources for the input material for their processes).
    - Consortia (aiming for improving logistics efficiency, product quality).

- **Testing, piloting and industrial demonstration (industry in co-operation with research institutes)**: a capital-intensive phase which is essential before large-scale installations are implemented into the commercial market.

- **Commercial exploitation (industry)**: also in this phase developments and innovation will continue.

Part of the development issues mentioned above have a site-specific or country specific framework, and therefore have to be developed at a regional or national level, paid by regional/ national industry, and financially supported by regional/national governmental organisations. Another part of the issues mentioned – those having a more generic character, or dealing only with the development of certain specific biorefinery chain composing subprocesses – potentially can be developed in an international (European) framework, making use of internationally available financial supporting mechanisms (a.o. EC FP7 programme). Making use of these internationally available funding mechanisms offers the chance to multiply available national governmental RD&D-budgets by 4-5 times, accelerating necessary RD&D developments and shortening the timeframe to successful final market implementation.

3 Moonshot approach

3.1 Moonshots

In order to optimise the effectiveness of the process and efforts to the implementation of the Dutch governmental Vision on the Bio-based Economy in the Energy Transition, so called 'Moonshots[4]' have been defined together with relevant stakeholders from industry, government, institutes and universities. A Moonshot is a promising biorefinery strategy specifically for The Netherlands, based on the SWOT analysis (see Section 1.6).

The defined Moonshots are (see Figure 3):

- Moonshot 1: Biorefinery of specific Dutch crops
- Moonshot 2: Biorefinery of aquatic biomass
- Moonshot 3: Biorefinery of imported biomass at Dutch harbour sites
- Moonshot 4: Biorefinery based on the valorisation of waste and residue streams

The identified Moonshots reflect promising feedstock sources (BIOPOL, 2009):

1. Specific Dutch crops with high biomass productivity (beet, maize, grass). Large-scale biorefinery of such crops will result in different demands to the raw materials than current chains do. Hence, alternative systems may be needed for agricultural production and harvesting.
2. Aquatic biomass (micro-algae and seaweeds) is an interesting new feedstock for biorefinery, characterized by high productivity per area unit, and a high content of valuable components for the Bio-based Economy, including: oils, proteins, polysaccharides and specific biomolecules. Due to the varied composition, micro-algae and seaweed biomass are highly suited for biorefinery with end-products ranging from fuels and bulk chemicals to specialty chemicals and food and feed ingredients. This Moonshot requires the development of production and conversion technologies, and the formation of logistic chains.

---

[4] *Criteria for Moonshots:*

- *Moonshots are ambitious, but attainable*
- *Moonshots demonstrate the real-life application of knowledge / technology*
- *Moonshots are scalable, so that industry can use them as blueprints for large-scale biorefinery realization*
- *Moonshots are driven by industry's priorities and ambitions to ensure that success will lead to large scale application*
- *Moonshots define the demonstration, development and research*

Identified Moonshots reflecting the most promising feedstock sources (continued):

3. Imported biomass at Dutch harbour and port sites (energy densified lignocellulosic raw materials and biomass-derived intermediates). Large-scale biomass import is common for food/feed and for energy (think of wood chips) already. For this Moonshot feedstock can be retrieved from (existing) commodity markets, with connected advantages (independent from variations in local agricultural production, reduced seasonal dependency).
4. Biomass residues and waste streams (multi-industrial intersectoral approach). A substantial fraction of the residues from food industries is used for feed (although the mineral contents mostly is far from optimal). A part of the organic residues is used for biogas production. New technologies and chain arrangements are needed for better use of these biomass streams.

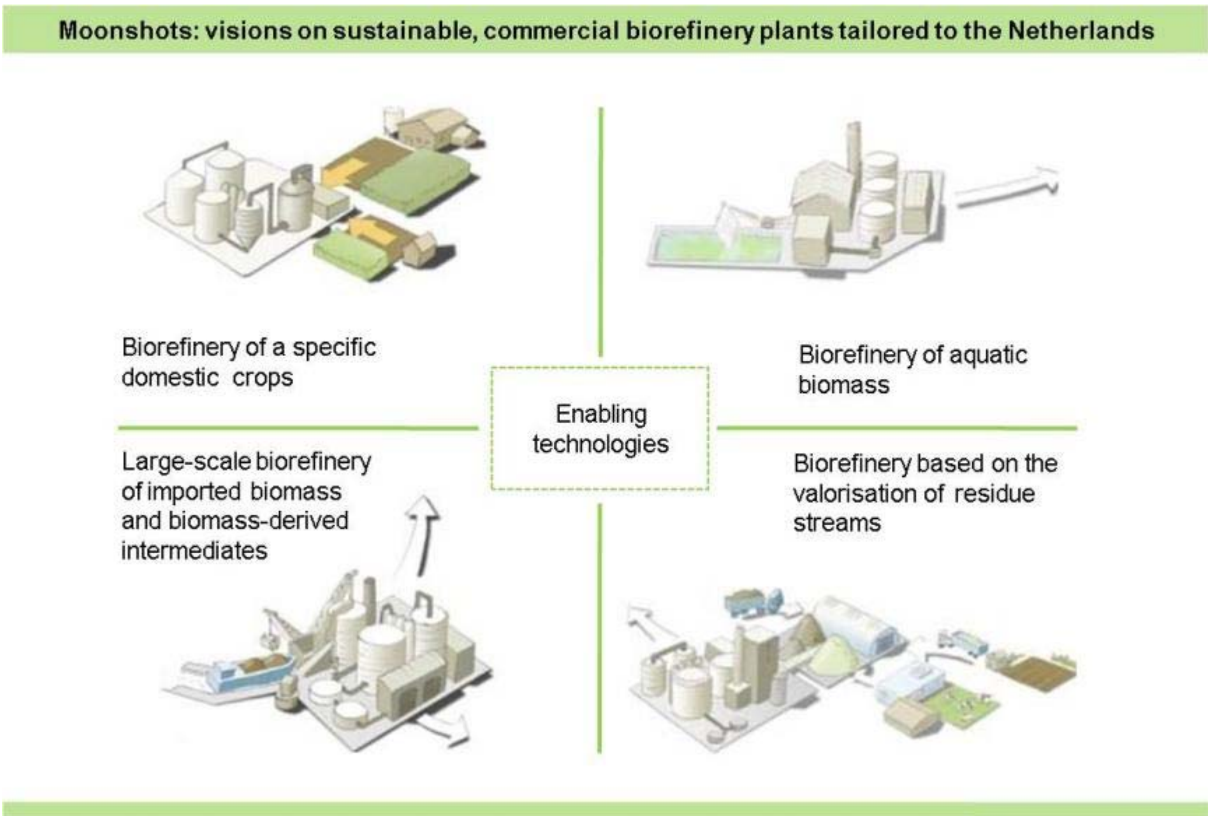


Figure 3 Four Moonshots defined based on specific Dutch strengths.

As mentioned before, a Moonshot is a typical Dutch biorefinery strategy, based on the SWOT analysis. Large-scale market implementation of full biomass-to-product chains, including different biorefinery-based conversion technologies, therefore will be part of the Moonshot framework, and will contribute to fill in the Long-Term Vision of the Platform Bio-based Raw Materials, that 30% of the fossil resources used as both raw materials and fuels should be replaced by bio-based alternatives in 2030. To fill in the biorefinery strategies (Moonshots), more specific biorefinery-based biomass-to-products value chains will be defined.
Depending on the current state-of-the-art, short-, mid-, and long-term activities will be presented that are necessary to support the successful and stepwise market implementation of these specific biorefinery-based biomass-to-product value chains. Depending on the specific value chains concerned, involved activities could be:

- applied technical and non-technical research at bench-, pilot- and demo-scale, specifically for value chains that are already close to the market;
- strategic technical (lab- and bench-scale) and non-technical research, for value chains that look very promising but still need significant time to market (a.o. for the development of some key biorefinery technologies that potentially are applicable in various biomass-to-product chains; examples are advanced pre-treatment, hydrolysis, fermentation and gasification technologies).

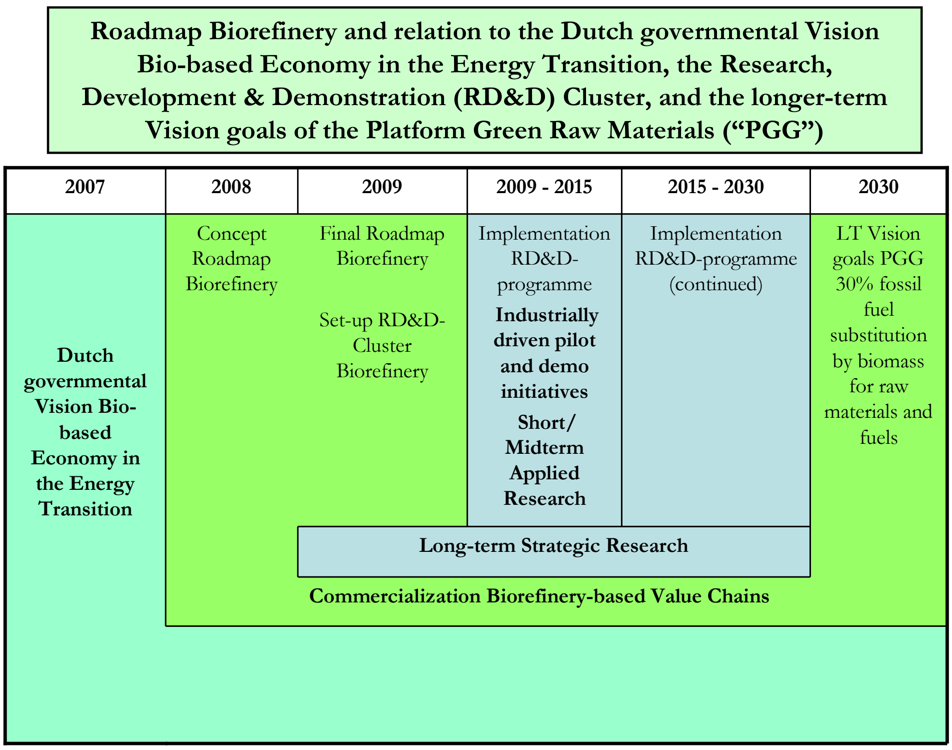


Figure 4 *Transition process to a Bio-based Economy, showing the Roadmap, the RD&D-Cluster, and the commercialization-trajectory of Biorefinery-based Value Chains in The Netherlands.*

3.2 General description of Moonshots

Moonshot 1. Biorefinery of Specific Dutch crops

Crops grown in The Netherlands or grown under the control and the direction of Dutch agro processors in NW Europe, are processed in local agrorefineries. Crops and crop production concept will optimally match with the refinery concepts for these crops, which allow the generation of maximum added value according to Dutch or European sustainability standards. All crop component and residues are maximally valorised into feedstocks for food, feed, energy, chemicals and materials.

Type of biomass	Both traditional agricultural crops (grass, beet, maize, hemp, …) and new non-food crops
Scale[5]	Small, Medium and Large
BR Technology	Mono and multi feedstock technology for both wet and dry biomass, i.e. various (bio)chemical and thermo-chemical based technologies; whole crop and green biorefinery technology Optimal valorisation crops by co-producing high value (food/chemicals) and low(er) value products (fuels, energy, fertilizer) Conservation methods for crops and intermediate products. Processing: separation/fractionation processes, drying technologies, etc.. Mobile biorefinery applications
Logistics	Biomass supply from different farmers to one central refinery location. Load-factor 100% possible by using different types of crops
Type of Customer	Agrofood/feed, chemical, material, energy sectors; potentially formation of new co-operations
State-of the-art	Various depending on the type of composing technologies
Dutch strengths	Agro-, chemical, plant breeding, machine building

[5] *Indicated scales are indicatively defined as:*

- *small: farm scale*
- *medium: co-operative organization*
- *large: industrial*

Moonshot 2. Biorefinery of aquatic biomass

Aquatic biomass cultivation and processing are regionally or locally integrated. These integrations will produce high-value components for pharmaceutical applications as well as bulk products (for chemicals, fuels and energy).

Type of biomass	Micro-algae, very wet Seaweeds, very wet
Scale	Micro-algea: Small to Medium Seaweed cultivation & processing: large scale e.g. in the North Sea, oceans
BR Technology	Marine Biorefinery; depending on type of algae/seaweed and products required, BR composing subprocesses could be physical, extraction or (bio)chemical based. Processing: separation/fractionation processes, drying technologies.
Logistics	Raw materials (nutrients, CO_2) input. Output several products Seaweeds: harvesting/dewatering, processing at sea?, recycle nutrients
Type of Customer	Energy, food/feed, chemical (incl. pharma and costmetics), materials, sectors
State-of the-art	Micro-algae: depending on type of cultivation used – closed vs open systems: lab/pilot-scale for bulk applications vs commercial scale for niche applications Seaweeds: worldwide application in food, feed, alginates, carrageenans.
Dutch strengths	Plant breeding and process development, offshore engineering, marine activities North Sea, microbiology

Moonshot 3. Biorefinery of imported biomass and biomass-derived intermediates

This Moonshot connects (petro-)chemical industries with agro industries through biomass. Imported biomass commodities will gradually replace fossil oil.

Type of biomass	Pre-treated biomass and/or biomass-derived intermediates
Scale	Large
BR Technology	Various both (bio)chemical and thermo-chemical based; fitting in the available port-industrial infrastructures
Logistics	Large-scale import of pre-treated biomass and/or biomass-derived intermediates and export of products to national and EU markets
Type of Customer	Chemical, energy, food, feed, fertilizer sectors
State-of the-art	Various depending on the type of composing technologies
Dutch strengths	Existing logistical and chemical infrastructure

Moonshot 4. Biorefinery based on the valorisation of residue streams

Different from the ones mentioned before (all using "new" biomass streams), this Moonshot aims for more effective use of existing biomass streams. The network of biorefinery processes will be connecting to existing production chains and networks. Cost reduction for residues is an important driver for development of this Moonshot.

Type of biomass	Residues from agrofood industry, biofuel industry, paper industry; mono and multi-feedstock, often wet and fiber/protein rich
Scale	Large and Medium
BR Technology	Multi-industrial, multi-sectorial complexes valorizing each others residues Conservation methods for residues and intermediate products of biorefinery processes. Processing: separation/fractionation processes, drying technologies, etc.. Type of BR technology depends on specific residues, available infrastructure, new common infrastructure
Logistics	Clustering industries to an (agro)industrial refinery complex; residue trading and logistics are important factors
Type of Customer	Currently often the feed sector, in the near future non-food/feed applications
State-of the-art	Valorization of single residue streams already applied for low-value applications; higher-value applications and the refinery of multi-residue streams requires additional R&D
Dutch strengths	Strong logistics and infrastructure

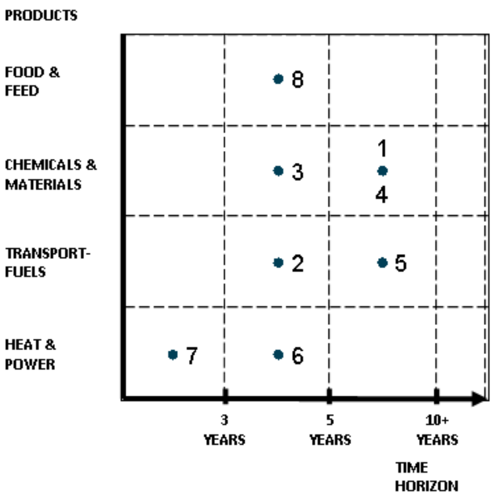
3.3 Stakeholders view on the Moonshots

The following figures give highlights of views of various stakeholders (from industries, governments, institutes and universities) on the Moonshots[6].

Moonshot 1. Biorefinery of Specific Dutch crops

Processed opportunities

Opportunities

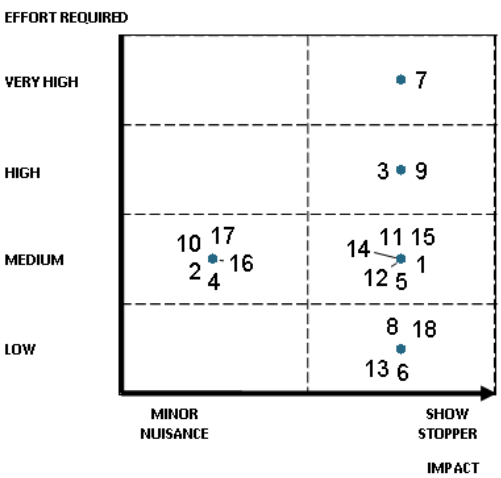


Explanation

1 Arable production of platform chemicals
2 Horticultural production of specialty chemicals
3 Lactic acid, succinic acid, propanediol
4 Perannual crops for biochemicals, fibres & materials
5 Closing CO2-cycles regionally
6 Small-scale CHP with local fuel or biogas production
7 Consortia of farmers & SME's for regional development
8 Breed new cultivars that have a) high concentrations of ingredients directly in plants & b) allow easy recovery by downstream processing

Processed barriers

Barriers – Technologies, legislation and logistics



Explanation

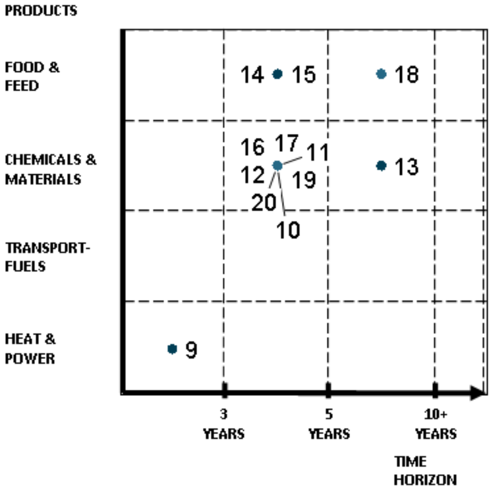
1	TECH	Separation & fractionation technologies (costs/scale issues)
2	TECH	Conversion technology
3	TECH	Multidisciplinairy approach
4	TECH	Multi-purpose biorefinery (food, feed, chemicals, fuel & energy)
5	TECH	Choice of crops crucial
6	TECH	GMO technology
7	TECH	Metabolic engineering of Dutch crops to acchieve low input/ high output
8	LEG	Improve fiscal regulations for biofuels
9	LEG	Permit GMO technologies in Europe
10	LEG	Permit use of minerals from biorefinery processes as fertilizer
11	LEG	Change and relax regulations in field of the treatment & logistics of waste & residue streams
12	LEG	Land use issues (competing claims)
13	LOG	Limited number of crops available that can be grown on a large scale
14	LOG	Large volumes low dry solids for chemical production
15	LOG	Process 'wet' crops locally/regionally & move 'dry' crops over larger distances (biocommodities)
16	LOG	Supply & demand security are necessary for investments
17	LOG	Year-round availability of biomass
18	LOG	Change of culture in agricultural sector needed when supplying to chemical sector

[6] *The reactions were gathered in workshop sessions. For practical reasons only a limited number of reactions are presented.*

Moonshot 2. Biorefinery of aquatic biomass

Processed opportunities

Opportunities

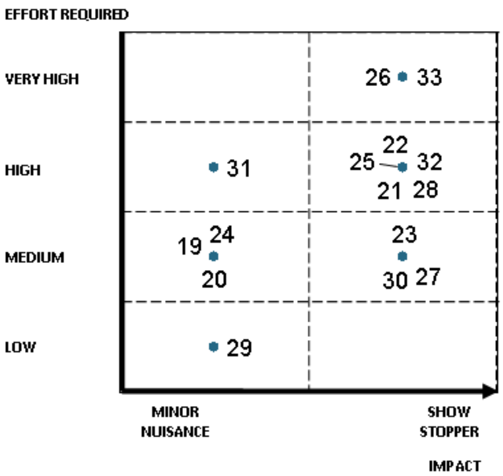


Explanation

9 fuels production by direct processing wet biomass via HTU, fermentation to ethanol, biogas
10 Major source of (combinations of) bulk and fine chemicals, materials, fuels via biorefinery
11 Major source for high value oils, fatty acids, proteins
12 Major source for cellulose for paper or for sugars for the fermentation industry
13 GMO algae for high value chemicals production
14 food & feed ingredients / structured protein fibres
15 Alternative application in aquaculture
16 Alternative application in water purification
17 Alternative application in flue gas cleaning (CO2 and NOx removal)
18 seaweed cultivation systems as nursery for fish
19 cultivation system with waste heat, CO2, NOX, nutrients at zero cost e.g. co-located at a paper or sugar factory
20 Monomeric carbohydrates for chemicals

Processed barriers

Barriers – Technologies, legislation and logistics



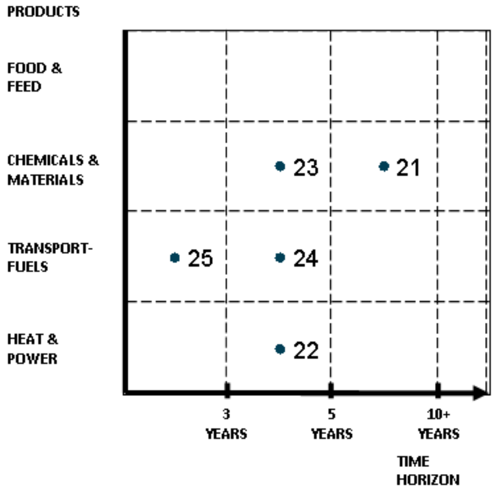
Explanation

19	TECH	Micro-algae cultivation on locations where nutrient residues are available
20	TECH	Optimize selection of local adapted algal strains
21	TECH	Optimize energy balance cultivation + harvesting
22	TECH	Harvesting and Down Stream Processing
23	TECH	Development of multi separation/purification technologies (DSTI)
24	TECH	Food-grade technology for extraction of high value minor components from diluted streams
25	TECH	Closing the nutrients balance
26	TECH	Cost reduction esp. CAPEX for biofuels production
27	LEG	Regulations related to spatial arrangement in rural areas and for the use of GMO are needed at the national level
28	LEG	Issues with regard to HACCP sensitivities for open pond systems (esp. feed and food) should be addressed at the EU level
29	LOG	Identify optimal locations for algae farms (in relation to space and availability of resources) and transport of nutrients and residues.
30	LOG	Removal of water and efficient harvesting are seen as potential show-stopper in scale up.
31	LOG	Investment needed in scale-up and demonstration facilities esp. for high tech SME's.
32	LOG	Application of algae reaches multiple sectors. To couple this in integrated systems is a major challenge.
33	LOG	Locations outside the Netherlands may be more suitable in terms of inputs (light, climate) and output quality

Moonshot 3. Biorefinery of imported biomass and biomass-derived intermediates

Processed opportunities

Opportunities

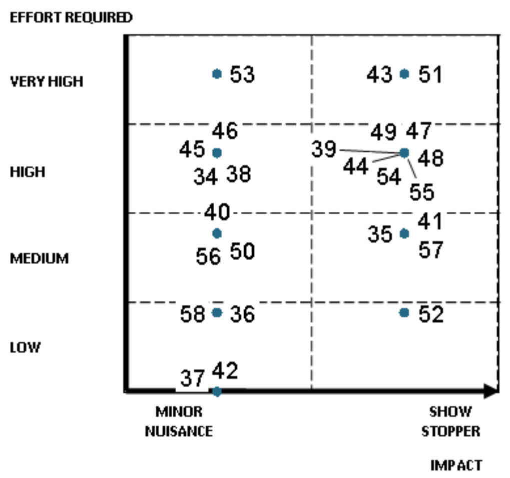


Explanation

21 Flexible bio-based products and bioenergy production depending on market request
22 High-value bio-based products and/or bioenergy from process residues
23 Production bulk chemicals by (advanced) fermentation
24 Demonstration advanced biofuels based biorefineries
25 Integration into conventional petrochemical complex

Processed barriers

Barriers – Technologies, legislation and logistics



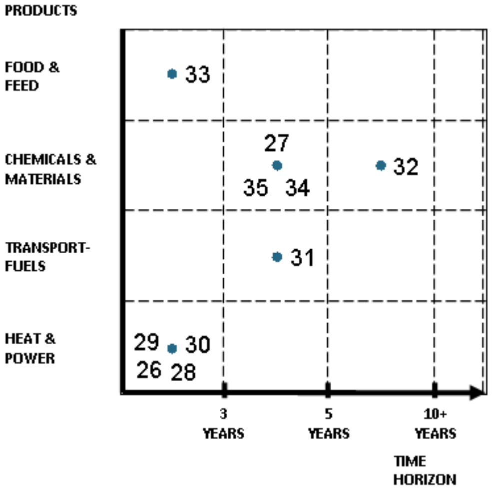
Explanation

34 TECH Large-scale pretreatment for secondary biorefinery
35 TECH Cost-effective and sustainable primary biorefinery processes: pretreatment/hydrolysis, torrefaction, pyrolysis, HTU, … ..
36 TECH Cost-effective and sustainable secondary biorefinery processes: fermentation, gasification, … ..
37 TECH Oleochemistry instead of petrochemistry
38 TECH Product separation processes: membranes, … ..
39 TECH Lignin valorization technologies: … ..
40 TECH Conversion wet biomass streams: HTU, supercritical gasification, digestion, …
41 TECH Mineral valorization technologies
42 TECH Short-term success stories (demos, applied research) as drivers for long-term developments (basic research)
43 LEG CO2 credits
44 LEG Policy making on EU level
45 LEG GMO legislation
46 LEG Availability raw materials dependence on import tarrifs – security of supply
47 LEG Full sustainable chain approach (production – conversion – use)
48 LEG Raw material and product sustainability criteria in international level
49 LEG Certification required
50 LEG Government as launching customer
51 LOG Biomass densification for transport
52 LOG Primary biorefinery at place of biomass production -> energy densification + minerals back to the field
53 LOG Import densified biomass, intermediates or final products?
54 LOG Feedstock types and place of birth?
55 LOG Combination with regional concepts
56 LOG Co-operation chain composing stakeholders necessary – which is the leading party?
57 LOG Feedstock supply on large scale
58 LOG Using existing infrastructure

Moonshot 4. Biorefinery based on the valorisation of residue streams

Processed opportunities

Opportunities

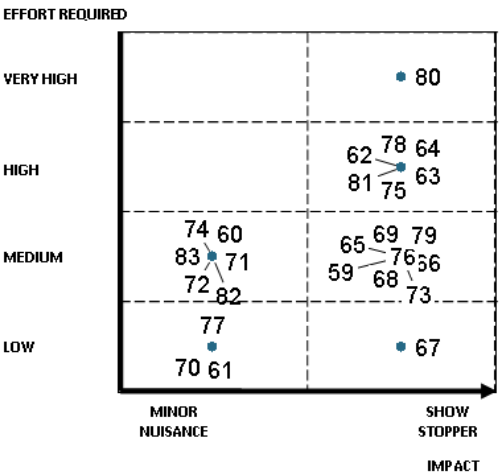


Explanation

26 Materials: manure, food waste, slaughter waste, plant waste, waste water, etc.
27 Mono streams: low economic value of products demands for inexpensive processing
28 Mixed residues (food waste, manure, ...):
29 currently mostly with negative economic value
30 little selective processes like biogas fermentation
31 biogas is potential input for Green gas, Bio LNG, etc.
32 create value through fractionation technologies
33 limited purity of half-products
34 Secondary refinery: increasing added value
35 Residues: potential for recycling minerals

Processed barriers

Barriers – Technologies, legislation and logistics



Explanation

59 TECH Upstream: measures for increasing residuals quality/homogeneity
60 TECH Downstream: homogenizing
61 TECH Downstream: biogas fermentation
62 TECH Downstream: thermal conversion
63 TECH Downstream: separation/fractionation processes
64 TECH Downstream: purpose-oriented purification
65 TECH Quality/safety management
66 TECH Downscaling technology (at scale size of local residual stream)
67 LEG Beware of label "waste"
68 LEG Manure legislation: limit possibilities
69 LEG Using food residuals and animal by-products for food or feed is troublesome
70 LEG Local permissions: forbid other activities locally
71 LEG Individuals can prevent local new permissions
72 LEG Variations in regulative behaviour by local government
73 LEG "Unreliable government": continuity of policy
74 LOG "Closing mineral cycles" at local/regional/national/global scale
75 LOG High volumes, expensive (collection) logistics
76 LOG Residues have low economic value (often negative)
77 LOG Low priority for quality
78 LOG Need for continuity of supply/buyers
79 LOG Need for matching demand and supply in place and time
80 LOG Residuals-based commodities as bulk materials
81 LOG Multi-industrial multi-sectorial clustering for valorization each others residues
82 LOG New collection logistics methods, aimed at product quality
83 LOG "Biomass yard": one-stop delivery point for biomass residues that combines biomass collection and various biorefinery processes

4 Roadmaps for applied research and demonstrations

4.1 Short-term Demonstrations: Connection to the future Bio-based Economy

The Moonshots are envisaged general biorefinery strategies that after being more specified and implemented at industrial scale will be the foundation of the future Bio-based Economy. Parts of the Moonshot composing biomass value chains potentially can be ready for demonstration on the short-term. In interactive workshops with a broad range of stakeholders (representatives from industries, governments, research organisations and universities) a number of suggestions for specific short-term (<2015) demonstrations have been identified per Moonshot. Two examples per Moonshot were elaborated (as listed in Table 8) to illuminate major barriers for implementation, and to identify actions for removal of these barriers. By collecting the barriers and actions from these specific examples, and grouping them into general items, the generic themes for further development of biorefinery-based value chains have been determined (which are described in the following chapters).

Table 8 Examples of Moonshot composing biorefinery demonstration cases.

Moonshot	Examples for demonstration
1. domestic crops	• whole crop sugar beet • grass
2. aquatic biomass	• micro-algae • sea weeds
3. large scale biomass import	• syngas production • integral valorisation of biomass for biofuels, feed, and chemicals
4. biomass residues	• food residues (undefined streams) • residues of food production (defined streams)

Note that the named demonstration cases are not a pre-selection of initiatives to be started, but are examples. Other obvious examples are:

- Whole Crop Biorefineries based on other crops, such as: winter beet, fodder beet, corn, wheat, new protein crops (such as lupine or bean); crops under development e.g.: Crambe for wax ester production with full use of plant oil and seed protein for industrial uses, and beets for production of chemical building blocks
- Lignocellulosic Feedstock Biorefineries (willow, Miscanthus, forestry residues)
- Verge grass processing
- Production of hydrogen out of wet biomass

Typical targets, current status, barriers and needed actions for realisation of demonstrations are elaborated in the following sections. These are summarised in a roadmap (see illustrative example in Figure 5) per demonstration, illustrating the potential route towards realisation of the demonstration.

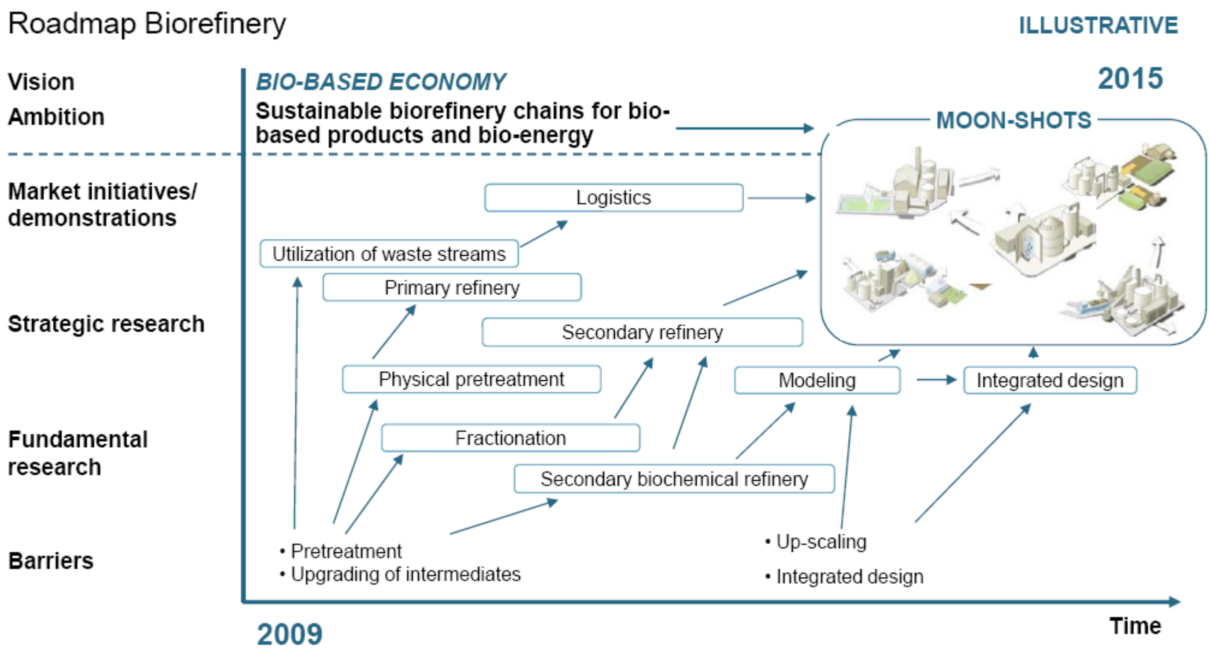


Figure 5 Illustrative example of a roadmap.

The aspects lines in the roadmap figures of the demonstration examples are indicated with different colours:

- Raw material availability and quality (dark green)
- Biomass pre-treatment (dark blue)
- Secondary refinery (light green)
- Final processing (purple)
- Market aspects (light blue)
- Policy & regulations (pink)

The examples of Moonshot composing demonstrations are described in the next sections. Further details, including a target description, barriers and actions can be found in Appendix D.

4.2 Demonstrations Moonshot 1: Domestic Crops

Demonstration Whole Crop Sugar Beet Biorefinery

Biorefineries based on domestic crops are essential to the Dutch economy to realize a measurable part of its energy and chemicals supply from biomass. The Whole Crop Biorefinery worked out in this example description is based on sugar beet (Figure 5; Table 10-12 in Appendix D). For a number of reasons, including the environmental sustainability, the expected economic revenues, and the potential to contribute to achieving the national targets for energy and chemicals production from biomass, sugar beet is considered the most optimal source of biomass for a Domestic Crop Biorefinery. Another reason is that Dutch beet processing facilities are among the most modern in Europe. Core technological competences available in traditional beet processing are extraction, juice purification, drying and evaporation, crystallization, and integrated energy and water management. These technologies are also relevant to other biorefinery concepts, including those from grasses, algae and imported biomass. The new Domestic Crop Biorefinery based on beet will be developed in two phases requiring different but overlapping roadmaps. More biomass per ha, more fermentable sugars from harvested biomass, more added value per ton biomass, access of Dutch industrial sectors to knowledge and ownership of technology and elite crops, are the main goals behind developing the Domestic Crop Biorefinery concepts.

<u>First stage Domestic Crop Biorefinery</u>
In order to enter the market for chemical or energy products (e.g. biofuels), a fermentable sugar feedstock is needed that is cheaper and more sustainable than cane sugar. To realize cost and sustainability goals, operational costs need to be reduced substantially, first by performing simple processing steps at farm level, secondly by developing concepts that allow year- round utilization of the main central (and high tech) factory. If appropriate, the first stage biorefinery will allow processing of other crops (such as legumes or other protein crops). Also new in the Domestic Crop Biorefinery is that, compared to today's beet processing, all crop biomass, including tap roots, root heads and leaves are harvested and converted into a plethora of possible products with a positive cost/value balance. The first stage biorefinery will be operational around 2015.

With regard to this first stage demonstration plant, the following concepts will be developed:

- New storage and processing concepts, to reduce operational costs, which allow the centralized factory to turn from seasonal to year-round operation.
- Next to centralized processing, near-field/near-farm pre-processing (on a scale of 105 farms) will be developed, to limit logistics costs, to recycle nutrients and water to the field, and to stimulate agricultural activities. This may include the following activities:
- adjustments to harvesting machines (including washing, but also later harvests)
    - longer storage times

  - o demonstration-scale tissue size reduction/pre-treatment
  - o mechanical (pressing)
  - o Pulse Electrical Field (PEF) because of lower energy use or other product pallet
  - o ultrasonic fibre fractioning
  - o fermentation-induced precipitation techniques
- To extend the harvest and processing period, new types of beets need to be developed. A very promising concept is the autumn or winter beet, which allow to start harvest and processing already in late summer or early winter. Breeding goals are improvement of frost hardiness and inhibition of cold-induced flowering.
- For the centralized high-tech processing the following demonstration activities will be developed and or tested:
  - o demonstration-scale fractionation technology:
    - solid/liquid separation
    - mild/ low energy dehydration (condense juice)
    - centrifugation
  - o demonstration-scale conversion technology:
    - simple chemical conversions, enzymatic degradations
  - o conservation/storage:
    - silage
    - concentrated solutes in tanks
    - use of additives

Relevant and relatively new core technological competences that will be applied in the first stage Domestic Crop Biorefinery, are: adsorption, de-mineralization, membrane filtration, supercritical CO_2 chemistry, and fractionating cool crystallization. Breakthroughs that are needed are the integration of these new technologies in the currently used state-of-the-art technologies to a total production concept for the simultaneous production of sugars, proteins, chemical building blocks, fibres, energy and fuel. The whole crop approach and 100 % feedstock efficiency in a year-round production is a concept which needs to be developed. This concept should lead to a competitive performance on economics and sustainability.

The main products of the first stage Domestic Crop Biorefinery will be:
- sugars, viz. high-value mono-saccharides from pulp, fermentable sugars from the pulp, and juice (for ethanol or chemicals production by industrial (white) biotechnology)
- proteins, both native proteins with food or pharmaceutical qualities or suitable as low cost substrate for enzyme production by white biotechnology, and coagulated proteins for feed (low-value)
- fibres and products that are derived from them
- minerals (recycling)
- power and heat

Gaining experience in the operational utilization of biorefinery concepts is of great importance for the development of the second stage Domestic Crop Biorefinery concept.

Second stage Domestic Crop Biorefinery

A second stage Domestic Crop Biorefinery will primarily focus on production of non-food products, such as feedstocks for industrial biotechnology (sugars and other nutrients for fermentative production of biofuels, high-value chemical building blocks for polymer industry, and others. In the first stage Domestic Crop Biorefinery, chemicals will be produced from fermentable sugars through industrial (white) biotechnology. In this second stage, chemicals will directly be produced by the crop, offering cost benefits and opportunities for easy processing. For the second stage Domestic Crop Biorefinery additional processing concepts need to be developed, as well as new types of sugar beets. The chemical building blocks need to be separated from the main sugar stream (or converted in the same chemicals by fermentation). Breakthroughs in the field of processing are essential to make the second stage Domestic Crop Biorefinery based on sugar beet an economically viable concept. A first major step is the development of new separation technologies which are highly molecule specific and suitable for large scale industrial processes. This leads to chemical building block production with the required purity for chemical application, sufficient yield (volume), and a competitive cost price. The separation technologies used in bulk processing are primarily based on differences in physical properties (solubility, molecular size, polarity and hydrophobicity), but it is assumed that these are not specific enough for the isolation of most chemical building blocks from a complex, aqueous mixture of different molecules. For pharmaceutical products high tech purification technology is available but only on very small scale and at relative high costs. The ideal separation technology has to be very specific for the chemical building block molecule, so that only the target molecule can be separated, while leaving all other components in the process stream.

The second stage Domestic Crop Biorefinery requires beets with a changed metabolism (GMOs), thus resulting in beets with still have the capacity to produce cheap fermentable sugars (for biofuel and chemicals production, through white biotechnology), but in addition have the ability to produce high value chemical building blocks, and have improved storage properties.

Possible chemical building blocks are among those listed in the NREL study (Top Value Added Chemicals from Biomass. Vol 1, 2004 NREL and PNNL report). Other high added-value molecules that could be produced by sugar beet are industrial enzymes (lipases, cellulases), either for production of pure enzymes or for controlled autolysis of beet pulp to increase the recovery of fermentable sugars or chemicals contained in de cell wall. The economic value and sustainability of Domestic Crop Biorefineries will greatly be improved if the crop yield per hectare could be enhanced by 50-100%.

The second stage Domestic Crop Biorefinery concept will include decentralised pre-treatment to limit the logistical costs, to recycle nutrients and water to the field. Decentralised pre-treatment is followed by large-scale central processing. The main activities of central processing are:

- Year-round extraction of granulated sugar from concentrated juice and chemical building blocks, enzymes or other by-products
- Year-round processing of chemicals from all fractions
- Year-round processing of preserved fractions (e.g. fibre production)
- Seasonal campaign processing of non-preserved fractions (e.g. proteins)

The main selection criteria for all approaches irrespective for first or second stage Domestic Crop Biorefineries, either small-scale or large-scale, will be: energy, end-product (quality & purity), robustness, investment costs, and scalability.

In general decentralised/small-scale pre-treatment will be performed if: senseless transport can be avoided, it fits in the farm practices, regulations allow it, the scale of operation does not really matter, and the utility needs can be realized.

Central/ large-scale pre-treatment on the other hand will be chosen if: high-tech is needed, the scale of operation effects are large, utilities are required, and regulations demand for it.

Roadmap R&D

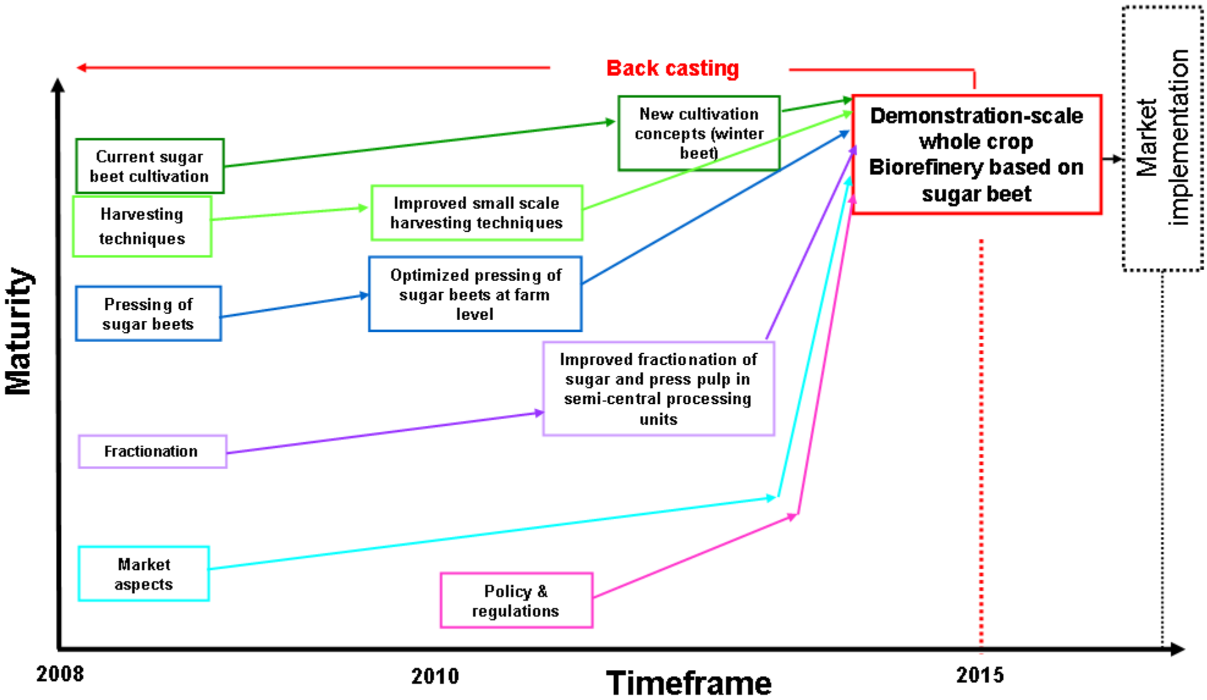


Figure 6 Roadmap Moonshot 1: Domestic Crops - Case Whole Crop Sugar Beet.

Demonstration Grass Biorefinery

Availability of grass

The Dutch arable area includes about 1 million hectares of grass land. The harvest from this land is currently about 5000 $ktonne_{dry}$/year of grass (on dry matter base), which is mainly used as silage and for hay production. The annual production from grass land is, because of mineral constraints as dictated by European environmental directives, limited to about 8 tonnes of dry weight per ha per year. By standard agricultural techniques the yields could be easily doubled, which ensures that grass from grass lands can be used as a raw material for a biorefinery without competing with food or feed. At annual field yields of 16 tonnes/ha, the additional production will be more than 10 Mtonnes (150 PJ), by far the largest biomass source produced in The Netherlands. Besides from grass land, grass can be obtained from roadsides (production about 400 $ktonnes_{dry}$/year) and from nature areas (accessible production estimated at 100 $ktonnes_{dry}$/year).

Green Biorefinery Process

The Green Biorefinery (Figure 6; Table 13-15 in Appendix D) is based on squeezing wet biomass, such as green grasses and green crops (lucerne, clover), resulting in a fibre-rich press cake and a nutrient-rich press juice (Van Ree & Annevelink, 2007). Typical for this biorefinery is the processing of *fresh* biomass. This means that specific measures must be taken, e.g. rapid primary processing or use of preservation methods (i.e. silage), to prevent degradation of the harvested materials. In the past ten years two national concepts have been developed for a biorefinery based on fresh grass.

- The Prograss consortium has developed a process around a large central unit. The primary refining stage consists of a patented separation stage using a refiner to open up the cells and a press to wash the fibres and upgrade them to become attractive as paper raw material. Proteins in the resulting juice can be recovered by heat and centrifuge technology, while the remaining sugars and amino acids in the juice could be used as raw materials for fermentation.
- Smaller initiatives (a.o. Courage) have developed a process that uses smaller mobile units and a screw press instead of a refiner. These decentralised processing units will benefit from short logistic chains so that high quality protein could be recovered before degradation occurs by natural fermentation processes. Furthermore, low transport costs can be envisaged with a crop that contains about 80% water. And finally the minerals (especially potassium) in the crop could be recycled without major concentration technologies that are energy intensive. There will be an opportunity also with small scale operations to recover phosphate and identify applications to substitute virgin fertilizers in The Netherlands or abroad.

Small scale processing might benefit from existing or to be built CHP plants running on agricultural residue streams, including the residues of the grass biorefinery itself. More often the heat that is produced as a consequence of the power generation can be applied efficiently in the processing of grass.

Both concepts will need further development, and more importantly need to be combined with secondary refining stages to produce high-value and high-quality products. These secondary refining stages can be performed either in a central processing unit, or intermediate products could be shipped to e.g. feed or paper producers, and processed on site of these final processers. The secondary refining stages for the grass biorefinery are still under development.

Grass Biorefinery Products

The main products of this kind of biorefinery are:

- (ligno-)cellulosic fibres for application in paper, insulation, building panels, and composites
- proteins:
  - native proteins with food, pharmaceutical and fermentation qualities (easily fermentable, low-cost substrate for enzymes)
  - coagulated proteins (for animal feed), thereby decreasing the need for imported protein sources, and consequently import of nitrogen, phosphate and potassium
- bulk chemical intermediates
- fermentation products
- phosphate
- biogas

Roadmap R&D

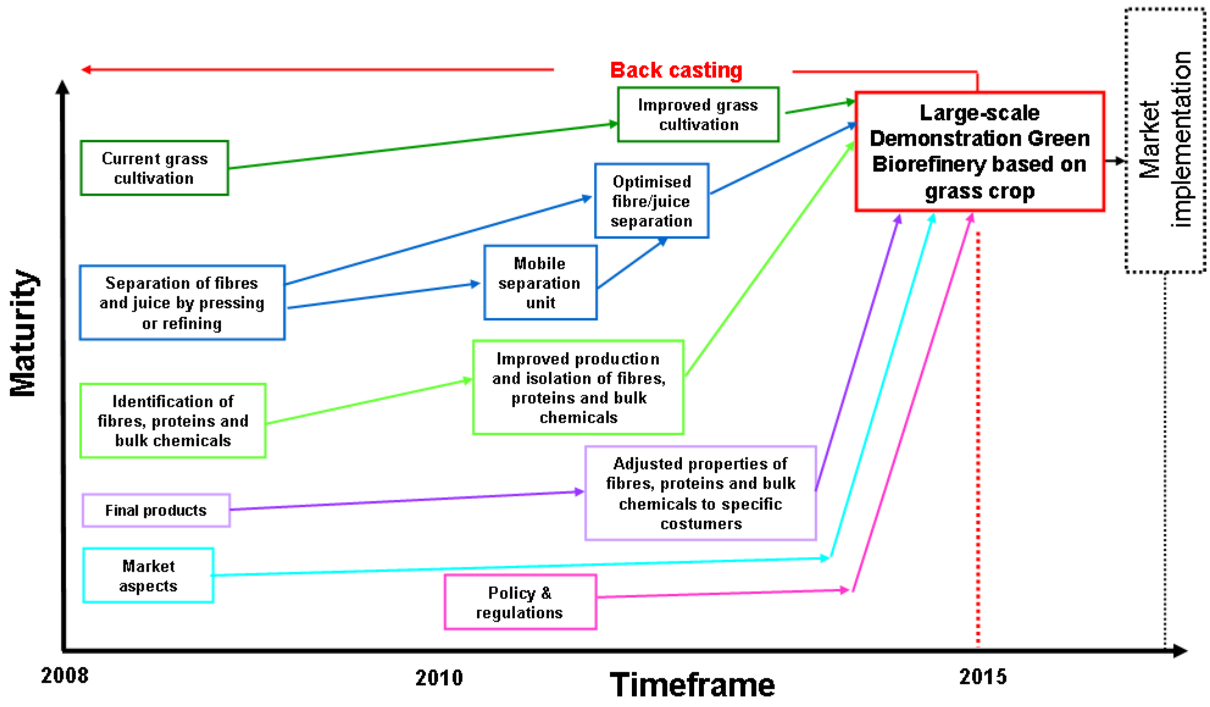


Figure 7 Roadmap Moonshot 1: Domestic Crops – Case Grass Biorefinery.

4.3 Demonstrations Moonshot 2: Aquatic Biomass

Demonstration Micro-algae

Introduction

Biodiesel derived from oil crops is a potential renewable and carbon neutral alternative to petroleum fuels. Micro-algae, like some other micro-organisms and higher plants, produce storage lipids in the form of triacyglycerols (TAGs) which can be used to synthesize fatty acid methyl esters (a substitute for fossil-derived diesel fuel). Micro-algae represent a very attractive alternative compared to terrestrial oleaginous species, because their productivity is much higher, and they do not compete for land suitable for agricultural purposes, providing therefore food security. Attractive features of micro-algae include: high areal productivity as compared to terrestrial crops, location of cultivation systems on marginal lands or other low-grade surfaces, the unique biomass composition incl. the ability to accumulate large amounts of oils, and the great variety in species and products. Furthermore, algal cultures lend themselves for combination with waste water treatment, CO_2 removal from flue gas, and useful applications for low-temperature waste heat.

Typical products from micro-algae include:

- Oils for food applications and nutraceuticals such as omega fatty acids
- Oils and derived fractions for non-food applications i.e. transport fuels, chemicals
- Proteins and derived products (amino acids, N-chemicals)
- Other bulk chemicals (e.g. ingredients for coatings)
- A range of high value specialties

Demonstration goal

The strategic objective of the demonstration micro-algae (Figure 7; Table 16-18 in Appendix D) is to convert micro-algae into a competitive and sustainable feedstock for bio-fuels and industrial biochemical compounds, with applications in the chemical, food and feed industry. The target for 2015 is to demonstrate several up-scalable, commercial concepts for integral micro-algae based production chains for:

1. Biofuels and co-products
2. Feed for aquaculture, including recycling of nutrients
3. Production of food or food ingredients and co-products

The envisaged cultivation systems are modular to enable easy scale-up. Through this development the Dutch algae sector can be positioned successfully in 2015 (and beyond) in an international setting with marketable production concepts and products. This includes international licensing of IPs, marketing of know how and technology.

Major barriers and research items

The current worldwide micro-algae production is limited to 10,000 - 15,000 tonnes per year, mostly for higher value applications, such as: food supplements and nutraceuticals (e.g. omega-fatty acids, carotenoids), aquaculture feed and ingredients for personal care products. Worldwide the micro-algae sector is growing fast. In recent years there is rapidly growing activity in the field of biofuels production from algal oils (many R&D companies) and aquaculture. In The Netherlands a limited number of companies is active in the field of cultivating micro-algae thus far at a smaller scale (typically up to 1 ha). Worldwide (e.g. in the USA, Israel) commercial cultivation systems are operational at a scale of several 10's of hectares usually with a modular set-up e.g. comprising a number of open raceway basins of 0.5 hectare each. Much larger modular systems on the order of 1000 hectares or more total area are currently being projected e.g. for biofuels production. The existing micro-algae sector is closed and fragmented; it serves mainly niche-applications/markets, and many companies concentrate on R&D.

An overall potential of micro-algae cultivation was not mentioned in the Workshops, but based on other sources[7,8]. The potential production in The Netherlands in 2030 could amount 1 Mtonne dry weight, equivalent to ca. 20 PJ. At a productivity of 30 tonne dry matter/year/ha, this would involve a cultivation area on the order of 20,000 ha realized on low-value land. The potential cultivation area outside The Netherlands, where more land is available at lower cost, is much larger. It has been estimated for 2030 at 1 million hectares, with a productivity 30 tonne dry matter/year/ha , 30 million tonnes of algae can be produced, this equals approximately 1 EJ.

Micro-algal biomass forms an excellent feedstock for biorefinery because of 1) the varied and high quality composition of the biomass and 2) the economic need to optimize valorisation of the biomass by extraction of multiple products in addition to e.g. fuels.

Recommendations for technology development in order to realize the targets for 2015 and beyond include:

- Strain development, by development of screening, selection of known and novel/unknown strains, and product optimization procedures and tools, incl. GMO applications
- Development of cell-biological tools (incl. metabolic flux analysis)
- Bioprocess optimization (for growth and productivity)
- Development of genomics-based diagnostic tools like microarrays and PCR, allowing to optimize product quantities and composition of algae biomass as biorefinery feedstock
- Improvement of harvesting and dewatering technologies, e.g. by bioflocculation, sedimentation and membrane separations
- Development of mild and efficient cell disruption, extraction and fractionation technologies
- Effective technologies for separation of oligosaccharides, lipids, proteins, amino acids
- Lipid/oil refining technologies

For all processing technologies capital costs, energy consumption, and environmental performance (e.g. the use of solvents or other auxiliary chemicals) should be substantially improved as compared to state-of-the-art technologies that are in use today.

Identified barriers for the development of the field for the cultivation phase include: the limited land availability and restrictive spatial planning rules, and the restrictive GMO regulations esp. for open cultivation systems. Successful development demands for integral focus on processing and products, and only to a limited extent on cultivation e.g. for raising desired product output or modifying biomass composition. However, biorefinery is also an area where a chain approach from feedstock to end products is essential.

---

[7] *Transitiepad Energie en Grondstoffen uit Aquatische Biomassa, 14 oktober 2003.*

[8] *J.H. Reith, J. Steketee, W. Brandenburg, L. Sijtsma, 2006. Platform Groene Grondstoffen. Werkgroep 1: Duurzame productie en ontwikkeling van biomassa. Deelpad Aquatische Biomassa,Eindversie juli 2006.*

Cultivation should not be ignored because downstream processing can only be developed if sufficient material is produced! Experience shows that both the products and the processing characteristics of micro-algal biomass are highly species and strain specific.

In the field of processing the CAPEX and energy consumption for harvesting, dewatering and product separations and upgrading is high, which hampers the implementation. In addition the current processing technology does not allow the generation of multiple end products. Regarding the output of marketable products several barriers are identified. Regulatory approval for use of algae in feed/food (e.g. novel foods) is lacking, as is broad consumer acceptance of algae and seaweed products in food. The full range of potential products and their market value is not clear yet, which hampers economic evaluation. In general, product development to commercial applications is a barrier. Other barriers include the fragmented nature of the sector, the lack of adequately trained personnel, and the high production cost of algal biomass as feedstock due to the high CAPEX for cultivation and harvesting systems. Budget is lacking for support of existing practical development trajectory e.g. biofuels development. Within (inter)national R&D projects a lot of fundamental knowledge is obtained, but the translation to applied projects is small. There is a need for pilot-scale facilities to apply the fundamental knowledge.

In order to overcome the identified barriers a number of actions are recommended. This includes strategic R&D topics and facilities such as the set up of High Throughput selection laboratory facilities, and pilot-scale cultivation facilities for the production of micro-algae. These cultivation facilities could be coupled to a biorefinery laboratory. Overall the establishment of an open innovation centre and dedicated laboratory facilities for algae biorefining are recommended. In addition performance of a pilot-scale test for effluent processing with algae systems (closing the minerals balance) is recommended.

In general, nutrients from effluents may serve as a nutrient source for non-food applications of the algal biomass. A general recommendation is to use as much as possible existing commercial facilities and initiatives developed by commercial parties and facilities set up by knowledge institutes. A to be formed coordination body could allocate technology R&D, piloting and demonstration for all process steps to the right location.

Establishment of a ‘learning company’ is recommended to optimize economic parameters under practical conditions. A similar recommendation is to enable and fund pilot scale production (set up like company) and R&D on a substantial scale. It is highly recommended to undertake development of novel product applications in cooperation with companies. Equally product standardisation is needed. Overall the formation of the logistic chain should be accelerated via linking with existing downstream infrastructure. Budget should be made available for outreach activities.

Creation of a biorefinery investment fund with co-venture capital funds is recommended. Cooperation with actor groups should be sought and realized from the beginning in pilot-projects. More detailed and very useful recommendations are:

- to integrate knowledge and facilities with those existing for the oil, food and fine chemical industries;
- to follow a 3-step approach for the definition of technological R&D programmes: 1) GAP analysis 2) Technology inventory + State-of-the-art 3) Fill in blank spaces/holes.

All of these actions should culminate in the realization of three up-scalable commercial concepts and a full-scale demo in 2015. This should enable the Dutch algae sector to be positioned successfully in 2015 and beyond in an international commercial setting with marketable production concepts and products.

Roadmap R&D

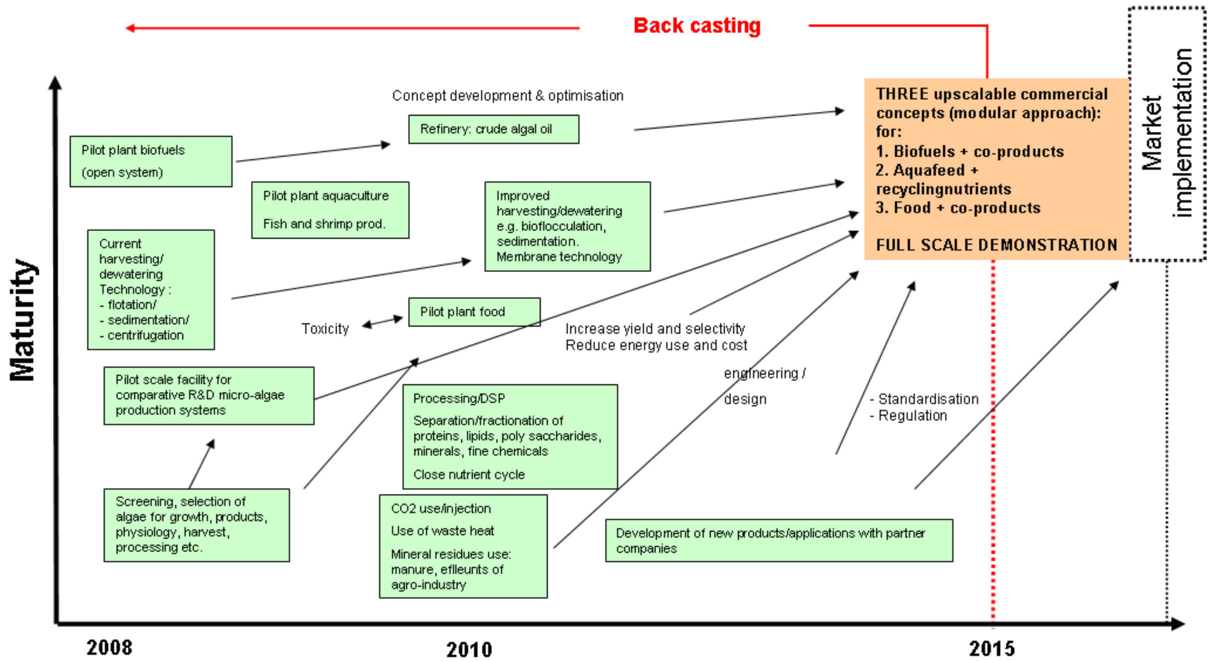


Figure 8 Roadmap Moonshot 2: Aquatic Biomass – Case Micro-algae.

Demonstration Seaweeds

Introduction

The cultivation of seaweed can be an enormous source of biomass in the future. Use of land for cultivation of biomass for the production of fuels, products & fibres is subject to debate due to the competition with food production. Expansion of biomass cultivation to the sea would increase the potential amount of biomass being available for non-food and non-feed purposes, and thereby increasing the potential share of biomass in renewable energy supply in the future.

Demonstration goal

The 2015 target is to demonstrate seaweed production and processing on a semi-commercial scale (Figure 8; Table 19-21 in Appendix D). The production demo could be situated in the area of a North Sea wind turbine park and be 1 square kilometre wide (approx. 100 hectares), with an estimated biomass productivity of 2000-4000 tonnes (dry weight basis) per year. The dedicated processing facilities will be on land, and will have a processing capacity of 0.5-1 tonne (dry weight basis)[9] per hour. Seaweed will be transported by ship and road to the processing plant. Currently, seaweed is predominantly used in high-value applications, where energy use for processing is a factor being considered. The challenge in the moonshot is to demonstrate that large-scale cultivation of seaweed is possible in an ecological acceptable way, and to demonstrate that the seaweed can be refined into energy carriers and high-value products in an economic sound concept.

Major barriers and research items

Currently, worldwide 2 million dry tonnes/year of seaweed are cultivated, and the total turnover of the seaweed industry is estimated to be 6 billion US$/year[10]. The seaweed currently produced is predominantly used in food, feed and for the production of specialty chemicals, cosmetics and pharmaceutics. About half of the current production is met by harvesting natural populations from the sea, whereas the other half is cultivated in farms in coastal or near-shore areas. Cultivation and processing of seaweed is a fast growing industry in especially Asian countries. In several European countries (Ireland, Norway, France, Spain) production processes are now mainly based on harvesting of natural seaweed populations. R&D on cultivation of seaweed in farms is in progress in several European countries.

The future contribution of seaweed to biomass supply is subject to large uncertainties. Assuming that 8.7% of Dutch area of the North Sea is used for seaweed cultivation, the seaweed production can be 25 million dry tonnes/year or 350 PJ[10].

---

[9] *The actual capacity on a wet weight basis depends on the extent of dewatering at sea. With current mechanical dewatering technologies the dry weight % after dewatering will be in the order of ca. 30 wt%.*

[10] *Reith, et.al., 2005. Bio-offshore: grootschalige teelt van zeewieren in combinatie met offshore windparken in de Noordzee. Energieonderzoek Centrum Nederland, ECN report ECN-C—05-008.*

The demonstration will comprise both the cultivation of seaweed and its subsequent processing. The production of seaweed at the North Sea will be limited by the existing nitrogen levels. The eutrophication of this area will be reduced by producing the biomass. The nutrition balance of the demonstration area will be subject to ecological evaluation. Potential positive effects on fish life will be a central issue. The demonstration can be used for experiments with extra provision of nutrients. As this demonstration may be located in an off shore wind park not many spatial planning problems will be apparent. The future need for seaweed farms can have these problems and therefore spatial planning studies will be part of the proposed programme. Public acceptance of seaweed farming on sea and seaweed derived products is important for the perspective of this new industry, and will be subject to further studies.

After harvesting the seaweed will be dewatered without loss of valuable ingredients. Dewatering has to be done offshore to reduce transport costs. The next step in the pre-treatment is extraction of secondary metabolites with high added-value without losing much energy and biomass.

For aquatic biomass several biorefinery processes seem to fit. Depending on the type of feedstock (the seaweed species), and the possibilities of process integration, a processing route will be selected. Hydro Thermal Upgrading (HTU), anaerobic digestion to methane, and ethanol fermentation and distillation, are possible processes. An important design factor will be the wish to scale-up to ocean scale facilities to harness the full potential of seaweed as source of energy, food and feed grade carbohydrates, proteins, and high added-value secondary metabolites.

North Sea operations will produce dewatered biomass that can be transported to land to be further processed. Energy outputs of further processing can be methane, ethanol or bio-crude. Some valuable ingredients for the food and chemical industries will be co-produced, such as: carrageen, alginates, agar, mannitol, and other products.

One of the described technologies (digestion, fermentation plus distillation or HTU) will be optimized and integrated in the other necessary process steps (dewatering, extraction, purification). The result will be an upscalable design for a commercial on shore conversion plant. Important knowledge will be generated to design an offshore plant to develop seaweed farming on the open ocean.

The conversion processes are mostly well known at least for the current product applications e.g. the extraction of hydrocolloids for a wide range of food and non-food applications. These technologies should be modified and improved with respect to costs, energy use and environmental performance. For new applications e.g. ethanol fermentation technology must be developed. The further challenge is selection, up scaling and process integration.

Existing extraction technologies are not suited for larger volumes, so better adjusted technologies must be developed. New innovative markets, mainly in the food sector, can be developed based upon larger volumes of carrageen, alginates and agar and other, newly developed products. This work will be done by partner companies on a commercial basis. The market for specific secondary metabolites – although with high added-value – is a mere niche market. The refinery processes produce also waste water that needs to be purified. Seaweeds generally contain a high concentration of minerals on the order of 20 to 30 wt% of the dry biomass. Therefore, there is a need for special attention for recovery of minerals (especially phosphate but certainly also a range of other nutrients) before and during processing and the potential use of these minerals for product application (e.g. Iodine), and/or recycling in the cultivation system.

The products from this biorefinery stream must and can be on specification to direct delivery on the market. Methane should be purified to gas grid quality. Ethanol should be dewatered enough to be sold on the European ethanol transport fuel market. If bio-crude is produced (HTU) then further upgrading will be necessary. For this step commercial plants exist in The Netherlands.

In the preparation stage of the programme a suitable demonstration location will be selected. Ecological measurements will establish the current situation. In the pilot facility (Bio Offshore) the design parameters for the demonstration will be tested. Native species from the North Sea will be selected to experiment with production and harvesting techniques under real weather conditions. In the mean time communication and outreach is organized to inform the public. Legal and policy barriers for the further expansion of seaweed farming on the North Sea and the open ocean will be identified.

In the construction stage the selected production and harvesting equipment will be put in place. Partner companies will be involved to give them ample opportunities to experiment with technologies that can be used on a commercial scale.

Together with the Bio Offshore project a pilot-scale test laboratory will be set up. In this lab all relevant steps in the pre-treatment and refinery process can be examined. Based upon this information a demonstration scale biorefinery will be designed for the processing of the selected seaweed crops. Next this demonstration plant (1 ton wet biomass per day) will be built and operated.

The demonstration will comprise a significant scale-up to a cultivation area of 1 km^2
(approx. 100 hectares) with dedicated processing/biorefinery facilities with a capacity of 0.5-1 tonne (dry weight basis)[11] per hour.

---

[11] *The actual capacity on a wet weight basis depends on the extent of dewatering at sea. With current mechanical dewatering technologies the dry weight % after dewatering will be in the order of ca. 30 wt%.*

An overall potential was not identified at the Biorefinery workshops. However, other sources indicate that the potential production in 2030 in the Dutch North Sea could be on the order of 10 Mtonnes dry weight, equivalent to approx. 130 PJ[12]

Roadmap R&D

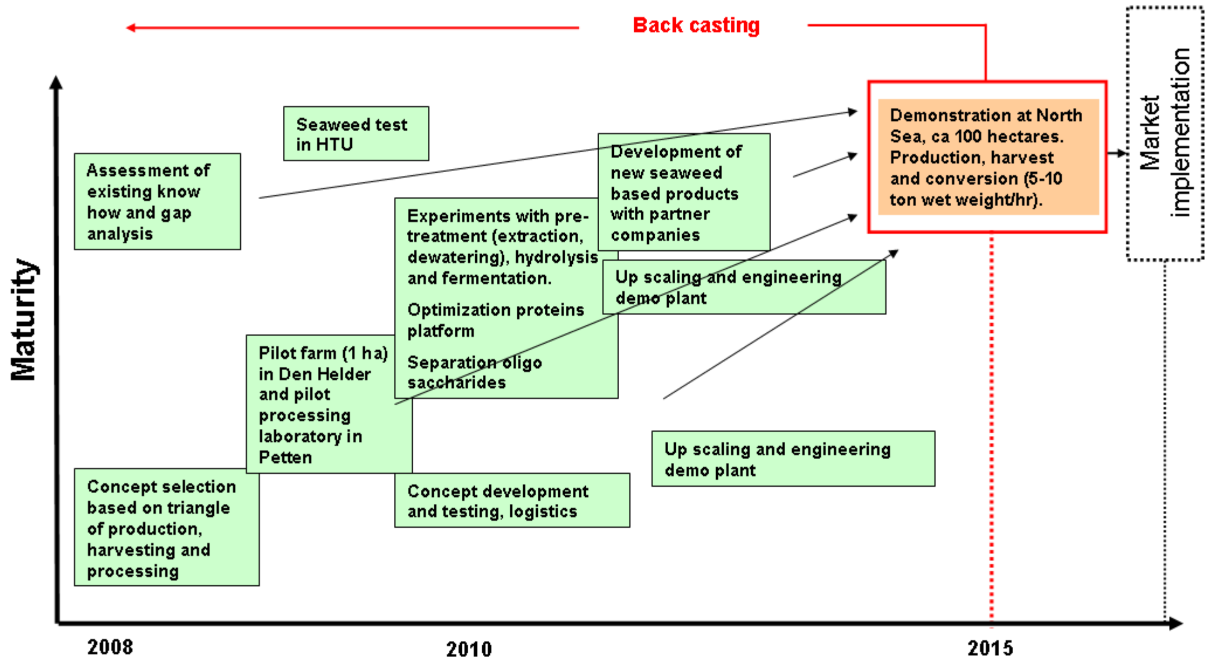


Figure 9 Roadmap Moonshot 2: Aquatic Biomass - Case: Seaweed.

[12] *J.H. Reith, J. Steketee, W. Brandenburg, L. Sijtsma, 2006. Platform Groene Grondstoffen. Werkgroep 1: Duurzame productie en ontwikkeling van biomassa. Deelpad Aquatische Biomassa,Eindversie juli 2006.*

4.4 Demonstrations Moonshot 3: Large-scale Biomass Import

Import of biomass is crucial to achieve high shares of renewables in The Netherlands in the future. To achieve a biomass share of 23% in energy supply in 2030, about 900 PJ of biomass or 60 million tonnes of dry biomass will be required[13]. The maximum availability of domestic biomass in 2030 is estimated to be 450 PJ, resulting in a need for biomass import of at least 450 PJ. On top of that, processing of imported biomass and export of biomass products offer important opportunities for economic development in The Netherlands. The harbours in The Netherlands, and the extensive infrastructure for petroleum refining, chemicals production and food processing, offer unique opportunities for The Netherlands for development of a Bio-based Economy.

Already now, with a relative low share of biomass in energy supply, import of biomass plays an important role. In 2006, import of biomass accounted for 28% of biomass supply for energy[14]. 894 ktonnes of biomass were imported in 2006 for energy purposes[145]. For a large-scale application like co-firing of biomass in power plants, the share of imported biomass was even higher: 70% in 2006. Furthermore, the Rotterdam harbour is a hub for liquid biofuels. In 2007, a total of 2,8 million tonnes of liquid biofuels were transhipped in the Rotterdam harbour[15]. Simultaneously, the production of biofuels in The Netherlands is taking off with large-scale conversion plants being constructed by e.g. Abengoa and Neste Oil. To maximise the economic value for The Netherlands, further development of biomass conversion by biorefining is an important topic.

In current as well as future biomass conversion processes, possibilities exist for the co-production of high-value products. In the Moonshot Large-scale Biomass Import the cases of synthesis gas production from biomass and co-production of high value products from residues from liquid biofuel production have been analysed.

---

[13] *Rabou, L.P.L.M., E.P. Deurwaarder, H.W. Elbersen & E.L. Scott, 2006. Biomassa in de Nederlandse energiehuishouding in 2030. Een studie door ECN & WUR Biobased Products voor het Platform Groene Grondstoffen gefinancierd door SenterNovem. Januari 2006, 54 pp.*

[14] *Richard Sikkema, Martin Junginger and André Faay, 2007. IEA Bioenergy Task 40 – Country report for the Netherlands 2007. Copernicus Institute Utrecht University, Report NWS-E-2007-197, December 2007.*

[15] *Verdubbeling Rotterdamse overslag biobrandstoffen, persbericht Port of Rotterdam, 29-02-2008*

Demonstration Synthesis Gas Production

Introduction

The synthesis gas route allows for biorefining options upstream as well as downstream the gasification process. Upstream, co-products can be generated in the pre-treatment required before gasification or in other words the gasification process can process the residues from the biorefinery process. Downstream, catalytic synthesis allows for the production of a wide range of different products. Finally, the product synthesis gas can serve as an important reactant in other conversion processes in biorefineries. The target for 2015 is to demonstrate synthesis gas production from biomass crops or residues at a scale of 10 MW based on entrained-flow gasification (Figure 9; Table 22-24 in Appendix D).

Demonstration goal

Entrained-flow gasification of coal is commercial available technology. Gasification of biomass requires proper pre-treatment of the biomass and modifications to the gasification technology. Furthermore, biomass pre-treatment can increase the volumetric energy density of the biomass feedstock, and thereby reduce the costs of long-distance transport required for biomass import. Biomass pre-treatment and handling of the pre-treated biomass should be an integral part of the demonstration as well as the consideration of other relevant aspects along the whole conversion chain. The synthesis gas can be used for multiple purposes like power, fuels and chemicals production via existing thermocatalytic processes. The major target of a demonstration is to prove the reliability of synthesis gas production at a sufficient quality for different applications.

Major barriers

On the feedstock side, the usual aspects like the global biomass potential, the cost of biomass supply and competitive claims for biomass for food/feed/fuel& fibres have been mentioned as barriers. The sustainability criteria to be applied to biomass supply are considered as an important barrier. It is clear that sustainability criteria are required and will be applied in the future. However, the boundary conditions for sustainable biomass supply are currently insufficiently clear and will influence large-scale import of biomass in the near future.

For synthesis gas production it is important that the process (including the pre-treatment step) can process residues as well and can accommodate variations in feedstock quality. Import of biomass results in the import of minerals and nutrients used in crop cultivation as well. Since minerals and nutrients are scarce commodities these preferably have to recovered for re-use. Pre-treatment and gasification should be designed to allow for recovery of minerals and nutrients in a useable form.

The quality of the synthesis gas for downstream use in power, fuel and chemicals production has to be clearly proven. Downstream processes (gas turbines, catalytic synthesis processes) have stringent requirements on gas quality. Reliable and long-duration operation of the processes on synthesis gas from biomass has not been demonstrated yet.

The whole chain (pre-treatment, gasification and conversion into final products) produces products (electricity, Fischer-Tropsch diesel) that are well accepted by society. On the product side the amount of barriers seems to be limited. The end products produced via this route will be more expensive than their fossil equivalents. Partly, this is caused by the price of the biomass feedstock, but also by the immaturity of the whole chain. Support by society to bridge the gap, between the price of bio-based products and its fossil counterparts, is considered to be insufficient at the moment.

Especially when residues are used as feedstock, but also when energy crops are used this requires the development of new supply chains with different actors. This requires the cooperation between sectors with different practices (e.g. the agro and petrochemical sectors). The different practices in different sectors can be a barrier for cooperation.

Large-scale import of biomass (and hence export in other countries) can on a macro-level result in new geopolitical issues. On a micro-level this asks for financing of different parts in the supply chain (crop cultivation, pre-treatment, transportation, conversion, end-product marketing). It is important to recognize that the power of different actors in the supply chain is different. This asks for careful distribution of the costs and responsibilities along the chain. These kind of socio-economic consequences are insufficiently mapped.

Research items

On the feedstock side globally valid criteria for sustainable biomass supply have to be developed and implemented. These criteria have to be translated in monitoring tools that can be used to prove sustainability of the biomass supply. Reliability of the individual conversion steps has to be proven for a longer period of time with simultaneous demonstration of the products quality. This is a crucial factor to proceed in the technology learning curve. Processes for recovery of minerals and nutrients have to be developed and tested. When possible the minerals should be recovered before the gasification thereby eliminating problems with processes downstream synthesis gas production and enabling the creation of value at the same time. The logistics along the whole chain have to be developed. This includes practical cooperation of different sectors as well as mapping of the socio-economic consequences along the whole chain at a micro- and macro-level. Policy support is required to compensate for the extra costs, due to immaturity of the chain and due to lower prices of fossil equivalents. This can be done both by financial support for demonstrations and regulations for obligatory use of the end products.

Roadmap R&D

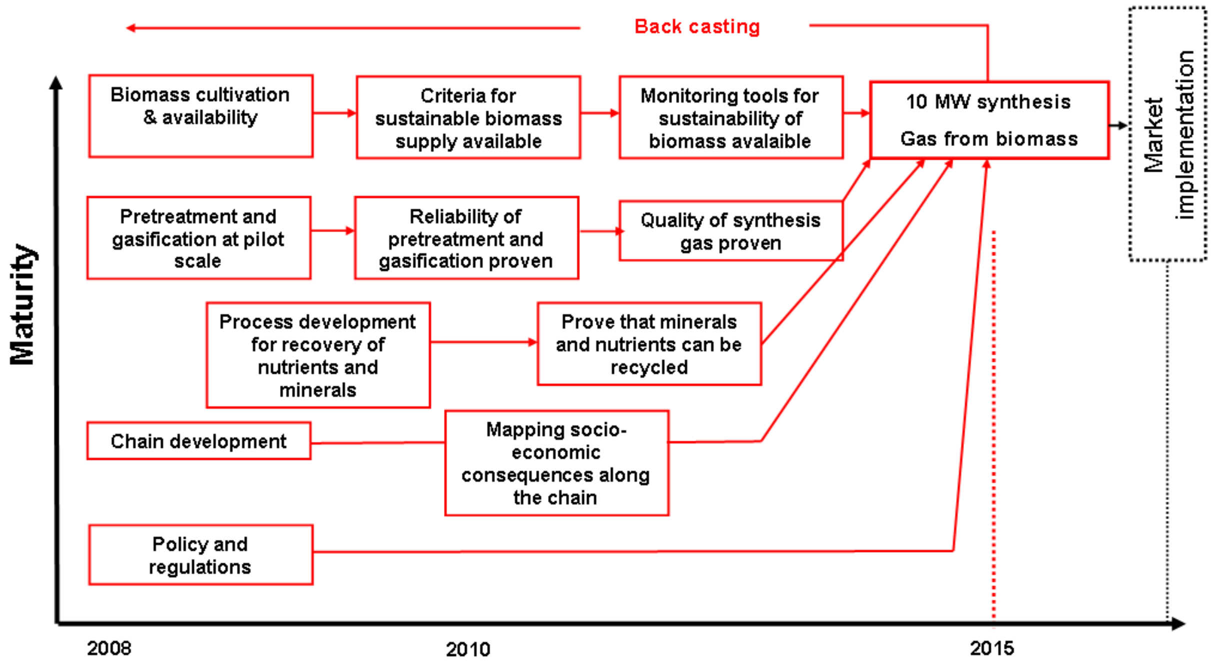


Figure 10 Roadmap Moonshot 3: Large-scale Biomass Import – Case Synthesis Gas Production.

Demonstration Integral Valorisation Biomass for Biofuels, Feed and Chemicals

Introduction, major barriers and research items

The Rotterdam harbour has a major position in import of fossil resources but certainly also in biomass resources. Rotterdam is an attractive harbour for manufacturing biofuels because of the large actual production and distribution function of fossil transportation fuels. The production of biofuels goes hand in hand with the production of residues that need an outlet in order to be valorised resulting in a better competitiveness of the biofuels produced. The feed industry in The Netherlands is well developed and uses large amounts of imported and domestically produced residues from food production (e.g. soy cake), which have a more or less comparable composition as residues from biofuel production from rape or from wheat: lignocellulose, pectin and hemicelluloses, minerals and protein. For soy cake in pig feed, the protein is the main functional component, whereas the cellulose and minerals are not functional (and increase the minerals surplus in manure). Enzymatic pre-treatment can improve the utilisation of both proteins and carbohydrates significantly. Furthermore, minerals could be extracted. Thermochemical pre-treatment might be required to use the hemicellulose and cellulose for further conversion.

Separation of the residues from biofuel production into its three components will maintain the nutritional value for pig, reduce the amount of manure, and in the same time will make lignocellulose available as input for power plants; minerals can be used by the fertilizer industry. In a later stage this refinery can be improved by separating essential amino acids as nutritional value for pigs and the non essential ones as building blocks for the bulk chemical industry.

The lignocellulose can be used as raw material for conversion into digestible animal feed, bulk biochemicals or biofuels.. In addition to today's 6 Mtonnes of soy, 5M tonnes of wheat and 3 Mtonnes of rape seed will lead to 150 PJ of transportation fuels, being about 30% of the domestic consumption. These amounts allow for the coproduction of 100,000 tonnes of each of the 20 amino acids per year.

Demonstration goal

The first demonstration of this biorefinery concept can take place in 2011, while the more advanced second step will need considerably more technology and market development (Figure 10; Table 25-27 in Appendix D). The technology is well developed in the seed biorefining industries. Bio-based Economy needs will require some adaptations like the full separation of proteins from lignocellulose as well as the recovery of the minerals (phosphate).

For the second phase, second generation ethanol technology is required as is now developed on many places in the world. Protein hydrolysis to single amino acids and the separation of the relevant amino acids will set some challenges under economic conditions.

The main products of this kind of biorefinery are: lignocellulose for power generation, later bio ethanol; proteins, later single amino acids; phosphate and potassium, and biogas. Also oligosaccharides, peptides and specific (food grade) polysaccharides will be valuable compounds.

<u>Roadmap R&D</u>

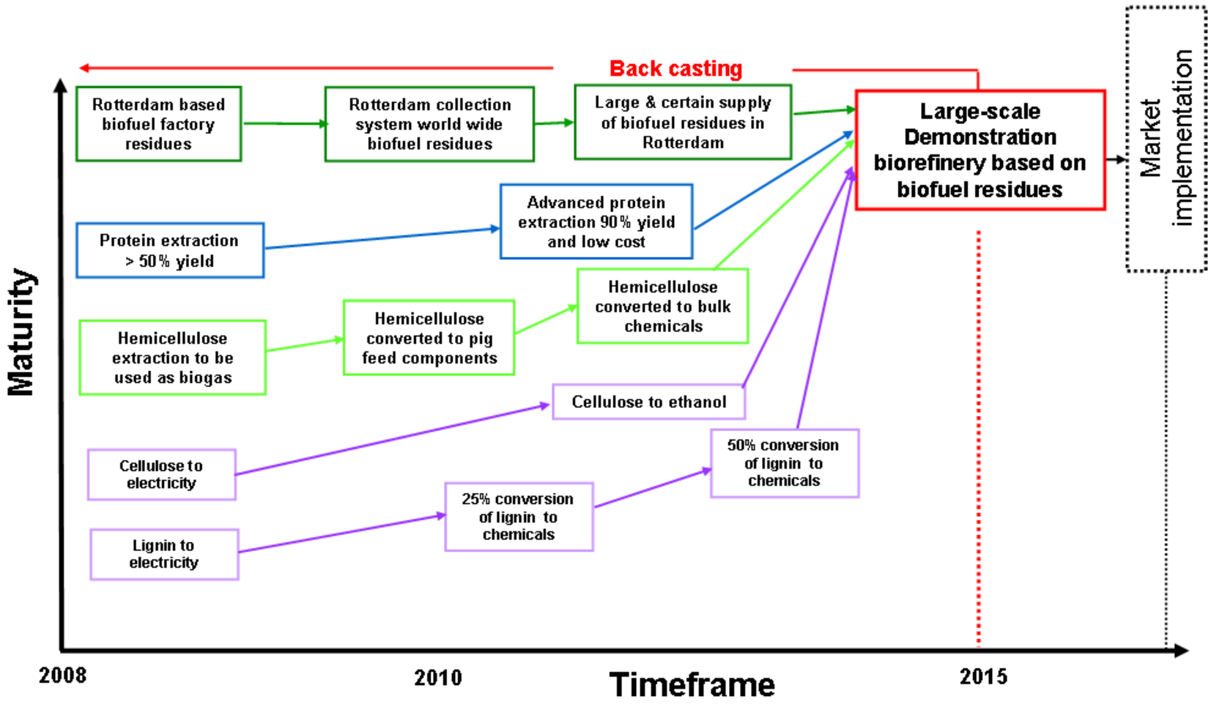


Figure 11 Roadmap Moonshot 3: Large-scale Biomass Import – Case Biomass for Biofuels, Feed and Chemicals .

4.5 Demonstrations Moonshot 4: Biomass Residues

Introduction

Biomass residues are the first candidates for biorefinery demonstration because they can be obtained easily in the current market at relatively low costs. Furthermore, using this biomass does not compete with food. Biomass residues can be grouped in two categories:

- Undefined residues (mixtures with varying composition and quality), such as:
  - food waste from restaurants and/or kitchens (swill)
  - residues from vegetable processing industries
  - garden waste
  - manure
  - digestate
  - sludge
  - verge grass
  - leaves
  - residues from processing industries like the paper industry
  - etc.
- Defined residues (more constant composition, usually crop residues or by-products from the food industry), such as:
  - beet pulp
  - potato steam peels
  - potato fibres
  - fruit pulps
  - soy bean hulls
  - cacao hulls
  - sugar beet leaves
  - beet root tops
  - comparable residues from agricultural production

Also residue streams from forest, nature and urban green should be taken into account.

Demonstration Food Residues (Undefined Streams)

Demonstration goal, major barriers and research items

"Undefined residues", like food waste, are still mostly considered as waste, and have low or negative economic value (Figure 11; Table 28-30 in Appendix D). Revenues from taking these products will give a first financial basis for the biorefinery chain. Annually ten-thousands tonnes food are wasted in restaurants (mainly kitchen waste plus leftovers from meals). Currently this class of products is mostly processed in a waste treatment plant. Food waste is mostly composted, which is – from a product potential perspective – far from optimal.

During the last decades a variety of new (more sustainable) processes has been introduced. So far, most of these processes only yield one valuable product (e.g. biogas), whereas a large residual/waste stream remains (e.g. digestate from biogas fermentation).

Added-value of e.g. digestate processing is still too limited for large-scale introduction. As a following step, valuable components can be extracted from these residues or digestate, such as fibres (for e.g. paper industry) and minerals. This separation does not only yield valuable materials but also reduces the amount and waste load of the digestate.

Some other examples of added-value processes already industrially realised:

- Production of biogas out of waste water (think of UASB reactors): feasible waste water treatment systems with sustainable added value.
- Biogas production out of sludge, manure and solid organic residues: is getting more popular, mainly because of the financial incentives for sustainable energy. Positive side-effect is improved dewatering behaviour of sludge after the biogas process.
- Recycling and bio-energy production out of B-wood.

Roadmap R&D

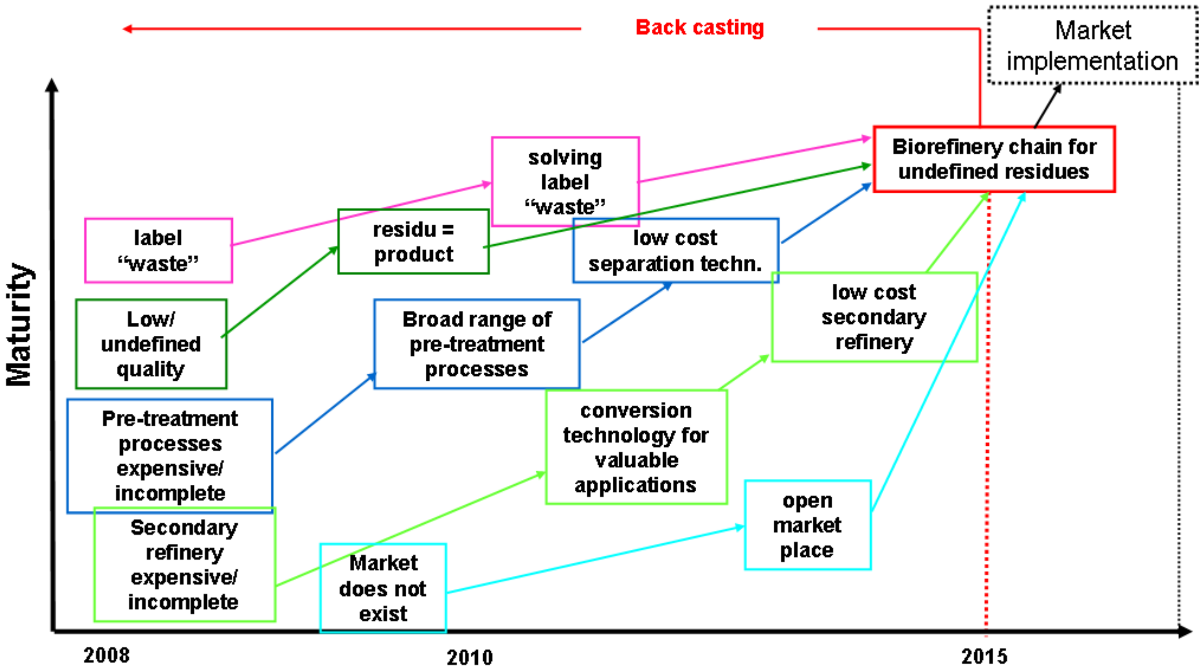


Figure 12 Roadmap Moonshot 4: Biomass Residues - Case Food Waste (Undefined Residues).

Demonstration Residues of food Production (Defined Streams)

Demonstration goal and major barriers

Residues from feed production are generally well-defined residues, which is rather favourable for biorefinery compared to many other residues (Figure 12; Table 31-33 in Appendix D). For utilising foliage, various obstacles must be overcome, such as:

- Need of adequate (inexpensive) processes
- Inefficiency of seasonal availability per crop type
- Exhausting the bottom (thus in the biorefinery process preferably the minerals should be recycled)
- No existing end-products and market

Research items

A current technological development is concentrated separation. Recently innovative separation processes have been successfully developed (primarily for food applications) that do not require additional process water. Potential and adaptation of these principles for biorefinery chains have to be worked out.

Roadmap R&D

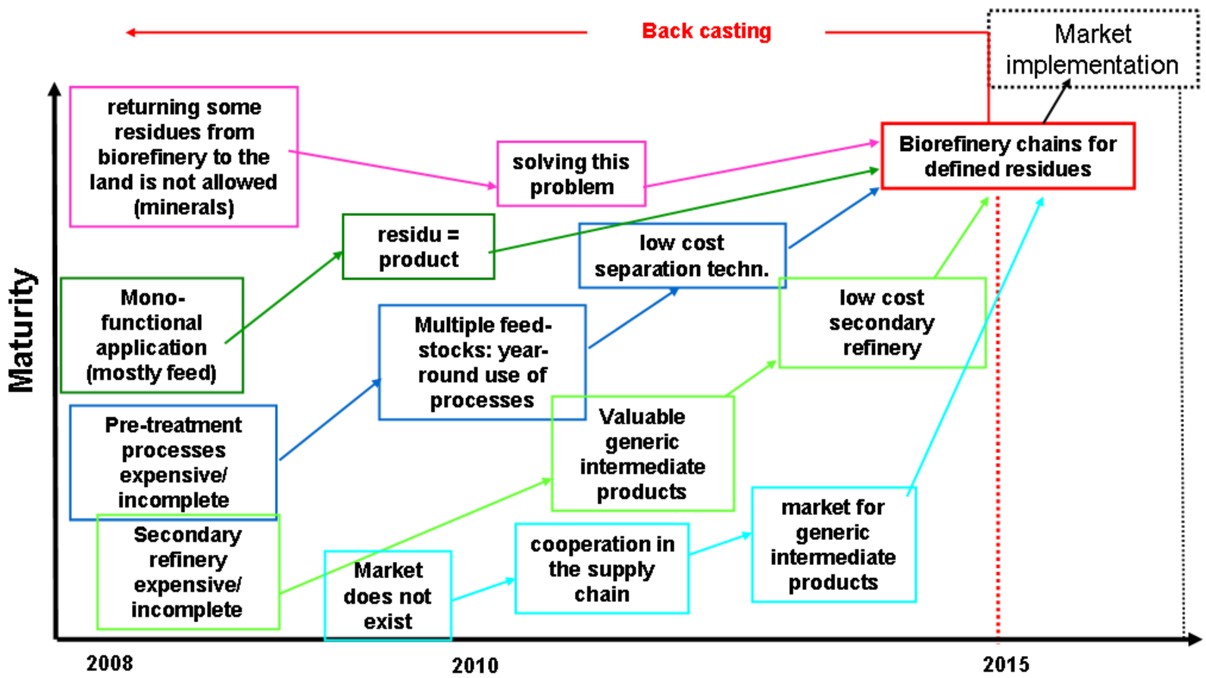


Figure 13 Roadmap Moonshot 4: Biomass Residues – Case Feed Waste (Defined Residues).

4.6 Concluding remarks

The demonstrations described in the previous sections have been formulated during an interactive process of a broad group of stakeholders. Based on the multiple demo-cases described per Moonshot, generalised research questions and connected actions will be identified in Chapter 6. The set of potential demo-cases in the previous sections is not complete. It is expected that in the forthcoming years new cases will be proposed and that others will be discontinued.

5 Roadmaps for strategic research

5.1 Introduction

In Chapters 3 and 4 Moonshot-based applied research and demonstration Roadmaps were defined in close co-operation with various stakeholders (from industry, knowledge institutes, universities and government). Some of the barriers mentioned are Moonshot or demo-specific, but most barriers (especially the longer-term questions) are more generic. These generic often strategic biorefinery barriers should be dealt with in an integrated approach.

5.2 Strategic research drivers

During a brainstorm meeting with people from industry, knowledge institutes, universities and government, a large number of technologies were identified that might contribute to the Bio-based Economy following biorefining approaches.

The technologies have been grouped and distributed over three long-term drivers:

A. High quality use of raw materials and low CO_2 emissions, including low capital costs (Figure 13 shows the general technologies; Figure 14 concentrates mainly on toolbox development).

B. Low raw material cost (Figure 15 concentrates on GMO, mobile units and high field yield; Figure 16 on photosynthesis and algae).

C. Social values, how to cope with growing competitive claims (Figure 17).

These drivers have been chosen because they will help to focus attention on the developments that will be most important to the successful biorefinery-based value chains implementation on the longer term. Other technologies that will be proposed in later stages will strengthen the technology base. The technologies have been ranked according to their maturity, viz.:

- basic science
- enabling technology
- basic hardware
- development/process engineering.

The maturity of the technology will determine at what moment this technology will contribute in practice. Many of the technologies become necessary after some other steps have been implemented. For example there is little use in developing a technology that enables the separation of 20 different components from a single crop at this moment.

There will not be market outlets for most of these products. First the technology platform that supplies a limited number of 'biocommodities' that can be derived from different crops at low cost have to be build, enabling a stable availability over the year at many places in the world with more or less defined standard quality properties. These 'first wave' biocommodities might be fats, carbohydrates, protein hydrolysates, ethanol, pyrolysis liquids, synthesis gas and specific mixtures or other. Once these biocommodities are available they will trigger further developments in cost price reduction of the upstream part of the value chain and they certainly will address the social issues of the supply chain. Also downstream further separation technologies will be developed that will enable more dedicated applications and more specific product streams. Also this 'second wave' will trigger new upstream and downstream developments. These developments can be predicted for a great deal from existing markets for fossil derived products, but certainly there will also be a lot of new (unpredicted) developments that we will encounter in later stages.

The biocommodities of the first wave will probably have to serve large markets with products that although standardized will not have high purity as their main quality. If there will be too many products in the beginning with too specific quality properties, it will be very difficult to sell the different products that come from one single biorefinery all at the same time and place. Large markets that fulfil these 'low quality' standards are food, feed, fermentation, biogas, thermal processes and maybe other. The technology paths indicate the expected moment that the technology will be implemented. Certainly there will be some overlap with the roadmaps from the Moonshots, but in the strategic research roadmaps here we concentrate on the longer term and the more general developments. The technologies have been placed in the different roadmaps (see Figures 14 to 18) and have been connected with arrows when it is expected that one technology will follow another. Squares and circles indicate that the technologies have something in common. Some technologies have not much in common (yet) with other technologies and are not connected with arrows.

5.3 High quality use of raw materials and low CO_2 emissions including low capital costs

From Figures 13 and 14 we can derive the following items for a long-term development agenda:

- Separation of different components like proteins, fats, carbohydrates, organic acids from different crop (part)s, using different technologies, to supply low cost standardized biocommodities.
- Separation technologies based on improved and/or combinations of existing technologies that still do not fulfil the severe demands of low-cost and large-scale availability. Membrane separations, dry separation technologies, low cost concentration from water solutions, application of enzyme specificity for separation purposes, and the microbial accumulation/separation of specific components as 'harvested' from dilute and complex watery solutions.

- Fermentative and thermo-catalytic conversion techniques to convert the biomass fractions and intermediate products in a wide range of different products; examples are: the conversion of sugars to fuels and chemicals, but also the conversion of products like ethanol, succinic acid to other chemicals.
- Upgrading of pyrolysis liquids to petroleum refinery feedstock by mild catalytic hydrogenation.
- Conversion of biomass and biomass residues to synthesis gas as a feedstock for syngas based biorefineries.
- Applications so that attractive markets outlets will sooner become available for each of the products that result from one biorefinery process.
- Recycling technologies for N,P,K and other minerals.

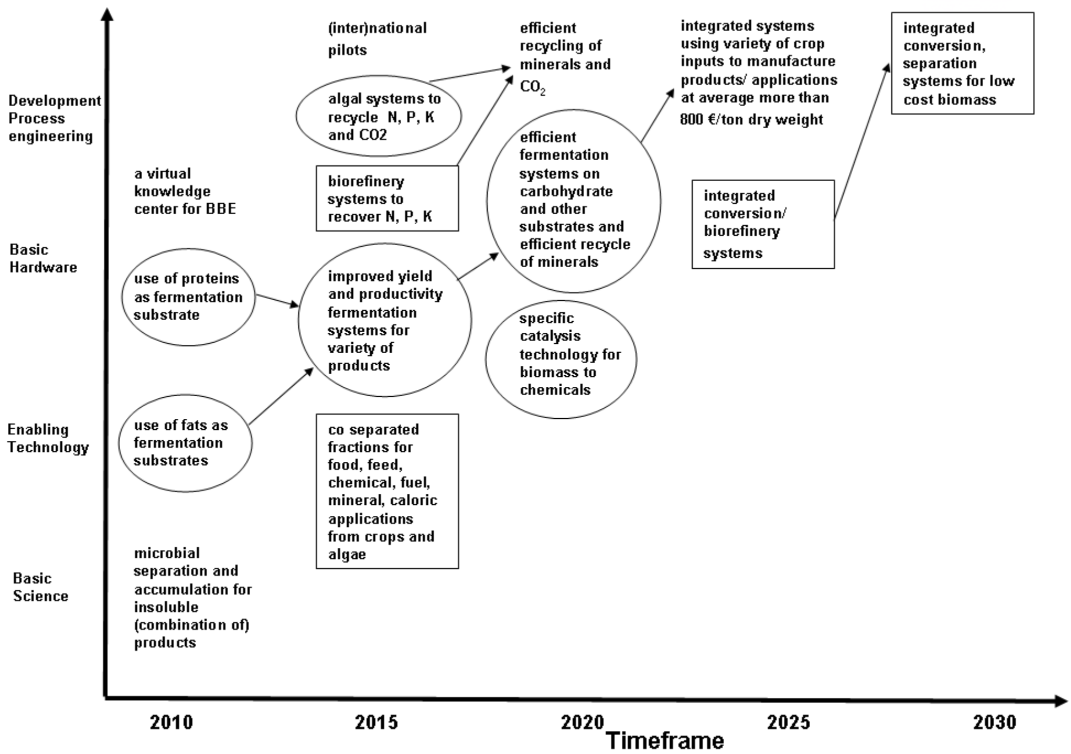


Figure 14 High quality use of raw materials and low CO_2 emissions incl. low capital cost.

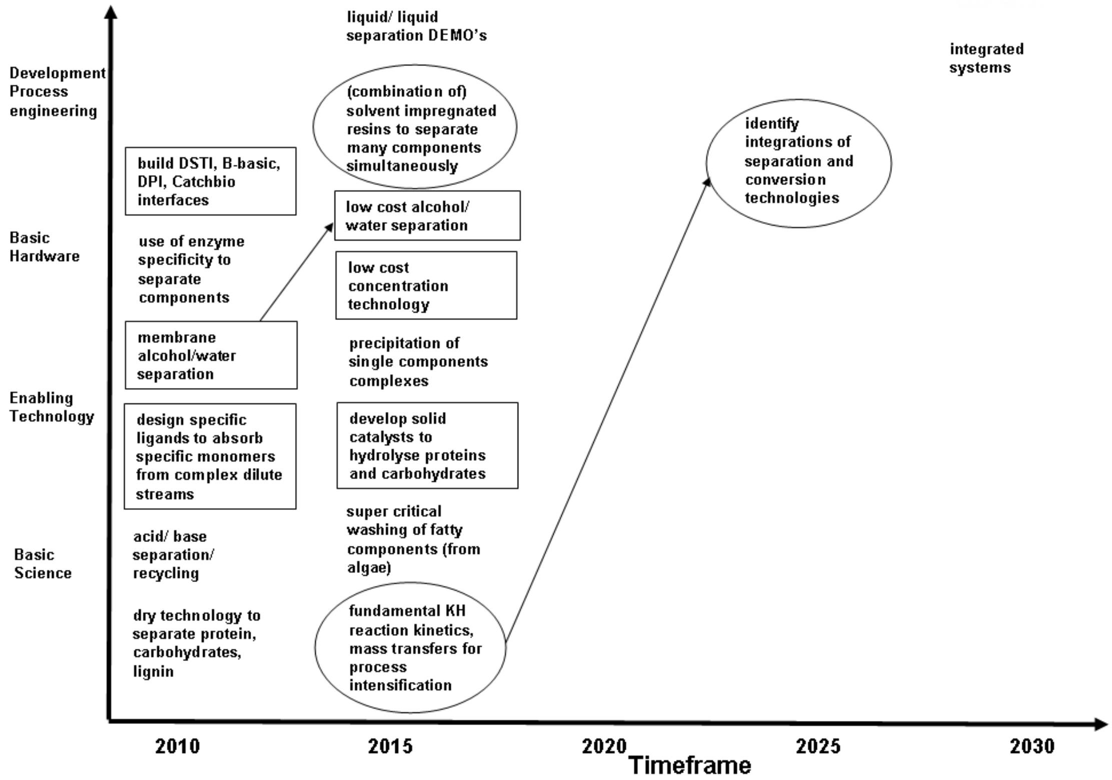


Figure 15 Tool box development.

5.4 Low raw material cost

From Figures 16 and 17 we can derive the following items for a long-term development agenda:

- Increase field yield and storage technologies to enable season independent supply of low cost raw materials.
- GMO production of bulk chemical (intermediates) in crops that are suitable for biorefineries, depending on outcome of political discussions.
- Technologies that have little drawbacks from small-scale and enable the reduction of undesired transport and high initial thresholds of investment costs. These small-scale biorefineries will speed up the overall development of high value biomass utilization.
- Technologies to harvest and process micro-algae.
- Materials to cultivate micro-algae in the sea.
- Artificial photosynthesis systems.

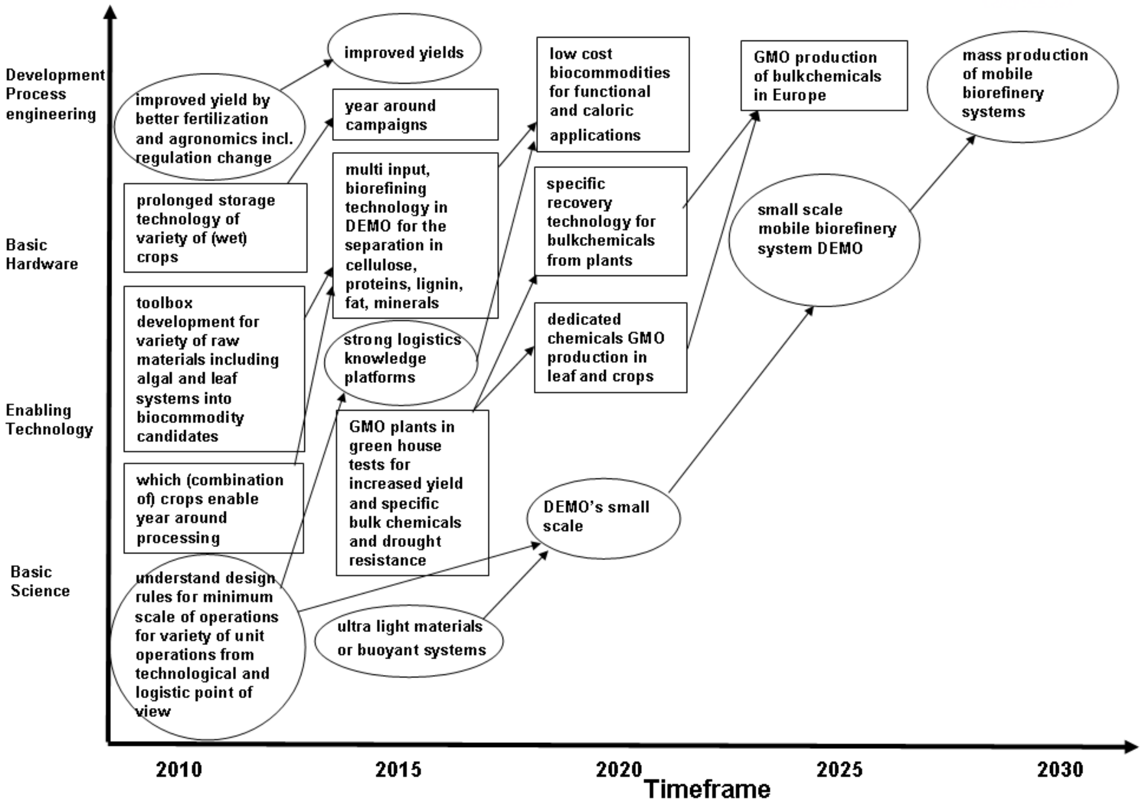


Figure 16 Low raw material cost (GMO, mobile units, high field yields).

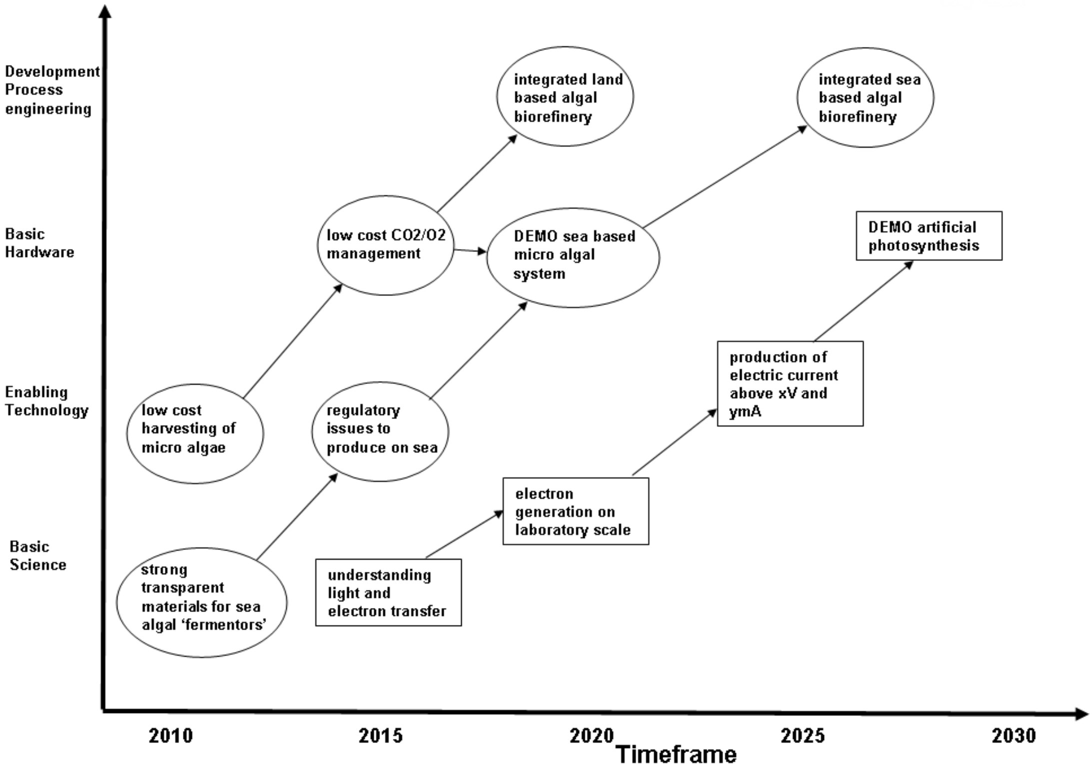


Figure 17 Low raw material cost (algae and photosynthesis).

5.5 Social values, how to cope with growing competitive claims

From Figure 18 we can derive the following items for a long-term development agenda:

- International consensus rules for the trade off of competing claims and build international platforms.
- Certification systems for different crop/process combinations.
- Price moderating financial systems to prevent low or high harvests (and other causes) to disturb industries to invest in biorefineries.
- New value chains with players from agriculture and the new application areas like bulk chemicals, energy, biofuels and develop value added sharing systems.

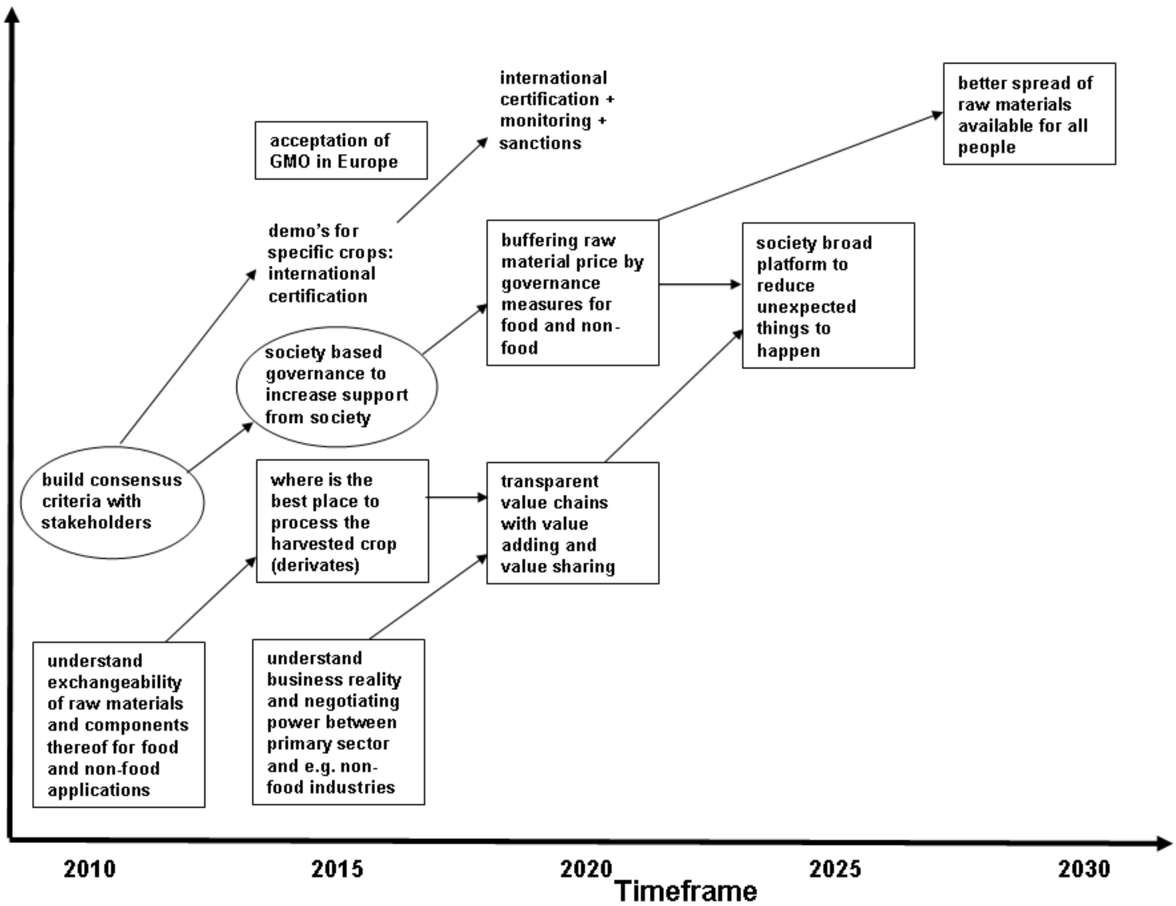


Figure 18 Social values: how to cope with ever growing competitive claims.

5.6 Some other strategic research issues

For successful implementation of biorefinery the following issues have to be addressed:

- Improving yield and efficiency of pre-treatment.
- Improving feedstock tolerance of the processes to (1) handle biological variation of input material quality, and (2) make the processes suitable for multiple feedstocks (broadening the applicability and thus improving the financial feasibility).
- Increasing purity (reducing undesired elements) in pre-treated fractions.
- Cost reduction and downscaling (in many cases pre-treatment near the source is desirable for many reasons; mostly this demands for small-scale processes).

A number of other challenges have been identified for the near future that need to be met in order to come to a successful biorefinery concept:

- New biomass catalysis. Most current catalysts are not suitable for biomass conversions as they are often water and oxygen intolerant. In order to efficiently convert biomass into industrially relevant products on large-scale, new, efficient and selective catalysts need to be developed.
- Deoxygenation. As the current chemical industry is totally based on hydrocarbon and aromatic feedstocks, short-term implementation of biomass as viable feedstock will require the transformation of mainly hydrocarbons into hydrocarbons and aromatics. In order to achieve this, new concepts need to be developed for removing oxygen from carbohydrates without sacrificing large amounts of hydrogen.
- Innovative chemo/enzymatic biomass fractionation. Recent advances in the fields of ionic liquids and hydrothermal chemistry, indicate that these technologies can be successfully applied to fractionate lignocellulosic feedstock and promote the constituent components for further conversions.

Finally research efforts are needed for:

- Strain development, by development of screening, selection of known and novel/unknown strains, and product optimization procedures and tools, incl. mutant and genomics applications, high-throughput screening and metabolic flux analysis.
- Development of cell-biological tools (incl. metabolic flux analysis).
- Bioprocess optimization (for growth and productivity).
- For the cultivation of algae, especially in open systems (as a source of biomass for subsequent biorefinery), the assessment and possible control of culture dynamics (e.g. light/dark, summer/winter, temperature effects) are of prime importance. Here, the development of genomics-based process diagnostic tools like microarrays, PCR can become an essential research subject, allowing to optimize and steer the cultivation process and thus, the product quantities and composition of (algae) biomass produced.

- Improvement of harvesting and dewatering technologies, e.g. by bioflocculation, sedimentation and membrane separations.
- Development of mild and efficient cell disruption, extraction and fractionation technologies.
- Effective technologies for separation of oligosaccharides, lipids, proteins, amino acids.
- Lipid/oil refining technologies.
- Production and isolation of valuable end-products like: biochemicals, proteins, polysaccharides, biopolymers, biofuels, starting from biomass fractions, intermediate products or even from pure building blocks like methanol, sugars that may arise at any stage of the biorefinery process.
- Extracting/removing minerals or other ingredients that are not functional in the end product.

6 Integrated Research, Development and Demonstration (RD&D) agenda for the transition to a Bio-based Economy

6.1 Individual key actions

In order to make the transition to a Bio-based Economy in the longer-term, and to realise industrial demonstrations in the short-term (<2015), a purpose-focussed (and demand-driven) integrated Research, Development and Demonstration (RD&D) agenda is needed. The previous chapter gave an overview of Research and Development (R&D) priorities with an eye on large-scale implementation of biorefinery on the longer-term. In order to (1) stimulate industrial demonstrations (which still face various technical and non-technical barriers) in the short-term, (2) keep on track with large-scale implementation of biorefinery-based value chains on the longer-term, and (3) control societal sustainability of the developments, large efforts will be needed, connected to the following aspects of biorefinery development:

- Feedstocks (availability and suitability)
- Biomass pre-treatment processes, including primary refinery
- Secondary refinery and final processing
- Market development and market-oriented biorefinery chain development
- Chain development and overcoming chain-wide challenges
- Societal and environmental assessment of biorefinery developments

Table 9 Individual key actions of the Dutch Roadmap Biorefinery for the different aspects of biorefinery development.

Aspects of biorefinery development	*Demonstration*	*Applied research and piloting*	*Strategic Research*
Feedstocks (availability and suitability)	• optimise logistics for collection • selection and screening of species and crops	• dedicated test facilities • standardisation + property certification of feedstock • on-site sustainable nutrients management • algae harvesting	• increase storage life • search other feedstocks for use in same process • increase productivity of crops • increase contents and accessibility of valuable ingredients in crop
Biomass pre-treatment and primary refinery processes	• scalability • demonstrate feasibility & reliability	• dedicated test facilities • proven long-duration operation • feedstock-tolerant technologies • on-site sustainable water management • optimisation of functionality of new ingredients in relation to processes applied and purity	• local pre-treatment • low-cost technologies • exploit potency of existing technologies • increase storage life feedstock • cost reduction • reduction energy use • determination of functionality of new (modified) ingredients

Aspects of biorefinery development	Demonstration	Applied research and piloting	Strategic Research
Secondary refinery and final processing	• demonstrate technologies for multiple-products • demonstrate feasibility & reliability	• dedicated test facilities • extraction of minerals • mild extraction / separation processes (low temp & low energy) • sustainable water management solutions	• low-cost separation • multiple feedstocks for year-round use of facilities • ensure high-purity end-products • develop design tool
Market development and market-oriented biorefinery chain development	• technology as export products • proof of product quality	• standardisation of products • integral valorisation of biorefinery products	• solve 1-1 dependency new supplier & customer biobased product • market-oriented product development: high-value chemicals and bulk materials
Chain development and overcoming chain-wide challenges	• financing options (e.g. financing fund) • optimal chain formation: scales & logistics & modular concepts • co-operation between sectors agro – chemistry – energy • found a knowledge centre • interface with other national programs (b-basic, catch-bio, ccc, dsti, process intensification)	• combine and integrate different technologies • use international available facilities • integrate existing knowledge agro & chemical sectors • integrate existing infrastructure agro & chemical sectors	• dissemination & education • international networking/ knowledge import • coupling withCO_2 capturing
	All three Phases		
Societal and environmental assessment of biorefinery developments	• approved demo locations north sea with nutrients supply at sea (aquatic biomass) • public acceptation • nutrients supply at sea • exploit international GMO context • solving legal label "waste" • rural development • integrated approach for food-feed-fuel production • adding value through regional production	• integrated approach for food-feed-fuel production • optimal use of residues • consumer acceptance • search for markets (new and existing, in price and volume) • cross-sector integration • risk management • chain formation/ consortium building	• implementation questions Cramer criteria (boundary condition) • environmental and spatial permits • nutrient cycles • transition to biobased system • guarantee sustainability and transparency of biorefinery chains, respecting food-feed-fuel demand • reward external benefits (GHG reduction, fossil input displacement

Table 9 summarizes key actions based on the actions and R&D priorities formulated in the previous chapters (connecting the R&D priorities to the Moonshots and demonstrations, formulated in close interaction with stakeholders from industry, government, research institutes and universities). Both short, medium and long-term key actions are specified. Technical as well as non-technical issues are addressed.

The individual key actions in Table 9 can be grouped under the following Key Action Groups:

- Sustainability assessment
- Cross-sector chain and network development
- Logistics
- Biorefinery processes development
- Availability of feedstocks
- Quality and homogeneity of input and output
- Solve seasonable availability inefficiencies
- Demonstrate feasibility and reliability
- Share experimental R&D and pilot facilities
- Legal framework
- Transition issues
- Dissemination, education and co-operation

These Key Action Groups are logical topics in the intended RD&D-programme.

6.2 Key Actions Groups

The following type of questions will be addressed:

- **Sustainability assessment**
  To guarantee sustainable and societal-desirable development, an evaluation framework is needed (think of ecological food-print analysis and Cramer criteria). Sustainability evaluation will address local as well as global effects, people and planet aspects, including nutrient cycles, water management and food-feed-fuel-competition. Furthermore, sustainability comparisons of bio-based and fossil-based products, and comparisons of bio-based routes, are essential. Also potential coupling with CO_2 capturing will be relevant. This key theme is relevant for social acceptance of biorefineries, for consumer acceptance of the products, and for consciously-oriented incentives by the government.

- **Cross-sector chain and network development**
  Biorefinery leads to the arrival of new companies and sectors. Existing companies will want to both work together and compete with each other. Furthermore, new relationships between new and existing sectors will develop: the agricultural world will step into the non-food world and vice versa. Several typical issues are:
    - How and where does pricing take place, and what types of contracts are used with regard to different flows of biomass and intermediate products?
    - How are the different links in the chain organised (degree of organisation)?
    - What are their specific interests and rules of the game?
    - What power of negotiation do they have with respect to suppliers and customers?
    - What influence do they have in public arenas?

- Opportunities for cluster forming (national/regional) versus international sourcing and supply.
- Needs and knowledge/experience gap analysis: promoting links and collaboration between two previously separate industries does not allow top-down management.
- What do the firms in the agrifood sector and the chemical industry see as barriers, and uncertainties, when considering opportunities, collaborations and activities?

- **Logistics**

  This connects distributed (relatively small-scale) primary production to the end-product: from harvesting to standardised end-products, taking into account the full biomass value chain. Relevant issues are:
    - Harvesting and on-site pre-treatment methods oriented at the intended use and at acceptable collection logistics.
    - Storage/quality preservation of the feedstock, intermediate and end products within the chain.
    - Scalability of chain actors.
    - Standardisation of the products.
    - Increase energy density for long distance transport.

- **Biorefinery processes development**

  From pre-treatment through various refinery processes until the output product, with focus on:
    - Production efficiency of the processes.
    - Optimisation of functionality of products in relation to processes applied and purity of the products.
    - Cost reductions.
    - Reduction of energy use.
    - Improvement of product quality.
    - New refinery/product development.
    - Sustainability of the whole chain.
    - Cost efficiency optimisation of the whole production chain for the various products.

The required technology development involves both physico-chemical or thermochemical processes, and biotechnological processes often in combination, depending on the type of feedstock and the desired biobased products.

In addition to technical process development, knowledge sharing and process modelling will facilitate deliberating about new biorefinery processes and chains. New concepts usually consist of new combinations of existing and potentially new technologies applied to existing biomass streams.

- **Availability of feedstocks**
  Sustainability and feasibility of biorefinery largely depends on availability of feedstock. Developing a biorefinery will affect the market for the feedstock material; therefore strategic analysis is required. Typical questions are:
    - What is the current and future availability?
    - What is the elasticity of price and availability?
    - What will the effect be of using the feedstock for biorefinery on cost price development?
    - What will be the effect on food and feed price?
    - What price fluctuation is expected, and how could this be influenced?
    - Build technologies that lead to several high volume standardized intermediate products.

  With regard to this issue there is a strong link with the intended *Sustainable Biomass Production Programme*. This aims at ensuring the optimal quality of biomass feedstocks.

- **Quality and homogeneity of input and output**
  What input quality is available, and how could this be improved (e.g. increasing contents and accessibility of valuable ingredients in the crop through crop and cultivar choice, improved primary production and through plant breeding)? What quality does the intended market (food, feed, pharma, chemistry, energy) demand? One of the typical properties of agricultural products is "biological variation". Products used for biorefinery will also have large variations, especially residue streams. Biorefinery processes should be able to handle large variations of input quality, and produce sufficiently homogeneous outputs. What standardisation is possible?

- **Solve seasonable availability inefficiencies**
  Agricultural crops are produced seasonably. Seasonal processing in biorefinery chains results in inefficient use of the equipment and discontinuous supply of outputs to the market. Search for:
    - Ways to increase storage life (of feedstocks or half-products).
    - Multiple feedstocks for year-round use of facilities (e.g. storage in the field).
    - Miscanthus, winter beet, combining import with domestic production, storability.
    - Other solutions.

- **Demonstrate feasibility and reliability**
  Prove technical feasibility and reliability of the processes and products through long-during industrial demonstrations. This question is crucial to convince industries to further develop biorefinery.

- **Share experimental R&D and pilot facilities**
  There is a broad range of biorefinery processes; a large variety of experimental facilities is needed. Setting up a complete set of facilities is not feasible (neither for industry nor for one research organisation). Sharing existing infrastructure and co-operative setup of new facilities (agro and chemical sectors) is needed, preferably in co-operation with international partners (to be selected).

- **Legal framework**
  Existing legislation is not optimal for biorefinery development. For example, the use of the label "waste" hinders a broad range op potential biorefinery initiatives. Furthermore, local environmental and spatial permits are limiting possibilities (also think of marine or off-shore algae production). Questions are oriented at how to facilitate biorefinery developments without unwanted societal harm.

- **Transition issues**
  Development of the Bio-based Economy and biorefinery is a major challenge, requiring involvement of government, non-governmental organisations, firms and centres of knowledge. Interaction between those four major players (which measure, at what time, by whom?) is needed to develop the biorefinery from a niche-market to a well-developed new economy. One of the goals of demonstrations is to learn about the transition process of this development towards the Bio-based Economy and biorefinery (from a perspective of entrepreneurs as well as society). Assessment of the demonstrations and other results will speed-up further development of the Bio-based Economy.

- **Dissemination, co-operation and education**
    - "Import" international state-of-the-art knowledge and make this available for stakeholders in The Netherlands.
    - International networking/ knowledge import.
    - Integrate existing knowledge agro & chemical sectors.
    - Build new academic and professional education programmes.

The relative position of the Key Action Groups is given in Figure 19.

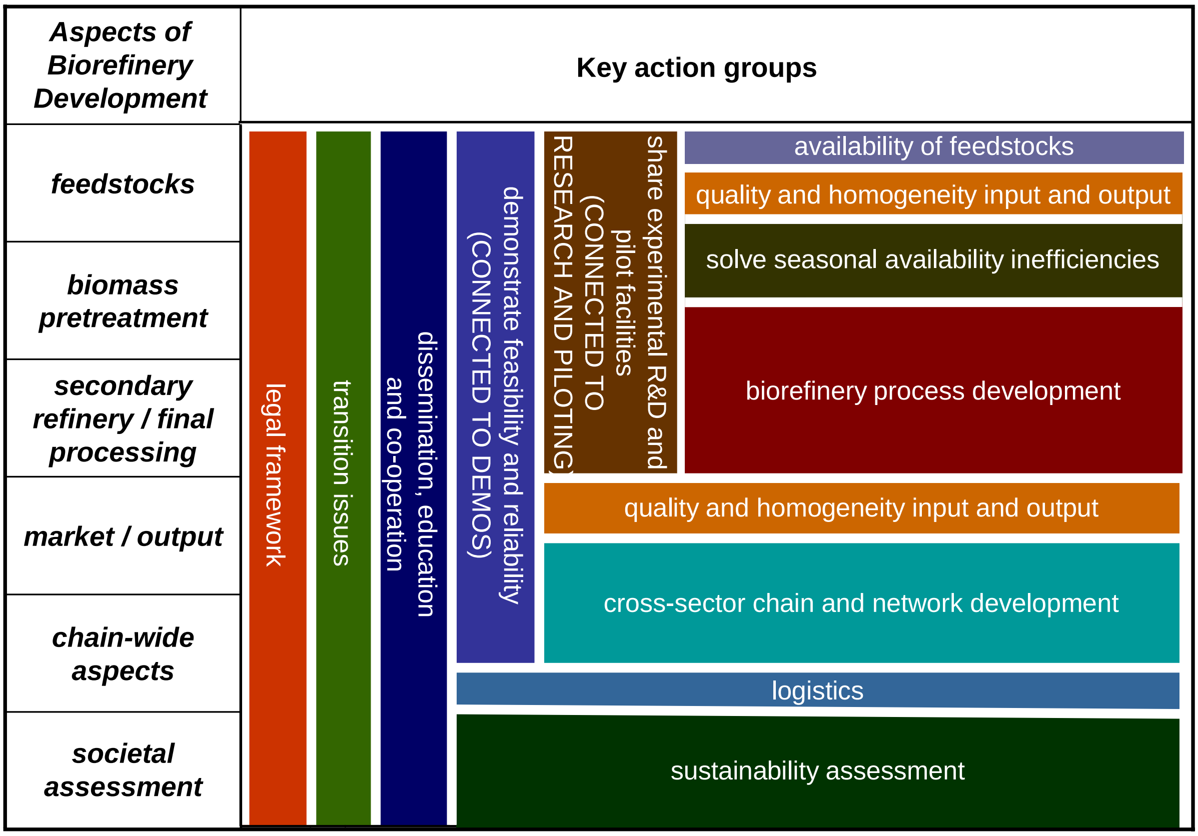


Figure 19 Overview of Key Action Groups of the Dutch Biorefinery Roadmap.

Per Moonshot, and even per specific biorefinery-based value chain within a Moonshot, a specific combination of most suitable technologies and tools will have to be chose to cover the necessary RD&D-programme, to pave the road both technically and non-technically to full market implementation.

Further recommendations

- The development of a bio-based economy requires the large-scale implementation of biorefinery strategies.
- Short-term pilots and demonstrations of (parts of) biorefinery chains are required to arrive at large-scale implementation in the future.
- There is a large number possibilities for biorefining of biomass. Since the objective is to contribute to the development of a bio-based economy, it is industry who has to pull the developments in this area.
- Support of pilots, demonstrations and accompanying (strategic) research is required to accelerate the development of a bio-based economy.

References

BIOPOL, 2009. Final report. EU-FP6 project, Deliverable 7.6, 68 pp; including underlying deliverables to be found on www.biorefinery.nl/biopol/public-deliverables.

EZ, 2008. Innovatieagenda energie. Report, 117 pp.

FAO, 2008. (testimony of FAO director general Diouf to the Italian parliament).

Hoogwijk, M., A. Faaij, R. van den Broek, G. Berndes, D. Gielen & W. Turkenburg, 2003. Exploration of the ranges of the global potential of biomass for energy. Biomass and Bioenergy, Vol. 25, No.2, 119-133.

LNV, 2007. Overheidsvisie op de bio-based economy in de energietransitie; 'de keten sluiten'. Report, 36 pp.

Nowicki, P., M. Banse, C. Bolck, H. Bos & E. Scott, 2007. Biobased Economy: State-of-the-Art Assessment (With reference to data for 2005). Wageningen UR (LEI & A&F), Report, 54 pp.

PGG, 2006a. Potential of Co-production of Energy, Fuels and Chemicals from Biobased Renewable Resources.

PGG, 2006b. Duurzame productie en ontwikkeling van biomassa, zowel in Nederland als in het buitenland (in Dutch). Report, August, 93 pp.

Rabou, L.P.L.M., E.P. Deurwaarder, H.W. Elbersen & E.L. Scott, 2006. Biomassa in de Nederlandse energiehuishouding in 2030. Een studie door ECN & WUR Biobased Products voor het Platform Groene Grondstoffen gefinancierd door SenterNovem. Januari 2006, 54 pp.

Van Ree, R & E. Annevelink, 2007. Status Report Biorefinery 2007. Agrotechnology & Food Sciences Group. Report 847.

Reith, J.H. (ed), 2004. Duurzame co-productie van fijnchemicaliën en energie uit micro-algen. Openbaar eindrapport E.E.T. project K99005/398510-1010, ECN-C--04-037, april 2004, 41 pp. http://www.ecn.nl/docs/library/report/2004/c04037.pdf

Reith, J.H., E.P. Deurwaarder, A.P.W.M. Curvers, P. Kamermans, W. Brandenburg & G. Zeeman, 2005. Bio-offshore: Grootschalige teelt van zeewieren in combinatie met off-shore windparken in de Noordzee. ECN-C--05-008, augustus 2005, 137 pp. http://www.ecn.nl/docs/library/report/2005/c05008.pdf

Sanders, J., E. Scott & H. Mooibroek, 2005. Biorefinery, the bridge between agriculture and chemistry. In: Proceedings of the 14th European Biomass Conference and Exhibition : Biomass for Energy, Industry and Climate Protection, Paris, France, 17-21 October 2005.

De Vaan, M.J.M, C. Rippen & H.J.K. Haverhals: SWOT analysis for the industry letter, 2003. Strenghts, Weaknesses, Opportunities and Threats of industry and services, Dutch Ministry of Economic Affairs, publication number 04 01 03.

Wirsenius, S., 2000: Human use of land and organic materials, Goteborg University, Goteborg, Sweden, PhD-thesis.

Acknowledgements

The editors of this Roadmap would first of all like to thank all participants of the workshops (mentioned below) for their valuable input. Furthermore we are grateful to all contributing authors of Wageningen UR, ECN and Roland Berger. And finally we would like to thank the Ministry of Agriculture, Nature and Food Quality for the given opportunity to write this Roadmap and for all their support.

Workshop 1 – Kick-off Meeting

Abengoa	Rob Groeliker
Agricultural Promotion Projects	Anne Mast
Agrobiocon	Rob van Haren
Akzo	Hans Feenstra
Akzo	Maikel van Iersel
Albemarle	Frans Plantenga
AquaPhyto	Robert Baard
AquaPhyto	Nico Goosen
AquaPhyto	Annette Veenendaal
Ballast Nedam	Mark Raming
Beethanol	Douwe-Frits Broens
Bio-based Business Professionals	Hans Derksen
BioDetection Systems B.V.	Bram Brouwer
BIOeCON	Armand Rosheuvel
Biomass Research	Hans Langeveld
BPN Bedrijfsadviseurs BV	Erik van Nijkerken
BTG	Wolter Prins
BTG	Robbie Venderbosch
Bureau Ecologie en Landbouw Wageningen	Schoenmaker Elma
Cargill	Rita Delrue
Cosun	Ad De Laat
Courage	Carel de Vries
DSM	Edwin Berends
DSM	Jan Boon
DSM	Jarno Kuijvenhoven
DSTI	Nijhuis Herrie
ECN	Herman den Uil
ECN	Paul Lako
ECN	Hamid Mozaffarian
ECN	Hans Reith

ECN	Raimo van der Linden
Ecofys	Jacob Vermeulen
Essent	Nicolas Brizard
Evelop	Rob Remmers
EZ	Elisabeth Schless
Genetwister Technologies	Michel Ebskamp
Havenbedrijf Rotterdam	Wijnand Schonewille
Havenbedrijf Rotterdam	Jan van der Zande
Hoofdproductschap Akkerbouw	Arjan Kuijstermans
Kodok BV	Joep van Doorn
Koninklijke VNP	Annita Westenbroek
LEI	Tom Bakker
LEI	Marieke Meeusen
LEI	Eric ten Pierick
LEI	Eveline van Mil
LNV	Tjeerd de Vries
LNV	Irene Mouthaan
LNV	Jo Voet
Meneba	Johan Plijter
Meneba	Arthur van der Meijden
Meneba	Jeroen van Soest
Nevedi	David de Glint
NOM	Eisse Luitjens
NZO	William Wold
PMVO	Frank Bergmans
Provincie Lelystad	Hans Rijnten
Purac	Tony Else
Roland Berger Strategy Consultants	Jeroen Althoff
Roland Berger Strategy Consultants	Koen Besteman
Roland Berger Strategy Consultants	Maarten de Vries
Roland Berger Strategy Consultants	Arnoud Stibane
Roland Berger Strategy Consultants	Benno van Dongen
Roland Berger Strategy Consultants	Jeroen Vugts
Sabic	Cees Hettinga
SenterNovem	André de Boer
SenterNovem	Diana Guzijan
Ten Kate	Hendrik de Vries
Thermphos Vlissingen	Tjerk Homminga
TNO	Paul Bussmann
TNO	Arij van Berkel

TNO	Mariet van der Werf
TNO	Johan van Groenestijn
TNO	Jan Zeevalkink
TU Delft	Gianluca Marcotullio
TU Delft	Luuk van der Wielen
TU Eindhoven	André de Haan
TUBITAK	Omer Gul
TUE	Wytze Meindertsma
Unilever	Gerrit van Duijn
Universiteit Twente	Sascha Kersten
Universiteit Twente	Henk van den Berg
University of Groningen	Erik Heeres
UVA	Wim Admiraal
Van Tongeren Kennemer	Dhr Van Gemert
VNCI	Nelo Emerencia
WUR	Bert Annevelink
WUR	Jan Broeze
WUR	Oene Dolstra
WUR	Anton Haverkort
WUR	Brenda Israel
WUR	Henk Jochemsen
WUR	Alexey Pristupa
WUR	Maarten Schutyser
WUR	Ingrid van der Meer
WUR	Adrie van der Werff
WUR	René van Ree
WUR	Erik van Seventer

Workshop 2 – Strategic Research

Avantium	Ed de Jong
Cosun	Harry Raaymakers
DSTI	Niels Flach
ECN	Jip Lenstra
ECN	Marc Londo
ECN	Hans Reith
ECN	Herman den Uil
LEI	Eveline van Mil
Roland Berger Strategy Consultants	Koen Besserman
Roland Berger Strategy Consultants	Jeroen Vugts
Shell	Teun Graafland
TU Delft	Wiebren de Jong
TU Delft	Luuk van der Wielen
VROM	Eli de Vries
WUR	Bert Annevelink
WUR	Andries Koops
WUR	René van Ree
WUR	Johan Sanders
WUR	Henk Schols
WUR	Emile Wubben

Workshop 3 – Demonstration Cases Moonshots

1. Domestic crops

ECN	Paul Lako
Kiemkracht	Rob van Haren
Purac	Tony Else
TU Delft	Cuellar
WUR	Bert Annevelink
WUR	Andries Koops

2. Aquatic biomass

Aquaphyto	Robert Baard
DSTI	Niels Flach
ECN	Hans Reith
ECN	Jip Lenstra
Essent	Jan de Jong
Genetwister	Marcel Ebskamp
Kodok	Joep van Doorn
Unilever	Geert van Kempen
UVA	Wim Admiraal
WUR	Rene Wijffels

3. Imported biomass

ECN	Herman den Uil
Shell	Teun Graafland
TU Delft	Luuk van der Wielen
UT	Sascha Kersten
WUR	Henk Schols
WUR	Eveline van Mil
WUR	Johan Sanders

4. Residues

Cosun	Harry Raaijmakers
BTG	Robbie Venderbosch
DSM	Edwin Berends
ECN	Marc Londo
TNO	Jan Zeevalkink
TUD	Wiebren de Jong
VNP/KCPK	Annita Westenbroek
WUR	Jan Broeze

Appendix A. SWOT analysis Biorefinery from a Dutch point-of-view

Strengths (internal)	**Weaknesses (internal)**
S1. Strong agrocluster, chemical sector & energy sector available, situated relatively close to each other S2. Advantageous geographical position in European market and logistical infrastructure (a.o. harbours in/export) S3. Food industry is already experienced with biorefinery processes S4. Good Knowledge Infra Structure (KIS, universities and institutes) S5. Position in White Biotechnology S6. Position in catalysis S7. Interest of chemical industry to use more biobased feedstocks S8. National R&D funding programmes (a.o. EOS LT) S9. Large biomass flux is common already (import) S10. National stakeholder platform (biorefynery.nl) available S11. International stakeholder platforms (IEA Bioenergy Task 42, EU TPs) available S12. Focus on zero-waste production processes – sustainable use process residues	W1. Insufficient co-operation between stakeholders of agro, chemical and energy sectors W2. Governmental departments do not work together closely enough W3. Key technologies partly still in R&D-phase W4. Most optimal biomass – product chains still not identified W5. Studying instead of implementing W6. Investment capital for pilot and demo initiatives difficult to find W7. Full chains often not yet market competitive due to relatively cheap fossil fuels W8. R&D funding programmes often fragmentised concerning budget and content W9. A common vision and roadmap is still lacking W10. Insufficient co-operation within the KIS W11. Funding instruments not tuned yet for co-production processes W12. Domestic terrestrial biomass potential limited even when optimal utilization is achieved
Opportunities (external)	**Threats (external)**
O1. Biorefinery central on national and European policy agendas O2. Challenging national and European policy goals for bioenergy (fuels, energy) lead to high demand and trade of biomass O3. Biorefinery is a necessity to meet the biofuel-related policy goals O4. Strengthening of the economic position of the agro, chemical and energy sectors O5. Preferential position in Europe still vacant O6. Interdepartmental approach potentially results in an integrated policy framework O7. Co-operation between stakeholders can boost the development and implementation of biorefinery concepts O8. Much regional interest to contribute O9. Potential energy savings and improved process economics O10. Optimal use of domestic biomass (e.g. insufficiently used agro residues) O11. Short-time implementation conventional biorefineries by upgrading residues O12. Development advanced biorefineries to prevent competition with food/feed O13. Development multi-purpose biorefineries in a framework of scarce raw materials and energy O14. Sustainability criteria in biofuels for transport will make biorefinery alternatives more attractive O15. Large sea surface available for biomass production O16. NL can use export power - producing more biofuels (3x) and bulkchemicals (2.5x) than our own consumption	T1. The biorefinery area is very broad, fashionable, and complex T2. US (and EU) are ahead on implementation T3. External costs fossil-based products still not taken into account T4. Fluctuating (long-term) governmental policies delay company investments T5. No policy goals for biomaterials and biochemicals yet T6. Focus on single products like biofuels and electricity only (no chemicals yet) and not on multiple products T7. Markets for complete product portfolio are a necessity for success T8. Existing industrial infrastructure is not depreciated yet T9. High initial investment costs for pilots and demos T10. Decreasing oil price will lower the urgency and economic feasibility of the biobased economy T11. Discussion food/feed/fuels and biomass sustainability T12. No level-playing-field for end-products T13. Companies using traditional production processes can slow down new developments T14. Lock-in effect of conventional biofuels caused by agricultural interests T15. Difficult biomass contractibility and sustainability T16. Uniform EU and worldwide sustainability criteria still missing T17. Insufficient sense of urgency T18. NL is depending on export (see O16)

Appendix B. Constituent components of lignocellulosic crops

From a chemical point of view the constituent components of lignocellulosic crops can be divided into four main classes; cellulose, hemicellulose, lipids, and lignin. For every class indications are given on how these materials can be converted into industrially relevant products and intermediates, based on current and future expertise.

<u>A. Cellulose</u>

- Conversion via chemical (catalytic) or enzymatic routes
- Can be used directly for cellulosic materials
- Depolymerisation to hexoses
    - Hexoses can be hydrogenated to alditols (e.g. sorbitol)
        - Alditols can be transformed into hexide building blocks (e.g. isosorbide)
        - Alditols can be hydrodeoxygenated to glycols (e.g. ethylene glycol, propyleneglycol)
    - Hexoses can be catalytically converted into syn-gas (CO/H_2)
        - syn-gas can be transformed into a multitude of substances via e.g. the Fischer-Tropsch process
    - Hexoses can be cyclodehydrated to HMF
        - HMF can be converted into furan acids (e.g. 2,5-FDA), levulinic acid and succinic acid

<u>B. Hemicellulose</u>

- conversion via chemical (catalytic) or enzymatic routes;
- further fractionation required;
- depolymerisation to pentoses and uronic acids;
    - pentoses can be hydrogenated to alditols (e.g. xylitol);
        - alditols can be hydrodeoxygenated to glycols (e.g. ethylene glycol, propyleneglycol);
    - pentoses can be cyclodehydrated to furfural;
        - furfural is the starting material for furan resins and THF;
    - pentoses can be dehydrodeoxygenated into butadiene and 1,4-butanediol; building blocks for polymers;
    - pentoses can be catalytically converted into syn-gas (CO/H_2) ;
        - syn-gas can be transformed into a multitude of substances via e.g. the Fischer-Tropsch process;
    - uronic acids can be transformed into furan acids (e.g. 2,5-FDA).

C. Lipids

- conversion via chemical (catalytic) or enzymatic routes;
- target chemicals are fatty acids and glycerol;
    - glycerol can be hydrodeoxygenated to glycols (e.g. ethylene glycol, propyleneglycol);
    - glycerol can be oxidized to e.g. acrylic acid;
    - fatty acids can be converted into fatty acid methyl esters (FAME's), also known as 1st gen. biodiesel;
    - fatty acids can be hydrodeoxygenated to (unsaturated) paraffins, also known as 2nd gen. biodiesel;
    - fatty acids can be decarboxylated to unsaturated paraffins;
    - unsaturated paraffins can be converted into -olefins for LLDPE and surfactants;
    - fatty acids can be used for producing alkyd resins;
    - fatty acids and fatty alcohols can be produced from wax-esters (esters of fatty alcohol and fatty acids); wax esters can be produced directly by plants (e.g. jojoba oil) and high yielding seed oil crops can be modified to produce these wax esters.

D. Lignin

- Conversion via chemical, hydrothermal of pyrolytic routes
- Target chemicals are aromatics (phenols, benzene, toluene, xylenes), and organic acids

Appendix C. Transition towards cross-industrial connections

Introduction

In the 'Biobased Economy', the use of renewable raw materials or biomass for the production of food and animal feed as well as materials, chemicals, transport fuel, electricity and heat is a central theme. The percentage of biomass that will be used for non-food applications is expected to increase significantly in the coming years. Around 75% of the products from the petrochemical industry can also be produced from biomass by means of biorefinery; this is thus the challenging target. The aim is also to use biomass sustainably and as efficiently as possible. In the context of The Netherlands, the development and implementation of biorefinery processes – or the sustainable processing of biomass into a range of marketable products and energy – is viewed as an absolute necessity in order to maximise the efficient use of the available biomass with minimum impact on the environment (Van Ree & Annevelink, 2007). Transition to a 'Biobased Economy' is a process in which several players (government, industry, NGOs and knowledge institutions) coordinate actions aimed at achieving a Bio-based Economy. This is a transition process which involves various issues.

Transition to a 'Bio-based Economy' implies that food and non-food production industries and sectors (for example, the chemical, petrochemical and pharmaceutical industries) become increasingly involved with each other. In order to be active in the biomass chain and respond in time to opportunities and developments, it is important that the non-food industry gathers insight into the structures, markets and organisation forms of the agricultural and food sector. Working in or collaborating with businesses in the agricultural and food sector requires non-food industries to be familiar with: (i) pricing within the chain; (ii) the various contract forms used in the agriculture sector and the associated hows and whys; (iii) political, institutional, spatial, demographic, social and economic influences affecting the agricultural sector; and (iv) social factors relating to desired and undesired developments in agriculture (e.g. gene technology, use of pesticides, artificial fertiliser and quality of space, biodiversity). In contrast, businesses in the agricultural sector will have to become acquainted with new partners in a changing agricultural chain, their working methods and organisation and specific needs in a competitive industrial, often international context.

In other words: <u>besides knowledge about the future technological development of biorefinery, knowledge of and about markets and socio-economic factors is vital to bring two different worlds (food-producing agriculture and non-food producing chemical industries) closer together and promote effective links and cooperative ventures.</u> <u>The concept of biorefinery therefore requires process integration of previously distinct industries by stimulating new relationships and mutual collaboration and dependencies.</u>

This gives rise to the following themes and questions:
Does the current situation regarding the developments, technology and market potential in biorefinery give us sufficient reason to assume that parties from the agricultural and food sector on the one hand, and the chemical (non-food producing) sector on the other hand will find each other on their own ('self organisation'), or is a stimulating or coordinating role assigned here for the government? Moreover, how can we detect this need? What should we be aware of in order to be able to track the progress of the transition process? And how can we choose and formulate the approach to remove any problems?

To address such an issue, one might consider an analysis of the current situation, the current needs of the parties involved and future primary and secondary objectives based on insights and concepts from the Transition Theory and Transition Management (Cf. Loorbach, 2007). Transition management is actually about managing a number of steering activities by a number of players in several domains, so that these activities can be adjusted and steered in a mutually desired direction.

Transition issues
The development of biorefinery requires coordinated action from a variety of players (government, industry, NGOs and knowledge organisations). Several players, several time paths, and several levels on which action has to be taken must be directed at changes in several domains.

- innovation assessment: milestone or calendar-driven regular assessment of each demonstration in a benchmark setting to timely expand, redefine or terminate projects. The tool provide the necessary input for stakeholder evaluations, as it will encompasses especially the sustainability check, economic feasibility issues, team-related factors, and product related aspects, such as input and output qualities;
- monitor the actions performed by some that can abolish problems in the development of biorefinery;
- establishment of new common frameworks, legislation, and societal contracts. Participation of stakeholder groups in discussions about technology and related themes is relevant.

Social acceptance and imbedding
Transition to a 'biobased economy' can be described as a long-term collective social innovation programme aimed at achieving a totally different system of raw material use based on a shared definition of sustainability (Cf. Loorbach, 2007). This is a system approach: both the supply and consumption of biobased products, as well as all the relevant social, economic, ecological, technological, cultural and institutional aspects (ibid: 257). In contrast to a predominantly plan-based approach or a market approach, transition management is based on a combination of both approaches, accompanied by 'society-based governance' approach.

The latter implies that social acceptance (i.e. by government, industry and 'civil society') of biorefinery is essential to ensure the imbedding of this new production philosophy and – technology. In other words, the social legitimacy of the biorefinery concept has not yet been established and is therefore still open to discussion. In all probability, social support for biorefinery will only be able to develop effectively on the basis of a broadly shared responsibility for the technological choice made and for the foreseen and non-foreseen effects of those choices.

Effects of biorefinery

Research has shown that 75% of the products of the petrochemical industry can also be produced through biorefinery. Environmental considerations, cost considerations and political considerations make it useful to explore this transition. The actual implementation of this transition has important consequences for industry and society. It is important to know these consequences. Biorefinery wants to contribute to a number of issues facing society: climate change, less dependence on the Middle East, energy diversification. At the same time, the bio-energy transition shows that contribution to this is insufficient for support. We must also be aware of the various side effects on people, planet and profit. The SSG can chart the effects on the people and profit component:

With regard to profit, we include (i) the economic feasibility of the biorefinery concept. In addition, it is about (ii) the effects arising from a shift in product flows. Businesses which currently enjoy a position of power will see this change to some extent. Businesses which are currently each other's rivals may join forces. The effects of this transition at sector level may result in an important shift of production flows. A third question is: (iii) what does biorefinery mean for the competitive strength of The Netherlands? (First scan based on Porter's diamond). What implications does that have for future developments (in terms of markets, knowledge, economic effectiveness, political support) and their speed?

With regard to people, we are mainly concerned with (i) the effects on agricultural commodity prices and their effects. What are the effects of such a large scale shift in agricultural commodities on global market prices? We also want to mention (ii) innovation in the countryside and associated job opportunities and quality of life. Biorefinery can be applied at both large and small scales. Large scale offers advantages of economies of scale but also has disadvantages such as the transport of raw materials to the processing location and the transport of waste flows. Small scale biorefinery has the advantage of limited transport costs, the advantage of low direct and indirect costs and the advantage of direct application of the products. Examples of a large scale versus small scale situation are the micro breweries. Beer can be produced, distributed and marketed at both a large scale and at local small scales, resulting in a much richer assortment. Innovation of the countryside is thus possible with all the associated social and economic consequences.

Research at macro, meso and micro level can help optimise management of this transition.

Output/Markets/ Profitability

- A range of raw materials is available, which can often be processed into different end products using different techniques. Biorefinery usually produces a selection of end products, each of which is sold on a market.
- Where do they come from? What is the market price? What is the current availability of the various raw materials? What is the foreseen future availability? How 'elastic' is the availability and what factors affect the availability of and access to raw materials?
- What are the production costs with regard to biorefinery? What are strategic inputs which predominantly determine those production costs? What is the value added per link in the chain?
- What are the bottlenecks in the chain (and what is their nature, e.g. competitive industries (established regimes)? What are the prospects for the chain (and what factors affect them)? For this last aspect, one can consider an analysis of potential markets / customer segments.
- Risk management. Often the total concept is only attractive on condition that all the products can be sold for a certain minimum price. The questions are (i) under what conditions the concept is economical, and (ii) how stable/robust is that system?

Chain and network collaboration and governance

Biorefinery leads to the arrival of new companies and sectors. Existing companies will want to both work together and compete with each other. Furthermore, new relationships between new and existing sectors will develop: the agricultural world will step into the non-food world and vice versa. Here we mention several issues:

- How and where does pricing take place and what types of contracts are used with regard to different flows of biomass and intermediate products?
- How are the different links in the chain organised (degree of organisation)? What are their specific interests and rules of the game? What power of negotiation do they have with respect to suppliers and customers? What influence do they have in public arenas?
- Opportunities for cluster forming (national/regional) versus international sourcing/supply.
- Needs and knowledge/experience gap analysis: promoting links and collaboration between two previously separate industries does not allow top-down management. What do the firms in the agrifood sector and the chemical industry see as barriers, and uncertainties, when considering opportunities, collaborations and activities.

With the second question, we should take into account changes in the market. (i) As a result of development of supply and demand, prices of raw materials can fluctuate. Combining and applying transition techniques so that – depending on raw material prices – the most economically interesting alternative can be chosen could lead to the most cost-effective biorefinery. (ii) As a result of various developments in the market, the yield prices of the various end products can fluctuate. This means that flexibility must be incorporated on the raw material side and the end product side. We thus arrive in the field of risk management.
With the third question, we come to chain distribution issues. Which link must invest in what, and what costs and benefits must each link make so that it (i) fulfils its requirement to be able to operate in the chain and (ii) is overall economically profitable?
For these three issues, a model approach is the most appropriate.

Development of the concept "Cradle to Cradle"
Sustainability is an important political, social and economic focus. The recycling and revaluing of waste and residual flows contributes to the closing of chains and the reduction of environmental impact. The development and concretisation of the Cradle to Cradle concept in agricultural chains for the spearheads of the Dutch agricultural sector could contribute to further development of this sector. Application of qualitative and quantitative methods and techniques contributes to the quality of conclusions. LEI and WUR data and models could form the basis for this. This subject can be developed at global, EU and national scale.
Moreover: because there are so many inputs and outputs on the raw material and product side, biorefineries should not only capture a place in a one-dimensional chain, but above all within a network of companies. This situation leads to change in the economic field, but requires focused actions to bring about these new connections. The less frictional energy is lost with this transition, the more cost-effective the new situation will be. Advantages, disadvantages and limiting conditions play an important role in this framework. Analysis of the way in which such a process develops in the framework of biorefinery can contribute to its successful implementation.
Here we mention several issues:

- How and where does pricing take place and what types of contracts are used with regard to different flows of biomass and intermediate products?
- How are the different links in the chain organised (degree of organisation)? What are their specific interests and rules of the game? What power of negotiation do they have with respect to suppliers and customers? What influence do they have in political bodies (with regard to legislation and regulations, subsidies, institutional development)?
- Opportunities for cluster forming (national/regional) versus international sourcing and supply. How 'strategic' is a certain customer/supplier? If the input for biorefinery has to comply with certain quality requirements, strategic collaboration with specific parties from the agricultural and food sector seems obvious, and they will seek each other out and perhaps even form industrial clusters.

However, most chemical industries are internationally active to some extent and even agricultural products are traded on global commodity markets. If the input does not have to comply with specific quality requirements, the necessity to work together is not so great. This raises the question: what types of relationships will be created between the agricultural and chemical industry? One can think of markets, contracts, strategic alliances; formal collaboration and horizontal integration (Cf. Wysocki, 1998, edited by De Graaff, 2000). And the nature of the relationship may vary per commodity (input).

- What is the probable geographical scope and reach of the production networks and sales markets with respect to biorefinery? This is important to determine what potential relationships are possible between agricultural and non-food industries. What basic and advanced factors predominantly determine the scope of activities (logistical costs, infrastructure and developments, investment climate, technological knowledge, subsidy regulations and other legislation), and what influence might these factors have on links between food and non-food producing industries?
- Needs and knowledge/experience gap analysis: promoting links and collaboration between two previously separate industries does not allow top-down management. It is important to find out what the parties in the agricultural and food sector and the chemical industry see as barriers, uncertainties, questions and gaps in knowledge when considering opportunities and activities with respect to biorefinery and links with new parties.
- Making an inventory of transaction intentions of companies from both worlds based on the TRIAD model. The Triad model is a model for behavioural management, developed by Professor Poiesz (1999). Poiez is Professor of Economic Psychology at Tilburg University (then known as the Catholic University of Brabant). The Triad model tries to provide insight into behaviour by bringing this down to three factors: motivation, capacity and opportunity. This model could be used (as an experiment) to acquire insight into how different parties view developments, links, opportunities, barriers with respect to biorefinery. It will not be able to give concrete prognoses about the extent of investments and activities in biorefinery. However it will be able to give an indication and an analysis framework that helps chart problems and opportunities with respect to motivations, capacity and estimated opportunity and transaction prospects of the player involved.
- Making an inventory of and analysing external developments which encourage parties to join forces. For example, uncertainties in sales potential (for parties in agriculture and the food chain), global competition and the necessity to innovate as a competitive advantage (for the chemical industry). The assumption here is that an uncertain, competitive and volatile market environment promotes collaboration between parties because this could create a higher degree of coordination, stability and thus flexibility in the accessible company processes (see appendix: interfirm partnering framework by Mentzer et. al, 2000)
- IP matters, patents.

Appendix D. Targets, barriers & actions of demonstration cases

Demonstration whole crop sugar beet

Table 10 Target description moonshot 1: domestic crops; case whole crop sugar beet.

Feedstock	Central Refinery
• Multi-feedstock: sugarbeet & leaves • Whole crop beet • Whole crop harvesting • Legumes (stem and seeds)* • Other feedstocks* • Low cost harvesting	• Purification: aim is to loose water - super-critical extraction (CO_2) - ultrasonic - membranes • Conversion - chemical - physical - thermal - bio-chemical - microbial • Spinning technology of 'liquid' fibres* • High pressure liquification of fibres* • Membrane refining (long-term)* • Production of enzymes: standard fermentation • Fibre fractionation technology
Pretreatment	**Output (first and second stage bioerfinery)**
• Pretreatment both at farm and at refinery • Conservation - for storeability at farm (scale) - year-round supply - freeze-drying* - cover with salt water* - enzymes • Separation (test several techniques) - press - Pulse Electrical Field (PEF) - ultrasonic - microwave	• High-value sugars • Low-value sugars (monsaccharides & olichosaccharides) als cheap intermediate product • Fibre fractions (high performance) • Proteins - native (nutrients & pharma quality) - coagulated (low quality) • Enzymes (second stage) • Chemical building blocks (second stage) • Electricity & surplus heat • Biofuels • Biochar • (ligno)cellulose, starch, pectines*
Other	
• * = not part of demo, but of future developments based on the demo • Input larger than 1 ton/hour fresh feedstock (demo) • Target low-value sugars as feedstock for fermentation at 30% lower price than cane sugar	

Table 11 Barriers corresponding to moonshot 1: domestic crops; case whole crop sugar beet.

Feedstock	Central Refinery (first and second stage biorefinery)
• Whole crop harvest of beet is non-conventional • Combined whole crop harvesting technology not available yet • Getting consortium together (farmers) • Insufficient knowledge at farm level • Need switch in mind of farmers • Soil exhaustion & erosion when too many nutrients will be extracted • New farm logistics, including concepts for nutrient recycling	• Technologies should be robust enough for processing different feedstocks • Making a design that is flexible for feedstock (but produces same end products) • Reducing possibilities for process design • Very complex mixtures; difficult to obtain homogenous components • Separation of end product streams • Availability of separation techniques for obtaining the right quality at low costs • Expensive technologies at bulk scale • Experience in all these technologies with complex solutions • Social and political acceptance of non food GMO crops (second stage) • New alliances directly between Agriculture and Chemicals sectors (second stage)

Pretreatment	Output
• Process for storage • Process for pretreatment • Process for separation • Unclear if multi-feedstock needs combined or single stream technology • Farmers are not used to pretreatment (= non-core activities) • Technologies should be robust enough for processing different feedstocks	• High claims purity end products (chemistry & enzymes) • Producing low cost substrate for fermentation • Production chain issues for production low cost substrate fermentation • Are customers available for all our outputs?

Other
• Combination/ integration of different technologies • Ministry of Economic Affairs does not want state support • Competitive/pre-competitive • Pre-treatment requires financing by client → prepayment • Scale-costs issue • The 1 ton/hour barrier (financial, technical & mental): processing capacity of pilot refineries • Energy intensity of processes • Knowledge in NL versus buying foreign knowledge • Acceptation by R&D institutes that large amount of budget will be spent on installations • Novel-food regulations based on new separation & fractionation technologies • First pilot plant should not want everything: 3-4 end-products; 1-2 (pre)treatments; 1-2 upstream processes • Reversal of design principle: start with the relatively low-value products instead of high-value products

Table 12 Actions planned to overcome barriers corresponding to moonshot 1: domestic crops; case whole crop sugar beet.

Feedstock	Central Refinery
• Create trust (farmers, companies, government) • Close nutrient cycle • Legislation • Develop new storage systems for wet biomass • Combine near farm (semi-central) pre-treatment → consortium building • Develop new harvesting & logistic systems	• Choose/ develop robust technologies → secondary refinery • Actively screen/ look for new technologies • Use flexible designs • Develop new technology for the separation of end products
Pretreatment	**Output**
• Farmers should do part of pretreatment → shift in the value chain / knowledge transfer to farmers • Develop adequate and low cost separation technology • Develop robust technologies for processing different feedstocks	• Access market demand/ product requirement • Consider production chain issues • Guarantee purity end products
Other	
• Design tool for integration of biorefinery components • Lobby towards the government: finance, subsidies, legislation (e.g. waste) • Industrial symbiosis • Share intellectual property in an optimal way • Develop financing options • Develop processes with lower the energy intensity • Create political acceptance	

Demonstration grass biorefinery

Table 13 Target description moonshot 1: domestic crops; case grass biorefinery

Feedstock	Secondary Refinery
• High yields of grass and/or other leafy materials • Low cost raw material • Storage of grass during winter period to enable year around production	• Ferment dilute sugars and amino acids to valuable products • Recover phosphate • Conversion of proteins to bulkchemicals and animal feed
Pretreatment	**Output**
• Washing leaves to remove sand • Opening up of the leaf cells • Purify fibers • Recover protein	• animal feed protein • amino acids • bulk chemcal intermediates • phosphate • (ligno-)cellulosic fibers • fermentation products • electricity

Table 14 Barriers corresponding to moonshot 1: domestic crops; case grass biorefinery

Feedstock	Secondary Refinery
• Storage of grass during winter period without deteriorating quality	• Novel fermentation processes that can be operated at decentral places • Upgrading grass fibers up to high quality paper standards • New separation technologies
Pretreatment	**Output**
• Complex processes to be operated in decentral areas • Automated equipment and tele-control systems • Unit operations not dependent on economies of scale • Unit operations robust for variable inputs • Logistics	• is there a market for all of the products? • How to store one or more products?
Other	
• Mineral directives might be changed to input/output principles • Does the operation fit in the rural area?	

Table 15 Actions planned to overcome barriers corresponding to moonshot 1: domestic crops; case grass biorefinery.

Feedstock	Secondary Refinery
• Develop low cost storage technologies	• Develop new fermentation technologies • Develop separation technologies
Pretreatment	**Output**
• Develop robust technologies • Chose and develop technologies independent of economies of scale	• Develop cost effective processing and build collaboration with industry
Other	
• Show the benefits of low charges of minerals to the environment to LNV and develop common approaches for the EU • Interact with stake holders to find out requirements and boundary conditions • Promotion and outreach to stimulate SME participation and investments	

Demonstration micro-algae

Table 16 Target description moonshot 2: Aquatic Biomass; case micro-algae.

Feedstock	Secondary Refinery
• Recirculation of nutrients back to the cultivation system • Production of algae in biofilms • Develop CO_2 injection systems • Screening, selection and product optimization: – Develop procedures – Strain selection (e.g. for fatty acid yield and composition, optimization and tuning – Produce algae with thin cell walls to simplify extraction – Optimal algae for NL climate plus “flexible” products – Breeding/select mutants, GMO or non-GMO • Select several “work horses” (micro-algal species and strains) for full analysis and characterization analogous to agro-crops (composition, harvesting, physiology) • Harvest algae from nutrient rich inland water bodies + refinery on-site. Pilot by 2015	• Separation of oligosaccharides • Separation of lipids, proteins, oligosaccharides + fine chemicals leaving functionality intact • Lipid refinery i.e. fractionation of lipids to 1. short chains to kerosine 2. medium chains to transport fuels + chemistry + PUFAs • Fractionation of proteins: 1. water soluble fraction for food and emulsions 2. water insoluble to food • Separation of amino-acids (affinity separation)
Pretreatment	**Output**
• Development of harvesting and dewatering technology e.g. - bioflocculation - coagulation/sedimentation - membrane technologies • Efficient cell disruption + fractionation technology • Mobilisation and fractionation of mixtures e.g. via ultrasound, mechanical, enzymatic? • Develop and improve (mild) extraction technologies	• Lipids/ hydrocarbons/oils and derived fractions e.g. Kerosine, transport fuels, chemicals, PUFAs • Proteins • Chemicals: bulk + fine chemicals • Specialties • Oxygen • Nutrients from dilute effluents concentrated in algal biomass as new natural fertilizer • Restfractions • Algae sector positioned successfully by 2015 and beyond in international setting with marketable production concepts and products
Other	
• Support and make use of existing initiatives and facilities at companies and R&D institutes • Methods must be mild to preserve existing molecules (= always the case) • Possibility to split out/extract specific product(s) as entrance to niche market • Algae as a production platform for fuels and chemicals is still in its infancy. Many fundamental questions in all areas of RD&D still have to be solved before commercial production is feasible	

Table 17 Barriers corresponding to moonshot 2: aquatic biomass; case micro-algae.

Feedstock	Secondary Refinery
• Scalability, also knowledge personnel • Routine technologies for other micro-organisms and plants are far behind in micro-algae (e.g. breeding, mutant selection, genomics, high-troughput screening, metabolic flux analysis) • GMO regulation, esp. for open cultivation systems • Lack of space/ high price per m2, while large-scale production systems are required • Spatial planning • CAPEX too high>> Biomass production cost is very high	• Energy consumption + CAPEX for separation technology is a barrier • Amino acid and protein separations are costly and complex • No flexibility exists at the moment for generation of multiple end products
Pretreatment	**Output**
• Energy consumption + CAPEX for separation technology is a barrier	• Regulatory approval for use of algae in feed/food (e\.gNovel foods) • Full scala of products + prices (proceeds) is not clear yet • Product to commercial application development is a barrier • Consumer acceptance of algae and seaweed products in food • Development of novel product applications is required to generate more market pull
Other	

• Education/training; lack of adequately trained personnel
• Existing micro-algae sector is
  - closed/fragmented/
  - Niche-applications/markets
  - rentability is doubtful (many R&D companies
• Budget is lacking for support of existing practical development trajectory e.g. biofuels
• Need for pilot scale facilities to apply the fundamental knowledge
• Only if sufficient material is produced can down stream processing be developed	

Table 18 Actions planned to overcome barriers corresponding to moonshot 2: aquatic biomass; case micro-algae.

Feedstock	Secondary Refinery
• Utilise/Support existing commercial pilot scale and production scale facilities • Set up High Throughput algae selection • Work on the development of a pilot scale facility for the production of micro-algae (business plan phase). In which: systems are compared 3-6 types at 25 m2 scale. New ideas/concepts are tested at 2m2 scale. Couple this facility to a biorefinery facility • Pilot scale test manure processing with algae (close minerals balance) • Develop 3 ha modular cultivation systems as demonstration units in collaboration with algae production companies; then replicate • Development of screening, selection of known and novel/unknown strains and product optimization procedures and tools incl. GMO applications • Development of cell-biological tools (incl. metabolic flux analysis), • Bioprocess optimization (for growth and productivity) • Development of genomics-based diagnostic tools like microarrays, PCR, allowing to optimize product quantities and composition of algae biomass as biorefinery feedstock	• Integrate knowledge & facilities for oil, food and fine chemical industry • Development of novel product applications to generate market pull • Effective technologies for separation of oligosaccharides, lipids, proteins, amino acids • Lipid/oil refining technologies

Pretreatment	Output
• Improvement of harvesting and dewatering technologies e..g. by bioflocculation, sedimentation and membrane separations • Development of mild and efficient cell disruption, extraction and fractionation technologies • Three step Approach – 1st step: GAP analysis – 2nd: Technology inventory, State-of-the-art – 3rd: To fill in blank spaces/holes	• Chain approach from algae to final product • Accelerate chain formation from alga to application through linking with existing (downstream) infrastructure • Realization of 3 upscalable commercial concepts and a full scale demo by 2015
Overall actions	
• Create a biorefinery investment fund with co-venture capital funds • Establish an open "learning company" (leerbedijf) under practical conditions to optimize economy • Budget for outreach activities • Cooperation of actor groups. Involve from the beginning in pilot projects • Establish dedicated laboratory for biorefinery of micro-algae • Coordination body to allocate technology R&D for all process steps to the right location • Enable/Fund pilot scale production (set up like a company), R&D (knowledge and R&D sector) on a substantial scale • Development of novel product applications to generate market pull / standardisation • Creation of expertise center to consolidate and diffuse knowledge	

Demonstration sea weeds

Table 19 Target description moonshot 2b: aquatic biomass; case Sea weed.

Feedstock	Secondary Refinery
• Demonstration at North Sea (ca. 100 ha, 2000 ton dw/yr) • Probably in wind turbine park • Demonstration of harvesting, processing and conversion on land • Take advantage of Bio Offshore pilot in Den Helder/ Zeeland • Look into agronomics of farm gate processes	• Hydrolyses, digestion, fermentation, distillation, or HTU • Demonstrate seaweed in HTU • Methane production for internal use • Process design for off shore use • Processing demonstration at scale of 10 ton (wet) per hour.
Pretreatment	**Output**
• Dewatering on sea • Extraction of proteins and oligosaccharines	• HTU oils • Ethanol • Methane
Other	
• Future plants could be offshore as seaweed production moves to the oceans. • The production volume of valuable compounds (secondary metabolites) will be rather high for the market. So development of new products can be an opportunity	

Table 20 Barriers corresponding to moonshot 2: aquatic biomass; case Seaweed.

Feedstock	Secondary Refinery
• Nutrition is hard to add at the North Sea due to ecological constraints • Spatial planning and regulations • Effect on sea animals unknown • Logistics • Severe weather damage • Consumer preferences unknown	• Seaweed contains much water • Processes need to be very efficient • Processes need to be usable off shore • Uncertainty of value of producible chemicals • Phosphate separation is expensive
Pretreatment	**Output**
• Dewatering should be done at sea • Extraction demands high energy inputs on a large volume • Markets for extracted valuables are small in volume	• Intermediate output (for transport to shore) could be necessary • Ethanol is not usable for all markets • Methane only transportable from sea by existing pipelines
Other	
• Public acceptation and juridical uncertainties	

Table 21 Actions planned to overcome barriers corresponding to moonshot 2: aquatic biomass; case Seaweed.

Feedstock	Secondary Refinery
• Find locations with high eutrophication • Investigate effects on fish life • Make production systems robust and weather proof (i.e. proof when we have Northwest 10 at very high tide!) • Use harvest systems to harvest escaped seaweed mass	• Do lab research on pilot scale to find optimum solutions
Pretreatment	**Output**
• Do lab research on pilot scale to find optimum solutions • Find new markets for high value compounds	• Look for production sites near off shore gas infrastructure if methane is output of choice.
Other	
• Reserve budget for outreach activities • Investigate juridical conditions in an early stage	

Demonstration synthesis gas production

Table 22 Target description moonshot 3: large scale biomass import; case synthesis gas production.

Feedstock	Secondary Refinery
• Multi feedstock: residues as well as cultivated crops, e.g. bagasse or willow	• Entrained flow gasification • Water-gas shift • Gas cleanup
Pretreatment	**Output**
• Drying • Sizing • Dedusting • Pelletising • Torrefaction • Pyrolysis • Hydrothermal upgrading • Storage • Blending for constant quality for secondary refining	• Synthesis gas (H_2 and CO) • Ash • Sulphur
Other	
• 4-6 ton/hr • Increase volumetric energy density for transport • Minerals cycles • Size 10 MW • Synthesis gas can be used for power, fuels and chemicals production	

Table 23 Barriers corresponding to moonshot 3: large scale biomass import; case synthesis gas production. Mind the other categories that have been used!

Feedstock, quality & price	Authorities & society
• Biomass availability • Biomass supply at low costs • Competitive claims for biomass for food/feed/fuel&fibres • Removal of sulphur and nitrogen from feedstock • Use of residues instead of energy crops • Variations in feedstock quality • Geopolitical issues in exporting country • Who takes the lead in chain: financing of different parts of the chain	• Use of GMO • International certification of biomass supply • Chain power: distribution of costs and responsibilties along the chain • Lack of support by society • Permits • Use of foreign (non-Dutch) technology in chain
Sustainability	**Product quality & technology**
• Minerals balance of whole chain • Keep minerals in usable form • Recovery of N, S and P in a sustainable form (integration with pretreatment?) • Energy balance of whole chain • Sustainability criteria for biomass	• Quality of syngas for different applications: power, fuel, chemicals • Choice of gasification technology 100% biomass or co-feeding biomass and coal • Different practices in different sectors agro vs. petrochemical

Table 24 Actions planned to overcome barriers corresponding to large scale biomass import; case synthesis gas production. Mind the other categories that have been used!

Feedstock	Authorities & society
• Develop logistics • Development of proper pretreatment technology to improve transport characteristics and to Improve properties for gasification • Conversion during transportation • Bring feedstock on specification for gasification process eliminating problems with downstream catalyst and with recovery of minerals	• Attractive incentives for pilot/demonstrations • Model chains to optimise: energy balance, minerals balance, sustainability and economy
Sustainability	
• Develop method(s) for recycling of minerals • Develop method for removal of “waste” components e.g. heavy metals which should not be recycled to the field. • Development of global valid crietria for sustainability (at least at EU level)	

Demonstration biomass for biofuels, feed and chemicals

Table 25 Target description moonshot 3: large scale biomass import; case biomass for biofuels, feed and chemicals.

Feedstock	Secondary Refinery
• Residual products from the soy oil industry as well as rape meal and wet distillers grain from the biofuels industry	• Hydrolyse and recover the remaining protein • Recover phosphate • Convert lignocellulose to electricity • Conversion of proteins/amino acids to bulkchemicals and animal feed
Pretreatment	**Output**
• Alkaline washing of protein from the residues	• animal feed protein • amino acids • bulkchemical intermediates • phosphate • electricity

Table 26 Barriers corresponding to moonshot 3: large scale biomass import; case biomass for biofuels, feed and chemicals.

Feedstock	Secondary Refinery
• The wheat wet distillers grain cannot be stored and represents large volumes to be transported	• Power plants need raw materials with little nitrogen residues • Potassium will be difficult to recover with economic limits
Pretreatment	**Output**
• Actual processes are not very energy efficient but will be difficult to substitute because of new investments • How to reduce capital cost?	• Public opinion against first generation biofuels • Level playing field problems for market entrants

Table 27 Actions planned to overcome barriers corresponding to large scale biomass import; case **biomass** for biofuels, feed and chemicals.

Feedstock	Secondary Refinery
• Develop technologies combining wet and dry streams in order to reduce water removal costs	• Develop technologies for lignocellulose to ethanol • Develop technologies for lignocellulose amino acid to bulkchemicals • Develop efficient phosphate recovery system
Pretreatment	**Output**
• Develop technologies for full protein removal and recovery	• Communicat that there is a good balance of using all the components from wheat and rape in a sustainable way • Support knowledge diffusion

Demonstration undefined residues

Table 28 Target description moonshot 4: biomass residues; case undefined residues.

Feedstock	Secondary Refinery
• garden and kitchen waste • manure/digestate • verge grass • sludge from waste water treatment • food waste (swill) • B-wood • mixed residues from vegetable processing industry • Varying composition • Mostly negative economic value • geographically dispersed availability	• fractionating pretreatment products to well-defined outputs • extract valuable components • upgrading biogas to green gas • distillation • pervaporation • what purity can be reached?
Pretreatment	**Output**
• Upstream measures for better definition of the residues ("separation at the source") • Pretreatment processes that can handle varying feedstock quality • Dry/wet separation • biogas fermentation • Thermo-chemical conversion (e.g. pyrolysis, HTU) • Small-scale pretreatment could prevent large-scale transport	• biogas, green gas • biodiesel • enzymes for biorefinery • oil • … • Bulk applications seem most suitable. • Output should cover costs of processing.

Table 29 Barriers corresponding to moonshot 4: biomass residues; case undefined residues.

Feedstock	Secondary Refinery
• Safety • No/low priority for quality • Varying quality and composition • Expensive collection logistics • Quality loss • Label "waste" leads to severe restrictions for processing	• Still varying composition of pretreatment outputs • Costs too high
Pretreatment	**Output**
• Flexibility with respect to varying input • Costs are too high	• Legal regulations with respect to use of materials out of waste. • Limited purity
Other	
• Local, regional, national, world-wide minerals cycles: legislation inhibits sustainable solutions • Long-term depreciation periods on waste processing equipments hinder fast introductions of novel processes • Expensive logistic consolidation of supplies	

Table 30 Actions planned to overcome barriers corresponding to moonshot 4: biomass residues; case undefined residues.

Feedstock	Secondary Refinery
• Upstream measures for quality and safety of the residues • Take upstream measures (possibly including pretreatment) in order to reduce collection costs • Solve label "waste" • Multifunctional biomass residues depot (one-stop delivery point)	• Develop adequate inexpensive processes
Pretreatment	**Output**
• Develop adequate inexpensive processes • Pretreatment for leaving minerals behind	• Take away legal obstacles
Other	
• Work out sustainability problems and effects of legislation for dialog with government • Find lead partners	

Demonstration defined residues

Table 31 Target description moonshot 4: biomass residues; case defined residues.

Feedstock	Secondary Refinery
• Beet pulp • potato steam peels • potato fibres • waste water from defined processes • vegetable and fruit pulps • Sugar beet leaves • beetroot tops • leaves from tomato and bell pepper production • Large volumes • Often seasonal production • Options for recycling minerals needed	• Fractionating • Conversion technology (chemical-catalytic, bio-chemical) • Mechanical processing • Remove non-functional surplus of minerals
Pretreatment	**Output**
• Fresh => limited storage life • Specific separation process for the feedstock	• Bulk applications • Building ingredients for food, feed, chemistry and pharma • Building blocks chemical and polymer industry • Sugars • (modified) Oligosaccharides • (modified) Polysaccharides • (modified) Proteins • (modified) Amino acids • enzymes • Minerals • Fuels • Energy (re-used in process) • Develop those combinations of products which allow maximum value creation. • All products must have a market • No waste • Search for bulk markets with relatively high added value

Table 32 Barriers corresponding to moonshot 4: biomass residues; case defined residues.

Feedstock	Secondary Refinery
• Seasonal processing of agricultural products => seasonal availability of residuals • Limited storage life of fresh residuals	• Costs are too high • Need for adequate processes/conversions • Increase selectivity and yield of conversion steps • Because of use of large amounts of (processing) water other problems are created (drying need, waste water) • Fractionation processes are not mild enough, not energy efficient and use too much water.
Pretreatment	Output
• Seasonal use of equipment is inefficient. • Costs are too high • Feedstock-specific processes have to be developed	• Market is underdeveloped • Substantial amount of material needed to develop the market • Cooperation in the supply chain is a critical success factor in the market development (Esp. the cooperation between agro-food industry and chemical industry needs to be developed). • regulatory issues with respect to re-use of minerals
Other	
• Legislation hinders recycling of mineral concentrates out of the products on the field • (Access to) pilot installations for pretreatment and secundairy refinery • Voluminous transports	

Table 33 Actions planned to overcome barriers corresponding to moonshot 4: biomass residues; case defined residues.

Feedstock	Secondary Refinery
• Increase yield / ha • Increase contents of valuable ingredients in crop • Select and develop other crops/residues to be used in the same processes (so that processing equipment can be used the whole year round) • Increase storage life of crop or residues (to lengthen the processing season)	• Reduce processing costs • Increase selectivity and yield of conversion steps • Separation technology: Develop mild, dry and selective separation processes (low energy low T, low water consumption) • Develop mild dewatering techniques • Recovery of minerals and make them suitable for re-use • Integrate power and heat production and use in the biorefinery, possibly by side-product conversion
Pretreatment	Output
• Look for ways to process different crops in the same plant. • Find less expensive processes. • Reduce costs for enzymatic (pre)-treatment • Process downscaling (consider centralized vs. decentralized processing).	• Search for market and chain structures. • Solve regulatory issues around re-use of minerals