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European Polysaccharide
Network Of Excellence

EPNOE Road Map 2010 - 2020

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Content

General Aspects

Research

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I. Brief description of the European Polysaccharide Network of Excellence (EPNOE)

The European Polysaccharide Network of Excellence (EPNOE) is a research and education network connecting 16 academic and research institutions and a large number of companies focusing on polysaccharide and polysaccharide-related business. The 16 institutions are composed of top-ranked universities and research centres, which have developed expertise and state-of-the-art technologies in polysaccharide-related disciplines such as chemistry, enzymology, chemical engineering, mechanics, materials science, microbiology, physics and life cycle assessment. EPNOE's main missions, in the field of materials, food, and pharmacy/medicine, are to organise education in polysaccharide science and to perform basic and applied research for the development of new products based on or containing polysaccharides.

II. Objectives and scope of the EPNOE Road Map 2010-2020

The EPNOE network prepared in 2005-2006 a research road map that was used to structure the basic research performed by the sixteen academic and research partners up to the end of 2009, only focused on materials based on polysaccharides. EPNOE took the decision end of 2008 to prepare another road map with a broader scope encompassing materials, food and health, and taking both research and education in consideration. The resulting road map, described here, was prepared from various social, political, industrial and scientific inputs coming from inside and outside EPNOE. The objectives of the EPNOE Road Map 2010-2020 are:

- to support EPNOE members in their research and education strategies,
- to help all stakeholders (research institutes, young scientists, companies, national and international agencies...) to identify new activity areas relevant for their purpose.

The present document is a condensate of a larger document which is only accessible to the sixteen academic and research institutions and to the companies members of the EPNOE Business and Industry Club. More information can be found on www.epnoe.eu.

Three main drivers are strongly pushing the use of polysaccharides:

1. The emergence of the bio economy increasing the contribution of bio-based products used in future.
2. The fact that polysaccharides are polymers with exceptional properties, far from being fully recognized, used in all sectors of human activity (materials science, nutrition, health care).
3. The availability and renewable characteristics of polysaccharides making them the primary candidates for transformation to a more sustainable world (potential increase of biodiversity, food safety and sustainability, decrease of pollution, able production of fuel and materials, low carbon footprint).

> Polysaccharides will be at the central point of the world of tomorrow for fuel, food, materials and medicine

Such new trends are not without questions and the motivations for using polysaccharides can be challenged:

- A severe shortage of oil to the point of threatening the production of oil-based polymers may not occur before a long time.
- The environmental assessment of using polysaccharide materials (as well as a lot of bio-based materials) does not always show a benefit.

- Bad planning and management of resources could lead not to an increase, but to a drastic decrease of biodiversity.
- Innovations like e-inked paper could lead to a strong decrease of paper production, decreasing side-product availability.
- Recyclability of bio-mass based materials could be difficult.
- Massive increase of polysaccharide use for energy and materials can compete with food supplies.

Taking care of these challenges as well as on the advantages of polysaccharides (decrease of CO_2 emissions, potential for innovative high value/performance products, and use of by-products/wastes…) was behind our efforts to build the EPNOE Road Map. Its main characteristics are:

- Definition of key issues able to help finding the relevant scientific challenges for polysaccharide research and development, a difficult task due to the very broad scope of use of polysaccharides in many different fields.
- Innovation booster: application and research is very multidisciplinary, starting from agronomy and biology up to the many disciplines needed to reach a marketable product. It is the combination of very different expertise that lies behind innovation.
- Translation of science into applications and of practical questions into science.
- Education dimension, a critical issue due to the multidisciplinary requests of polysaccharide science.

III. Main political, societal and industrial challenges where polysaccharide science can play a role

A detailed description of political, societal and industrial challenges as adopted by European Union and United States of America is in the private EPNOE web site open to academic and industrial EPNOE members. Only the main aspects are outlined below.

III.1. Political challenges (EU and USA)

III.1.1. European Union

The main areas where polysaccharides can play a role in the EU vision for future are energy and **materials, food**, **health,** agriculture, and mobility.

<u>Energy **and Materials**</u>**:** The European Union has adopted a Strategic Energy Technology Plan (SETPlan) where by 2020 the emission of greenhouse gases should be reduced by 20%, the renewable energy contribution should be tripled up to 20% of primary energy, and the share of appropriate biofuels will rise, while reducing the foreign dependence on the supplies [1]. For effective wide scale adoption there must be a demonstrable cost advantage to invest in low energy technologies. **Reducing the amount of polymer** to produce a product leads to energy reductions due to the fact that less material will need to be melted and processed (e.g. weight reduction through foaming; waste reduction through on-line quality control, faster change-over etc.) There is a need to more fully **understand** the true 'energy balance' for extrusion, injection moulding and other **polymer processing processes**. There is significant scope for the **development** of current **equipment and processing techniques** by the implementation of new technologies such as supercritical fluid processing, fluid assisted moulding. It should be remembered that plastics processing is very much more energy efficient than the processing of metals, glass and ceramics. Therefore the replacement of these materials with polymers in many applications is desirable [2-6].

<u>**Food:**</u> Increasing demands for ingredient performance require i) deeper physical, chemical and biological properties **knowledge** of materials science of **food matrices**, also at the nanoscale e.g.

antibacterial coatings based on nanomaterials [7]; ii) development of more **sustainable food** and farming systems; and iii) creation of entirely novel artificial organisms for use in **food processing** [8].

Health: Improving health, including the increase of effectiveness in fighting emerging epidemics, in addition to responding to the growing demand for food and for bio resources is a topic requiring urgent attention [1]. The **Health care** area, critical to the competitiveness of the US, will be significantly impacted by developments in polymer science and engineering in designing well-controlled polymer systems e.g. with **biological functionality**, to treat disease. In the area Defence and Protection significantly improvement will be done in protective clothing, **improved composite materials** and in **improved surface properties**. In the context of current challenges such as ageing population or the fight against possible pandemics (e.g. avian flu), effective **use of genomics**, **life sciences** and biotechnology appear to be of key importance [9]. The European Union promote **good public health** on equal conditions and improve protection against health threats as regard to appropriate health promotion and disease prevention strategies in cooperation with WHO, the Council of Europe, OECD and UNESCO; ensuring that by 2020, chemicals produced, including pesticides, would be handled and used in ways that do not pose significant threats to human health and the environment [10].

Agriculture: The impacts on agriculture of global warming depend on the specific region (e.g. lack of water; loss and mineralization of soil carbon content; heat stress; natural extremes; changes in pests and diseases; etc.). There is an expectation that the climatic suitability of crops will generally be moving northwards as a result of these impacts while in terms of forest systems, these impacts will manifest themselves at various scales, ranging from physiological changes through to ecosystem effects and then to major disruptions or disasters [11]. The European Union set out the Sustainable Development Strategy on how the EU will more effectively live up to its long-standing commitment to meet the challenges of sustainable development i.e. to identify and develop actions to enable the EU to achieve continuous **improvement of quality of life** both for current and for future generations, through the creation of sustainable communities able to manage and use resources efficiently and to tap the ecological and social innovation potential of the economy, ensuring prosperity, environmental protection and social cohesion [10].

Mobility: The substantial increase of Europeans over 65 years of age (17.6% in 2020) will create a strong demand for improvements in the existing mobility system. Research is needed to identify large-scale sustainable and cost-effective low carbon sources of hydrogen; renewable fuels from wind and solar power; and to develop more efficient pathways than the current ethanol and biodiesel, for fuel cell vehicles. **New materials concepts** are needed to address the competing pressures for weight reduction of cars and ease of reuse and to improve processes to facilitate effective recycling, including efficient dismantling and materials recovery methods [12].

III.1.2. United States of America

The main areas where polysaccharides can play a role in the USA vision for future are energy and **materials, food,** agriculture, and mobility [13].

Energy and **Materials**: The US National Science Foundation (NSF) put out the sustainability**,** as technology area to be critical to the competitiveness of the US, to be significantly impacted by **developments in polymer science** and engineering regarding **using plants as a renewable source** of monomers that can be polymerized into new materials and eliminate the use of toxic solvents as well by significantly enhancing energy output and durability, and **development of lightweight composites**. The focus will be oriented also in discovering **new polymer synthetic routes, catalysts, and processes** that use environmentally “friendly” solvents and require significantly less energy as well as on using polymeric materials for water purification and waste treatment [6]. Products Platform envisions the use of all biomass components (i.e. **cellulose**, **hemicellulose**, and **lignin**) as building blocks for **conversion** of raw material feedstocks **to useful “products”**. The **fermentation of cellulose based sugars**, which include the **xylose** and **arabinose sugars**, **is not** as **readily understood**. The primary need is to develop organisms (e.g. from yeast or fungus) capable of utilizing all the sugar components from a biomass hydrolysate to make value-added fuels or chemicals with minimum by-products at relevant process conditions. Fundamental research will be needed to support development of new catalysts for hydrogenation sugars and oils, as well as oxidation, dehydration, and selective bond cleavage. Catalyst selectivity and contamination are barriers to future use of syngas for products. Improved catalyst lifetimes via purification methods will need to be developed to ensure cost-effective production of fuels and chemicals. USA Multi-Year Program Plan Biomass and Biorefinery Systems R&D progressively enable increasing amounts of bio fuels and biomass derived chemicals and materials from a widening array of feedstock [14]. The approach will not only have a significant impact on oil displacement (bio fuels derived from biomass), at the earliest opportunities, but will also facilitate the paradigm shift to renewable, sustainable energy and chemicals in the future. Electricity from biomass combustion is projected to more than double by 2025; therefore the United States of America collectively has implemented hundreds of policies to promote the adoption of renewable energy, for reasons ranging from energy diversification, to economic development, through air-quality improvement and greenhouse gas reductions [14]. As the world's largest emitter of greenhouse gases (i.e. responsible for 23% of global carbon dioxide emissions and is the world's largest consumer of energy), USA will play a central role in avoiding dangerous climate change i.e. low-emission transport; capital investment towards climate-friendly solutions; renewable energy industry development etc. [15].

Food: Food production inevitably leads to the production of large amounts of solid and nutrient laden liquid waste. National policies like the Wisconsin Department of Administration one define as key challenge the identification of the **alternative uses for extraneous plant and animal material, packaging materials**, and the production of value-added products, including energy, **from these waste streams** [16].

Agriculture: The United States of America developed several approaches defining the use of agriculture residue (corn plant, corn stover, sugar cane, beet residue, **wood feedstock**, **lignin intermediate**, **ligno-cellulosic biomass**, biomass-derived bio refinery residue) aiming at processing fuels and chemicals, which should be the primary theme in the future [14].

Mobility: The U.S. transportation sector is almost entirely dependent on oil (97 percent), using only small amounts of bioenergy, natural gas, and electricity. The most direct and near-term alternative to oil for supplying liquid transportation fuels to the nation could be bio fuels derived from **biomass** as will be implemented through the American Recovery and Reinvestment Act of 2009 (Recovery Act), 17February 2009 and funding of 2nd generation biofuels research (Department of Energy at www.energy.gov).

III.2. Some Non Governmental Organisations opinions

III.2.1. Agenda 21

Agenda 21 was adopted during the United Nations Conference on Environment and Development (UNCED). It is the international plan of action that outlines key policies for achieving sustainable development that meets the needs of the poor and recognizes the limits of development to meet global needs.
Within the 4 main chapters, it addresses poverty & excessive consumption, agriculture & **food**, **health** & **education,** cities, and **natural resource management**. The section –conservation and management of biodiversity focuses on Protection of the Atmosphere, Land Resources, Deforestation, Desertification & Drought, Sustainable Mountain Development, Sustainable Agriculture & Rural Development, Conservation of Biodiversity, Biotechnology, Protection of the Oceans, Freshwater Resources, Toxic Chemicals – Management, Hazardous Wastes – Management, Solid Wastes - Management and Radioactive Wastes – Management [17].

Food: The Biotechnology area was applied in order to increase the **availability of food**, feed and **renewable raw materials, improve human health**, enhance protection of the environment and safety and establish enabling mechanisms for the development and the environmentally sound application of biotechnology [19].

Health: A great deal remains to be done to ensure the environmentally sound management of toxic chemicals, within the principles of sustainable development and improved **quality of life** for humankind [20].

Agriculture: With the aim of promoting sustainable agriculture and rural development they planed and integrated programmes in the light of the multifunctional aspect of agriculture, particularly with regard to **food security** and sustainable development [18].

III.2.2. Intergovernmental Panel on Climate Change

Intergovernmental Panel on Climate Change provides an integrated view of climate change [21]. Changes in atmospheric concentrations of greenhouse gases (GHGs) (i.e. CO_2; NH_4; N_2O) and aerosols, land-cover and solar radiation alter the energy balance of the climate system [22].

Food and Health: There are several impacts on future climate changes on systems, sectors and regions i.e. Ecosystem**, Food and Health** projected over the 21st century. Approximately 20-30% of plant and animal species assessed so far are likely to be at increased risk of extinction if increases in global average temperature exceed 1.5-2.5^{o}C. Globally, the potential for **food production** is projected to **increase** with increases in local average temperature over a range of 1-3℃, but above this it is projected to decrease (medium confidence). Critically important will be factors that directly shape the **health of populations** such as **education**, **health care**, **public health initiatives**, and infrastructure and economic development [23].

III.2.3. WWF

The WWF Climate Model solutions, base on 25 different low-carbon energy technologies reviews, claim to be able to reach the goal of meeting global energy demand avoiding adverse serious environmental and social consequences.
To halve the current rate of deforestation by 2015 and achieve a zero rate by 2020 would result in cumulative emission reductions of 27Gt carbon dioxide by 2020, and 105Gt by 2030 [25-28].
Energy **and Materials,** Agriculture: Some conventional crops, such as sugarcane or **woody biomass**, can provide net benefits if sustainably produced and processed, and are already available for use as bioenergy. **Future investments and research** should be oriented towards **ligno-cellulosic** or other crops that offer better options to reduce carbon dioxide emissions, as well as on a reduced impact on the environment [24-27].

III.3. EU industrial challenges

III.3.1 Strategic Agenda of the Forestry Technological Platform

Forest-Based Sector Technology Platform (FTP) is aimed at increasing the competitiveness of Europe by developing innovative products and services and is divided into three sections; the most important is moving towards common goals with research.

Materials and Health: The Strategic Objective as "Development of innovative products for changing markets and customer needs" covers 10 research areas; the most important concerning wood products are i) A new generation of functional packaging (**wood** and **fibre-based packaging materials**) and ii) Building with wood (**wood-based materials** used in construction and building). In strategic objective "Development of intelligent and efficient manufacturing processes, including reduced energy consumption", the most important areas in wood section are i) **Advanced technologies** for **primary wood processing** (material efficiency and lower energy consumption) and ii) **New manufacturing technologies for wood products** (advances in technology). The leading strategic core areas for "Enhancing availability and use of **forest biomass** for products and energy" are i) Recycled wood products - a new material resource (recycled products and new advanced materials) in wood products section, while in pulp and paper products section i) **Advancing hygiene and healthcare** (applying nano-, bio- and ICT-technologies), ii) **Pulp, energy and chemicals from wood bio-refinery** (contribution to a bio based economy), iii) **Re-engineering** the **fibre-based value chain** (advanced production concepts), iv) **More performance from less input in paper products** (growth in products and services with less environmental impact), v) **"Tailor-made" wood supply** (increase the productivity and value of forest products manufacturing), and in the section specialities "Green" specialty chemicals (production of **specialty chemicals from forest resources**), and **New**

generation of composites (wood-based composites for a new technical and life science applications) [28-29].

III.3.2 Strategic Agenda of Suschem

The **European Technology Platform (ETP) for Sustainable Chemistry (SusChem**) identifies strategically important issues with high societal relevance in the areas of chemistry and industrial biotechnology, determines the challenges in these areas, and defines R&D priorities, timeframes and budgets [29-30].

Materials, Food and Health: In the SusChem vision, several specific areas as: industrial biotechnology, **material technologies**, reaction and process design and horizontal issues, are outlined. The Industrial Biotechnology section details the approach to make Europe's industries leaders in biotechnology processes and technologies for various sectors, including chemicals, **food** and nutrition, textiles, leather, animal feed, **pulp and paper**, energy and waste processing. The technical aspects that have to be tailored with adequate technologies are i) **Novel enzymes and microorganisms**; ii) Microbial **genomics** and bioinformatics, iii) Metabolic engineering and modelling, iv) **Biocatalytic process** design and v) Innovative **fermentation** science and engineering. In order to provide guidelines for realising the goals and challenges set by the EU to address the societal needs of energy, **healthcare**, information and communications technology, **quality of life**, citizen protection and transportation, following research areas in **Materials Technology** section were identified as: i) **Fundamental understanding of structure property relationship**, ii) **Development of analytical techniques** and iii) **Bio-based performance** and nanocomposite materials (including synergies between bio and nano). The Reaction and Process Design section considers the developments necessary to achieve sustainable development and identifies the following research areas, which exert particular impact on the objectives and societal needs i.e. i) Novel synthetic concepts, ii) **Biotechnological processing** and iii) Purification & formulation processes [30].

III.3.3 Strategic Agenda of Plants for the Future

The European Technology Platform "**Plants for the Future**" presents a vision of plant research for the next 20 years and identifies challenges for Europe's society and economy to which the plant sector can contribute. The Strategic Research Agenda identifies two challenges for Europe's society and economy to which the plant sector can contribute: i) **Healthy, safe and sufficient food and feed** and ii) Sustainable agriculture, forestry and landscape [31].

Materials, Food and Health: European plant scientists should focus on the development and production of diversified and affordable **high-quality plant raw materials for food products**. The increased demand for animal products should be met by ensuring the sustainable production of high-quality, sufficient, and affordable feed. It is imperative that new biotechnologies, such as genetic modification, can be used to ensure a competitive position for Europe in the emerging bio-economy. Therefore the challenge will concentrate on Biochemical production, Bio-energy production, and enabling research for plant-based products. By 2025, 30% of the **raw materials** needed for chemical manufacture in the EU could be obtained from plant-derived renewable resources, subject to appropriate research and development. New plant raw materials may include **medicines**, speciality chemicals and enzymes, industrial feedstocks, **polymers** and fibres. These materials will have **applications in** the **health**, **nutrition** and **materials industries**.
Since the human population will continue to grow over the coming 25 years, urbanisation will increasingly encroach on agricultural land and forests, while reservoirs of new land are very limited. Therefore, Europe will have to find ways of boosting its contribution to global **output of food**, feed and renewable resources in a more sustainable way. To achieve this will require the use of novel tools to study plants at various biological and environmental levels. At the same time, genomics could help to enhance plant breeding techniques, leading to improved varieties and agricultural practices. An array of novel technologies has emerged which allow researchers to identify the sources of crop and tree improvements, namely the genes that contribute to the improved productivity and quality of modern crop varieties and the genes that enhance tolerance to stresses, whether biotic or abiotic, or to a better utilisation of inputs. A deeper understanding of how the domestication process works is likely to lead to the emergence of new approaches and methods. In addition to research in these fields, researchers should **develop predictive methods**, including modelling and simulation. That would

help **to forecast the adaptive response of crops and forest trees** to unpredictable environmental changes linked to global warming in various geographical regions in Europe [32].

Energy and Mobility: By 2020, 20% of transport fuel should be derived from biomass, according to the EU's recent Biofuels Directive. The key technological challenges for the production of renewable biomass-based fuels require a high degree of optimisation of the cost-efficiency of biofuel production, including biomass yield, nutrient and water use efficiency, and energy conversion efficiency. This can be achieved through the development of successive generations of biofuel crops [32].

III.3.4 Strategic Agenda of Food for Life

The **European Technology Platform (ETP) Food for Life** aims at an effective integration of strategically- focussed, trans-national, concerted **research in** the nutritional-, **food-** and consumer sciences and **food chain** management so as to deliver innovative, novel and **improved food products** for, and to, national, regional and global markets in line with consumer needs and expectation [33].

Food: To respond successfully to this concept, the food industry will need focus on **producing tailor-made food products**. The vision for 2015 and 2020 is new product functions arising from new ingredients or from processing via biotechnology, separation technology or nanotechnology, and to develop environmentally friendly sustainable food processes, such as better utilisation of side streams and innovations to avoid excessive packaging. In order to improve the competitiveness of the European food industry, innovations in process design and process control as well as **novel food packaging concepts** are required. To achieve this goal, the first major research challenges is providing improved Preference, Acceptance and Needs (PAN) functions through the redesign and **optimisation of food processing and packaging**, in order to increase competitiveness and sustainability. In order to solve the PAN key challenge by 2015, the New PAN function-driven **sustainable food processing** in synergy with **new packaging technologies**, should be considered. In addition, **Risk-benefit balanced innovative, sustainable, and safe food packaging** for implementation into integrated food chain concepts, as the second major challenge, should be taken into account. This key challenge could be solved by 2015 bearing in mind following two concept i) Novel intelligent packaging including the use of nanotechnology for **monitoring food quality and safety during transport, storage and processing**, and ii) **New active packaging that** would **reduce the food degradation** and as well be used for controlled delivery of functional components. Knowledge on **process-structure-property relationships** will increasingly allow the creation of tailor-made food products by new processing technologies. The most important research challenge is to **understand relationships of food structures from molecular via nano- to macro scale with respect to product and process design**, and to develop new processing principles for improved PAN profiles [33].

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IV. General scheme of the Research Road Map

The EPNOE Research part of the EPNOE Road Map is built around two main blocs, “Fundamental basis of polysaccharide science” and “Application fields”.

Fundamental basis of polysaccharide science

Application fields

	materials	food	health care
dis-assembly	biorefinery tools	isolation/extraction	extraction/purification characterisation
re-assembly	product manufacturing	texturation and structure creation	biocompatible, functionalized products
end of life cycle	recycling/composting biodegradation	digestion/nutrition	depends on function

“*Fundamental basis of polysaccharide science*” is common to all application fields and is aimed at understanding the major factors limiting and increasing the applicability of polysaccharides:

- Identification of sources taking into account under-utilized/new productions, climate challenges, GM possibilities, food/non-food competition, biodiversity and sustainable uses of resources in all countries
- Structure, extraction, dis-assembly and isolation of single PS or PS-based blocs
- Development of characterisation and qualification methods
- Polysaccharide-polysaccharide and polysaccharide- non-carbohydrate interactions
- *In-vitro* (enzymatic, mechanical, chemical, physical, …) and *in-vivo* (modifying natural sources to tailor bio-produced polysaccharides) modifications

Three distinguished application fields in industrial sectors are falling within the expertise of EPNOE:

- Materials
- Food
- Health care

For each of these Application fields, three levels are considered:

- Dis-assembly
- Re-assembly
- End of life cycle

In addition, the Materials field has a section on economical and environmental assessments.

The research part of the EPNOE ROAD MAP has been based on three main sources, (1) results of four brain-storming sessions by EPNOE scientists and students, (2) individual contributions of EPNOE scientists and (3) individual contributions of scientists outside EPNOE through an internet review. The full description of these contributions is available to the 16 EPNOE academic/research partners and to the companies members of the EPNOE Business and Industry Club. More information at www.epnoe.eu.

V. Fundamental basis of polysaccharide science and technology

Identification of new polysaccharide sources taking into account under-utilized/new productions, CO_2 neutral production and climate challenges, possibilities of genomics, food/non-food competition, biodiversity and sustainable uses of resources in all countries:

- Exploring the role and possible uses of less common polysaccharides in bio-assembly of materials (animal, seaweeds and algae, bacteria, and fungi).
- Utilisation of waste or by-products of industry and municipal waste treatments.
- Exploring the possible uses of not yet used plant polysaccharides.

Structure, extraction, dis-assembly and isolation of single PS or PS-based blocs:

- Study of genetic control or agronomic manipulations of polysaccharide bio-assemblies with the aim of understanding (a) how biosynthesis arranges the various components of the cell wall or carbohydrate storage, (b) the polysaccharide structural organization (tailoring) during biosynthesis and (c) polysaccharide construction/ layering, temporary structures and biological scaffolds.
- Understanding of the nature of supramolecular polysaccharide assemblies, the interaction of polysaccharides *in-vivo* with other organic components, the physics and chemistry of water in the interactions with polysaccharides; the differentiation between dry state / never-dried state / swollen state and the H bond network in natural environment.
- Characterisation and modelling of crystalline and not-fully ordered organisation, supra-molecular assemblies (helices, electrostatic interactions), surface hydrophilicity / hydrophobicity, charge / smoothness, pores.
- An understanding of the basic requirements of hydrogen and ionic bond breakage for extraction.
- The isolation of selected components with new “green” extraction methods reaching absolute (complete) extraction (retaining molecular structure) or to be able to perform partial extraction keeping some degree of supra-molecular organisation.

Development of characterisation methods:

Separation, purification, modification and application of polysaccharides require the use of suitable analytical tools to describe degree of modification e.g. degree of substitution, chain length, including degree of branching, chain conformation, crystallinity, and solvent interaction in structures in relation to physical behaviour. These techniques must be applied to polysaccharides studies in materials, food and health-related research. For materials, it should include gels, films and fibres, plastics and cross-linked resins. Of particular importance are accessibility, swelling and porosity.
While some of these data are available for rather pure substances and some simple states, there is a substantial demand to develop new analytical methods describing the intermediate states of polysaccharides (swollen state, gel, non crystalline areas), the various transition layers (like surfaces) and the interactions between polysaccharides or between polysaccharides and small molecules.
To achieve this, new analytical methods (e.g. immunochemical assays / lectins, bio-recognition and enzyme assisted cleavage) must be developed and existing ones improved for advancing in the structural characterization of polysaccharides.

Polysaccharide-polysaccharide and polysaccharide-non-carbohydrate Interactions:
Polysaccharides exhibit intensive interactions between (1) themselves (polysaccharide-polysaccharide interactions leading to polymer structure formation) and (2) with other polymers (e.g. proteins, lignins and phenolics, synthetic polymers) 3) with smaller molecules (e.g. water, and other (ionic) solvents, leading to swelling, dissolution). What must be understood is:

- Biosynthesis of supra-molecular polysaccharide assemblies
- Interactions of polysaccharides with other organic or mineral components/location and nature
- Physics and chemistry of water, dissolved additives and solvents / polysaccharide interactions
- The differentiation between hydrated / dry state / never-dried state / swollen state
- The amorphous and swollen state and recrystallisation
- H bond network and its changes during swelling, drying and dissolution.

- Accessibility of polysaccharide surface for chemical interaction (with enzymes / proteins or chemicals and solvents) in amorphous regions, in swollen state.

Interaction of polysaccharide with small molecules forms the chemical basis for sorption of substances and dissolution of polymers. Fundamental knowledge about sorption behaviour including hydrogen-bonding and hydrophobic interactions will be required to design materials for:

- Food applications (hydro-colloids)
- Medical and cosmetics applications (slow release conjugates, supports for cell culture growing, bioactive compounds, (anti)allergenic and anti-bacterial, antibiotic/ antiviral; immunogenic properties and physiological interactions)
- Technical applications (paints, solutions for shaping, casting, blending,...)

Interaction of polysaccharides with proteins or other biological components; specific molecular recognition (e.g. anti-bodies for analytical purposes, diagnostic, cross-linking etc).

In-vitro (enzymatic, mechanical, chemical, physical …) and *in-vivo* (modifying natural sources to tailor bio-produced polysaccharides) modifications:

In-vitro

- New media for enzymatic treatments (ionic liquid, supercritical fluids)
- Hydrolytic, oxidative/reductive and transferase enzyme catalytic efficiency improvements
- Selective enzymatic cleavage of chains, side groups and branches
- Hybrid physical chemical treatments (high temperatures, high pressures, supercritical fluids, enzymes, ultrasound, microwave...).
- Highly, reliable regio-selective chemical treatments
- Combining chemical-physical-mechanical treatments
- Structural alignment and polysaccharide orientation (template surface interactions)

In-vivo

- Genetic control of polysaccharide formation; effects on crop physiology and yields; bio catalysed agronomic (induced) manipulations of bio-assemblies to understand structure-properties relationships and to produce new polysaccharides with specific functions (functional genomics).
- Genetically-modified and physiologically improved crops, including cell culture production and agronomic testing of manipulated crops for understanding of different bio-assemblies and structure-properties relationships, with the aim of creating new materials or improved productivity.
- Use of molecular biology to alter the structure of starch and other storage polysaccharides within the plant material. Adaptation of methods on polysaccharides from genetically modified plants, study of special starch and polysaccharide sources (corn, pea, coffee, cocoa, etc.).
- Exchanging components inside the biological structures (e.g. production of chitin in plants?). Inventing exchange techniques.

VI. Materials

Polysaccharides in many forms play a central role in all living organisms for supply and storage of energy and structural integrity and protection of cells. The science for use of polysaccharide-based substances is well evolved in manufacturing of health and cosmetic products, food and feed production, and for cellulose derived materials (wood products, paper and cellulose derivatives, or textiles). Innovation should:

- impart novel functional properties in (CO2-neutral) materials,
- increase performance in bio plastics, bio films, protective coatings, structural performance materials,
- decrease environmental impact (search for non-polluting methods).

This will require novel tools for manipulation of structures and smart design of processes. Much of the existing technologies for synthetic polymer processing and material testing apply for biopolymers, but there are significant differences with respect to the role of water and hydrogen bonding. The affinity of polysaccharides for water implies dimensional instability when uptake (swelling) and drying (shrinking) occurs. At elevated temperature when water is evaporating, polysaccharides quickly loose their flexibility and mechanical properties to become brittle and they easily decompose. On the other hand hydrated polysaccharides are susceptible to microbial attack and biodegradation, which needs to be prevented for durable use of materials. The search for alternative conditions and tools for polysaccharide processing, modification and conversion into technical applications and commercial interesting materials deserves a high priority from a scientific research point of view.

VI-1 Dis-assembly

Separation / Fractionation
Nature provides polysaccharide-materials embedded into a complex matrix of compounds, which define the function of specific assemblies like cell walls, grain, marine animal shells. The future use of polysaccharide material is directly coupled to the availability of suitable methods to extract and purify the desired fraction of polysaccharides up to the quality defined by the processing route and application. Important routes to follow for achieving this are:

- Sequential eco-efficient extraction processes without degradation (new enzymatic processes) to give high yields of "pure" polysaccharide components e.g. glucomannans, xylans and other hemicellulose
- Fractionation by sequential removal of various compounds / components; Fractionation in well-defined forms using new environmental-friendly chemicals (ionic liquids, ..).
- Enzymatic degradation (homodispersed fragments of cellulose, cleavage of side groups and branches, new modified enzymes / chimeric enzymes, enzymatic processes in emulsion reaction areas/interfaces) and combination of different processes (high pressure & enzymes, high temperature & enzymes)
- Genetic modification of raw materials to improve subsequent fractionation.
- High energy processes e.g. dissolving and degrading cellulose in supercritical water prior to fermentation
- Controlled separation of preserved cell wall structures
- New isolation and purification methods which require method development for hemicelluloses
- Use of hemicelluloses from lignocellulose processing side streams

Polymer Chemistry
When the natural organisations are dis-assembled, there are then a lot of possibilities to modify them before using them into re-assembled structures.
Besides the high number of polysaccharide materials available directly from Nature, an endless number of polysaccharide-based materials can be generated by modification in homogenous and heterogeneous states. Biotechnological methods e.g. genetically modifiying techniques will enlarge the range of available materials even further. While chemical, biotechnological modification e.g. via derivatisation of the polysaccharides from solution state allows to modify the polymer as a whole, heterogeneous derivatisation will focus more on topochemical access of reagents or enzymes and thus will change the properties of the part of the polymer "accessible" to the chemicals dissolved in the liquid /gaseous surrounding.
Chemical conversion must be studied, like regioselective derivatisation, introduction of anchoring group, grafting of polymers, formation of hydrophobic polymers, modification of swelling behaviour and solubility, introduction of special functions for stimuli responsive behaviour.
Biotechnological methods will include enzymatic introduction of functional groups, oxidation and derivatisation, including attachment of polysaccharide polymers as side chains and formation of tailored polysaccharide polymers. Controlled chain degradation and chain formation, particularly with use of enzymatic methods will support production of well defined polysaccharide materials with high potential for medical applications e.g. scaffolds, tissue engineering, materials with anti-thrombotical, antimicrobial activity. Specific chemical treatments should be applied to starch like substitution and cross-linking of starch granules, homogenous substitution and functionalities (incl. regioselectivity) and use of new solvents (incl. ionic liquids). Improved characterisation methods are required particularly for distributions of substituent, amylopectin fine structure and the molecular size of starch polysaccharides.

VI-2 Re-assembly

New structures
New processing technologies will be based on understanding of the principles determining the shaping of polysaccharide based materials. Beside conversion of polysaccharides materials by homogeneous or heterogeneous derivatisation or chemical or enzymatic modification, further variability will be achieved by tailoring structures at all size levels, specifically:

- Blending or formation of hybrid concepts of polysaccharides with other polysaccharides / modified polysaccharides / non-polysaccharides polymers by extrusion, molding, coating, deposition or biotechnological methods
- Coating of different synthetic polymer surfaces by polysaccharides in order to make them biocompatible or bioactive
- Use of polysaccharide materials as fillers or reinforcing agents in synthetic polymers from the nano to the millimetre scale
- Simple methods for the microspherization and nanospherization of polysaccharides
- Encapsulation of chemicals in polysaccharide-based microspheres or nanospheres
- Dendritic structures based on polysaccharides
- Crosslinking of polysaccharide-based polymers

New processing technologies
New processing routes include:

- The use of new solvents for processing (like ionic liquids) to allow 3D shaping of solid polysaccharide materials from solutions, high pressure processing
- Bio-inspired polysaccharide engineering, layer by layer template and scaffolding material architecture
- Thermoplastic cellulose as a result of a combination of new plasticising solvents and physical environments e.g. ultrahigh pressure
- Production of bacterial cellulose on a large scale
- Production of new high viscosity extracellular other polysaccharides by fermentation
- Blends of starch and cellulose fibres (starch being the major component)
- New methods for the large scale production of polysaccharide whiskers and nanofibrils
- Tempo-& enzyme introduction of carbonyl groups
- Enzymatic preparation of highly crystalline cellulose,
- Production of tailor made glucose derivatives e.g. large cyclodextrines
- Reconstruction of structural composites from polysaccharides and other biomass polymers

Products
Intensification of research should be directed towards both bulk products and specialty products.
Bulk products include:

- Preparing copolymers assembled from different polysaccharide units
- Novel polymers synthesised from polysaccharide building blocks
- Hybrids and composites built form polymer blends or coated structures as 3D-materials

Specialty products include:

- High performance and functional fibres and fibre-composites for innovative textile and technical products and textiles and technical processes (e.g. flame retardant, hydrophobic, high strength, conductive, antibacterial)
- Films with defined surface and permeability properties for packaging (e.g. defined permeability, antioxidant function), high transparency polysaccharides films
- Multifunctional polysaccharide/cellulose derivatives for polysaccharide/cellulose-based materials or drugs
- High sorbing structures
- Stimuli responsive materials (e.g. changing structure, form, thickness dependent on moisture, temperature, incorporated indicators)
- High performance materials containing whiskers
- Membranes with selective barrier function
- L-Glc polysaccharides

- Carbonized polysaccharide products
- Molecular recognition systems
- Aide to extraction of oil as existing wells become depleted
- Cellulose nanopaper structures of high toughness

Durable products based on initially-degradable polysaccharides

VI-3 End of Life Cycle

The end of life of materials is an increasingly critical issue. The target is to have polysaccharide-based materials end of life being either degraded by various composting methods or recycled:

- Composting: All natural polysaccharides are degradable by natural means.
- Recycling: It is urgent to start studying the recyclability of polysaccharide-based materials, especially when they are parts of complex products made with high melting temperature oil-based polymers. Recyclability is then a real issue.

VI-4 Economical and Environmental Assessments

The depletion of fossil resources, climate change and toxicity impacts are among the most important issues that are currently on the environmental sustainability agenda. One of the key strategies pursued to resolve these issues is the use of biomass for the production of heat and power, liquid biofuels and bio-based materials. There are different views about which role biomass use as a whole will play in the medium to long term (e.g., as compared to other forms of renewable energy and nuclear power) and moreover, how important the various types of using biomass will become. Environmental life cycle assessment (LCA) is a tool to assess competing options in terms of their environmental performance. It can provide a decision basis not only for process selection but also for process improvement by providing insight into the impacts per process step.

Among the bio-based materials, polysaccharides are among the key options for the future and they therefore serve as highly relevant cases for LCA studies including the development and testing of novel methodologies. Some prominent methodological and empirical challenges related to LCAs of bio-based materials are the assessment of i) land use efficiency ii) land use changes and its impacts on carbon emissions and biodiversity iii) soil carbon losses and other forms of soil degradation vi) water use v) fertilizer use including phosphates vii) the development of widely accepted single-score methods.

Further very important issues which go beyond the realm of LCA only are economic aspects, the competition of food versus non-food and the assessment of other social aspects; in order to cover these aspects suitable assessment methods are urgently required, too.

Concrete topics which can serve as case studies for the development of novel methodologies and for their application are:

- Polysaccharide-based materials versus their petrochemical counterparts
- Competing feedstocks for cellulosics, e.g. comparison of wood versus cotton linters versus bamboo
- Environmental assessment of bio-based packaging films accounting for the lower barrier properties as compared to the petrochemical counterparts
- Competing processing options for cellulosics, e.g. ionic liquids versus conventional processes
- Novel processing (synthesis, separation and purification) making use of new membranes

The future development of integrated tools able to involve multi criteria (like environmental assessment, recyclability of biomass based materials, non toxic aspects) is probably what is needed

VII. Food

Some of the food related challenges facing industry and society are outlined in section III 3.4 above. Polysaccharides have always played a central role in food products. It is possible to distinguish between two classes:

(i) **Polysaccharides as additives**. Within the European Union these are precisely defined and given an E number. A list of these polysaccharides is given below:
E400 – Alginic acid, E401 – Sodium alginate, E402 – Potassium alginate, E403 – Ammonium alginate, E404 – Calcium alginate , E405 – Propane-1, 2-diol alginate, E406 - Agar, E407 - Carrageenan, E408 - Furcelleran, E410 – Locust bean gum, E411 – Oat gum, E412 – Guar gum, E413 - Tragacanth, E414 – Gum Arabic, E415 – Xanthan gum, E416 – Karaya gum, E417 – Tara gum, E418 – Gellan gum, E440 - Pectin, E460 - Cellulose, E461 – Methyl cellulose, E462 – Ethyl cellulose, E463 - Hydroxypropyl cellulose, E464 - Hydroxypropylmethyl cellulose, E465 - Methylethyl cellulose, E466 - Carboxymethyl cellulose.

Starches that are modified by chemical treatments are also considered as additives. The following belong to this class:
E1404 Oxidised starch, E1410 Monostarch phosphate, E1412 Distarch phosphate, E1413 Phosphated distarch phosphate, E1414 Acetylated starch, E1420 Acetylated starch, E1422 Acetylated distarch adipate, E1440 Hydroxyl propyl starch, E1442 Hydroxy propyl distarch phosphate, E1450 Starch sodium octenyl succinate, E1451 Acetylated oxidised starch

These materials have a range of functions in food products of which the most important are as thickeners, gelling agents and emulsifiers

(ii) **Polysaccharides are also important component of food ingredients**. To an extent a distinction can be made between an ingredient that can perform some of the functions of an additive (for example wheat flour used to thicken a wide range of food products and cell wall polysaccharides (cellulose, hemicellulose and pectin) being the critical components controlling the texture and structure of fruits and vegetables).

VII-1 Dis-assembly

Bio-assembly/Isolation/Extraction and Characterisation
The majority of polysaccharide additives are natural materials. A consequence of this will be **natural variations between materials**. This will be due to both genetic and environmental factors. This natural variation is compounded by changes in the polysaccharide as a consequence of the extraction process. We see three major opportunities and challenges here:

- As previously alluded to, an understanding of the plant genome will allow the structure of the polysaccharides in the plant to be modified both by accelerated breeding programmes and through genetic engineering. What is important for foods is to include a food end use dimension in such programmes. For example producing new high yielding disease resistant wheat will have much less value if it does not have functionality required for use in human foods.
- Global warming will require crops that can survive in marginal soils, higher temperatures and lower rainfall environments. It is known that starch structure will change under these conditions resulting in different behaviour in foods but the reasons for this are not yet understood.
- **Optimization of extraction processes for maximum functionality** and minimisation of negative factors is required. Through EPNOE the food world is beginning to appreciate that solvents for cellulose may be used to assist in the extraction of food polysaccharides.

To meet these opportunities and challenges, a deeper understanding of biosynthesis must be improved. It is also necessary to develop further tools for polysaccharide characterisation. Two examples are:

- The starch granule is a complex bio-assembly. Some progress has been made in the development of new starches with different amylose amylopectin ratios and amylopectin fine structures but we still are not confident about measuring the molecular size of the two main starch polysaccharides partly because of difficulties in extraction.

- It has recognised for some time that there are health negative aspects associated with the low molecular weight “tail” in carrageenan preparations. We currently do not have the analytical capabilities of determine with the precision required the amount of this low molecular weight material <50kD. If this can be achieved, then it will allow extraction procedure and source to be selected to minimise the levels of this undesirable low molecular weight material

VII-2 Re-assembly

Re-assembly, texturisation and structure creation
As mentioned, a major role of polysaccharide additives is to create structure in food products by acting as thickeners, gelling agents and emulsifiers. Gelation in particular can be regarded as a reassembly process. The food industry is looking for new materials that can fulfil these functions which do not require additional chemical modification and preferable can be considered as ingredients rather than additives. Examples are:

- **The use of natural fibres** such as citrus fibres which are a cheap by-product from the fruit juice industry. There is scope for modifying such structures by combinations of physical, enzymatic and chemical treatments. However to achieve this, a better understanding of the relationship between structure and function is required.
- **The development of semi refined materials** building on the success of semi refined carrageenan.
- **Physical modification to alter the structure and function of an ingredient** and in some cases replace chemically modified ingredients: An example is the relatively recent success in producing physically modified starches which have of the function of chemically crosslinked starches. Another example is extrusion processing of xanthan gum at low water contents to produce an ingredient that unlike the unprocessed material disperses readily and generates viscosity on heating.

Central to the use of polysaccharides is the **structuring of food products for improved perception**. **An important challenge is to produce low calorie (preferably low fat) products** which match the organoleptic quality of current high calorie products. To achieve this it is necessary to:

- Understand the relationship between product microstructure and perception. For example what microstructure is required for a high perceived creaminess? Further developments in the relationship between rheology and perception are required.
- The creation of the desired microstructure, Particles fabricated primarily from polysaccharides which can trap water will be central to this. Also important will be the development of polysaccharide nanoparticles. These “Pickering” particles if fabricated with appropriate surfaces have the potential of stabilising water/oil/water (WOW) emulsion.

In order to create these new microstructures, an understanding of structure function relationships is critical. An important tools in progressing this understanding is the ability to selectively and specifically modify polysaccharide structures using both chemical and /or enzymative methods. Of course the use of these tools must be accompanied by improved methods of determining polysaccharide fine structure.
Dried food products have the attraction of being shelf stable and light to transport. A fundamental problem is that the structure after drying and rehydration is different from the original structure. Learning about reversibility of water sorption and irreversible collapse of cellulose structures on rehydration will be applied to develop dried food products of improved quality on rehydration

Polysaccharide films will become increasingly important:

- Polysaccharide films can be used as barrier materials within food products. For example, reducing water migration between low water and high water environments in a pie to increase shelf life.
- Incorporation of polysaccharides into packaging film laminates can impart biodegradability.
- Active packaging films for example the incorporation of chitosan to provide an antimicrobial function or sensors to measure oxygen levels.

VII-3 End of Life Cycle

End of life (nutrition/digestion)
The understanding of the relationship between diet and health will develop rapidly over the next ten years. This increased understanding will provide many opportunities for polysaccharides as food ingredients and also as medicines. The latter will be discussed in the next section on health.

- Largely because of their potential as thickening and gelling agents, polysaccharides can be used to control transit through the GI track. For example, gastric emptying time can be reduced as a result of hydration/swelling of polysaccharide structures in the stomach or galation or in this acidic environment. This will increase satiety with the potential of reducing the level of obesity.
- Nutrients can be encapsulated in polysaccharides to provide controlled release. A potential negative is the undesirable consequence of fermentation of polysaccharides in the colon.

To achieve these benefits without the disadvantages **a better understanding of the behaviour of polysaccharides in the GI track is required**. This will form the use of physical/biochemical models of the digestive systems some of which are already available and the use of new techniques to image food in the GI track (MRI imaging, confocal endoscope) and animal studies. Progress in this important area will come as a result of collaboration between polysaccharide scientists, nutritionists and medical scientists

New Products

- Ingredients based on polysaccharide fibres
- Physically modified polysaccharides with added functionality
- Semi refined polysaccharides for low cost functionality
- Polysaccharide with improved functionally developed through enzymatic modification, plant breeding and genetic modification. These will partly be a consequence of an improved understanding of structure/function relationship
- Polysaccharide nanoparticles as emulsion and foam stabilisers
- Dehydrated food products with improved rehydratability
- Polysaccharide films for food packaging and as edible barrier materials
- Functional food ingredients consisting of nutrients encapsulated in biopolymer (particularly polysaccharide matrices. These will allow controlled release of nutrients along the GI contract playing an important role in promotion of a healthy society
- Fat replacers in foods

VIII. Health

Polysaccharides are a very diverse group of molecules, due not only to the different monosaccharide building blocks, but also the diverse way the constituent units are linked. Additional structural complexity may be obtained by insertion of branches into the polysaccharide chains and side chain substitution with either organic or inorganic molecules. Polysaccharides are non-toxic, biocompatible and biodegradable, they are water soluble and have high swelling ability as such or by simple chemical modification, and these are properties that make them extremely suited for biomedical, pharmaceutical and cosmetic applications. A wide range of polysaccharides have already found applications in human health and well being, among which chitosan, cellulose (both plant and bacterial) and cellulose derivatives, alginates, dextran, starch, hyaluronan, heparin, k-carrageenan, pectins and guar gums, with applications like :

- Drug delivery (starch and starch derivatives, cellulose and cellulose derivatives, chitosan, modified, dextran hyaluronan, pectin, carrageenan).
- Wound healing (chitosan, alginates, bacterial cellulose, hyaluronan)
- Tissue engineering scaffolds and implants (cellulose, hyaluronan, chitosan, alginates)
- Bioactive compounds (antimicrobial, anticlothing of blood, drugs and vaccines); (heparin, chitosan)
- Skin hydration, anti-aging agents, skin protection (antibacterial agents), (hyaluronan, chitosan)

VIII-1 Dis-assembly

The majority of polysaccharides used in health care and well being (cosmetic, hygiene) are natural materials derived from plants and animals or produced by microorganisms. This implies a naturel variation that is also increased during the extraction and purification process. In addition, most polysaccharide-materials are embedded into a complex matrix with other compounds, like proteins, lignins etc. The consequences of these intrinsic complexities are discussed in detail in the section related to materials and polysaccharides for food, and all the items there are valid for health applications also. However, for biomedical and pharmaceutical applications, there are more strict criteria imposed to purity, homogeneity and constant quality, including chemical structure and composition. Therefore, major challenge and opportunity are the development of improved processes for polysaccharide extraction, isolation and purification, with special attention to:

- Integration of new enzymatic, mild and non-destructive processes with mechanical processes and use of new solvents for the sequential extraction polysaccharides to give high yields of highly pure polysaccharide components.
- Development of further tools for the structural and molecular characterisation of polysaccharides, as well as tools for quantitative determination of (trace) impurities.

The specific focuses of polysaccharide for health-related applications are thus **function** and **purity**.

VIII-2 Re-assembly

As mentioned above, the major roles of polysaccharides in biomedical and cosmetic applications are:

- to create structure (i.e. in tissue engineering, scaffolds for cell growth, and texturisers in body care products)
- to serve as carriers and protectants for drugs in the body (from the administration point to the place in the body where the drug should be released to exert its activity)
- to act as bioactive materials (i.e. antimicrobials, anticlothing). The biomedical, pharmaceutical and cosmetic industry is looking for new materials that can fulfil these functions, being in the same time non-toxic, biocompatible and biodegradable.

Central to the use of polysaccharides is their property to form gels as well as more rigid structures upon dying, and this can be regarded as a reassembly process. Also, in most applications, reconstitution of complex spatial architectures by grafting the polysaccharides with other polymers (organic or inorganic) or blending to create new composite materials with new architecture is carried out, and these are also re-assembly processes.

- **Development of new spatial architectures.** For application of polysaccharides in tissue engineering, there is a need to improve their mechanical properties, as well as the thermal, chemical and biological stability. Ideal systems will be close to the nature-set parameters of sophistication, miniaturization, hierarchical organization, hybridisation, resistance and adaptability. These degradable and bio-resorbable polymeric structures must fulfil severe criteria related to biocompatibility and bio functionality. Polysaccharides can be tailored to bring specific behaviour in response to environmental stimuli, in which the design, chemistry, structure and function are intimately correlated. Important parameters are the morphology, the shape and size, the porosity, the size of the pores and the surface and surface functionality. There is a place for development of novel composite materials through blending or formation of hybrid concepts of polysaccharides with (1) organic and inorganic polymers and (2) with other polysaccharides or modified polysaccharides using various technologies. Another approach is coating of different synthetic polymer surfaces by polysaccharides in order to make them biocompatible or bioactive.

- **The development of polysaccharide derivatives with multiple functionalities such as bioactive hydrogels.** An example is native or modified chitosan as antimicrobial polymer in wound healing. Chitosan, however, has only a narrow spectrum of antimicrobial activity and have only limited applications in products due to its poor solubility at neutral and alkaline pH. There is a need for developing new antimicrobial polymers derived from polysaccharides as antimicrobial non-leaching coatings for food packaging and medical devices, antimicrobial thickeners in personal-care products and antimicrobial hydrogels for wound healing, in pharmaceutical and medical products. Important tools in creating these bioactive hydrogels is the ability of selectively and specifically modifying the polysaccharide structure by inserting new side chains with the desired bioactive property using both chemical and enzymatic methods.

- **Smart polymers for target delivery of drugs.** Due to their intrinsic properties, polysaccharides are extensively used for the delivery and controlled release of drugs. There is however the need of "smart" drug delivery system. New materials with new and improved properties, like self assembly polymers, thermo sensitive and pH sensitive polymers exhibiting reversible sol-gel transitions or self-crosslinking must be developed. In orderv to prepare new materials able to target the drugs to a particular place in the body, through selective chemical and enzymatic modification of polysaccharides:
  - to change the hydrophilic-hydrophobic balance
  - to increase their hydrophobicity for target drug delivery to the colon, to add charge or reactive substituent for self-assembly or cross-linking
  - to crosslink the polysaccharides with other natural or synthetic polymers
- **Structure-function relationships**. In order to create these new nano- and microstructures, an understanding of the relationships between the structure of the new materials developed and their function and properties is critical. Also, the understanding of the interaction with water and the effects of hydrodynamic pressure is important. In progressing the understanding of structure-function relationships, several tools are needed, including the ability to selectively modify polysaccharide structures and to create new spatial architecture, the availability of methods of determining polysaccharide structure, and tools for determining the biological functions. This requires bringing together specialists from the fields of polysaccharide chemistry and physics, with material scientists and medical scientists.

Desired new products

- High water content polysaccharide gels for wound healing
- Functionalised polysaccharide-based materials for target delivery of drugs
- Polysaccharide based thickeners & texturisers with antimicrobial properties
- Sensors
- Polysaccharide-based scaffolds for tissue engineering
- Novel polysaccharide based products from alternative sources (microorganisms, algae, crop residues, and new crops, etc) for use in medical, pharmaceutical and cosmetic applications

VIII-3 End of Life Cycle

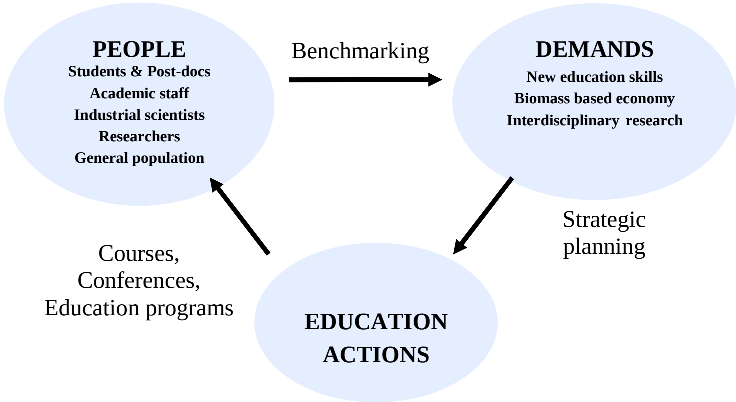
Most polysaccharides are biodegradable and prone to bacterial and enzymatic degradation, and this is an advantage for application in tissue engineering and drug delivery but might be a problem for applications requiring a long life time, like polymeric antimicrobial agents in cosmetic formulations or packaging. The challenge is therefore to control the rate of degradation and the degradation time of polysaccharide based materials for each specific application. For example, cellulose is poorly biodegradable in the body and is not digestible, but it can be made hydrolysable by changing its high ordered structure.

The understanding of the relationship between the structure of the polysaccharide materials used in a specific application and its biodegradability as well as the ways/means of triggering biodegradability is essential. This will come from the use of physical/biochemical models of the *in vivo* degradation of biopolymers and will require the collaboration between polysaccharide scientists, biochemists and medical and cosmetic scientists.

In health-related applications, the end of life cycle is strongly dependent on the function of the polysaccharide.

IX. EPNOE Education Road Map

Education within EPNOE is an interaction between *People*, *People's Demands* and *Education actions*. The targeted users of EPNOE education are: students and post-docs, academic staff, industrial scientists, researchers and the general population. All these people have specific demands. The aim of EPNOE education is to meet these demands with the help of education actions, which are divided into three action points under which most of the activities take place: Academic education, Courses and e-learning and Dissemination. *Benchmarking*, *strategic planning* and *education programs* are the major instruments or methods to reach the goals.



IX-1 People

Students and post-docs

The higher education curriculum in Europe has three cycles: Bachelor, Master and PhD / Doctorate. EPNOE is not focusing on Bachelor level.

Master: polysaccharides are an important topic in a general bio-based material master program including several universities. At this level, students will interact with high level researchers and teachers. We believe these students should be exposed to new ways of thinking and develop skills by working in an international environment and have the opportunity to perform part of their studies in a foreign country.

PhD: Within EPNOE, there are many PhD programs focusing on various aspects of polysaccharide science. The PhD students should perform best possible research and be in contact with experts from other, connected, fields of research. Students should develop personal skills useful for their career, start connecting professionally to the research community and be immersed in an international environment.

Post-doctoral scientists: these scientists are already experts in aspects of polysaccharide science and are often considering a career in polysaccharide research. They have all the demands of PhD students described above. In addition, they must start to learn how to manage scientific projects and research groups.

Academic staff

There are two categories of academic staff, those with expertise in polysaccharide science and those who are not polysaccharide experts but wish to know about this increasingly important class of materials.

Polysaccharide experts: Their demands are to be well trained in new societal and scientific challenges and on non scientific issues like proposal writing for the junior members of the staff.

Other academic staff: Many biologists, physicists, chemists and material scientists are now moving to the field of polysaccharides. Their demand is to be able to move in a fast and efficient way to this field of research, from the basic to more sophisticated issues.

Industrial scientists and researchers

As already seen now, industry is slowly moving to polysaccharide-based activities. The scientists that are presently working in the polymer-related industry have a general background based on polymers coming from oil. These polymer scientists are an important target for education on polysaccharides. This is seen as crucial by the European industry. Their demands are thus to be able to move in a fast and efficient way to this field of research, from the basic to more sophisticated issues, but from a more applied viewpoint than academic staff.

IX-2 Demands

The demands to be fulfilled by EPNOE education are defined by periodic benchmarking regarding the needs of interdisciplinary research and new education skills for an emerging biomass based economy. Benchmarking is one of the EPNOE instruments described in IX-4.

IX-3 Education Actions

The main aim with education actions within EPNOE is:

- To promote the knowledge and study of polysaccharides.
- To educate the young generation of academic and industrial specialists in polysaccharide related topics through e-learning modules, master, doctoral and postdoctoral programmes in order to facilitate the transition from an oil-based to a renewable resources-based economy.
- To facilitate the dissemination of specialized information/results by editing dedicated issues in different scientific journals.
- To promote high level polysaccharide research dissemination through participation in/organization of conferences, seminars, workshops, fairs, etc.
- To make aware European citizens to the problematic of renewable resources.

The education within EPNOE has different action points under which most of the activities take place. The action points are academic education, courses and web based learning and dissemination.

Academic education

Europe will soon need well-trained scientists able to master the various aspects of biomass-based polymers, i.e. to understand what polysaccharides are and how they can be transformed into valuable products. Within academic education, EPNOE strives to offer students at different level the best education available. With the help of the network, students can participate in courses organised by other members of EPNOE. The members can offer education within their own subject.

Academic education activities will disseminate EPNOE competence on academic level to qualify future experts in utilization and management of polysaccharides. Therefore, academic education activities will:

- benefit of EU Lifelong Learning programme 2007-2013, with particular focus on the EU Erasmus programme with project budgets for mobility of students and academic staff and for organization
- be with partner institutions qualified by EUC (European University Charter)
- refer to locally already established or going to be established master programmes of participating partner institutions
- include efforts for institutional cooperation between EU, US, Canada, Japan and South America for exchange of staff and students.
- develop / implement of Master-level modules and/or programmes at local EPNOE partner institutions or associated institutions
- participate at EU-supported Master-level education modules, e.g. Intensive Programmes operated by EPNOE partner institutions
- participate at Master-level education modules (series of Intensive Programmes)
- connect regular programme modules and activities at EPNOE partner institutions (network of bi-lateral agreements for e.g. diploma supplements)

EPNOE can give students the opportunity to be mobile and to get to know research areas, methods and techniques used by other members. The aim is to do joint and common work as well as cooperation between the members.

After achieving a degree, the aim of EPNOE is to help these graduates to find a job. As these graduates have received the best training, they will be attractive to companies within this field as well as to universities who are searching for researchers.

Courses and e-learning

To spread knowledge outside the network, courses can be offered to industry and research institutes. Mainly these courses are meant for training researchers from industry and research institutes that work within the field of renewable materials, polysaccharides or environmental issues. In addition to conventionally taught courses, training can also be offered with the help of e-learning and videoed lectures.

Dissemination

Dissemination activities within EPNOE include organisation of and participation in scientific conferences, publications in special issues of journals and translation of conferences into English. The aim is to spread excellence and to disseminate knowledge and experience both inside and outside the network.

IX-4 Instruments

Instruments are the methods used for reaching our goals. The methods used within education are described below.

Benchmarking

Benchmarking is a tool that is used for defining the demands of people. The methodology used for benchmarking is:

- Internal benchmarking, where existing members within EPNOE are analysed.
- Shadow benchmarking, where players outside of EPNOE are analysed. The possibility of entering the market without a ready product is analysed.

Strategic planning

The strategic planning of education actions is a process of defining directions and making decisions on allocating resources. Business analysis technique called SWOT (Strengths, Weaknesses, Opportunities, and Threats) must be regularly used to identify the specific actions needed in academic education, courses and e-learning and dissemination. The analysis is based on state-of-the art and prospective scenarios of education activities in Europe and Worldwide.

Funding

External funding for education activities within EPNOE is needed and potential funding sources are:

- Erasmus, which is an integral part of the Lifelong Learning Program (LLP) 2007-2013.
- FP7, e.g. Marie Curie network
- Industry

Mobility

Mobility is an important factor that will allow EPNOE members to visit other members. The advantage is that members can learn about the research areas and methods at different research institutions. Mobility promotes cooperation.

Joint and common work

Research groups from different EPNOE members are brought together in order to create joint research, and therefore, have the ability to create new ideas. We must use our scientific base to innovate more efficiently than we have done in the past. Integration is more important now than ever. EPNOE is exploring the interaction between different fields, e.g. starch vs. cellulose and food vs. fibres.

Multidisciplinary work

The aim is the education of new professionals with a European perspective and multidisciplinary skills. People with different backgrounds are brought together within EPNOE in order to create new research topics and education programs.

Master program and PhD curriculum

At the Master level, it is planned that students from several EPNOE and non-EPNOE universities are provided a European Master on Renewable Materials where polysaccharides will be a major item.

PhD students have the possibility to attend courses offered by EPNOE members. Specific PhD programs are motivated to be developed with time. The researchers are encouraged to do joint and common work.

Courses

The general objectives are to design and run advanced course modules allowing researchers outside the network to benefit from the knowledge of EPNOE members. The aim is to design and produce common EPNOE-labelled polysaccharide courses for the external academic and industrial worlds.

Courses aimed at industry can be:

- Conventional short courses.
- A linked programme of courses which would be accessible to industry and to students.
- In house courses to a single company. EPNOE will offer an “innovation service” primarily aimed at synthetic polymer processing companies that are considering the implications of the pressure to move to natural materials. This consists of a single day course followed by a brainstorming session with company representatives.

E-learning

High quality lectures of 30 minutes each are available to members and general public at the EPNOE web site. The lectures broadly cover all polysaccharide fields and work as introduction to traditional 1-3 day-courses that can be sold to the industry. The series of free lectures on the web site should is shaped as a tree, starting from something general and going bit by bit into more specific topics.

Conferences and publications

Conferences and publications are a major part of the dissemination activity. EPNOE organises conference of its own and have scientific sessions in already organised conferences. Non-English language courses are translated into English. Special issues of journals and book series concentrating solely on polysaccharides are suggested and edited by EPNOE members.