SusChem

Strategic Innovation and Research Agenda

SUSCHEM
European Technology Platform
for Sustainable Chemistry

Version 2017

SUSCHEM

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Contents

Foreword

When the European Technology Platform for Sustainable Chemistry "SusChem" was established in 2004, we followed the European Commission's wish that the chemical and the biotechnological industries, along with other important European industries, should "get their act together" and formulate a strategy and a plan. This strategy and plan outlined how we could rejuvenate our industries through research and innovation, how this aligned with European Commission funding initiatives, in particular the Research Framework Programmes 6 and 7, and most effectively improve the competitiveness and sustainability of our industries.

This was not an easy task since a "European Technology Platform" was a new concept and had to be first shaped into a lively, creative and impactful organisation, open for all interested stakeholders from industry, academia, SMEs Research and Technology Organisations (RTOs). But we succeeded and during our 10th anniversary celebration at our 2014 stakeholder event we demonstrated how far we have come.

Specifically, an analysis of SusChem activities showed that "SusChem inspired" ideas accessed 7% of total funding in FP7. That is impressive, but needs to be compared to the 20% value for the Gross Value Added (GVA) that the chemical industry contributes directly and indirectly to European GVA. We can see that SusChem has come a long way, but there is still room for growth in how sustainable chemistry and biotechnology can leverage European Commission funding.

The Horizon 2020 programme emphasises one particular aspect, namely the "bridging of the valley of death". Essentially, Europe is very strong in research but often struggles to transform this research into innovation that has a competitive impact in business. To help tackle this challenge pilot and demonstration projects are one focus area of Horizon 2020 and SusChem takes up this theme in this Strategic Innovation and Research Agenda (SIRA).

Another important point is the clear focus on societal challenges in Horizon 2020. Everything we do with our tax payers' and our companies' money should be focused on ultimately improving societal conditions, in particular, with respect to sustainability for "People, Planet and Profit". Our work will be fully justified if we can simultaneously create jobs, improve the environment and generate greater economic success and wellbeing.

In this spirit, the new SIRA is a great opportunity to clearly present our plans for the Horizon 2020 period. I hope that this document adds value to the societal, scientific and industrial debate and helps all SusChem stakeholders to concentrate on the real challenges that we all face.

As a long-time member of SusChem I can clearly say that our momentum and our success is based on the personal commitment of all SusChem members. I am sure that this SIRA will help and inspire us all to take SusChem to the next level.

Dr Klaus H. Sommer

Chairman SusChem
Head Customer & Product Management
Bayer Technology Services

Executive Summary

Some 20% of the annual total Gross Domestic Product (GDP) of the European Union (EU) is due to the direct and indirect contributions of the chemical industry. Chemicals contribute substantially to wealth creation along nearly all value chains and across industrial sectors ranging from pharmaceuticals and crop protection to the automotive sector, defence, construction, textile and consumer goods. The European chemical industry plays a pivotal role in supporting Europe 2020: the EU's growth strategy for the next decade that aims to transform the EU into a smart, sustainable and inclusive economy.

This Strategic Innovation and Research Agenda (SIRA) explains the strategy and role of SusChem in this context. It highlights a portfolio of sustainable chemistry research and innovation actions that the platform believes can make a significant contribution to improving competitiveness and sustainability, address societal challenges and contribute to achieving jobs and growth.

The SusChem vision and its connection with key characteristics of the European chemical industry is clearly stated: to work in an open innovation mode with its stakeholders and provide sustainable solutions to societal needs.

These characteristics are also a feature of the priorities set by the industry with other platforms. The strategic roadmaps developed by the Sustainable Process Industry through Resource and Energy Efficiency (SPIRE) Public-Private Partnership (PPP) and the Bio-Based Industries (BBI) Joint Technology Initiative (JTI) have benefitted from SusChem contributions. SusChem's priorities in this document are more connected to industrial value-chains and wider societal challenges.

Societal challenges

The key societal challenges facing Europe are one of the main pillars for the current European Commission Framework programme for Research and Innovation: Horizon 2020.

This SIRA document is primarily organised around five of the seven key societal challenges (SC) in Horizon 2020[1] and highlights the sustainable solutions that SusChem's stakeholders in the European chemical and industrial biotechnology communities propose to tackle these challenges. Each challenge is covered in a dedicated SIRA chapter. The five challenges correspond to the first five chapters and are:

- Climate action, resource efficiency and raw materials (SC5) where issues around the circular economy, raw materials and feedstock, water and waste management, resource and energy efficiency, and process intensification for the chemical plant of the future are addressed.
- Food security, sustainable agriculture and the bioeconomy (SC2) where the platform aims to contribute solutions along the full bioeconomy value chain from planting to new biobased products and fuels.
- Secure, clean and efficient energy (SC3) examines where SusChem can deliver benefits for energy efficiency gains within industry and in the wider society and its contribution to low carbon energy production and advanced energy storage technologies.
- Health, demographic change and wellbeing (SC1) illustrates SusChem's potential to enable personalised healthcare and advanced diagnostic techniques.
- Smart, green and integrated transport (SC4) shows how sustainable chemistry will contribute to greener vehicles providing mobility with low or no emissions.

SusChem SIRA priorities also relate to the Horizon 2020 pillar 'Leadership in Enabling and Industrial Technologies' (LEIT) in particular in the thematic areas covering Nanotechnologies, Advanced Materials, Advanced Manufacturing and Processing, and Biotechnology (NMPB) and Information and Communication Technologies (ICT).

Two further chapters of the SIRA cover:

- Information and Communication Technologies (ICT) describing how more sustainable processes can be enabled by ICT and how sustainable chemistry can enable advances in ICT and related sectors including additive manufacturing (3D printing).
- Horizontal Issues illustrating SusChem's ambitions to build skills capacity, better assess sustainability in a manufacturing context, address issues around the uptake of beneficial technologies by society and promote innovative business models.

1: http://ec.europa.eu/programmes/horizon2020/h2020-sections

The table below (Table 1.1) maps the expected impact of SusChem research and innovation priorities (listed in the left hand column) described in the SIRA with Horizon 2020's pillars LEIT and Societal Challenges (indicated in the top row). A green dot indicates an area of expected impact.

Table 1.1

● Area of expected impact

	1 Leadership in enabling and industrial technologies (LEIT)		2 Food security, sustainable agriculture and the bio-economy	3 Secure, clean and efficient energy	4 Smart, green and integrated transport	5 Climate action, resource efficiency and raw materials	6 Health, Demographic Changes and Wellbeing
	NMPB	ICT					
Raw Materials							
Enhancing Availability and Quality of Existing Sources	●						
Alternative Carbon Sources			●	●	●	●	
Critical Raw Materials	●		●			●	
Sustainable and Competitive Bioeconomy			●		●		
New Processing Technologies	●					●	
Waste Reduction and Recovery	●		●			●	
Energy Source for Chemical Processing							
Energy Efficiency in Chemical Industry	●			●			
Chemical Energy Storage	●			●	●		
Photocatalytic Conversion of CO2	●			●	●	●	
Fuels from Cellulosic Materials			●	●	●	●	
Alternative Energy Sources			●	●	●	●	
Water and Energy Efficiency				●		●	
Process Technology							
Process Intensification	●			●			
Model Based Design and Optimisation		●					
Advanced Process Control		●					●
Water Treatment and Recovery	●					●	
Industrial Biotechnologies	●	●	●		●		●
Materials For:							
Energy Generation	●			●			
Energy Storage	●			●	●		
Energy Efficiency	●			●			
Health and Wellbeing	●						●
Transportation	●			●	●	●	
Smart Materials	●	●			●		●
Water Treatment and Recovery	●		●			●	
Packaging	●		●			●	

SusChem and Key Enabling Technologies (KETs)

SusChem priorities are also connected to Europe's Key Enabling Technologies[2] (KETs): six technologies identified as vital to European Industry's competitiveness, increased growth and jobs (see Table 1.2). The chemical industry is a leading actor in four KETs: advanced materials, nanotechnologies, advanced manufacturing, and biotechnologies. And it is a significant contributor to the remaining two: photonics and nanoelectronics. Implementing the SusChem SIRA will reinforce Europe's capability and competitiveness across all KETs. In the following table, each SIRA topic (listed in the left hand column) is mapped against the KETs (indicated in the top row) together with an additional enabling technology: Information and Communication Technologies (ICT). A green dot indicates an area of primary impact and a purple dot indicates an area of secondary impact.

Table 1.2

● Primary impact

● Secondary impact

	Advanced Materials	Advanced Manuf.	Biotech	Nano Technology	Photonics	Micro Nano Electronics	ICT
1 Climate Action, Environment, Resource Efficiency and Raw Materials							
1.1 Raw Materials and Feedstocks							
1.1.1 Access to critical raw materials	Primary	Primary	Secondary				
1.1.2 Exploiting sustainable carbon resources: Biomass & CO2	Primary	Primary	Primary	Secondary			
1.1.3 Enhancing availability and quality of existing resources	Primary	Primary	Primary				
1.2 Water Conservation, Recycling and Reuse							
1.2.1 Water treatment and recovery	Primary	Secondary	Primary	Primary			Secondary
1.2.2 Water and energy efficiency		Primary					Secondary
1.2.3 Water supply	Secondary	Primary					Secondary
1.3 Waste Reduction and Recovery							
1.3.1 Waste reduction		Primary					
1.3.2 Internal waste recovery		Primary					
1.3.3 Downstream & end of life materials for waste recovery	Primary	Primary	Secondary				
1.4 Energy Efficiency in the Chemical Industry							
1.5 Chemical Plant of the Future							
1.5.1 Process intensification		Primary					Secondary
1.5.2 Advanced process control solutions		Primary					Secondary
1.5.3 Plant reliability and maintenance		Primary					Primary
1.5.4 Model based design and optimisation		Primary	Secondary				Primary
1.5.5 Industrial symbiosis		Primary	Secondary				Secondary
2 A Sustainable and Inclusive Bioeconomy							
2.1 Sustainable Agriculture and Forestry							
2.1.1 Recovery of nutrients from fertilizers		Primary	Secondary				
2.1.2 Crop protection							
2.2 Sustainable and Competitive Biobased Industries							
2.2.1 Biobased feedstocks: Chemicals from advanced biorefineries		Primary	Primary				
2.2.2 Industrial biotech process		Primary	Primary				
2.2.3 Conversion of CO2 by bioprocesses		Primary	Primary				
2.2.4 Biobased products and materials	Primary	Secondary	Primary				
2.2.5 Water issues	Primary	Primary	Primary	Secondary			

2: http://ec.europa.eu/programmes/horizon2020/en/area/key-enabling-technologies

	Advanced Materials	Advanced Manuf.	Biotech	Nano Technology	Photonics	Micro Nano Electronics	ICT
3 Secure, Clean and Efficient Energy							
3.1 Energy Efficiency in the Chemical Industry							
3.1.1 Energy efficiency in process	Secondary	Primary	Secondary	Secondary			Secondary
3.1.2 Alternative energy sources for processing	Secondary	Primary	Secondary				
3.2 Products for Energy Efficiency							
3.2.1 Materials for energy efficiency of buildings	Primary	Secondary		Secondary	Primary		
3.2.2 Lightweight materials: for energy efficiency	Primary	Primary		Secondary			
3.2.3 New packaging solutions for better energy efficiency	Primary	Primary					
3.2.4 Efficient lighting: New materials for OLED Lighting	Primary			Secondary	Primary		
3.3 Competitive Low Carbon Energy Production							
3.3.1 Advanced materials for photovoltaics	Primary	Primary		Secondary	Primary		
3.3.2 Materials for wind energy production	Primary	Primary		Secondary			
3.3.3 Electricity from vibrations and heat	Primary					Secondary	
3.4 Enhanced Energy Storage Technologies							
3.4.1 Electrical energy storage	Primary	Secondary		Primary			
3.4.2 Thermal energy storage	Primary	Secondary		Secondary			
3.4.3 Chemical energy storage	Primary	Primary	Secondary	Secondary			
3.4.4 Direct photo-conversion of CO2: A long-term option	Primary	Secondary		Secondary			
4 Health, Demographic Change and Wellbeing							
4. 1 Personalised Healthcare							
4.1.1 Personalised diagnosis using imaging	Primary			Secondary			
4.1.2 Active & healthy ageing: Responsive materials	Primary			Secondary			
4.1.3 Active & healthy ageing: Formulation for delivery	Primary	Secondary		Secondary			Primary
5 Smart, Green and Integrated Transport							
5.1 Green Vehicles							
5.1.1 Lithium-ion batteries for EVs and HEVs	Primary	Primary		Primary			
5.2 Reducing Energy Consumption							
5.2.1 Multifunctional lightweight construction	Primary	Primary		Secondary			
5.2.2 Temperature management	Primary	Primary					
5.2.3 Green tyres	Primary	Primary		Secondary			
5.3 Materials and Systems for Sustainable Design							
5.3.1 New joining technologies	Primary	Primary					
5.3.2 Separating fibres from the polymer matrix	Primary	Primary					
5.3.3 Other advanced materials for transportation	Primary	Primary					
5.4 Making Internal Combustion Engines more Sustainable							
5.4.1 Exhaust Catalysts	Primary	Primary		Primary			
5.4.2 Alternative fuels for transportation		Primary	Primary				
6 ICT and the Chemical Industry: Smart Process and smart materials							
6.1 Smart Chemical Processes							
6.1.1 Process control		Primary					Primary
6.1.2 Monitoring		Primary					Primary
6.1.3 Modelling for fast-track innovation	Primary	Primary					Primary
6.2 Smart Materials							
6.2.1 Nano-structured materials	Primary			Primary		Primary	
6.2.2 Advanced Thin, Organic and Large Area Electronics	Primary	Primary		Primary	Primary		
6.2.3 Materials for additive manufacturing (3D printing)	Primary	Primary		Secondary			

Introduction

The SusChem Vision

Ten years ago SusChem published its first Strategic Research Agenda (SRA) prior to the European Commission's Seventh Research Framework Programme (FP7). Many of the SRA's priorities were successfully incorporated into FP7 calls, especially in the areas of Knowledge Based Bioeconomy (KBBE) and Nanosciences, Nanotechnologies, Materials and new Production Technologies (NMP). With the Horizon 2020 programme now underway it is time to update SusChem's priorities in line with the increased emphasis on innovation and societal challenges at the heart of Horizon 2020.

Sustainable solutions

Over the last ten years, global changes have made the aspirations of the SusChem SRA even more relevant and urgent. The world population is projected to exceed nine billion by 2050[3]. Yet available resources remain finite leading to greatly increased pressure on them. Major strategic implications (security, economic and geographic) follow from projected shortages of some raw materials. Significant pressures on water and energy supplies, living space and agricultural land are also anticipated.

Positive solutions to these pressures are critically dependant on sustainable chemistry and biotechnology. The chemical industry is at the centre of many value chains in important economic sectors including energy, construction, mobility and electronics. There are no robust solutions to the problems that society faces without the involvement of innovative sustainable chemistry to solve resource problems and deliver new innovative materials and solutions to industry.

SusChem: A catalyst for growth

Europe 2020, the EU's growth strategy, aims to make the EU a smart, sustainable and inclusive economy. The new EU Research and Innovation funding instrument, Horizon 2020, differs significantly in emphasis from its predecessors by directly supporting the goals of smart, sustainable and inclusive economic growth through the stimulation of industrially led innovation.

This aim is in addition to continuing FP7's support for excellent fundamental and applied research.

This is a significant shift of focus from input (research) towards output (innovation). Consequently, Horizon 2020's programme priorities are focused both on the key enabling technologies that are critical to boosting competitiveness and industrial leadership, and also on a set of major societal challenges that underpin the Europe 2020 agenda including climate change, energy and food security, health and the ageing population.

The SusChem Strategic Innovation and Research Agenda (SIRA) formulates the platform's priorities in line with those of Horizon 2020 to catalyse the achievement of Europe 2020 objectives through sustainable chemistry and biotechnology. The SIRA also supports the objectives of the new European Commission to boost jobs, growth and investment; create a resilient and sustainable Energy Union; and strengthen the European industrial base.

Why research and innovation?

Research is not a means of creating wealth in itself. The act of investing money, time and other assets into a research project can turn these resources into potentially useful outputs: new knowledge, fresh ideas and creative inventions. The word "potential" is critical here; none of these research outputs automatically changes society, improves health or creates wealth. It is the role of innovation to achieve this. Innovation is a complementary activity to research: turning knowledge, ideas and inventions into new business opportunities that can transform the world.

3: http://www.un.org/en/development/desa/population

Delivering Horizon 2020 Objectives

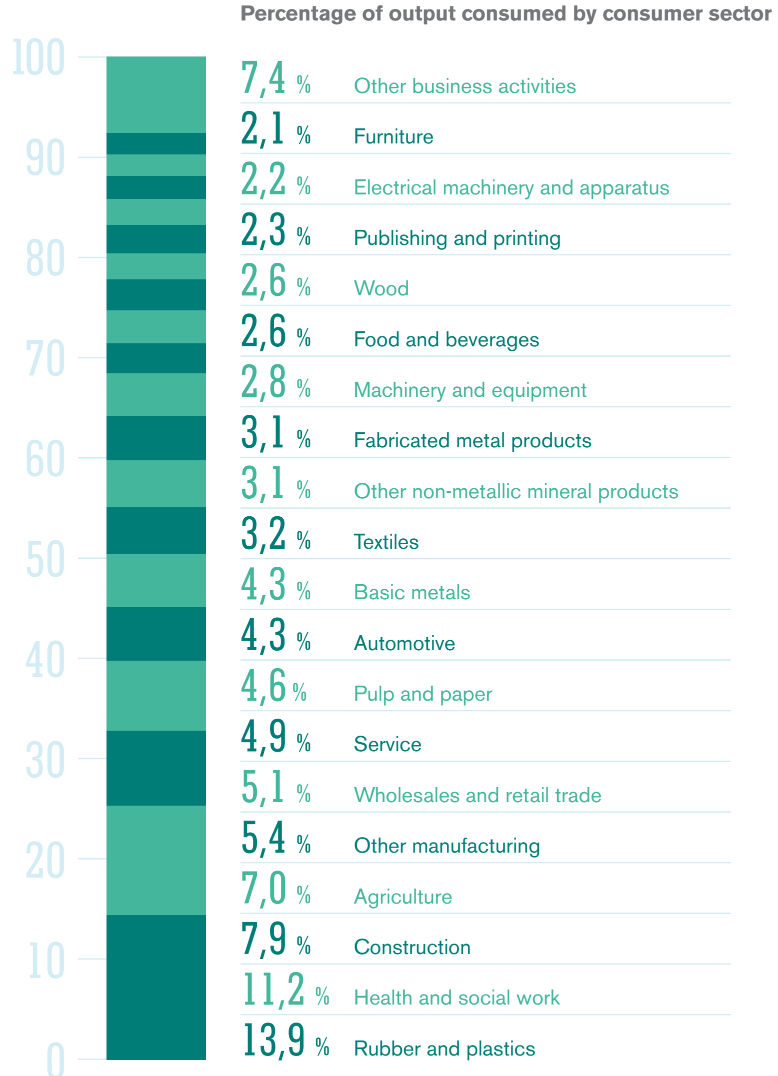
The chemical and biotechnological industries in Europe:

In 2013 EU chemicals sales totalled 527 €billion out of a world total of 3156 €billion. Since 1993 although EU chemicals sales have doubled this represents a decline in global market share from 32% (282 €billion) to 17% in 2013. However, the decline is not due to any shrinkage of EU chemical industry capacity and competitiveness, but because of the enormous expansion of China's market share from 8.7% (119 €billion) in 2002 to 33.2% (1 047 €billion) in 2013.

The EU chemical industry has generally held its own in market share compared to other world regions and remains a net exporter of goods[4].

The total contribution that the chemicals sector makes to annual EU GDP (3.6%) severely understates the overall importance of the chemicals sector to the EU economy. Chemicals contribute very substantially to wealth creation along nearly all value chains across most industrial sectors (Figure 1).

Figure 1: Contribution of the chemical industry to the EU economy



Sources: European Commission, Eurostata data (Input-Output 2000) and Cefic analysis.

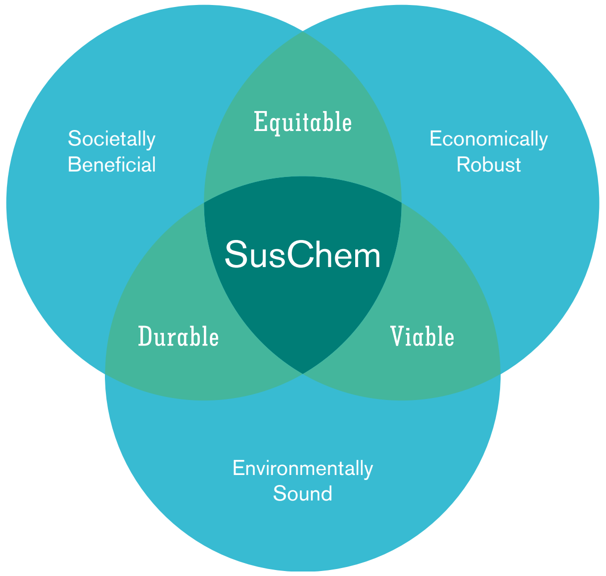
4: Cefic Facts and Figures 2013 http://www.cefic.org/Facts-and-Figures

A better measure of the chemical sector's contribution is Gross Value Added (GVA). The direct and indirect contributions that chemicals make to EU GVA is equivalent to some 20% of total annual EU GDP.

Opportunities for innovation in chemistry and biotechnology

Chemistry and biotechnology contribute to the Europe 2020 Growth Strategy through sustainability, not only through the development of better resource efficiency, but also by contributing to sustainable innovation. When the sustainability of a process or product is considered, it is vital to optimise possible solutions using the three pillars of sustainable development by addressing together environmental, economic and societal issues along the value chain, using measurable indicators that are scored using independent proof points. In the technology areas addressed in this SIRA, SusChem aims to set its operations squarely in the central region of the venn schematic shown in Figure 2.

Figure 2: Criteria for sustainability



Sustainable chemistry improving resource and energy efficiency

The record on sustainability for the European chemical industry over the last decade demonstrates that it is well-placed to build further substantial improvements. Overall, the chemical industry has achieved great improvements in energy efficiency. Energy intensity, defined as the energy input per unit of production of chemicals and pharmaceuticals, has improved dramatically over the last two decades – performing much better than industry generally (Figure 3):

Figure 3: Energy intensity: chemicals vs total industry

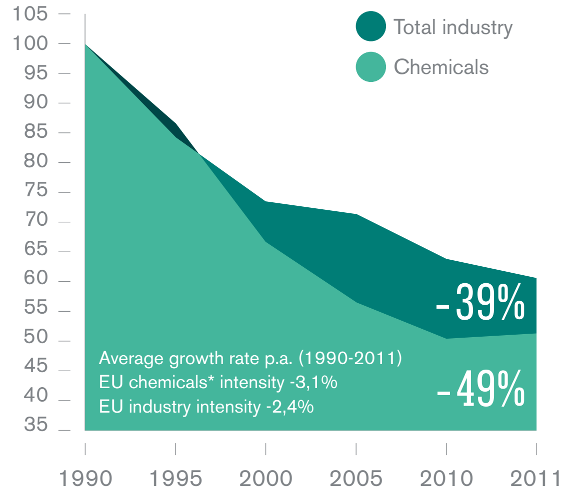
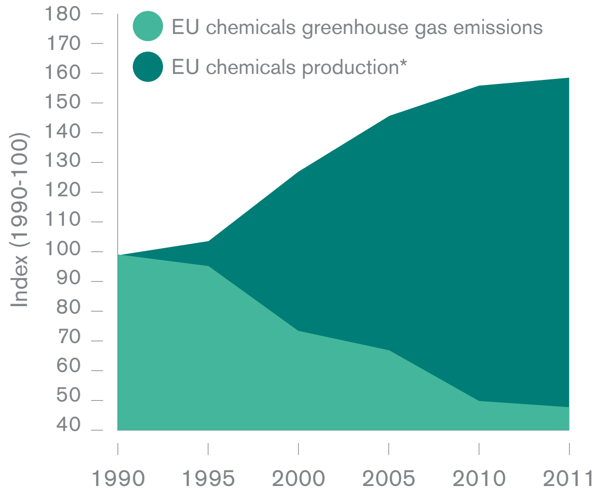


Figure 4: EU chemicals greenhouse gas emissions



Source: Cefic Chemdata International (2013), Eurostat and European Environment Agency (EAA)
** including pharmaceuticals*

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Chemistry and biotechnology contribute to the Europe 2020 Growth Strategy through sustainability.

The industry's performance in reducing greenhouse gas emissions over the last twenty years is also very encouraging. Despite a 60%+ increase in units of production, GHG emissions have been halved (Figure 4). The chemical and biotechnology industries will continue to deliver further energy and resource savings by 2020 and beyond through the identification of technology areas that can most effectively deliver against the key relevant Horizon 2020 targets: this is a key purpose of the SusChem SIRA.

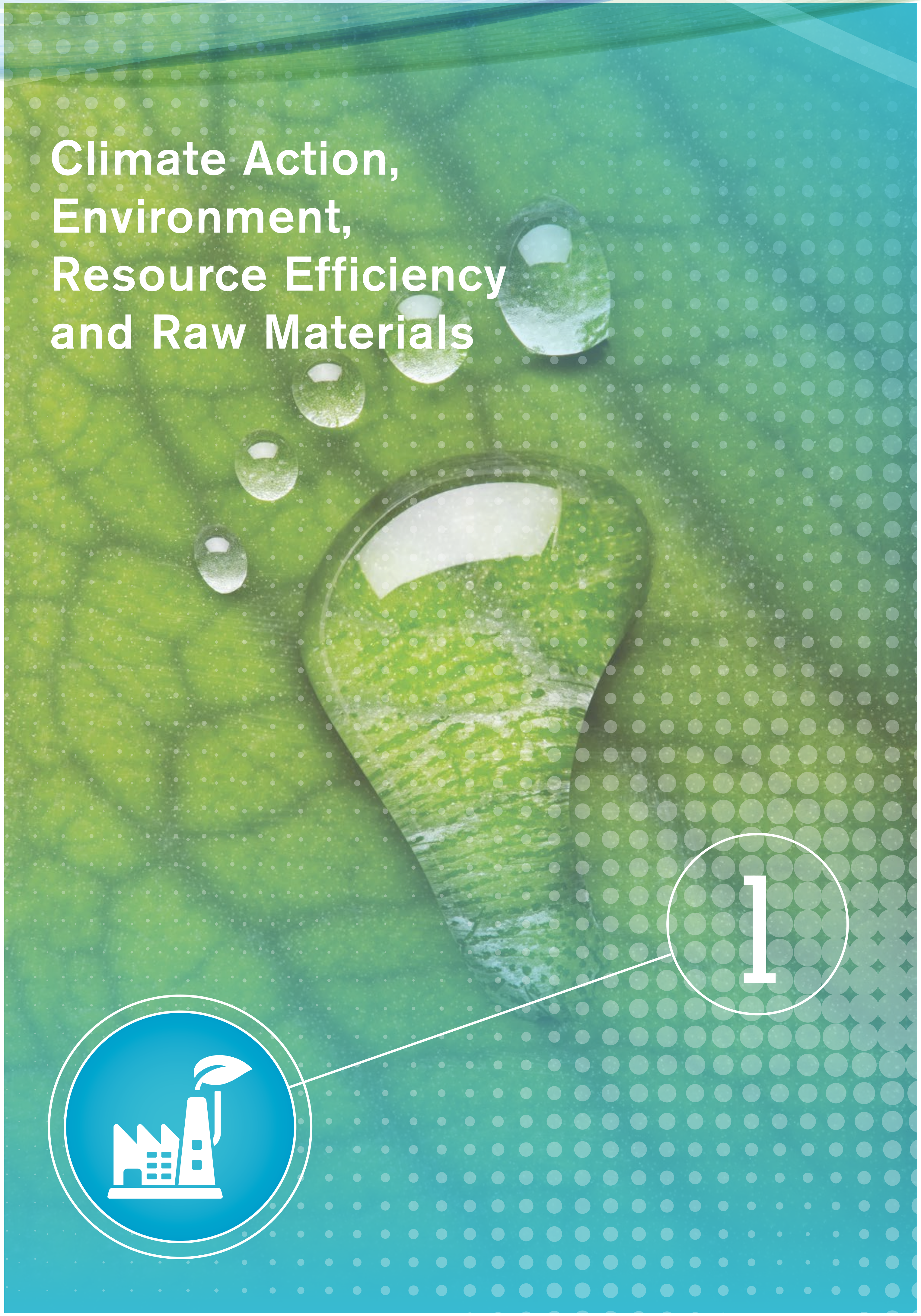
Technology improvements and innovation opportunities

Just as it is important to distinguish carefully between research and innovation, it is also important to understand what leads to innovative thinking that can change society, create wealth or transform the market place. Innovation arises from thinking differently about commonly accepted norms, from swiftly identifying market opportunities and then exploiting them. It relies on a variety of skills, including cross-sectorial and cross-disciplinary knowledge and thinking, informed market research, opportunistic thinking, business acumen, communication and entrepreneurial skills. The SusChem SIRA also addresses the education and skills needs that will be required to deliver the Europe 2020 growth strategy.

Incremental changes in technological capability, and their combination, are at least as capable as step changes in technology to lead to major market innovations. This is most important for the chemical and biotechnology sectors because even small incremental changes in these sectors, operating along and across numerous value chains, can result in profound positive competitive changes in a wide range of manufacturing processes, products and consumer perceptions.

Investment in sustainable chemistry solutions can deliver the sustainable innovation that Europe needs for competitiveness and more jobs and growth.

Climate Action, Environment, Resource Efficiency and Raw Materials



Part 1

SusChem will continue to play a leading role in the areas of climate action, environment, resource efficiency and raw materials that are grouped under Horizon 2020 Societal Challenge 5. Moves to embrace Industrial Symbiosis in its broadest sense, with materials and energy synergies integrated into a circular economy approach will enable enormous benefits for the future environmental, social and economic climates.

The chemical and process industries play a key role in taking raw materials and converting them into useful materials which are used to make products and components. The valorisation of waste as a secondary raw material is dependent on eco-design of process and products and the integration of waste material in a circular flow driven by the process industries. Utilisation of renewable resources, such as biomass and CO2, and the valorisation of waste are particularly dependent on having the correct technologies to drive a sustainable circular economy. In addition to technological challenges, the legal framework for a circular economy governing transport and reuse of waste will need to be aligned to enable a truly sustainable future.

1

1.1 Raw Materials and Feedstocks

There is continuing growing demand for raw materials that are essential for the development and deployment of new consumer and industrial technologies. Many raw materials used by the chemical industry are rarely found within Europe. For example, Europe imports more than 90% of its crude oil; more than 95% of Rare Earth elements (REE) are produced in China; and platinum group metal (PGM) deposits are outside Europe. Interruptions or future restrictions in supply may have a strong negative impact in the development of new technologies and the competitiveness of the EU chemical sector.

The chemical industry aims to reduce its dependence on petroleum and natural gas feedstock and to address a future scarcity of some raw materials. The transition to alternative sustainable feedstock, including switching of raw materials, needs to consider numerous factors: the global chain for developing new feedstock, new transformation pathways and new chemical processing technologies, and methods to reduce the volume of material used.

1.1.1 Access to Critical Raw Materials

The challenge

Europe's access to many Critical Raw Materials (CRM) is vulnerable and may impact on the development of new technologies in the EU. In May 2014 the European Commission published its latest 'Report on Critical Raw Materials for the EU'[5] listing 20 CRM including phosphate rock, fluorspar, PGMs (used as catalysts in pharmaceutical, chemical and petrochemical processes and crucial in electronics) and REEs (widely used in alloys, catalysts and batteries). In addition, there are other raw materials, which are or might become critical for specific applications or sectors not currently covered by the Commission study. SusChem will contribute to foresight activities identifying potential CRM in particular working with the European Innovation Platform (EIP) on Raw Materials[6].

The chemical industry can provide innovative solutions to reduce dependency on CRM through more efficient and environmentally friendly technologies to enable processing, recycling or reducing the amounts of materials used. Substitution of CRM by new materials or technologies in specific applications while maintaining or improving performance is a complementary strategy to enable a competitive raw materials supply for Europe.

Research and innovation actions

- Develop separation and purification processes for CRM: the performance of primary extraction and recycling of critical raw materials like PGM or REE can be improved through, for example, more efficient hydrometallurgical processes.
- Develop substitutes for CRM that are compatible with the expected level of performance in targeted applications, for example by using new (bio)catalysts.

Expected impact

Improved access to CRM and/ or substitution with new materials and technologies will ensure a positive economic climate for industries that depend on these materials and can provide opportunities for increased growth and jobs.

5: http://ec.europa.eu/enterprise/policies/raw-materials/files/docs/crm-report-on-critical-raw-materials_en.pdf
6: https://ec.europa.eu/eip/raw-materials/en

1.1.2 Exploiting sustainable carbon resources: CO2

The challenge

Switching to biobased raw materials requires the development of new growing, harvesting, supply and preparation infrastructure, discovery of new (bio)chemical pathways and the design of new processing technologies that take into consideration water management, energy efficiency and by-product valorisation.

The utilisation of CO2 as a feedstock by the European chemical industry could be a key solution to reduce use of fossil fuels, reduce the EU's dependence on imports of fossil resources and improve security of supply of carbon feedstock, while reducing pressure on biomass, land use and other environmental stressors. CO2 from industrial flue gases could represent a new alternative feedstock to produce chemicals, materials (polymers and inorganic materials), fuels (see chapter 5) and store renewable energy through power to gas and power to liquid technologies (see chapter 3).

The conversion of CO2 to chemicals and materials requires reduction either with renewable sources of energy (electricity or non-fossil H2) or via reaction of CO2 with high-energy molecules.

Research and innovation actions

The research and innovation actions related to biomass are detailed in chapter 2.

Among major areas for technology development to enable the chemical utilisation of CO2 are:

- Development of catalysts for the conversion of CO2 into chemicals and polymers.
- Development of energy efficient process technologies for CO2 conversion.
- Integration of renewable energy and efficient technologies for renewable H2 production.
- Development of sustainable technologies to recover CO2 from industrial streams, (including new membrane technologies for CO2 separation and purification from flue gases and advanced materials for CO2 capture).

A further key breakthrough in the chemical utilisation of CO2 will be the direct photo-conversion of CO2. This is a longer-term option that requires specific research actions (see chapter 3). For other priorities related to energy storage and fuels applications see chapters 3 and 5, and chapter 2 for biotechnology routes.

A pragmatic approach to Life Cycle Analysis (LCA) evaluation will also need to be developed, as well as regulation that allows inter-industry use of flue gases and an appropriate labelling system.

Expected impact

Exploiting sustainable carbon resources, such as biomass and CO2 will enable production of more sustainable chemicals and materials with lower net CO2 emissions. This shift will result in reduced utilisation of fossil resources, and take industry a step closer to a true circular economy. Integration of renewable energy in chemical production will also bring added benefits, reducing CO2 emissions and fossil fuel usage and establishing the chemical sector as a leading provider of clean technologies for other sectors.

1.1.3 Enhancing availability and quality of existing resources

The challenge

With the advent of 'peak oil' and while the industry moves to alternative sources of sustainable feedstock society will need to maximise the output of existing oil and gas resources with sustainable technological advances and increase the energy and resource efficiency of existing operations.

Research and innovation actions

- Develop new efficient technologies to convert gas to valuable liquid products: an example is gas-to-liquids (GTL) technology that converts natural gas into other high-value liquid transport fuels and chemicals (see also section 3.4.3).
- Integrate the evolution of gas supplies (tight gas, shale gas, coal bed methane etc.) to meet demand and improve European competitiveness: develop safe, sustainable and responsible access to new and unconventional hydrocarbon sources through innovative technologies.
- Develop advanced technologies for tracing and monitoring oil and gas reserves.
- Olefins are the basic building blocks in the production of many different chemicals and polymers. Alternative sources to produce olefins need to be developed including from coal and gas (natural, syngas, shale gas), de-polymerization (see also section 1.3), biomass (see chapter 2), and routes from CO2 (see section 1.1.2 and in chapters 2 and 5).

Expected impact

By enhancing the availability and quality of existing resources, the economic competitiveness of Europe will be strengthened in the short-medium term enabling the development of new technologies that can deliver long-term sustainable, renewable raw materials solutions.

1.2 Water Conservation, Recycling and Reuse

The challenge

Water is a scarce resource and a critical element for the development of our society and economy. The continuing increase in urbanisation and agricultural production combined with new demands from the development of biobased and eco-industries and the need to preserve biodiversity and the natural ecosystem put high demands on water management. The chemical industry is a user of water but it is also an important solution provider of innovative products, technologies and services which can enable more sustainable water management. On this front, SusChem and the chemical industry are very active in the European Innovation Partnership Water (Water EIP)[7].

Water is used in the chemical industry for several purposes including processing, washing, diluting and heating, cooling, and transporting product. The chemical industry aims at near-zero discharge using closed-loop systems. The control of impurities in closed water systems needs a combination of real time monitoring tools and sensors, highly selective separation processes and new water treatments to prevent fouling and corrosion.

Water efficiency measures are also aligned with targets to reduce energy consumption: energy consumption is a critical indicator when developing new technologies for water management and water treatment.

Water symbiosis and delivery of 'fit-for-purpose' water are considered as key elements to ensure and enable the optimal and integrated (re)use of water not only for the chemical industry but also in collaboration with other sectors including urban and agricultural use.

Research and innovation actions

1.2.1 Water treatment and recovery

- Development of new chemical additives (antifoams, biocides, coagulants, corrosion inhibitors, oxidants) for water treatment facilitating the reuse of water and closed-loop systems.
- Development of cheaper solutions to recover salts and/or to eliminate refractory chemical oxygen demand (COD) from an aqueous waste.
- Development of advanced membrane technologies. Membranes are an effective solutions but still require development to reduce operating costs, lower pressure of operation, increase throughput, improve selectivity, use less energy and reduce maintenance operations (fouling resistance).
- Development of novel highly selective and energy-efficient separation technologies for impurities present in relatively low concentrations, such as adsorption or ion exchange systems, sorbents with higher selectivity and low-energy regeneration, or biological processes compatible with standard treatment technologies, is required that can maintain high efficiency under a wide variety of industrial water conditions.
- Water monitoring systems and tools (including in-line monitoring) are required for assessment and control of quantity and quality to enable closed water cycles in or around industrial parks.

7: http://www.eip-water.eu

1.2.2 Water and energy efficiency

- Integrated tools for energy and water optimisation are required to promote the use of renewable energy in water production and treatment systems.
- Development of new separation technologies for waste water treatments with lower energy consumption.
- Systems to extract valuable low-energy in water are required to enhance synergy between water and energy.
- Energy-efficient systems to extract valuable molecules in low concentration will allow control of closed-loop systems and improve the economics for water recycling and reuse.

1.2.3 Water supply

- Sources of water which have not been widely used, are now increasingly considered as important sources including desalination, re-use of treated wastewater and other solutions like rainwater harvesting or gas humidity condensation. Different technical options can be developed to access these sources with their specific implementation strongly dependant on local conditions.
- Development of a 'water footprint' indicator is required to assist selection of appropriate solutions, processes and products.

Expected impact

Implementation of SusChem's action on water will help achieve the overall objectives of EU water policy defined in the Water Framework Directive[8] and the Resource Efficiency Roadmap[9]. These objectives include providing safe, available and affordable water for all, while ensuring sufficient water for the environment; achieving the relative decoupling of the use of water resources from the level of economic activity in the chemical sector; and maintaining and enhancing the good status of water in all EU river basins in terms of quality, quantity and use.

1.3 Waste Reduction and Recovery

The challenge

Waste can provide raw materials and energy sources provided appropriate technologies to extract, separate and purify the components in waste are available. Waste constitutes an alternative strategic source of raw materials. Extraction of resources from targeted waste flows, for example Rare Earth Elements (REE), will help guarantee Europe's supplies of strategic raw materials. Re-use of rare or high-value raw materials requires the development of specific processes, a circular economy approach and increased awareness of the value of waste streams.

Waste reduction and recovery have important potential benefits for the chemical industry, allowing lower production cost and reduced environmental footprint, improved productivity, energy efficiency and resource conservation. Waste reduction can occur via changes in the manufacturing process. Recovery is the largest opportunity but requires technological developments. For end-of-life products we need new technologies and processes for collecting, identifying, sorting and processing to make the recycled waste viable for re-use and ensure this has a net positive sustainable impact.

8: http://ec.europa.eu/environment/water/water-framework/index_en.html
9: http://ec.europa.eu/environment/resource_efficiency/about/roadmap/index_en.htm

Research and innovation actions

1.3.1 Waste reduction

- Improved manufacturing processes will generate less waste and enhance sustainability. This can be achieved with new equipment implementation, more efficient processing steps, processes using less water due to more effective chemical pathways and/or catalysts, and advanced process control strategies.

1.3.2 Internal waste recovery

- For gaseous waste, there is an opportunity to recover useful products or energy from these streams and remove contaminants. A variety of technologies are applicable, but further development is required to recover dilute concentrations of valuable components in large volume streams.
- The same challenge holds for liquid effluent resource recovery. Concentrating valuable species from dilute streams requires costly and energy intensive separation technologies. Highly selective technologies capable of handling high throughput need to be developed using robust materials to avoid fouling or corrosion. Efficient component recovery from aqueous flows will also enable enhanced recovery of water for re-use.
- Solid wastes include process sludge and residues, process consumables, and low value by-products, and have variable potential value and use. Process improvement for reduction of solid wastes is required - in particular to improve the yield of useful and valuable products.

1.3.3 Downstream and end of Life materials for waste recovery and valorisation

- Development of life cycle analysis (LCA) methodologies for reuse and recycling of used materials taking into account the overall environmental benefit compared to the extraction of new raw materials.
- Design methodologies for new products must consider end of life in order to facilitate recycling (eco-design) drawing on the experiences of other industries that have developed recycling to a high level (glass, steel, aluminium).
- Develop new processes to minimise the energy required to generate raw materials from complex waste formulations.

Expected impact

Reducing, recovering and re-using waste is an essential element in achieving a circular economy in Europe and the chemical sector will play a key role in enabling this. Technologies and systems to close the loop within the chemical sector are the initial step. SusChem's proposed developments are aligned with the SPIRE PPP[10] roadmap with respect to waste to resource initiatives within the process industries.

10: http://www.spire2030.eu

1.4 Energy Efficiency in the Chemical Industry

The challenge

The chemical industry is committed to playing its part in achieving the European 2020 Growth Strategy target for climate change and energy sustainability to increase energy efficiency by 20% or more [11].

Energy efficiency in chemical processing is a key step to sustainable manufacturing and achieving a rapid impact on competitiveness. Most competitive and standard solutions have already been implemented in the chemical industry, but several existing practical energy efficient technologies have not achieved widespread implementation because of cost and perceived technical risks. The industry needs new systems and solutions that maximise the economic returns and extend the operating range of energy-efficient technologies.

Alternative energy sources is a second area with barriers for effective deployment in the chemical industry. Solar, Wind, Geothermal, and Biomass energy sources offer sustainable solutions and will reduce dependence on fossil fuels. In many cases, approaches will vary depending on the cost of energy, energy supply chain characteristics, incentives and the potential for alternative energy sources locally.

For more detailed discussions on energy efficiency in the processing sector and alternative energy sources for processing, including proposed Research and Innovation actions, see section 3.1 Energy Efficiency in the Chemical Industry.

1.5 Chemical Plant of the Future

The challenge

"Doing more with less" is the orientation for the future chemical industry. In a carbon-constrained future, the energy and resource efficiency needs, the need for enhanced performance and competitiveness, as well for sustainable eco-processes, will orient the chemical industry beyond incremental improvements in process development.

An integrated approach to process innovation is required from design to industrialisation and operation together with breakthrough technologies using new raw materials as feedstock, heating technologies, insulation designs and energy intensive operations. Systematic integration of best practice technologies into existing plants (retro-fitting) is essential to achieve efficient processes.

Design and systems engineering methodologies, such as process modelling, simulation and control strategies are essential to optimise existing and prospective processes. In addition it is crucial to enable the dissemination of advanced process technologies across all kinds of industrial production units. Process control and supervision of industrial operations, from regulatory control to manufacturing planning and optimisation, have a major role in assuring high quality standards and optimal operations in terms of resource use and economic viability.

Many of the actions outlined below relate to extended use of advanced ICT technologies and are also further described in section 6.1.

1.5.1 Process intensification

Process Intensification presents a set of radically innovative principles in process and equipment design, which can bring significant benefits in terms of process and value chain efficiency, capital and operating expenses, quality, wastes, process safety, and more. The topic features in the SPIRE roadmap. Here we cover the main orientations for the chemical industry.

Research and innovation actions

- Development of new catalysts or new transformative technologies for existing asset retrofit.
- Development of process-intensifying equipment: highly effective process equipment for continuous processes, optimising the strength of processes with easier maintenance and low impact on the environment.
- Development of process-intensifying methodologies: hybrid and multifunctional technologies such as integration of reaction and separation, heat exchange, or phase transition, allowing for energy efficiency and competitiveness improvements.
- Implementing new energy forms (photochemical, microwave, ultrasonic, electron beam) that can have many applications in thermal processes and could offer lower energy use and improved process control.
- Development of more flexible scalable process and manufacturing capabilities to address developing markets and reduce dependence on large scale asset investment.

1.5.2 Advanced process control solutions

Controlling processes to continuously run at maximum efficiency can deliver enormous benefits in terms of resource efficiency, product quality and competitiveness.

Research and innovation actions

- Development of reliable and cost-effective fast in-line measurements: advances in the field of microelectronics, nanotechnologies as well as ICT can provide the chemical industry with intelligent sensor networks with disruptive capabilities, delivering massive information about chemical composition, process equipment preventive maintenance, resources and energy usage, and environmental impact, while also being capable of self-calibration and self-adaptation.
- Development of ground-breaking changes in software and hardware infrastructure to deliver the highest value of 'big data' in real time and develop decision support systems that provide answers to complex queries instantaneously. With the development of smart factory concepts with sensor-equipped machinery that is both intelligent and networked, the application of Big Data approaches will bring efficiency gains and enable effective predictive maintenance.
- Implementation of new closed-loop control concepts that emphasise process automation will make it possible to operate industrial processes at their optimum both economically and ecologically with enhanced safety.
- Development of Operator Training Systems (OTS) that simulate process operations together with associated supervisory systems will need to accompany the changes in advanced process control and anchor this culture deeply in the European chemical industry. OTS should permit faster development of processes through advanced modelling and optimisation of manufacturing conditions.

1.5.3 Plant reliability and maintenance

With aging assets and limited investment in large plants in Europe, it is critical to ensure the reliability of the current infrastructure. Plant maintenance to provide long-term reliability at lowest possible cost is critical to maximising production time and yield, and ultimately the use of resources.

With the development of new plants, particularly with new technologies and products, it is essential to consider long-term reliability, total cost and resource usage to ensure maximised efficiency and competitiveness.

11: http://ec.europa.eu/europe2020/index_en.htm

Research and innovation actions

- Development of plant maintenance techniques, monitoring, and predictive maintenance technologies to improve the reliability of plants.
- Integration of monitoring and data exchange with process control to provide an integrated plant and site management approach.
- New models are required to improve predictive maintenance techniques.
- New and extended technologies for remote monitoring, inspection and repair, with extensive use of robotics and automated techniques to improve safety and reliability.
- New business and cooperation models to maximise the competitiveness and the introduction of innovative technologies.

1.5.4 Model based design and optimisation

In order to improve plant performance the use of modelling will provide designers and process developers with the opportunity to develop and optimise new technologies and processes before implementation and to gain insights into running processes to enable improvement.

Research and innovation actions

- Development of new concepts, tools and frameworks to deal with complex systems: detailed models built and validated from designed ab initio numerical and physical experiments will allow simulation of the behaviour of new processes with unprecedented accuracy.
- Methodologies to build, link and use models that span larger length and time scales from high resolution computational fluid dynamics to plant-wide models must be developed, especially in the field of multiphasic and reactive intensified processes.
- Robust data-driven and knowledge-driven molecular models are key to design and select efficient chemical routes, catalysts, green solvents and to predict basic process data.
- Model-based multi-objective and multidisciplinary optimisation will be done off-line and on-line to identify scenarios that simultaneously minimise raw materials and energy use, capital intensity, environmental footprint and consider all relevant scales of their relevant value chains.

1.5.5 Industrial symbiosis

Industrial symbiosis (IS) occurs where waste and side streams are used in an integrated concept for complete resource management within an industrial park, site or region. The strategic challenge for IS is to increase resource efficiency and turn waste (by-products and CO2) into resources as secondary raw materials. IS addresses resource flows to identify opportunities to reuse these materials and energy resources, optimise resource efficiency in manufacturing, and reuse CO2 in new products. SusChem's efforts here are aligned to the SPIRE PPP roadmap to ensure synergies and avoid duplication of effort.

Research and innovation actions

- Developments are required at an organisational, policy and technological level to maximise the effectiveness of IS. This requires close cross-sectorial cooperation to ensure maximum use and re-use of resources and application of cascading principles to approach a closed circular resource use system. Integration of waste and by-products use within sites and regional processing is critical to success. Policies related to definition and re-use of waste will affect the implementation of IS, especially where cross-border material flow is required.
- Policies and practices need to be extended to include other sectors and surrounding processes to enable full IS. Technologies for separation, purification, transport and integration into other process will need to be developed. An understanding and close cooperation with adjacent industries is required to maximize the benefits from waste and by-products which could enable optimal process efficiency in chemical processes.
- Retrofitting current technologies and assets to facilitate new sustainable industrial processes.

Expected impact: Chemical plant of the future

Through a focussed approach to developing a resource efficient and competitive system for the chemical plant of the future, the resource efficiency and emissions of chemical plants will be greatly improved. Existing plant performance will be enhanced, optimising processes, reducing waste, reducing energy usage and maximising yield.

New plants will be designed to use the latest technology and will target resource efficiency as a fundamental part of their development. Many production units will become smaller and more efficient, with a possible modular approach.

These environmentally and resource efficient plants will be more economical than traditional plants, making the European industry more competitive on a global scale. The new technologies and designs involved will require new skills and provide high-quality jobs.

A Sustainable and Inclusive Bioeconomy

Part 2

The bioeconomy encompasses the production of renewable biological resources and the conversion of these resources and associated waste streams into value-added products such as feed, food, biobased products and bioenergy. Many sectors (agriculture, forestry, marine, chemicals and materials, energy, food) are impacted by the emergence of the bioeconomy, meaning that its development will require an integrated systems approach, which will provide very significant opportunities for new innovations, more sustainable value chains, jobs and economic growth.

Integrated biorefineries are central to the development of the bioeconomy and will deliver new sources of chemical building blocks that are either structurally similar to fossil-based feedstock or new with novel functionalities and improved properties. In order to unlock the full potential of a sustainable biomass supply, it is essential to consider all possible sources including second generation biomass and waste streams (such as municipal wastes). The bioeconomy can improve resource efficiency and is a key element in achieving the broader concept of a circular, integrated, renewable economy.

SusChem is an essential link between the chemical industry, industrial biotechnology and stakeholders in the bioeconomy and is actively involved in two large and relevant PPPs between the European Commission and industry launched in 2014:

- The joint technology initiative 'Biobased Industries' (BBI)[12] that brings together research and industry partners along the whole value chain of biobased products and focuses on innovation for products from biobased feedstock.
- The PPP 'Sustainable Process Industry through Resource and Energy Efficiency' (SPIRE)[13] that provides a solid basis for academia, SMEs, and multinational companies to collaborate on cross-sectorial initiatives in these areas.

SusChem contributes to the alignment of both initiatives. The interface between BBI and SPIRE is the provision and use of biobased platform chemicals. In addition, both PPPs may support projects using biotechnological conversion processes and specific improvements of biotechnology processes may be eligible for funding through either PPP. SusChem will enable the coherence of on-going and future funding initiatives and the deployment of flagship projects that demonstrate technological leadership and that Europe is a globally competitive location to invest in the bioeconomy.

12: http://bbi-europe.eu
13: http://www.spire2030.eu

2.1 Sustainable Agriculture and Forestry

Agriculture and forestry are at the start of biobased value chains providing a sustainable, competitive and consistent supply of biomass for industrial use whilst safeguarding both animal feed and human food value chains. Sustainable production, efficient processing and use of biomass (including waste streams) are essential to the successful development of the bioeconomy. SusChem will help the Agriculture and Forestry sectors to improve resource efficiency and develop more sustainable practices working in alignment with the EIP 'Agricultural Productivity and Sustainability.' [14]

2.1.1 Recovery of nutrients from fertilizers

The challenge

Sustainable production of biomass faces the challenge of depletion of vital plant nutrients in soils. There is a need for new and improved technologies for recovering and recycling these essential biological elements: phosphorus is the main challenge but other vital elements such as nitrogen and potassium should also be considered.

Research and innovation actions

- Development of technologies to cost effectively separate and purify nutrients from agricultural and forestry wastes (including food wastes and waste waters).
- Development of technologies for the direct re-use of nutrients from waste streams, for example as feed to bioreactors.
- Development of technologies to separate and, where possible, recycle to other processes any detrimental components, for example heavy metals.

Expected impact

The recovery and recycling of nutrients from waste streams will provide an alternative to primary supply and contribute to the circular economy. In addition to environmental benefits, optimised nutrients recovery will mitigate Europe's import dependency for many raw materials, especially for phosphates.

2.1.2 Crop protection

The challenge

To secure more sustainable harvests of Europe's major crops (cereals, potato, sugar beet, oilseed rape and vegetables) environmentally safe chemical compounds and formulations have to be developed as the basis for the provision of pesticides (insecticides, fungicides, herbicides) and growth enhancers. Many current pesticides are partially banned by the European Commission because of unwanted side effects, especially when used in non-recommended higher concentrations.

Research and innovation actions

- The chemical compounds used in pesticides need to be modified and/ or replaced by new highly efficient and environmentally safer chemicals requiring intensified research and development. New pesticides are urgently required because of resistance to current formulations. This is especially urgent for herbicides to which only a limited number of chemicals are currently applied.
- In addition to the development of new active compounds, the development of additives (such as wetting agents) and optimised crop protection formulations is necessary.
- Development of new chemical compounds that promote plant growth and performance is required. This is an area where new modes of action are expected to be discovered.

14: http://ec.europa.eu/eip/agriculture

Expected impact

The introduction of novel pesticides in agriculture and horticulture will support the urgent global challenge to ensure food, feed, fibre and biological fuel production. Securing adequate food production in developed and developing countries is one of the major challenges facing the world, which will require the harvest for most crops to double over the next decades [15]. The growing demand for new generation pesticides and pesticide formulations will form a stable, prospering market in which the chemical industry will play a major role. Novel growth enhancers could open enormous opportunities for a worldwide market for new generation chemical products.

2.2 Enabling Sustainable & competitive biobased industries

2.2.1 Biobased feedstock: Chemicals and energy carriers from advanced biorefineries

The challenge

The development of biofuels (biodiesel, bioethanol) has accelerated in the last decade. This is a very significant step towards fully developed biobased industries. Nevertheless, the overall eco-balance is still an area of concern because of the energy requirements (and corresponding CO2 emissions) for crop seeding, fertiliser, harvesting, transport and conversion. In addition, biobased feedstock required for biofuels can compete with food and feed value chains and this is an issue that must be avoided.

Further development of biofuels and biobased chemicals face similar technical challenges and can benefit from each other in integrated, advanced biorefineries, especially when transitioning to second generation biomass sources. An advanced biorefinery takes advantage of the various components in biomass and therefore maximises the value derived from the feedstock.

The chemical industry uses and will continue to rely on first generation biomass (for example sugar, starch, fats and vegetable oils) provided the supply is sustainable and is not competing with food use. It will also work increasingly with second generation biomass (ligno-cellulosic and residual biomass) which offers tremendous potential for increasing resource efficiency and implementing a circular economy. Rural networks and new logistic capabilities to collect feedstock will need to be established.

The main hurdle for biobased products is the supply of sufficient amounts of feedstock that are price competitive, have a low volatility and do not compete with food or feed production. To overcome this hurdle, the use of other feedstock streams like municipal waste, recycled feedstock, algae or energy-related crops will be required.

15: http://www.fao.org/docrep/x0262e/x0262e23.htm

Research and innovation actions

- Develop ligno-cellulosic biomasses as an ideal candidate for a secure biorefinery feedstock. The biomass is widely available, does not adversely impact on food security, can grow on marginal lands, or be supplied as agricultural or forestry residues. Ligno-cellulosic biomasses can be used to produce a variety of chemicals and energy carriers. To provide sustainable biomass feedstock requires the development of technology (in addition to logistics) to minimise the loss of perishable agricultural material from harvesting to end-use.
- Improved large-scale processes for the separation of lignin, cellulose, hemicellulose and starch need to be developed.
- New processes to convert lignin into suitable raw materials for feedstock are required, either by cracking the polyaromatic structure into aromatic monomers or by gasification to syngas and subsequent conversion (Fischer-Tropsch, methanol route or use of syngas for fermentation).
- The use of biological waste streams as feedstock is an option. However, this will require that constant quality is ensured, or the processes of bioconversion and downstream processing must be flexible enough to handle variation in feedstock quality. Potential biomass waste streams could be ligno-cellulosic residues (straw, bagasse, residual wood from forestry) and food industry residues. For new waste streams, logistics will have to be established regarding storage and transport especially for perishable waste. The collection and comparison of current best practices for identifying, sourcing and processing various wastes across Europe could provide useful data for countries or regions facing similar challenges.
- Micro- and macro-algae are promising candidates as feedstock sources with very high growth rates and high lipid content. However, production chains with net energy output need to be identified and costs in all segments of production need to be reduced significantly. Cultivation, harvesting and drying of algal biomass is not yet economically and environmentally sustainable. Quality, availability and price of CO2 sources are also important hurdles.

To achieve significant results in this area it will be necessary to undertake research and demonstration actions to build demonstration/ industrial units that bridge the gap between basic research and industrial scale.

Expected impact

The production of new biobased fuels and chemicals using ligno-cellulosic raw material and a cost-efficient biomass conversion process will show benefits both in terms of environmental impact, sustainability of the process and value creation along the value chain including in rural areas.

2.2.2 Industrial Biotech Processes

The challenge

Industrial biotechnology (IB) processes mainly use fermentation or biocatalysis to develop new, biobased, industrial applications. They are implemented in dedicated biorefineries as well as in conventional chemical process plants.

IB processes can be a more resource and energy efficient alternative to conventional chemical processes yielding products with excellent purity. Enzymatic synthesis also facilitates products which cannot be produced with classical chemical synthesis providing new products with new properties. To increase production efficiency of these processes, deep biological understanding must be combined with process-engineering expertise.

A key limitation in current bioconversions is that most industrial microbial production strains can only convert relatively pure and non-complex feedstock. Another frequently encountered hurdle is that the by-products or target products produced during fermentation inhibit productivity and complicate product recovery. Removing bio-impurities may require several separation processes and can represent up to two-thirds of total process costs. In addition many bioprocesses require large amounts of water.

Research and innovation actions

- Develop new energy and resource efficient processes for the use of biobased and other feedstock including pre-treatment, conversion processes, downstream purification and transformation.
- Develop alternative raw material transformations by balancing the use of existing facilities (retrofit approach to lower the barrier-to-entry costs) with the design of new modular and flexible processes to match available local biomass infrastructure.
- Development of bio-platform technologies for improved enzyme strain engineering (e.g. improved '–omics' methods for system understanding, high-throughput engineering, high-throughput screening in variable fermentation conditions including non-conventional reaction systems and media).
- Development of new microbes resistant to by-products and target products.
- Identification and engineering of more active and robust enzymes that improve bio-catalysis.
- Integrated optimisation and development of metabolic engineering, pre-treatment, bioconversion, product recovery and downstream processing.
- Optimisation of pre-treatment and enzymatic hydrolysis to achieve a hydrolysate quality for maximised microbial conversion and improved process yields.
- Development of realistic models of the production process and realistic models of reactor types equivalent to the computational systems already used in other engineering fields.
- Development of microbe strains that are resistant to reversion to mutant strains and are focused on biomass production.
- Development of combined chemo-bio-processes looking at novel ways in which bio- and chemo-catalysis steps can be combined to improve process economics.

Expected impact

The availability of optimised biotechnology processes will increase the overall economics and life cycle analysis of bioconversions and biobased value chains. Advanced biotechnology processes are essential for the development of a successful and sustainable bioeconomy.

2.2.3 Conversion of CO2 by bioprocesses

CO2 can be used as a raw material with a source of energy (light or hydrogen) and transformed into useful feedstock by bioprocesses such as microalgae technologies, bacterial CO and CO2 fermentation, advanced biotechnological processes and bio-electrochemical systems. Some companies are already using microalgae technologies (for instance using flue gas from cement production to produce a biocrude similar to biodiesel) or bacterial CO and CO2 fermentation (for example, production of ethanol and butane diol from steel mill flue gases or bioplastics through bacterial CO2 fermentation,) to convert CO2 to useful products.

The challenge

Microalgae technology can produce biomass without the need for agricultural land. It can also capture flue gas emissions and contribute to GHG reduction targets. However, the technology also faces challenges including design of reactors and/ or ponds to obtain the best yields and minimise energy use (for illumination and stirring). Increased photosynthetic efficiency, O2 striping and CO2 mixing, increasing biomass content, cost effective, robust and large scale cultivation methods are also key steps to make phototrophic algae an economic and attractive crop. Harvesting, disruption, fractionation and refining of the algae biomass must also become more efficient. Large amounts of water are also processed making the process costly and energy demanding.

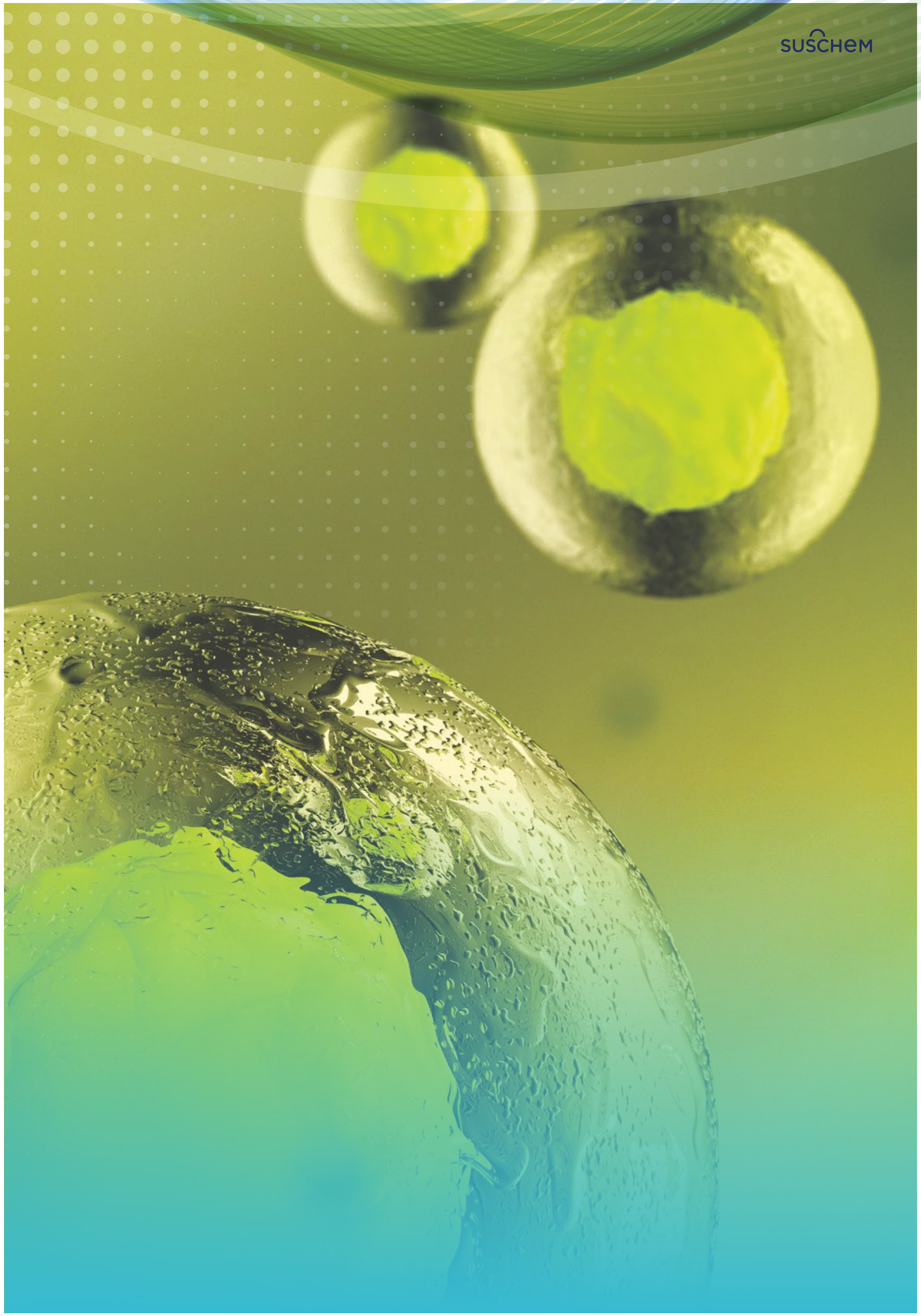
In comparison to microalgae technologies the cultivation media for bacterial CO2 fermentation is more expensive due to high hydrogen costs, however, the process does not require light, reducing the complexity of the bioreactor.

Research and innovation actions

- Development of genetically engineered algae will be required and this will need clear regulatory guidelines and legislation. For bacterial CO and CO2 fermentation, bacteria may also be genetically modified to improve yields. An important goal will be to reduce the production of by-products.
- A limited number of artificial products have been produced by bacterial syngas fermentation. In order to reap the benefits of this ubiquitous and low cost feedstock, its fermentation to high value products should be a development target.
- For bio-electrochemical systems, more research is needed to design suitable, cheap and robust electrodes and appropriate reactor systems to maximise the contact surface between the electrodes and the reaction media.
- For all of these technologies it will be necessary to co-locate the bioconversion facility where the CO2 or CO is produced. This requires the identification of the prime locations where opportunity in the highest. Identifying the most appropriate source of energy (or combination of energy sources) is another important factor to take into account for CO2 bioconversion projects.

Expected impact

Through successful technological developments, the promise of CO2 or syngas conversion by bioprocesses can be demonstrated. Once the technological challenges are addressed, appropriate registration legislation is in place, and environmental impact has been determined large-scale production sites could be developed providing sustainable chemicals and fuel.



2.2.4 Biobased products and materials

Biobased products and materials can be structurally identical to those obtained from fossil-based feedstock, but there is a huge potential to develop new biobased products and materials that are not accessible from fossil feedstock with equal or better properties and superior economics compared to fossil-based products or materials. The potential of biobased products and materials spans the entire product spectrum of the chemical industry.

- Bulk chemicals: biobased platform chemicals that already receive strong commercial interest include 3-hydroxypropionic acid, succinic acid, 1,3-propanediol, furfural and isoprene.
- Building blocks for polymers: new building blocks can lead to a variety of high performance polymeric materials for a variety of markets. Some building blocks are already on the market including long-chain amino-acids or di-acids or di-amines for polyamides, diols or polyols for polyurethanes or polyesters. New biobased materials in the consumer market include sachets for laundry detergents made from polylactic acid (PLA). Polymers based on lactic and glycolic acids are fully biodegradable in the body.
- Specialty chemicals: Biobased specialty chemicals, such as solvents, surfactants and lubricants have already been identified and are in commercial production.
- Fine chemicals, including intermediates for pharmaceutical active ingredients: Some raw materials and intermediates, in particular chiral molecules such as amino acids, have long been obtained from biological sources and used in the fine chemicals industry for making high value ingredients in the cosmetic and pharmaceutical industries.
- Composites: Biobased composites, including composites containing natural fibres as replacement for synthetic fibre reinforced composites, and biocomposites where both fibres and resins are obtained from biomass. Biobased composites have received increasing attention from the building, automotive and packaging industries.

The challenge

Research and innovation efforts are needed to develop production processes (combining biotechnologies and chemical processes) and extend the list of available platform chemicals, as well as to develop the new value chains.

Research and innovation actions

- Develop new biobased platform chemicals meeting the value chain requirements in terms of quantity, price, specification etc., including the use of pilot units to demonstrate process scale-up.
- Development biobased materials with improved or novel performance including pilot units to demonstrate the viability of large scale commercial production.
- Demonstration of the use of new biobased materials in a range of commercial applications through cooperative projects between companies along the value chain.
- Evaluation of how higher sustainability/ added value in biobased products can be communicated.

Expected impact

Research and innovation will lead to the emergence of new biobased products with unique features, differentiated from fossil-based products in terms of properties and environmental profile (as measured by LCA), in a range of market segments. This market trend will be assisted by materials suppliers who have a clear strategy around biobased materials.

2.2.5 Water issues

The challenge

The contribution of SusChem to water conservation, recycling and reuse is detailed in section 1.2 and most of the topics are relevant for the bioindustries. The bioeconomy faces specific challenges as it requires the availability of sufficient water of the right quality all along the value chain including crop production, processing, IB processes and waste water treatments.

Research and innovation actions

Important research and innovation actions required for biobased value chains include:

- Development of alternative water sources via industrial symbiosis.
- Development of specific and appropriate waste water treatments.
- Development of more accurate/specific separation technologies.
- Development of IB processes that require less water such as fermentation with high solid content.

Expected impact

The above actions related to water issues will strongly support the emergence of a sustainable biobased economy and improve the water footprint of these new biobased processes, products and value chains.

Part 3

Energy efficiency in chemical process and proposed solutions is key for the competitiveness of the chemical industry and the industry's technologies and products contribute to energy efficiency and clean energy production and storage for the wider society.

3

3.1 Energy Efficiency in the Chemical Industry

The Chemical industry is committed to playing its part in the European plan on climate change that sets the overall objective of reducing energy consumption by 20% between 2007 and 2020.

3.1.1 Energy efficiency in process

The challenge

Energy efficiency in chemical processing is a key step to sustainable manufacturing and competitiveness. Many competitive and standard solutions have been implemented in the chemical industry, but several practical current energy efficient technologies have not achieved widespread implementation because of cost and perceived technical risks.

Research and innovation actions

- Development of new catalytic processes with new, more effective catalysts and biocatalysts can transform manufacturing processes with improved yield and selectivity, and decreased process temperatures (where appropriate) making significant gains for net energy consumption, production costs and sustainability.
- Developing downstream processes including separations technologies. These are energy-intensive and development and implementation of advanced technologies for low-energy, low-cost, flexible separations will foster competitiveness and sustainability. Such technologies include membrane separations, advanced distillation systems, and new solvents for sorption.
- Improvements to high temperature process, such as combustion and gasification, to boost efficiency, operational control and reduce losses including through improved insulation materials.
- Development of advanced energy technologies that integrate energy systems, energy resources and technologies including flexible cogeneration, heat and power, and hybrid sources.
- Improved energy management to develop integrated solutions combining software, sensors and controls that allow monitoring and optimising energy flows within the production process, at different scales from individual unit operations to plant-wide facilities and the local environment.

Expected Impact

Implementation of the above measures throughout the industry will lead to reduced energy consumption above the 20% target - in some cases reductions greater than 50% can be achieved.

3.1.2 Alternative energy sources for processing

The challenge

Alternative energy sources, such as Solar, Wind, Geothermal, and Biomass-to-energy, will reduce the sector's dependence on fossil fuels. However, there are barriers for their effective deployment in the chemical industry. The local approach to implementation will vary depending on local energy costs, the local energy supply chain, incentives and available alternative energy sources.

Research and innovation actions

- Development of biomass to energy applications focusing on the integration of processing technologies in existing energy production assets to allow flexibility of energy sources, adaptive processes and operational maintenance improvements.
- To cope with intermittent energy supplies systems will be developed to predict and accommodate production processes. Enabling use of renewable energy sources will require advances in energy storage and distribution, thermal insulation, and efficiency.
- Use of H_2 as a feedstock and fuel will require development of new sustainable routes such as biomass to H_2, waste to H_2 and solar H_2, and improved technologies for gasification, biological production and/ or electrolysis.
- Waste heat valorisation requires the development of innovative technologies to recover, store and re-use heat and transform it into a useful source of energy. This will require the development of new materials and solutions to recover this 'lost' source including phase change materials and heat pump systems.

Expected impact

Alternative energy sources and smart systems to recover and re-use energy will enable the chemical industry to exceed its 20% energy reduction target and contribute to resource efficiency through activities such as industrial symbiosis (see section 1.5.5) and CO_2 conversion (section 1.1.2).

3.2 Products for Energy Efficiency

3.2.1 Materials for energy efficiency of buildings

The challenge

Integrated solutions for energy-efficient building are an essential requirement for the sustainable development of modern residential areas and to enable Europe to sustainably renovate its current building stock.

Europe's chemical industry is at the forefront of developing and providing high-performance materials in this area. Intense research is required to maintain this position in an increasingly competitive economic environment. To successfully innovate in energy-efficient buildings will require close partnerships along the value chain with the chemical industry taking an integrating role.

Research and innovation actions:

- Development of high performance foams for wall and roof insulation or high performance Vacuum Insulation Panels with highly insulating nano-structured foams.
- Development of specific combinations of materials for external insulation of buildings.
- Development of reflective coatings for roofing, particularly for commercial buildings in hot climates to cut air conditioning costs, or reflective decorative coating for interiors that reduce lighting requirements.
- Development of Phase Change Materials (PCM) that provide thermal inertia for the building envelope and contribute to saving energy through easier temperature control or can be used to store thermal energy including from local renewable energy sources.
- Development of long-life sealing materials for the building envelope or for new Light-emitting Diode (LED) lights and new materials for Organic Light-emitting Diodes (OLED). The adoption of LED and OLED for building lighting will drastically reduce energy consumption.

- Development of specific coatings or films for photovoltaic (PV) panels integrated in buildings to improve light transmission.
- Development of materials to enable light-weight structures that will lower logistic costs and improve workers' conditions.
- Development of biobased materials for use in this application area.

Expected impact

The implementation of materials with energy-saving characteristics has already proven to be a very effective for developing integrated solutions in energy-efficient building. The demonstrated significant energy savings will help to substantially broaden the market for such materials in sustainable building and housing programmes in Europe and worldwide.

These new materials will contribute to the Smart-City concept. The chemical industry is committed to work with smart-cities stakeholders (cities, architects, owners) to continuously improve the performance of its products. This will contribute to creating a European market, particularly for building renovation, that will both contribute in the overarching goals of reducing GHG emissions and also boost growth and jobs. But these innovation efforts must be coupled by demand-side measures. In this respect, the chemical industry is actively participating in the EIP 'Smart-Cities and Communities'.[16]

3.2.2 Lightweight materials: key enablers of energy efficiency

The challenge

The implementation of lightweight materials as a replacement for existing solutions is essential to improve the energy efficiency of many types of engineering equipment and systems in fields including energy production, transportation and construction. Aspects of interest around the targeted minimisation of structural mass should start at the development of energy-efficient systems.

Research and innovation actions

- Development of a better understanding of the long-term performance of materials and structures under dynamic loads to allow a reduction in safety factors.
- Minimisation of material waste in production through the development of, for example, near-net-shape part manufacturing processes.
- Development of novel recycling concepts for both production waste and end-of-life components. This could include research into thermoplastic resins or resins to allow easy depolymerisation at the end of life.
- Produce a better description of materials performance and process technologies in future simulation tools to enhance design efficiency.

Expected impact

The primary target is to minimise energy consumption and emissions in a range of products.

16: http://ec.europa.eu/eip/smartcities

3.2.3 New packaging solutions for better energy efficiency

The challenge

Today approximately 500 billion plastic bottles are produced annually of which around 30% are consumed in Europe. 80% of global production is based on the Injection Stretch Blow Moulding process (ISBM) and utilises Polyester (PET) and 20% is based on Extrusion Blow Moulding (EBM) and utilises High Density Polyethylene (HDPE). An average bottle weighs 30g meaning that overall some 15 million tonnes of plastic resin is consumed every year in bottle production.[17]

Research and innovation actions

- New technologies and materials should be developed to radically increase the efficiency of ISBM. This combination of material enhancement and higher manufacturing efficiency would allow net weight reduction of 40%.

Expected impact

This development could save 1.2 million tonnes of polymer per year and reduce energy and CO_2 emissions by 20%. It would also offer opportunities of technology licencing, the creation of new jobs and the growth of small and medium industries.

3.2.4 Efficient lighting: New materials for OLED lighting

The challenge

Solid State Lighting (SSL) is expected to become the dominant lighting technology by the end of this decade. LED technology has rapidly penetrated the lighting market and SSL has the potential to reduce lighting energy consumption by up to a factor of three. OLED technology lags behind LED in terms of technological and market development but is generating great interest due to its intrinsic characteristics: quality of light (an emission spectrum close to natural light), the possibility to develop large area light sources, absence of glare, and new form factors opening new design possibilities.

Research and innovation actions

- The penetration of OLED in the lighting market requires breakthroughs in terms of intrinsic performance (luminance, energy efficiency and lifetime) and reduced manufacturing costs. Materials development is key to solving this cost-performance issue.
- In addition optimised materials (in particular, higher efficiency blue emitters) are needed to enable OLED lighting to perform on a par with LED technologies.
- The development of new materials compatible with wet-processing, such as printing and coating, is required to access high throughput and less capital intensive manufacturing technologies. The ultimate objective is to develop roll-to-roll (R2R) processes with high materials yield.

Expected impact

European chemical suppliers have traditionally been strong in the global market for electronic materials and leading European chemical companies are key suppliers of OLED materials. They can leverage their long standing relationship with European-based, global experts in the lighting industry and the very strong European lighting industry supply chain to establish a competitive global presence.

17: The Future of PET Packaging to 2015 - Global Market Forecasts. David Plat, PIRA International Ltd, page 35.

3.3 Competitive Low Carbon Energy Production

Research and innovation actions by the chemical industry are required to strengthen Europe's position in the field of low carbon energy production technologies or renewable energy sources.

3.3.1 Advanced materials for photovoltaics

The challenge

Europe's aim is not necessarily to be able to produce the cheapest advanced PV materials on the market, but rather to develop and market those materials and processes that can provide the best performance in terms of cost / benefit ratio and sustainability for PV systems as a whole. In the short term the emphasis will be to develop a range of specialised materials required for PV system including encapsulants and conductors. In the longer term the development of next generation advanced materials, low cost manufacturing processes and substitute advanced materials systems that can mitigate the impact of the lower cost base enjoyed by competitors outside Europe [18].

Research and innovation actions

- Advanced materials for thin film inorganic PV and lower cost manufacturing with a focus on various band gap semi-conductor materials (including absorber materials not relying upon critical metals such as copper zinc tin sulphide (CZTS) technology) for single and multi-junction devices, new materials for back-contact and buffer layers, cost-effective multifunctional coatings, functional (nano) materials for non-vacuum absorber deposition processes and/ or light management by plasmonic effects or scattering and ultra-thin (mono crystalline) silicon layers (below 50 micron) to replace the current state-of-the-art silicon wafers (below 200 micron).
- Advanced materials for thin film organic photovoltaics (OPV) and lower cost manufacturing with an emphasis on optimisation for increased efficiency with broader / tuned spectral response for single and multi-junctions. Durability of these materials is also a key point to be addressed. High throughput printing / R2R processes for OPV needs advanced materials adapted to ink formulations. Increases in efficiency through light management by plasmonic effects and scattering in active layers as well as at various other interfaces will require functional nanomaterials with a controllable and scalable production process.
- Advanced materials for improved barrier layer encapsulants and adhesives that include novel flexible, lightweight, low cost, transparent barrier materials (possibly including composite materials) with appropriate water vapour transmission rates.
- Advanced materials for alternative conductors or materials that do not rely upon potentially scarce metals and are significantly cheaper than current Indium Tin Oxide (ITO) materials for large area coatings but provide at least a similar performance.
- Advanced materials for light management to provide low cost improved light coupling and absorption to photoactive layers using optical coatings, nano imprinting / nano structuring, photonic structures, multi-layer optics, plasmonics / nano particles, and reflective layers with high haze for ultra-thin Silicon solar cells.
- Advanced materials for building-integrated PV (BIPV) to develop specialty substrates (glass or other materials) that are easy to integrate into buildings.

Expected impact

These developments will result in cheaper and more flexible devices that will expand the range of application of PV technology. This will secure a European energy source and restore Europe's technological leadership in this area.

18: http://www.eupv platform.org/publications/strategic-research-agenda-implementation-plan.html

3

3.3.2 Materials for wind energy production

The challenge

Weight reduction of components is one of the most important goals for wind energy. Blades with reduced weight enable larger sized blades leading to increased power and increased energy yield at low to medium wind speeds and smaller-sized bearings, bed plates etc. A high priority goal is the development of cost effective carbon fibres and alternative fibre and particulate materials, including graphene, with an excellent stiffness/weight ratio, respective fibre reinforced composites and corresponding manufacturing processes. Another challenge is to substantially improve corrosion resistance to extend the life time of components and reduce maintenance effort. This in turn leads to reduced life time costs. Engineered base materials and protective coatings are a crucial development goal especially for offshore wind turbines[19].

Research and innovations actions

- Advanced materials for new wind turbines are needed to provide functional and protective coatings for blades operating in harsh environments (erosion and UV light resistance, self-cleaning, anti-fouling and icing etc.), fibre reinforced composite materials (based on carbon fibres, high stiffness glass fibres, new easy-to-process resins etc.), advanced composites using novel thermoplastic polymers, sandwich core materials for blades, and adhesives and joining/bonding materials for new resin composite blade materials. Consideration has to be given to recyclability of materials to recover the components at end of life.
- Advanced materials for tower, support structures, housings and mountings are needed including reinforced composite materials for large, lightweight durable structural elements, high strength and heavy gauge steels for wind turbine towers, and silicone materials for improving concrete durability. A key component is improved, higher performance corrosion protection coatings to extend operation in harsh environments especially for offshore wind farms.

Expected impact

These developments will allow European manufacturers to produce large durable wind turbines with higher generation capacity suitable for deployment in harsh environments (offshore and cold climates). This will help secure energy supplies for Europe and boost the competitiveness of the European wind turbine sector.

19: http://www.ewea.org/fileadmin/files/library/publications/reports/TPWind_SRA.pdf

3.3.3 Electricity from vibration and heat

The challenge

Piezoelectric polymers can harvest mechanical energy from vibrating or mechanically strained structures, such as bridges and roads, and transform it into electricity. In addition using waste heat below 100°C is economically viable only to a limited extent currently. But converting low-grade thermal into electrical energy can increase the efficiency of existing energy generation processes and reduce costs and $CO2$ emissions. Thermoelectric and piezoelectric generators can offer modern, efficient and economically viable alternative energy sources for deployment in energy autonomous systems operating in difficult-to-access locations.

Research and innovation actions

- Development of new energy recovery devices based on the piezoelectric principle for appropriate markets.
- Development of new transition-metal thermoelectric compounds with improved thermal and mechanical stability and without toxicity or supply problems (critical raw materials).
- Development of new thermoelectric materials with improved efficiency in the range <200 °C with respect to ambient temperature.
- Development of hybrid technologies for energy harvesting such as combining photovoltaics and thermoelectric materials.

Expected impact

New market opportunities will open up for a new generation of higher efficiency and more sustainable thermoelectric and piezoelectric materials and devices. These include harvesting power from vehicle exhausts, solar thermal energy, industrial processes, walkways, buildings and in wearable devices.

3.4 Enhanced Energy Storage Technologies

Renewable energy sources will help to reduce our emissions and reduce our dependency on fossil resources, however they have the inconvenience of depending on weather conditions and therefore have highly variable rates of energy production, which is a challenge for the management of energy distribution grids. Although solutions have been developed that enable good prediction of supply requirements and management of the supply/demand ratio through smart-grids, the possibility to store and/ or transform energy on the large-scale would provide a more favourable situation [20].

3.4.1 Electrical energy storage

The challenge

Currently energy storage relies on rechargeable batteries. The development of other potential technologies is key to support the intermittent character of energy production based on renewables and enable their market deployment for stationary energy applications and can greatly contribute to the smooth management of electricity supply grids. There remain many materials-related challenges to make this vision a reality.

Research and innovation actions

- Advanced materials for lithium ion batteries include low cost high capacity and higher voltage cathode materials, high energy density anode materials with long life time, and materials for solid state battery production. As well as cathode and anode materials higher performance and safer electrolytes, binders, and separators are required.
- Advanced materials for vanadium-based redox flow batteries includes the development of low cost membrane materials with long life time and associated alternative electrolytes. In the long term new chemistries for faster kinetics, high voltages and energy densities are also needed.
- Advanced materials for metal air batteries (focusing on lithium-air batteries) requires the development of new electrode materials with improved life cycle and performance. Also required are new ceramic and glass membranes as well as new electrolytes and composite lithium electrodes.
- Advanced materials for electrochemical capacitors (redox-based pseudo-capacitors) need development of appropriate metal oxides, nitrides or polymer films.

Expected impact

Advanced battery technologies will impact how energy is used and stored at many levels from regional power distribution applications to improved sustainable mobility and new generation electronic consumer goods.

3.4.2 Thermal energy storage

Thermochemical energy storage is based on reversible chemical reactions with a large enthalpy difference between reactants and products. It allows in principle for permanent, loss-free, high-energy heat storage. Thermal storage media are used in a variety of areas with differing material profiles depending on the application and the temperature range. The lower temperature range (20-120 °C) is currently dominated by water based systems. Phase change materials (PCM) can also store thermal energy and operate around a constant temperature depending on the specific phase transition.

Sorption storage using reversible desorption / adsorption processes are suitable for temperature ranges between 100-150 °C. At higher temperatures (up to 1000 °C), heat in the form of sensible heat can be stored and plays a key role in storing energy at solar thermal power plants.

20: http://www.iec.ch/whitepaper/pdf/iecWP-energystorage-LR-en.pdf

Research and innovation actions

- Development of reversible thermochemical reactions, such CaO/CaCO3, to provide high energy density applications that cover as large a temperature range as possible.
- Development of heat transformation systems to efficiently upgrade low temperature (waste) heat to relevant temperature levels to (re-)introduce thermal energy into the process.
- Development of combined systems, for example, sorption with a thermo-chemical reaction and bridging of different temperature ranges for the controlled supply of heat or cooling energy.
- Development of procedural issues regarding system integration and heat transfer in integrated energy systems.

Expected impact

Thermal energy storage will be an essential contribution to an integrated effort towards energy efficiency in the building sector, the process industries and the energy system as a whole, each with their specific requirements. The proposed research will develop tools and solutions for a more efficient utilisation of thermal energy. In industry this will help to decrease energy intensity and fuel use in primary production and contribute to enabling industrial symbiosis.

3.4.3 Chemical energy storage

The challenge

Chemistry and more specifically catalysis will be a crucial actor in designing a future energy scenario built on innovative, efficient technologies and new materials that can both save energy and protect the environment. Excess electrical energy at peak periods can be transformed into chemical energy in the form of H_2 via electrolysis. Both, the generation of H_2 as well as the secondary conversion of H_2 into storage mediums such as methanol or methane require highly transient processes. This is in strong contrast to conventional catalytic processes which are usually operated at steady state. New catalytic processes and catalysts which allow for such a dynamic operation are therefore needed.

Research and innovation actions

- Advanced Materials for H_2 storage (composite structural materials) and purification (membrane materials) are required. For the storage of H_2, numerous lines of development are currently being pursued. Light metal complexes for H_2 storage are still largely unexplored, and for many known hydrides neither structure nor thermodynamics are known. As for sorptive storage, Metal Organic Frameworks (MOFs) seem to offer storage capacities that go significantly beyond the addition of carbon. Both for MOFs and hydrides, the use of theoretical methods for the exploration of the possible parameter fields is promising. Hydrocarbon molecules, such as carbazole, as a storage media for hydrogen should also be considered.
- Power to gas and power to methanol. These chemical energy storage technologies require actions at various technology readiness levels (TRLs). More fundamental research is needed to elucidate the effect of dynamic process control on materials and especially on the catalytic conversion of CO_2 to methane and methanol. The development of cost-effective sustainable H_2 production is essential.

The conversion of H_2 to methane or methanol and also the supply of H_2 by electrolysis will both be affected by the intermittent nature of operations, so activities to investigate these effects should be prioritised. The improvement of catalysts for sustainable production of methane and methanol using CO_2 as a carbon source will be key. Actions should include development and scale–up of improved catalysts and microreactor technologies for CO_2 to methanol conversion.

- Development of new innovative materials, for example new noble metal-free electrode materials for electrolysis, should also be considered as the basis for efficient and cost effective future processes.
- Demonstration of these technologies at commercial or semi-commercial scale and in a relevant environment with power grid connection will be required.

Expected impact

The extensive use of renewable energies requires systems which have the capacity to store substantial amounts of energy over an extended period of time. The proposed programmes will help to provide the materials for efficient and competitive chemical energy storage to accomplish the secure transition to an economy based on renewable energy sources.

3.4.4 Direct photo-conversion of CO_2: A long-term option

The challenge

Direct photo-conversion of CO_2 is a radical long-term option going far beyond the state of the art, to develop 'artificial leaves' able to capture CO_2 and convert it into renewable chemicals and fuels using only sunlight and water.

Research and innovation actions

- This will require breakthrough technology, with the development of new photo-electro-catalytic devices for direct solar-to-chemical energy conversion. Conceptually, new approaches are necessary with respect to the current state-of-the-art to enable the approximately 50-fold increase in productivity necessary to move to exploitable results.

Devices with stable performances, robust operation at higher temperatures than those explored currently, which allow an easy recovery of the reaction product, are necessary.

Expected impact

Since CO_2 is the only carbon resource that is available in abundance in Europe, the direct photo-conversion of CO_2 would be a breakthrough enabling reduction of fossil feedstock utilisation, reducing the EU's dependence on imports of fossil resources and improve energy security, while reducing pressure on biomass, land use and other environmental stressors.

Health, Demographic Change and Wellbeing

Part 4

An important unifying theme in Horizon 2020's societal challenge on Health, Demographic Change and Wellbeing (SC1) is personalisation in healthcare. The choice of this theme has been "informed by the ageing of the European population, an increasing communicable and non-communicable disease burden and the fall-out from the economic crisis", which is seen as "jeopardising the sustainability and equity of European health and care systems, on which Europe already spends nearly nearly 10% of GDP".

Cost is often a major barrier to more inclusive implementation in the area of health. None of the desired societal developments will be achieved unless they are affordable by public health services.

4

4.1 Personalised Healthcare

4.1.1 Personalised diagnosis using imaging

Following the analysis of the first human genome a revolution in healthcare thinking has taken place, based on the possibilities of diagnosing and managing diseases at the personal level. Diagnosis is key to effective personalised medicine and personalised chemical interventions will become a main means of curing and managing an individual's ongoing health and lifestyle. This is an area where SusChem can complement other European initiatives, such as the Innovative Medicines Initiative (IMI) [21].

The challenge

Personalised diagnosis requires substantial improvements in imaging sensitivity and site specificity through better imaging techniques which use exogenous or endogenous contrast agents to accurately identify the onset of medical issues at an early stage. Major improvements in diagnosis, prognosis and disease management may arise from incremental improvements in the specificity and sensitivity of novel molecular probes and contrast agents. Such imaging contrast agents must improve diagnosis and treatment of diseases in patients at lower costs per capita than is current practise.

Current medical imaging technologies include Magnetic Resonance Imaging (MRI), Single Photon Emission Computed Tomography (SPECT), X-ray Computerized Tomography (CT) and ultrasound. However, current imaging methods do not provide adequate information on the precise localisation of, for example, a lesion nor its pathophysiological characteristics. Therefore, major improvements in the specificity, sensitivity and contrast enhancing capabilities of exogenous contrast and/or labelling agents themselves are required. Current agents provide only visual evidence of gross anatomical abnormalities induced by the progression of an underlying disease, but little or no information on the nature of the disease. Also, many current contrast agents need to improve their poor dosing efficiency.

Research and innovation actions

- Development of new exogenous labelling and contrast agents that enable better mapping of metabolic abnormalities at the cellular level without requiring further investment in new imaging technologies.
- Development of efficient, cost-effective hybrid exogenous labelling and contrast agents, designed to complement hybrid instrumental platforms that are being developed or already available from major European-based instrument manufacturers.

Expected impact

More selective and effective contrast agents will improve diagnoses, reduce wastage and therefore enhance sustainability. In conjunction with currently available imaging instruments, molecular and nanoparticle innovation will make possible routine personalised medical imaging at lower cost which in turn will enhance societal inclusivity.

21: http://www.imi.europa.eu

4.1.2 Active and healthy ageing: responsive materials

In focusing on the ageing European population, the emphasis for Horizon 2020 is not just on treatments and management of disease, but also on the development of technologies that enable those who are disabled to continue to contribute positively to society. This should include the development of novel materials, with designed properties, which help healthy individuals to overcome physical disabilities. SusChem envisages an enhanced future role here for innovative 'smart' materials such as haptic materials, as well as improved prosthetic and biomedical implant materials.

The challenge

The principle objective is to create and develop novel materials that will transform the abilities of disabled and elderly people to live fuller lives and contribute positively to society resulting in reduced care costs.

There is a gap between current capabilities and what is needed for affordable personalised systems to enable the disabled and elderly to live full and productive lives. This gap could be closed through incremental improvements in responsive materials coupled with improvements in body-powered and directed prosthetic devices.

For haptic materials, further innovative developments need to take place in concert with the systems within which they are used, including computer hardware, sensing and feedback software and the associated servomechanisms. Further advances in touch-coordinate specific responses of the haptic materials combined with (say) a pressure response facility, using novel electro-active or piezoelectric polymers, are where further innovative chemical design is strongly needed.

Secondly, the interfaces between prostheses and body tissues or the use of biomedical implants require two material properties of great importance: biocompatibility and softness. Therefore interface materials must not only be intrinsically compatible with the living tissue they are in contact with (be 'biocompatible') but also be hard-wearing and possess appropriate viscoelastic properties.

Research and innovation actions

- Development of new or improved low-cost and flexible electro-active and piezoelectric polymers for use in second, third and fourth generation haptic material devices.
- Development of the next generation of smart, sustainable, biocompatible materials, non-textile fibres and polymers for use in prosthetic devices and sanitary uses.

Expected impact

Innovative advances in the control of haptic-prosthetic interfaces, which require innovative chemistry coupled with biotechnological advances, will open the way for the disabled and elderly to contribute more positively to society, provided these advances can be made at reasonable cost. Making such systems readily available will save money for national health providers by enabling patients to continue a level of self-sufficiency whilst lowering the need for high level care provision.

4.1.3 Active and Healthy ageing: Formulation for delivery

A key area where continuing chemical, biotechnological and materials development is required is that of formulation. Successful formulation technology forms the basis of not just the medical and pharmaceutical industries, but also sectors including the processing, manufacture and the delivery-in-use of foods, personal products, cosmetics, paints, crude oil extraction, and vehicle lubrication systems.

Formulation is about putting the ingredients of a product together in such a way that it is not only attractive to the consumer but also delivers the required benefits efficiently and effectively.

The theory that underpins formulation is primarily physicochemical and is concerned with the quantification of the forces that operate at interfaces between discrete physical domains, and how these forces operate and change over a hierarchy of length and time scales. These forces combine to yield the observed useful properties of these systems. This requires more than 'knowledge'; it involves employing high-level skills derived from extensive experience.

SusChem highlights the need to nurture and build this skill set under the Leadership in Enabling Industrial Technologies (LEIT) area, but also as a key target within Health, Demographic Change and Wellbeing and across other societal challenges in Horizon 2020.

The challenge

As innovation takes place, potential gaps between the invention of new actives and the formulation of suitable media for their delivery are likely to develop, especially as times between invention in the laboratory and launch on the market reduce. The ability to close these gaps lies with those physical chemists and chemical engineers who possess formulation skills based on theory and experience. This skill and knowledge base must be nurtured and protected.

The objective is to continuously develop novel sustainable solutions for formulating innovative products, in both medical and non-medical applications, to enable effective delivery of actives in cost-effective and efficient ways in consumer applications across society.

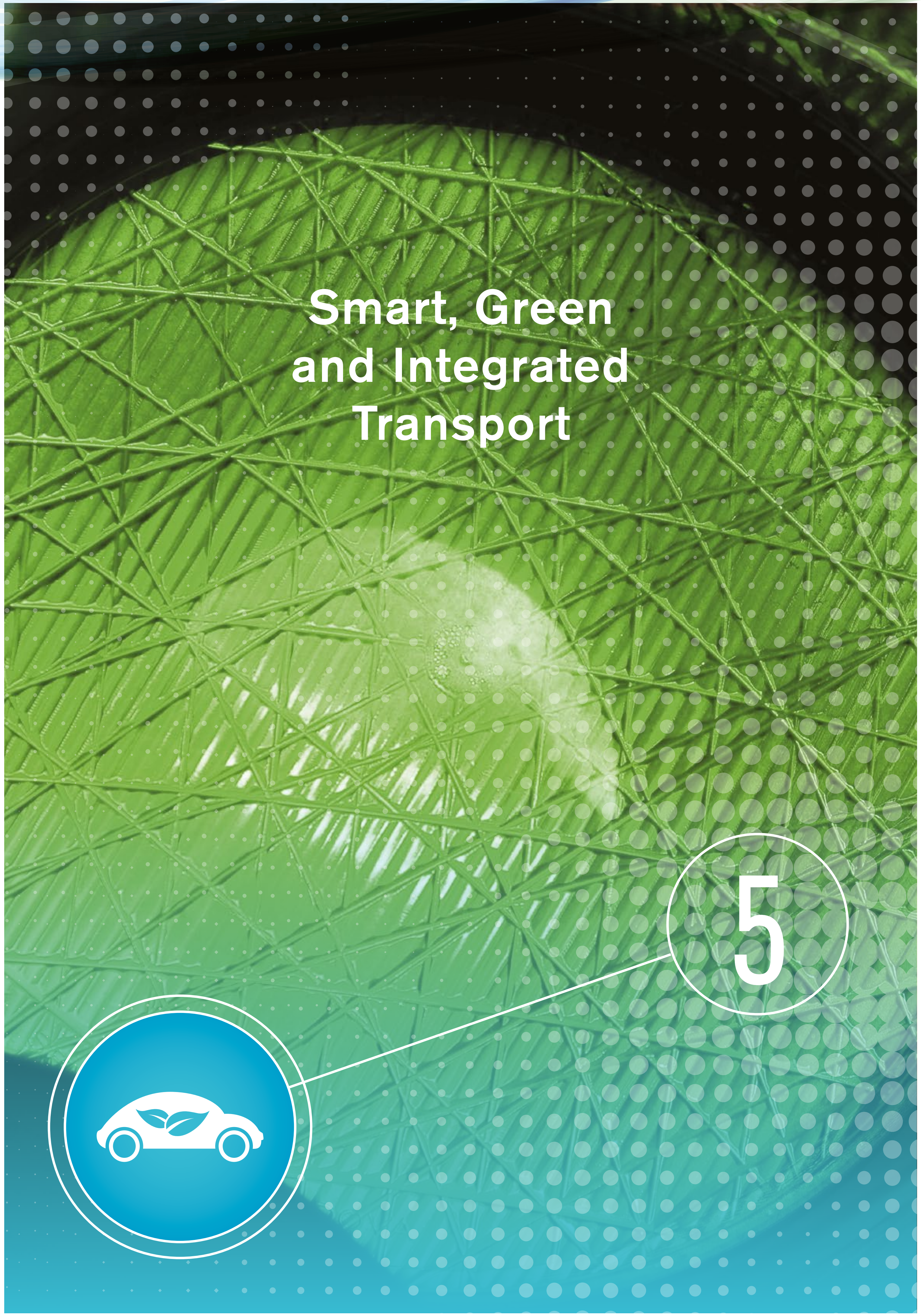
Research and innovation actions

- Development of technologies for Formulation for Delivery that improve the precisely controlled and targeted use of ingredients, or which provide new formulation architecture or product microstructure.
- Development of methodologies for Formulation Process Design which can be implemented in a production environment to provide better products, improved quality and/or a significant economic and/or environmental benefit. Novel process technologies would figure highly in these calls and there is a synergy here with the SPIRE PPP.
- Development of methods for Formulation for Stability to predict, measure, control and optimise the stability of formulated products which can bring economic and environmental benefits, leading to better regulatory compliance, better supply chain management and improved shelf-life properties.
- Development of programmes on Formulation for Medical Imaging to provide formulation skills and technology to underpin novel advances in exogenous agents for medical imaging for personalised diagnosis, and treatment of disease.
- Coordination activities should bring together formulation expertise and skills employed across diverse manufacturing sectors, including other initiatives such as IMI, to assess common issues and exchange best practice.

Expected impact

Without an active, innovative formulation skills base, new molecular entities and materials that have been developed to deliver real benefits in terms of efficacy, sustainability and cost-effectiveness will not realise their potential. Innovation in sectors that extend well beyond chemistry and biotechnology will be constrained, and consequently European society and economy will not benefit.

Smart, Green and Integrated Transport



Part 5

Global trends such as population growth, climate change, urbanisation and a rising demand for energy are major challenges to future mobility concepts. In this context electric mobility will play an important role and chemistry already offers numerous products and solutions in this area. The battery is the key component in the electric vehicle (EV). Chemistry can make this technology more affordable, powerful and secure with the aim of increasing the range of EVs to over 250 kilometres.

In addition, lightweight design of vehicles is important. If the weight of a vehicle drops, its range can increase. The chemical industry offers tailor-made polymers for different applications in EVs: the body, exterior and interior and even for the engine compartment. New tyre concepts can reduce rolling resistance and also extend range.

Energy management is a specific challenge for EVs. In summer, air conditioning consumes additional energy, while in winter good insulation is important. In contrast to internal combustion engines (ICE) the electric motor produces nearly no 'waste' heat. Chemical products can help here: special pigments applied on the windows reduce the warming of the interior in the sun, while high-performance foams offer perfect insulation in the winter.

Even if the ICE remains the dominant propulsion source, contributions from the chemical industry will make it more sustainable: new catalytic exhaust gas treatments can remove organic compounds and fine particles. And fossil fuels will gradually be substituted by synthetic fuels made, for example, by the conversion of CO2 with solar energy or by fuels made from renewable (biomass) sources.

5.1 Green Vehicles

The chemical industry is a key provider of materials and components for EVs, for the batteries powering the vehicles but also the lightweight materials and performance materials that contribute directly to EV performance in terms of emissions and vehicle range. These materials are adapted to the high productivity rates of manufacturing in the automotive industry.

5.1.1 Lithium-ion batteries for EVs and hybrid EVs (HEV)

The challenge

Compared to other battery concepts, the lithium-ion battery has considerable advantages and is the most powerful battery concept currently on the market. The chemical industry with other industry partners is working to improve the system and make lithium-ion batteries the energy storage of the future, offering entirely new opportunities not only in vehicles (HEV and EV) but also as intermediate storage for renewable energy.

Research and innovation actions

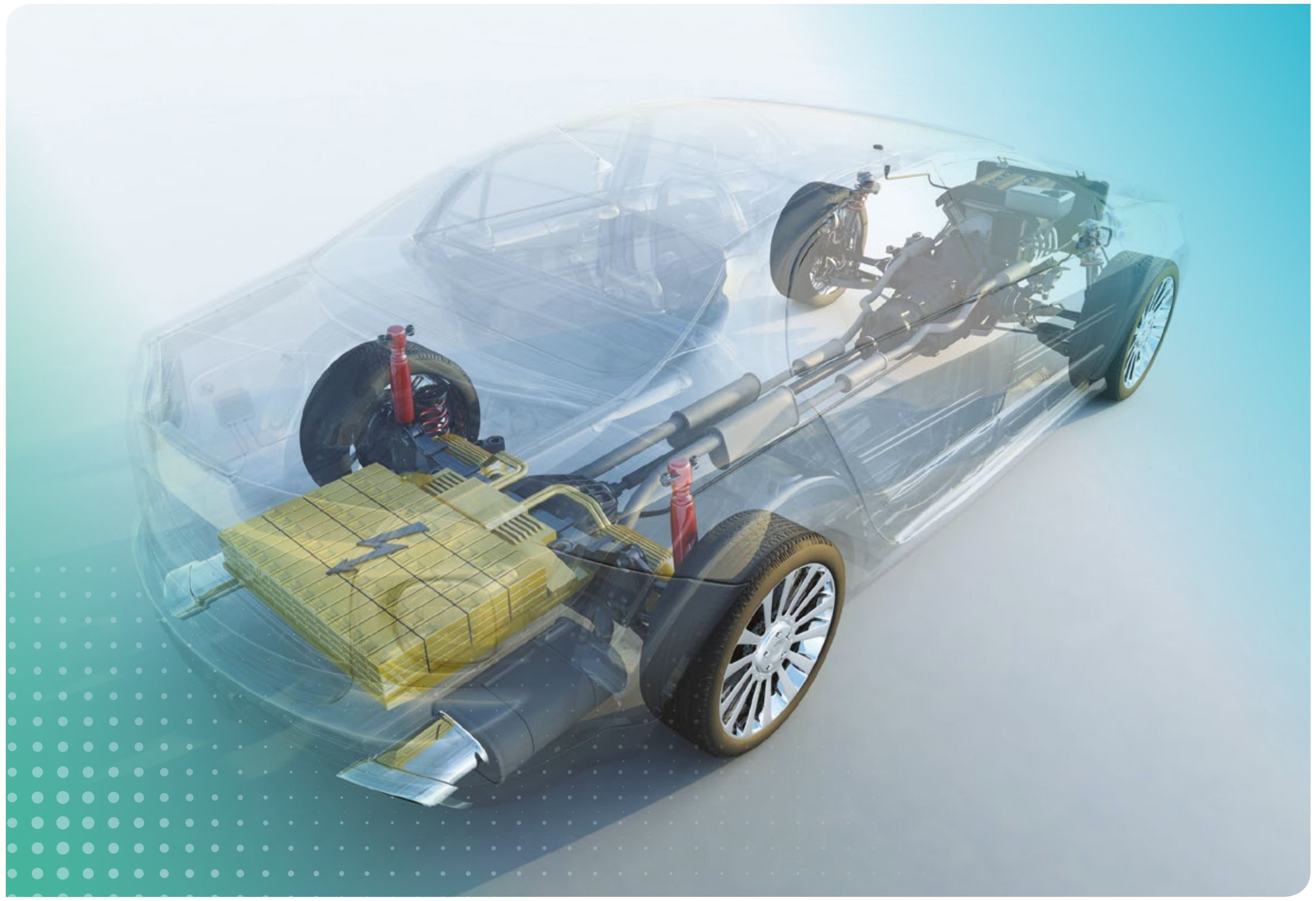
- Development of cathode materials for the next generation lithium-ion batteries that will have higher energy density, longer life and improved safety. Key to boosting performance are cathode materials which allow a dense uptake of lithium ions in a structure which is stable for a long time under realistic cycling conditions. More stable cathode materials structures under extreme conditions that provide higher safety margins are also an important target.
- Development of high-quality, tailor-made electrolytes. Electrolytes are complex formulations consisting of different chemical building blocks that function as a charge transport medium in batteries. High-quality, customised electrolytes are an essential prerequisite for high battery performance. New electrolytes should offer similar or higher ion mobility and be more stable (and safer) than present electrolytes.
- Separators are an essential component of the overall battery performance and safety. The chemical industry should develop new separator concepts including composite materials that optimise mechanical robustness and porosity, are safer and more stable at higher voltage (>5 volts), are chemically inert and contribute to improved energy and power density. The development of gel and solid state separators could reduce or eliminate liquid electrolytes.
- A systems approach to battery development should be encouraged since each individual battery material is in constant interaction with other materials in a battery cell and its performance strongly depends on the cell design and operational conditions. Integrated research on materials and cell manufacturing should be undertaken to bring down manufacturing costs and find substitutes to some toxic solvents used to prepare electrodes.
- Research for future battery concepts is required to develop materials for high performance lithium-ion batteries, which include solutions for new anodes and separators, and also future battery concepts such as lithium-sulphur or lithium-air designs. These new technologies promise higher energy densities and the potential to significantly reduce weight and cost.

Expected impact

High-performance battery technologies are key to extending the adoption of EV mobility and to European competitiveness in the automotive sector. This technology will also make a significant impact in the secure integration of renewable energy sources in (inter) national power grids.

5.2 Reducing Energy Consumption

There are many chemical technologies that directly contribute to vehicle performance in terms of fuel-efficiency, reduced emissions or extended range for EVs. Most of these technologies aim to reduce the weight of the vehicle, but there are also technologies that contribute to better thermal management or provide vehicle tyres with lower rolling resistance.



5.2.1 Multifunctional lightweight construction

The challenge

Reducing the structural mass in transportation applications from future passenger cars to heavy-duty trucks is one of the most important targets to reduce fuel consumption and CO_2 emissions. However, targeted weight reduction must be consistent with all other performance and safety requirements and the demands of modern-day design and manufacturing concepts and processes. This requires a spectrum of chemical innovation from raw materials to energy-efficient processes.

Research and innovation actions

- Minimisation of structural mass requires the development of energy-efficient materials and processes as well as the minimisation of material waste including near-net-shape part manufacturing processes and the development of novel recycling concepts for both production waste and end-of-life components.
- To complement and guide these developments enhanced numeric descriptions of novel materials are required to predict long-term performance under static and dynamic loads and varying environmental conditions for specific process technologies leading to high-quality material models for optimised material use.

Expected impact

These developments will help achieve the stringent cost-requirements for transport sector energy consumption and emissions targets. As a rule of thumb for each 100 kg of weight saved in a light vehicle, about 0.6l/ 100 Km of fuel is saved and further indirect weight-savings can be achieved in, for example, the engine and braking systems. Weight reduction and other technologies can help the European car industry meet its new emissions targets of 95 g/ km CO_2 on average in 2021.

5.2.2 Temperature management

The challenge

Heating and air conditioning are major energy consumers in any vehicle and thus significantly impact driving range. This will become more critical for the next generation of EV and HEVs as the heat generated by the engine will be limited. The energy demand can be reduced by integrated temperature management using innovative materials from the chemical industry.

Research and innovation actions

- Development of innovative pigments for automotive coatings and interior trim will help to reflect the thermal radiation of sunlight in the summer and control temperature rise inside the vehicle.
- For vehicle windows, the chemical industry can develop new polymer films which reflect solar radiation and help the vehicle interior stay cooler. In turn, this will reduce the power consumption for air conditioning, enhance driving comfort and extend the range. The optical properties of such films may even be switchable at different ambient conditions.
- For colder climates and during winter high performance foam insulation should be developed to minimise heat loss from vehicles reducing heating requirements and, again, enhancing comfort and extending range.

Expected impact

By installing these high performance materials in EVs heat can be better managed with the net effect of reducing non-power train load on the battery and extending driving range.

5.2.3 Green tyres

24% of CO2 emissions for passenger vehicles relate to the tyres. For trucks this increases to 40%. By safely reducing its rolling resistance, a tyre can considerably improve the overall fuel efficiency of a vehicle. The EU introduced a tyre labelling scheme in 2012 that empowers consumers to protect the climate when purchasing tyres by purchasing higher performance tyres with lower rolling resistance[22].

The technology is already available and can be implemented at minimal cost. However market uptake is low as fleet operators have no reliable data to assess fuel savings for purchasing decisions. In addition, the share of tyres within overall fuel consumption depends on many criteria, including freight weight, city-rural-highway driving, aerodynamics, driving style etc.

Research and innovation actions

- Further research on how much fuel green tyres can actually save for different transport scenarios is required. Reliable data is required to convince buying departments and public procurement of fleet vehicles that purchasing green tyres can make a tangible impact on their fuel consumption and emissions.
- Green tyres need to be continuously improved to enhance fuel saving technologies with the use of functionalised rubbers and new silica materials.

Expected impact

The potential impact of green tyres is huge: road transport accounts for 18% of total CO2 emissions in the EU and for 82% of the energy consumption in the transport sector. It has been shown that fuel consumption can be brought down by 8.5% when simply switching from D-labelled to B-labelled tyres. If all road transport ran on green tyres, EU-wide emissions could be brought down by more than 1.5%.

22: http://ec.europa.eu/energy/efficiency/tyres/labelling_en.htm

5.3 Materials and Systems for Sustainable Design of Vehicles

The challenge

In order to recycle the materials used for the construction of a vehicle, disassembly and separation needs to be considered in the design phase. The systems used become more complex when substituting novel materials for steel, joints have to be durable for the anticipated life and use of the vehicle but should be easy to disassemble for recycling. The properties of fibres and polymers decrease in current recycling processes and this puts a limit on some uses of recycled materials.

Research and innovation actions

- Development of new joining technologies: in vehicle construction welding, screwing and riveting is being replaced by gluing. For each new material introduced into a vehicle the appropriate joining technology has to be developed concurrently. For good recyclability, joining technologies that re-open by an external trigger would enhance the options for high-end second life applications.
- Development of fibre separation technologies: currently fibre reinforced polymers can either be chopped and blended with new material or incinerated to realise their energy content. In principle using thermoplastics in the polymer matrix would facilitate separation of fibre and matrix during recycling.
- Advanced materials for transport: with improved performance of compact engines the temperature ‘under-the-hood’ has increased drastically challenging the use of lighter plastic materials. A new generation of high temperature polymers with high resistance to engine fluids and a long life-time that can be used in the engine compartment is required. These polymers can replace metallic parts or combinations of metals and rubber giving enhanced design flexibility and lower assembling costs while contributing to weight reduction. In some cases, biosourced monomers could be used, contributing to improved performance in LCA.

Expected impact

The introduction of these technologies will reduce cost of manufacture, contribute to weight reduction of vehicles and ensure that vehicles that use advanced materials can be recycled and support the establishment of a true circular economy in Europe.

5.4 Making Internal Combustion Engines more Sustainable

ICE vehicles will remain the main type of vehicles on the roads for a long period as the market for EV and HEV develops. In the interim the fuel-efficiency and emissions performance of ICE vehicles must be continuously improved.

5.4.1 Exhaust catalysts

The challenge

Heterogeneous catalysts enable the removal of noxious components from the exhaust gas of ICE vehicles; typically removing more that 90% of the emissions such as carbon monoxide, hydrocarbons, nitrogen oxides and particulate matter. This performance is delivered with a unique durability that typically matches the service life of the vehicle.

Emission control catalyst technologies have significantly contributed to making ICE vehicles more sustainable. New and challenging emission regulations mean that even higher performance is required from these catalyst systems to further reduce emissions and boost fuel economy.

Research and innovation actions

- Development of catalysts operating at reduced temperature to achieve high conversion rates for pollutants (lower temperature catalyst light-off).
- Further increases in catalyst resistance to deactivation especially at very high temperatures, beyond 1000 K (high temperature durability).
- New catalyst formulations are required that minimise the use of PGMs that are classified as critical raw materials.
- The weight and space required to fit catalytic depollution devices on the vehicle must be reduced while maintaining high performance and low additional pressure drop characteristics.
- Studies are required to increase the fundamental understanding about catalyst function and deactivation mechanisms to enable reliable simulation that can guide their application in vehicles with reduced practical experimental effort.

Expected impact

Improved catalyst technologies will enable road transport to further reduce emissions of CO2 and noxious pollutants during the transition to more sustainable energy sources.

5.4.2 Alternative fuels for transportation

The challenge

The use of CO2 as a raw material is addressed in chapters 1, 2 and 3. Some conversion routes (catalytic or biotechnology) can be oriented towards the production of fuels: methane, methanol, gasoline, diesel with significant reduction in net CO2 emission intensity compared to fossil-based fuels.

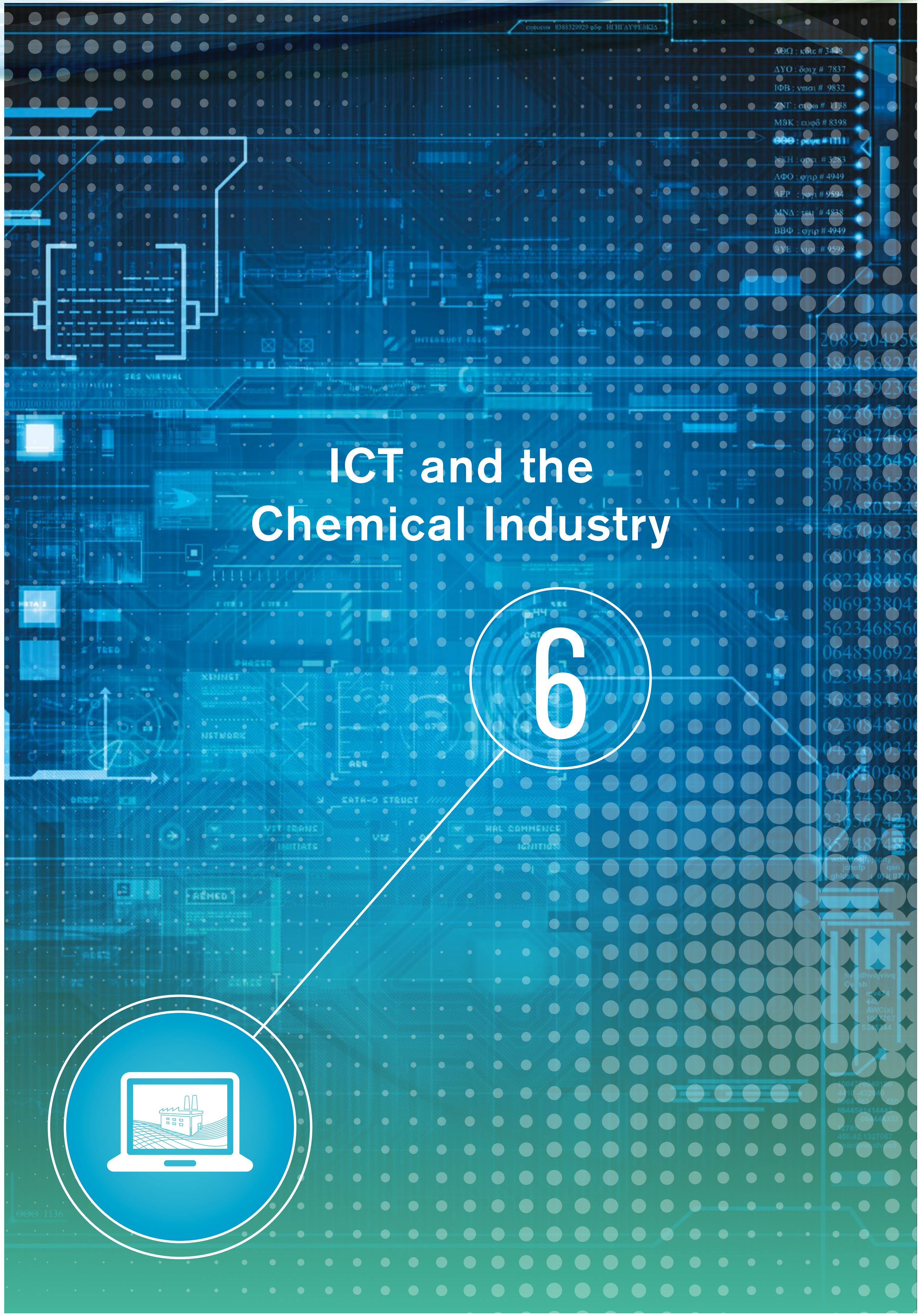
The use of fuels derived from biomass must demonstrate that they are more sustainable than conventional fossil-based fuels. New concepts are required that avoid any possible conflict between providing the food for a growing world population and fuel for transport demand.

Research and innovation actions

- The chemical industry is developing processes that use CO2 (or CO) as a raw material to react with H2 obtained from renewable energy sources. To fully develop this approach requires the development of cost-effective technologies to recover CO2 of appropriate quality from industrial flue gases, new catalysts and process technologies for CO2 conversion, and more efficient technologies for renewable H2 production.
- In parallel to technology development, regulatory barriers relating to the use of CO2 from flue gases as a renewable resource for production of fuels, and carbon price/tax management between the various parts of this value chain must be addressed.
- Using ligno-cellulosic biomass the first treatment aims at separating the components and making these product streams easier to handle and accessible for further biochemical treatment. Various processes are being developed but they need to be refined and demonstrated at large scale.
- Since classical fermentation of sugars has its limitations, with one-third of the carbon converted to CO2, alternative biological routes need to be explored including use of bacteria, acetic acid routes, and conversion of C5-sugars resulting from hydrolysis of hemicellulose.
- The lignin fraction of the biomass is not accessible for biochemical conversion. New synthesis routes need to be developed to convert it into an accessible raw material either by cracking the poly-aromatic structure into aromatic monomers or by gasification to syngas with subsequent conversion of the syngas into fuel via chemical or biochemical routes.

Expected impact

Use of these types of technologies could substantially reduce the CO2 emission intensity of hydrocarbon transport fuels compared to conventional fossil-based technologies. A longer-term option would be the development of processes to use atmospheric CO2 via direct photo-conversion (chapter 3).



ICT and the Chemical Industry

6

Part 6

ICT is an important technology area for the chemical industry. For decades the chemical industry has made extensive use of ICT systems throughout its value chain, from logistics, to modelling, design, control, monitoring and repair. In addition, the chemical industry is a key provider of materials and technologies that form the basis for many ICT solutions.

6.1 Smart Chemical Processes

Within the total chemical industry value chain from product design to delivery to the customer, ICT plays a key role. In the current chemical process environment, and particularly in the future, ICT will be key to a successful, efficient and competitive industry.

As chemical products, process and plants become ever more complex and resource usage and performance requirements become tougher, it will not be possible to compete globally without significant improvements. In current plants and in new developments, ICT can deliver a large portion of the innovation needed to keep the European chemical industry competitive on the global stage.

6.1.1 Process control

The challenge

Process Control is a critical factor for sustainability in the production process. Advanced process methods allow production units to run at optimal operating points under appropriate constraints. Today, advanced process control tools such as linear multivariable predictive control (LMPC) based on empirical models are state of the art for continuous production units. The main success factor of LMPC is the efficient identification of models during normal plant operation. Although for many processes the use of identified linear models leads to very good results, there are other processes, for example batch processes, where linear models are not sufficient to represent true process behaviour.

Research and innovation action

- Non-linear models and non-linear optimisation problems must be considered, but these methods are not widespread in industry. The main obstacles are the complicated model-building process and a lack of professional software tools. The model-building process for non-linear process models of batch processes requires expensive, time-consuming experiments. Innovative methods to facilitate model-building must be developed to allow the necessary empirical information for parameter identification to be gathered during normal plant operations or with limited testing.

Expected impact

These improved model-building methods can dramatically reduce the costs and effort for model-building. To ensure that these methods are applicable in the process industry, it is necessary to combine academia and software developers to procure efficient future software tools.

6.1.2 Monitoring

The challenge

Monitoring methods in the process industry are mainly used for early fault detection and performance monitoring of equipment or for the early detection of anomalies during a production process, for example due to varying quality of the raw material input. In the first class of applications, the aim is to detect problems in equipment and therefore increase the availability of plant by an improved condition-based maintenance strategy. The second class of applications addresses deviations in the chemical production process itself and aims to optimise plant operation by the implementation of early measures to counteract any variations.

Current state of the art monitoring methods are based on the analysis of single signals such as vibration measurements or reactor temperatures. For these single signals, thresholds are defined to detect abnormal behaviour. More advanced methods like model-based approaches are only used for critical equipment that suffer frequent variations. These models are either empirical or first principle and are high cost and effort intensive. The most common approach in the process industry is to capture the behaviour of normal operation in these models and detect any deviation from the modelled behaviour. When the root-cause for the deviation is to be determined, these methods are of limited use.

Research and innovation actions

- From other sectors like the automotive or aviation industries, it is known that incorporating both normal and abnormal behaviour in models helps significantly to find the root-cause of a process deviation. Capturing abnormal behaviour in the monitoring models significantly increases the modelling effort. To overcome this problem various approaches like component model libraries or generic fault models need to be further developed.

Expected impact

Improved modelling will increase plant availability, reduce production costs and improve product quality. These developments will have a direct influence on competitiveness and therefore growth and jobs in the sector.

6.1.3 Modelling for fast-track innovation

The challenge

The time required from an initial idea to innovation for new smart materials or new process technologies ranges from a few to many years. Based on experience, 10 years or more are needed to bring new products and processes to implementation. Laboratory and pilot phases are conducted sequentially with occasional iteration loops for adaption and optimisation. Work flows and research processes lack a standardised and systematic approach and are based on individual skills and experiences. Real understanding of application demands to efficiently tailor products and processes needs confident interaction between stakeholders and a profound preparation phase.

Research and innovation actions

- Concepts enabling simultaneous modelling and synthesis of products and/or design of processes from the initial idea or concept are required. This needs a joint and mutual approach between disciplines including chemistry, engineering and modelling. Standardised tools and procedures to conduct research work more systematically are required to review outcomes and track development including selection of case studies with operational relevance to prove concepts.

6

6.2 Smart Materials

Expected impact

ICT-enabled innovation can significantly reduce (20-40%) time lines for product and process developments and save costs. The risk of failure might increase, but learnings and benefits from the new concepts would outweigh the risks by providing early indications to stop or redesign developments. By using best practices and standardisation of work procedures in an organisation, future product and process development will benefit.

Overall ICT technologies can enable increased resource efficiency (chapter 1), will enable new process and product capabilities, and strengthen the chemical industry and European competitiveness. These developments will provide new jobs for high-skilled personnel, improving employment as Europe becomes a leader in the field of ICT in the process industries. Extension and leveraging of ICT technologies developed in the chemical industry to other sectors and the import of such technologies from other sectors will further extend the ICT base in Europe.

Smart materials are materials, provided by the chemical industry, which enable the development of some important ICT such as nanoelectronics and haptic devices (chapter 4).

The chemical industry will also provide the specialty polymers and other materials that will be required for the new 3D printing technologies able to produce a range of components with demanding specifications.

6.2.1 Nano-structured Materials

The challenge

Polymers with specific structures enabling nano-structured self-organisation can be used as templates to support advanced nano-lithography or other nanoelectronic fabrication techniques (Directed Self Assembly) for the fast prototyping and production of complex electronic devices.

Research and innovation actions

- Sophisticated polymerisation techniques must be developed to prepare these challenging polymers, with properties such as low polydispersity in composition and molecular weight, and at very high purity, working in close collaboration with partners in the microelectronics industry.

Expected impact

Widespread introduction of advanced fabrication techniques, such as templated or directed self-assembly, will reduce development time for microelectronic devices and boost the capability and competitiveness of the European ICT sector.

6.2.2 Advanced Thin, Organic and Large Area Electronics (TOLAE) technologies

The challenge

The chemical industry supplies key polymers and polymer-based ink formulations for use in printed fabrication techniques, such as ink-jets and roll-to-roll lithography, that allow mass production of low-cost microelectronic circuits for a wide range of applications including RFID tags, flexible displays, OLED lighting and haptic devices. The technologies allow circuits to be printed on a variety of substrates especially flexible substrates including paper.

Research and innovation actions

- The polymers to be developed include conductive polymers, piezoelectric and electro-active polymers. These require the use of sophisticated polymerisation techniques in a very clean environment to produce product with very reproducible structures and high purity. Further development of polymers is required in partnership with process equipment manufacturers to optimise current polymers and ensure new polymer formulations are ‘fit-for-purpose’ for new and emerging specific end-use applications.

Expected impact

Printed circuits, especially for flexible substrates, is potentially a huge market for electronics, for example in wearable applications. Development of appropriate materials, including semiconductors and dielectrics, is essential and will have a direct impact on European ICT competitiveness.

6.2.3 Materials for additive manufacturing (3D printing)

3D printing will change the way society manufactures and its development is in full bloom heralding an era of mass-customisation. 3D printing or Additive Manufacturing produces a three-dimensional object from an electronic data set through an additive process making material layers in successive steps under computer control.

The first 3D printers were developed 30 years ago and since 1990 the currently dominant plastic extrusion technology was commercialised as 'fused deposition modelling'. 3D printing allows the production of products in small quantities that cannot be produced by injection moulding or die casting due to high tool costs.

A vast, and growing, array of applications have been found including in the medical and dental industries (see chapter 4) and in biotechnology (human tissue replacement), but also in architecture, industrial design, the aerospace and automotive industries. The global market for materials and services for 3D printing (excluding the printing equipment) was estimated to be US$ 1.8 billion in 2013 and is projected to grow to US$ 10.8 billion by 2018.

The ability to produce small lot sizes and highly specialised added value products makes 3D printing technology a key technology for the next generation of industry: Industry 4.0.

Innovation and pre-industrialisation, competitive small series production, improved time-to-market, custom made parts for personalised products, manufacturing of complex structures and geometries are all drivers for the development of additive manufacturing technologies. 3D printing also contributes to lower energy and resource use in the manufacturing process.

The challenge

Polymers with appropriate end-use performances and adapted to specific 3D printing technologies are needed along with suitable metallic or ceramic materials. The European chemical industry delivers many of these materials which are often derivatives of existing polymers. Metal producers provide special powder or granulated products. A significant issue for 3D printing is surface quality that is lower than for products made in conventional processes and the range of materials suited for additive manufacturing is limited compared to, for example, injection-moulding. The 3D printing process does not allow for a high gloss finish which would be necessary for the next step in consumer applications. For many devices, due to form restrictions or colouring, it is also important to be able to use multiple materials which must be compatible during the manufacturing process. The efficacy of 3D printing is also an issue due to the low speed of current printing processes. Close collaboration with the manufacturers of 3D printers and for specific value-chain applications will be essential.

Research and innovation actions

- Research is needed to widen the range of materials and mechanical properties of polymers, from soft to stiff materials. Development of new electrically and thermally conductive materials will provide new opportunities for the development of additive manufacturing. Solutions to improve the gloss of finished part are required and also to widen the range of colours available.
- Polymer characteristics must be tuned to match the requirements of sintering and fusion deposition technologies. More efficient powder manufacturing technologies should be developed to achieve powder morphologies and formulations suited to additive manufacturing processes.

Expected impact

Additive manufacturing is a key technology for fostering the European innovation and manufacturing industries. 3D printing technologies can reduce the gap between innovation and manufacturing and could stimulate the renewal of European manufacturing industry and boost industrial research and design opportunities too. Additive manufacturing technologies enable customised and personalised product manufacturing, can inspire new designs, significantly enhance performances and reduce component costs, while generating very little waste.

SusChem Horizontal Issues

Part 7

The successful development of SusChem technologies and their impact on societal challenges and economic growth in Europe will depend on the sustainability of the technology developed and also on some non-technological horizontal issues including human capital, societal acceptance of new technologies and innovative business models. The integration of horizontal actions in SusChem innovation projects is therefore key to the overall success of SusChem.

7

7.1 Building Skills Capacity

For Europe to become a sustainable, smart and inclusive society requires an appropriately trained workforce. In order to meet SusChem's goals, innovate successfully and remain sustainably competitive the European chemical sector needs people equipped with the right mix of skills. Therefore, one of SusChem's priorities is to ensure higher education and the European chemical industry work together to build the skills capacity required for tomorrow.

SusChem aims to facilitate a continuing and constructive dialogue between stakeholders to create synergies between the chemical industry and higher education, and to introduce systematically sets of key innovation skills into European curricula.

Following a number of surveys, including the Cefic "Skills for Innovation"[23] study, which investigated the scientific, technical, business and personal skills that scientists and engineers will need in order to boost innovation in the future European chemical industry, SusChem has defined two priorities:

- To develop industry–academia cooperation on the provision of skills for innovation.
- To disseminate good practices in relation to learning resources, teaching methodologies and the involvement of industry.

SusChem has initiated the SusChem Educate to Innovate programme, which aims to exploit innovation outputs from SusChem's Research and Innovation (R&I) projects in order to enhance the innovation skills of future generations of European scientists and engineers through the effective engagement of industry and higher education institutions (HEIs).

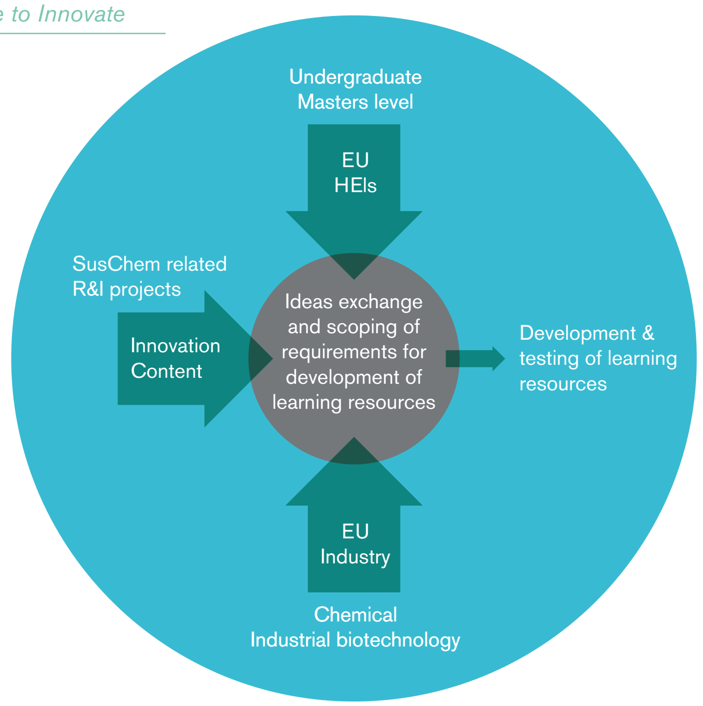
Figure 7.1: SusChem strategy to leverage education value from SusChem innovation projects

23: http://www.cefic.org/Documents/PolicyCentre/Skills-for-Innovation-in-the-European-Chemical-Industry.pdf

The SusChem Educate to Innovate programme aims to establish a collaborative framework for building innovation skills capacity by:

- Capturing innovations emerging from SusChem R&I projects that could be used as case studies for the development of educational resources.
- Facilitating constructive dialogue and exchange of ideas between industry and HEIs.
- Designing appropriate educational resources to be used at undergraduate and masters degree level to develop the skills needed to enhance innovation in the chemical and biotechnology sectors.

Figure 7.2: SusChem Educate to Innovate



SusChem aims to develop Educate to Innovate learning resources that will be accessible through the SusChem website and across different media platforms and would:

- Enable awareness and understanding and support exploitation of key innovation output from SusChem innovation projects.
- Enable students to learn through failure as much as success, understand how/why decisions were made, with documented methodologies for problem-based studies.
- Be adaptable to different teaching curricula and learning approaches: the resources should appeal to a broad community and be easy to integrate in existing modules and curricula, adaptable by teaching staff at undergraduate and master degree level in chemistry sciences, chemical engineering and industrial biotechnology and also for use with lifelong learning courses.

For SusChem to contribute to building skills capacity for the European chemical and biotechnology industry, skills related activities should be fully integrated into SusChem innovation projects alongside engagement with teaching experts at appropriate stages of the project to enable development of the Educate to Innovate programme. Additional specific programmes and dissemination activities will have to be considered and developed by SusChem to ensure appropriate impact.

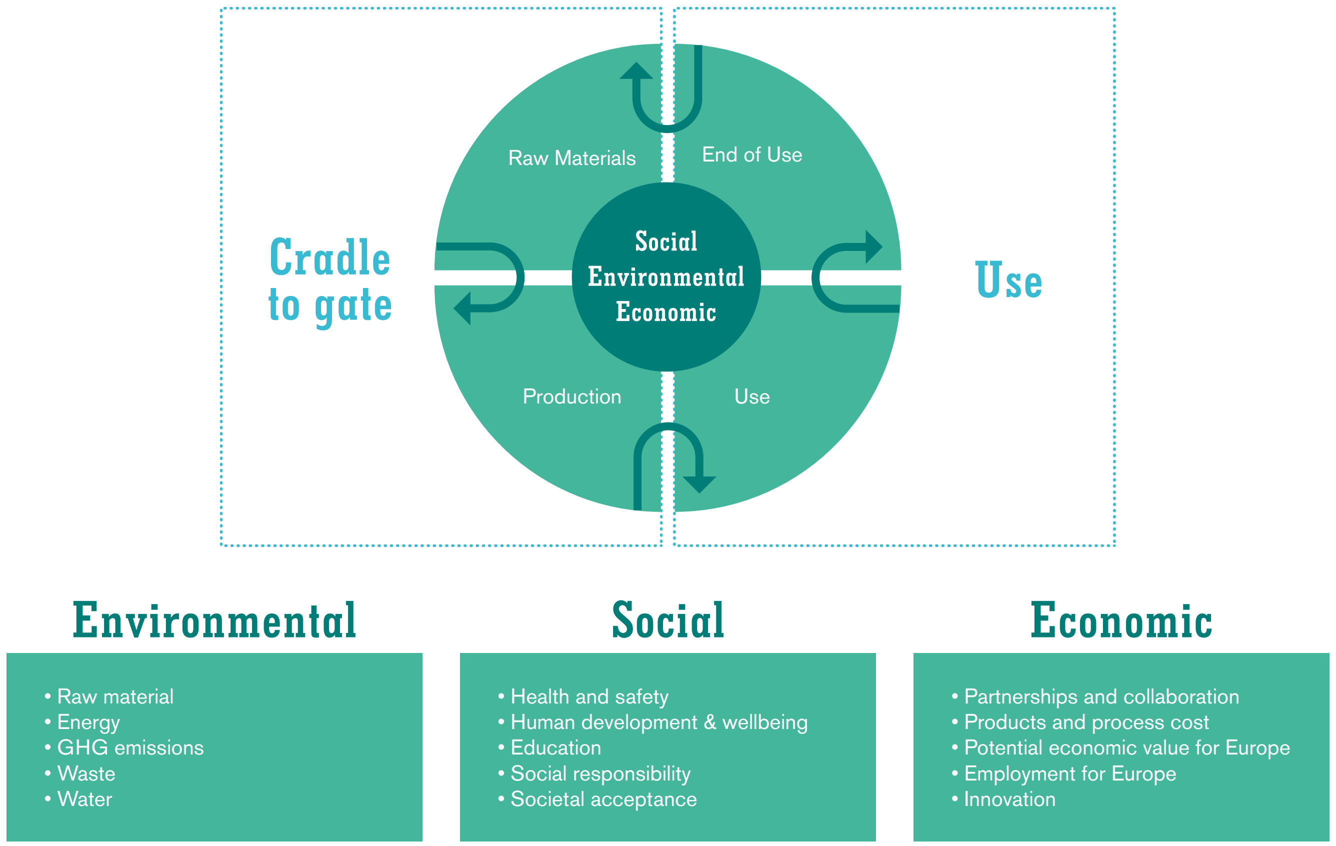
7.2 Towards a SusChem Assessment of Sustainable Chemistry

SusChem projects and programmes aim to support the development of products and technologies that address societal needs while being environmentally sound and economically viable. They aim to enable a future in which chemical research and innovation brings new, safe, high performance products and technologies rapidly to market: enabling society to “do more with less”.

The integration of all aspects of sustainability into the framework of projects at an early stage of the development of new processes and products will be key to the success of SusChem, but this requires a consistent sustainability framework for the objective assessment of projects. SusChem criteria for sustainable chemistry should be the drivers for the definition, prioritisation of topics and communication of results towards stakeholders.

A framework for sustainable chemistry applies not just to the products themselves, but to the whole product life cycle, from cradle-to-grave. It means fully considering the impacts all along the value chain, from raw material sourcing, logistics, manufacture (cradle-to-gate), to product use and finally recycling or disposal processes (gate-to-grave). Note therefore that the SusChem approach to sustainable chemistry takes a value chain perspective, assessing social, environmental and economic sustainability and accounting for impacts as well as contributions to societal challenges.

Figure 7.3: SusChem value chain approach and triple bottom line (Criteria are mentioned as examples)



7.3 Societal Uptake of Innovation

The relative positive and negative direct impact (cradle-to-gate) and the indirect (gate-to-grave) impact of new products or technologies related to the current state of the art needs to be evaluated using appropriate indicators, methodologies and tools that lead to effective communication to value chain partners, policy makers and society as a whole.

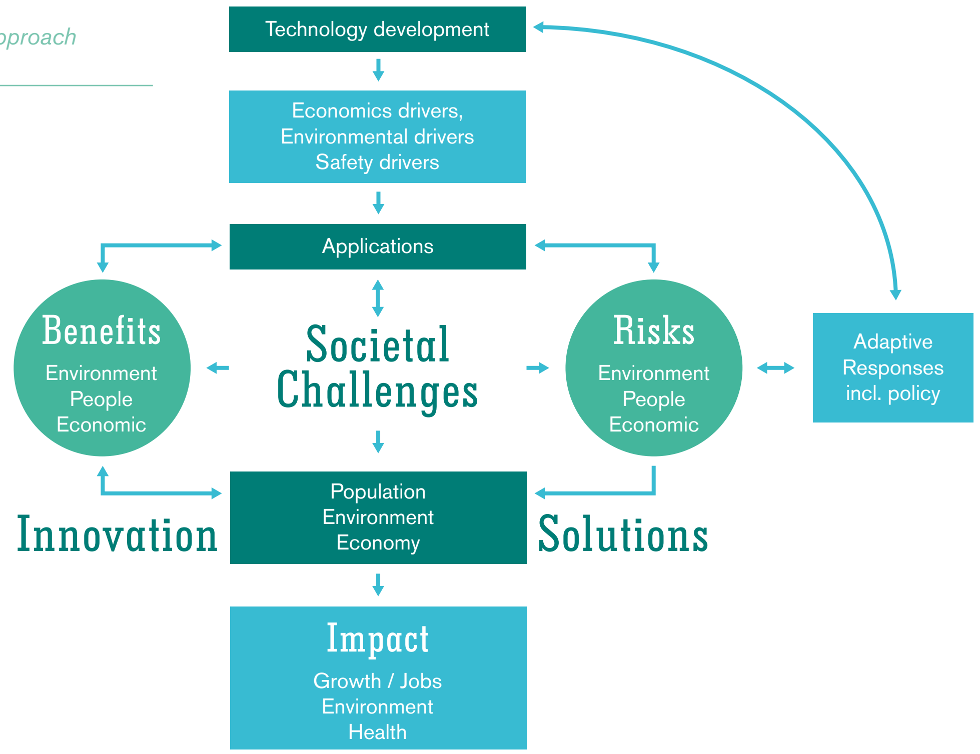
To deliver these indicators, methodologies and tools, SusChem aims to support the development of a pragmatic approach to sustainability assessment that builds on existing methodologies and initiatives from companies that are consistent with on-going collaborative programmes such as those from the World Business Council for Sustainable Development (WBCSD), whilst emphasising a value chain approach and relationships with societal challenges. Further development in this field should also build on past European projects such as Prosuite [24] and the SPIRE 4 -2014 call projects [25].

To benefit from new, innovative technologies they have to be accepted by society. Compared to other regions, Europe tends to be a more conscientious society with regards to new technologies, tending to be more risk-averse, especially when the risks (to the environment and human health) potentially associated with these technologies are still the subject of research.

With increasingly complex, and often contradictory, scientific data and without a structured and open debate the public tends to merge technologies and all their applications requiring political and company decisions to be made on an emotional level rather than on a firm evidence base. This situation hampers Europe’s capacity to address both societal challenges and to improve its competitiveness and growth.

The current model of research delivers large amounts of data in new risk areas rather than providing precise knowledge that could be used for practical decision making. More data tends to create more opportunity for uncertainty - and this troubles the public and society.

Figure 7.4: Benefits-risks approach to innovation



24: http://www.prosuite.org
25: http://suschem.blogspot.be/2015/02/evaluating-sustainability-in-process.html

Europe has a duty to society to take advantage of the benefits to be gained from new technologies while ensuring that there are mechanisms in place to prevent, identify and manage potential risks that may come about with their use. Responsible governance needs to be established that works in parallel with market development activities.

This benefit and risk mechanism should be part of a future European innovation governance that will bring together value chains from different industry sectors and support a speedier uptake of breakthrough innovations. Work in this area should link with programmes such as Cefic's Long-range Research Initiative (LRI) [26] and other responsible innovation initiatives in Europe.

Current European societal challenges need solutions that are dependent on innovative technologies. Given the variety of actors needed for their appropriate management, political leadership is a primary element required to signal that Europe is a place where scientific and technological excellence will be used to the maximum benefit of society while minimising potential risks through robust governance.

There is need for a careful distinction between the various applications (in which one technology is used) that depends on their potential, specific impact on the environment and/ or health.

Research and innovation actions

- Research in this field should be targeted to address defined questions on defined risk uses with open publication of findings, perform transparent analysis, communicate conclusions and propose or adapt policies.
- Cross-disciplinary projects, including social science, toxicology and technology expertise, should be established in the Horizon 2020 programme and thematic areas for Societal Challenges to assist assessment of risk / benefit and perform foresight activities to prepare for technology governance.
- SusChem through specific activities integrated in relevant innovation projects should contribute to link (qualitatively and quantitatively) technologies and specific uses and/ or applications to solutions for priority European challenges.
- The outcome of such activities would contribute to understanding how to address the barriers for innovation uptake by value chain partners and society, in particular understanding value chains and their needs, and devising incentives for market breakthrough such as through demonstration projects and PPPs.
- Such actions would also contribute to the definition of political, financial and administrative measures (in the framework of European initiative such as EIPs) that target specific benefits for specific European challenges in order to achieve an effective critical mass for European success.

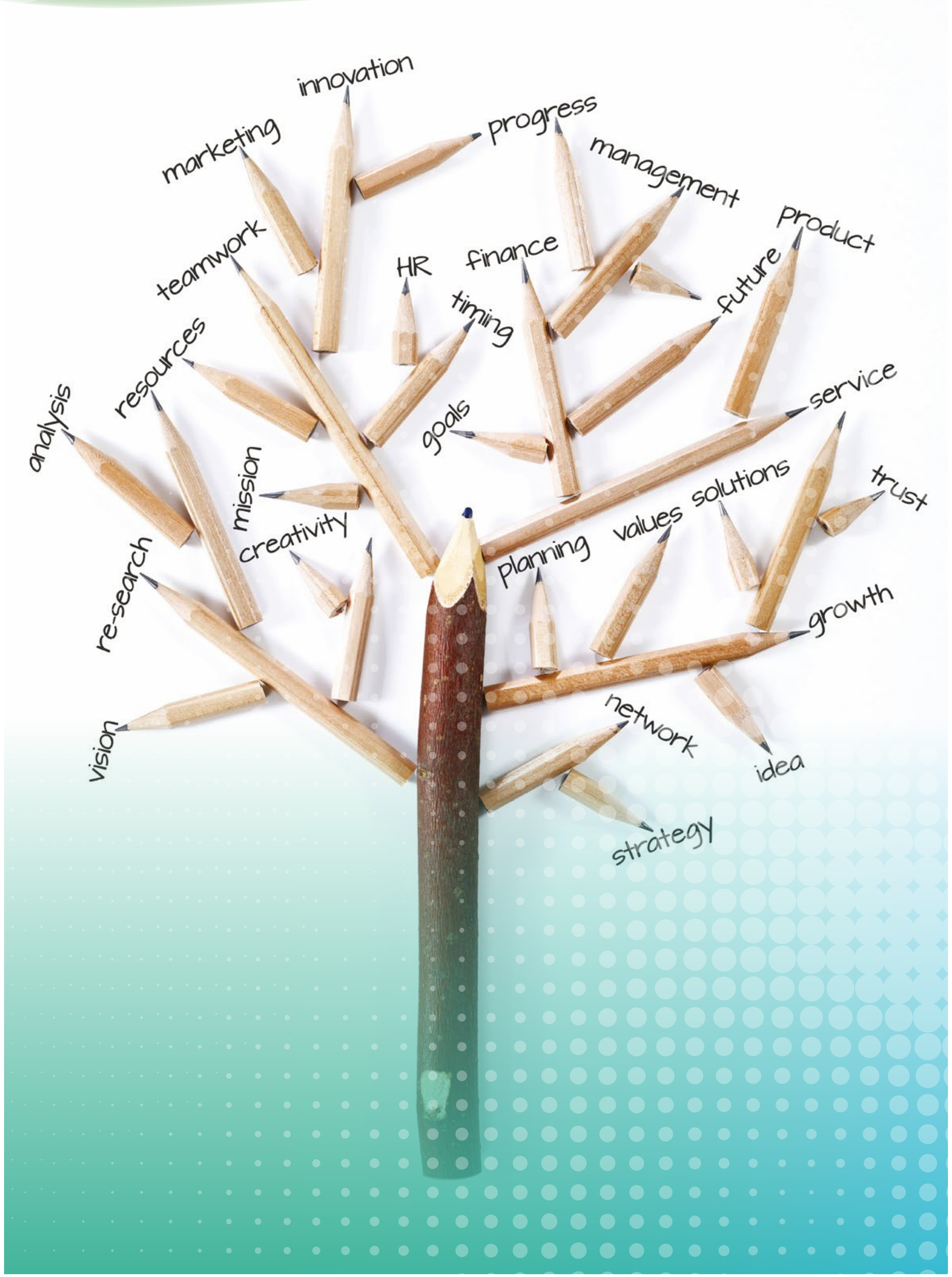
7.4 Innovative Business Models

As the economic and industrial climate changes in Europe, there is a need to re-assess the business models that are currently used in the process industry. The deployment of some emerging technologies, such as industrial biotechnology solutions or the chemical valorisation of CO2, pose both challenges and new opportunities, which may not be best addressed by traditional business models.

Collaboration with other sectors will be key for success and SMEs will play an important role in these developments. But to succeed there needs to be the right conditions for investment, value sharing and long-term development. Cooperation between large and small companies on technology development needs to be encouraged to enable entrepreneurship and breakthrough development.

In conclusion, it is inevitable that new business models will be required to boost the initiative capability and competitiveness of the European chemical sector. The identification and development of appropriate new business models, both new to business in general and new to the chemical sector, will be integrated into SusChem innovation projects as a matter of policy, in particular those models that address issues related to the development of the circular economy and industrial symbiosis.

26: http://cefic-lri.org



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The production of this Strategic Innovation and Research Agenda has involved contributions from many SusChem stakeholders. In particular, the SusChem board, SusChem National Technology Platforms, Cefic Innovation Strategy Implementation Group, Cefic innovation managers, company experts and delegates at our tenth anniversary stakeholder event in Brussels on 11-12 June 2014.

We look forward to working together with our stakeholders and other partners to implement these ideas and demonstrate the key role that sustainable chemistry can play to boost competitiveness, growth and jobs in Europe.

Glossary

BBI	Biobased Industries
BIPV	Building-integrated PV
CO2	Carbon dioxide
COD	Chemical Oxygen Demand
CT	X-ray Computerized Tomography
CZTS	Copper Zinc Tin Sulphide
EBM	Extrusion Blow Moulding
EIP	European Innovation Partnership
EV	Electric Vehicle
FP7	European Commission Seventh Research Framework Programme 2007 - 2013
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GTL	Gas-to-Liquids
GVA	Gross Value Added
H2	Hydrogen
HDPE	High Density Polyethylene
HEI	Higher Education Institutions
Horizon 2020	European Commission Research and Innovation Framework Programme 2014 - 2020
IB	Industrial biotechnology
ICE	Internal combustion engine
ICT	Information and Communication Technologies
IMI	Innovative Medicines Initiative
IS	Industrial symbiosis
ISBM	Injection Stretch Blow Moulding
ITO	Indium Tin Oxide
JTI	Joint Technology Initiative
KBBE	Knowledge Based Bioeconomy
KET(s)	Key Enabling Technology/ies
LCA	Life Cycle Analysis
LED	Light-emitting Diode
LEIT	Leadership in Enabling and Industrial Technologies
MOF	Metal Organic Framework
MRI	Magnetic Resonance Imaging
NMP	Nanosciences, Nanotechnologies, Materials and new Production Technologies
OLED	Organic Light-emitting Diodes
OTS	Operators Training Systems
PCM	Phase change materials
PET	polyethylene terephthalate (polyester)
PLA	Polylactic Acid
PGM	Platinum Group Metal
PPP	Public-Private Partnership
PV	Photovoltaic
R2R	Roll-to-roll
R&I	Research and Innovation
REE	Rare Earth elements
RFID	Radio Frequency IDentification
SIRA	Strategic Innovation and Research Agenda
SPECT	Single Photon Emission Computed Tomography
SPIRE	Sustainable Process Industry through Resource and Energy Efficiency
SRA	Strategic Research Agenda
SSL	Solid State Lighting
TOLAE	Thin, Organic and Large Area Electronics
TRL	Technology Readiness Level (European Commission TRL definition for Horizon 2020) [27]
WBCSD	World Business Council for Sustainable Development

27: http://ec.europa.eu/research/participants/data/ref/h2020/wp/2014_2015/annexes/h2020-wp1415-annex-g-trl_en.pdf

About SusChem

SusChem

SusChem is the European Technology Platform for Sustainable Chemistry.
It is a forum that brings together industry, academia, governmental policy groups and the wider society.

SusChem's **mission** is to initiate and inspire European chemical and biochemical innovation to respond effectively to society's challenges by providing sustainable solutions.

SusChem's **vision** is for a competitive and innovative Europe where sustainable chemistry and biotechnology together provide solutions for future generations.

SusChem's **priority** areas include: Catalysis, Information and Communication Technologies (ICT), Materials for Energy, Sustainable Bioeconomy and Water.

SusChem across Europe

SusChem has established a network of National Technology Platforms in 14 countries across Europe (Austria, Belgium, Czech Republic, France, Germany, Greece, Italy, Netherlands, Poland, Romania, Slovenia, Spain, Switzerland and United Kingdom) that work on sustainable chemistry initiatives within their own country, support national engagement in EU collaborative projects and programmes and contribute to transnational collaborations.

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