SAHYOG Project Grant agreement no: 289615

Deliverable report

4.3 Upstream Downstream Roadmap

Responsible Beneficiary: VITO, Belgium

Project Co-ordinator: ENEA

Expected Delivery date: 30st November, 2014

Submitted to Coordinator: 30st November 2014

Leading Authors: K. Elst, L. Diels, D. Pant

Co-Authors: Kees Kwant, Rebecca van Leeuwen, Neeta Sharma, Silvia Tabacchioni, Priyangshu Sarma, Piyush Joshi, Reeta Goel, Neera Sarin, Rob Bakker.

Project co-funded by the European Commission within the 7th Framework Programme		
Dissemination level		
PU	Public	**x**
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential only for members of the consortium (including the Commission Services)	

This report has been produced within the framework of the project **SAHYOG (Strengthening Networking on Biomass Research and Biowaste Conversion – Biotechnology for Europe India Integration).**

The objective of SAHYOG is to actively and effectively link research activities implemented within EU research programmes and related programmes by Indian national institutions in the fields of biomass research and bio-waste conversion to prepare a Strategic Research Agenda and a roadmap for the advancement of RTD with mutual benefits.

We would like to acknowledge the hard work and support of all the members of the SAHYOG Consortium:

ENEA - Italian National Agency for New Technologies, Energy and Sustainable Economic Development, Italy (EU Coordinator)
TERI - The Energy and Resources Institute, India (Indian Coordinator)
ARTI - Appropriate Rural Technology Institute, India, Pune
CSIR - Council for Scientific & Industrial Research, India
DLR - Deutsches Zentrum für Luft - und Raumfahrt e.V., Germany
GB Pant University of Agriculture & Technology Pantnagar, India
Jawaharlal Nehru University, India
National Technical University of Athens, Greece
RVO., Netherlands Enterprise Agency – Ministry of Economic Affairs, Agriculture and Innovation, The Netherlands
Tezpur University, India
VITO - Vlaamse Instelling voor Technologisch Onderzoek, Belgium
Wageningen University & Research Centre Food & Biobased Research, The Netherlands
WIP Renewable Energies, Germany

SAHYOG Coordinator Contact:

Neeta Sharma
ENEA Research Centre, Italy
E-mail: neeta@enea.it
Tel: +39 0835 974603

SAHYOG website: http://www.sahyog-europa-india.eu/

Department of Biotechnology
Ministry of Science & Technology,
Government of India

SEVENTH FRAMEWORK PROGRAMME

SAHYOG is supported by the European Commission within the 7th Framework Programme (FP7-289615) and by the Department of Biotechnology (DBT) of the Indian Ministry of Science and Technology. The sole responsibility for the content of this report lies with the authors. The SAHYOG project duration is December 2011 to November 2014 (Contract Number: 289615).

LIST OF CONTENTS

1. Introduction **4**

2. Needs and challenges **4**

2.1 Needs and challenges in Europe *4*

2.2 Needs and challenges in India *6*

3 Designing the Roadmap **8**

3.1 Vision *8*

3.2 Topics relevant for the EU-India collaboration *13*

3.3 Roadmap *17*

4 Conclusions **25**

1. Introduction

This Upstream/Downstream Roadmap compiles the needs and challenges, and the shared vision for the EU and India on the latest developments in the bio-based economy in line with the SRA. Based on several stakeholders meetings, both in Europe and India, research recommendation have been formulated that are considered to be of importance for the EU-India collaboration. Through a survey, 250 stakeholders have been consulted, both from Europe and India, from academia, government and industry, and from the various sectors of the bioeconomy. In line with the results of this survey, the most important research topics for the EU-India collaboration have been selected, and in this deliverable the short-term, mid-term and long-term actions are discussed. From the stakeholders meetings and survey, also important policy, markets and legislation recommendations were derived, but are not discussed here, since the deliverable is limited to the upstream and downstream research and development actions

2. Needs and challenges

2.1 Needs and challenges in Europe

Europe, with a current population of approximately 507 million living for 40% in urban areas[1], is expected to grow steadily till 526 million inhabitants in 2040[2]. Europe had many decades of growth based on the intensive use of resources, but currently faces a dual challenge of stimulating growth needed to provide jobs and well-being to its citizens, and of ensuring that the quality of this growth leads to a sustainable future.[3] To tackle these challenges the EU-economy requires a fundamental transformation to a low carbon society in its various economical areas including energy production and chemical industry, and the build op of new value chains between these sectors with for instance forestry, agriculture and/or waste processors.

Securing energy supply, while reducing its impact on the environment and human well-being is a major challenge of the European energy sector. The EU has set itself the ambitious target to increase the share of **renewable resources** in final energy consumption to **20% by 2020**[4], and already makes significant efforts to bring and implement new, high performant low-cost, low carbon sustainable energy technologies to the market. Moreover, additional actions are currently taken to ensure and facilitate the further transition to a low carbon society. The roadmap of the European Strategic Energy Technology Plan (SET plan)

[1] EUROSTAT, Newsrelease 51/2012, Urban-Intermediate-Rural regions (2012). In addition, also 35% of the population lives in intermediate regions.
[2] EUROSTAT, Newsrelease 80/2011, Population projections 2010-2060 (2011).
[3] Communication from the commission to the European Parliament, the council, the European economic and social committee and the committee of the regions, Roadmap to a Resource Efficient Europe (COM(2011)571 final (2011).
[4] European commission, Directive 2009/28/EC.

aims that bioenergy from biomass represents at least 14% of the EU energy mix, while at the same time guaranteeing greenhouse gas emission savings of 60% for bio-fuels and bio-liquids as compared to fossil ones under the sustainability criteria of the new RES directive.[5] Based on the NREAPs, it is expected that by 2020 biomass will represent 17.4% of the planned EU heating and cooling mix, 6.6% of the electricity consumption and 89.9% of the renewable energy in transport.[6]

Europe is the cradle of the **chemical industry** (first based on coal, later developed on petroleum), but also of bio-technology with a strong green bio-technology, a relatively good red bio-technology and a strong focus now on white or industrial biotechnology. The sector, still strong and very important for the European economy, is however facing a reduction in production capacity, and is searching for new resources based on biomass, waste and CO_2. Europe has a definite scarcity in primary materials and shale gas is not expected to be able to make Europe self-sufficient in natural gas as is expected in other places in the world[7] Indeed some places in the world will rely on C_1 – C_3 hydrocarbons (gas) for energy and chemicals and others must rely on very complex oxygenated (including also N, S, ...) chemicals from biomass. In this choice biomass and especially residues are expected to become a key in the European approach. The challenge will be to make use of these functionalities via the reduction in energy costs in conventional oxidation of hydrocarbons or via the innovative use of these functional groups in new applications and materials.

Biomass availability will be a critical issue to achieve the targets on bioenergy production as well as to facilitate the transition of the chemical industry towards renewable resources. Europe has 114 Mha of crop land, 60 Mha permanent grass land and 177 Mha of forests and some 80 Mha of other land, including inland waters and artificial areas.[8] The European forests, covering 42% of the land area, are highly productive and largely available for wood supply. Forestry is already a very important biomass resource in Europe for energy and conventional materials application. In the case of agriculture, on the other hand, there will practically be no future capacity to bring further land into production for new crops, since current fallow or set-aside land in the EU-27 is limited. By re-using abandoned and/or contaminated land, especially in the former East-European countries, additional land will become available for new crops. Therefore, focus will be needed on breeding of multi-purpose plants (in order to use the biomass in a more complete value chain) and on increasing the already high yields. Increased yields per ha are still possible (e.g. sugarbeets) Large efforts will be needed in the value chain development of the biomass treatment in a bio-refinery with a complete and the optimal use of every molecule and the highest possible value and with more attention to chemicals and materials than to energy. Energy will be seen as the end of the cascade approach and as the end of the life cycle of materials. Several types of agricultural and forestry by-products are generated in the EU that form a potential feedstock for the biobased economy. These include for instance straw residues, horticulture pruning and cuttings, manure or residues from wood harvesting and processing. Nevertheless, many hurdles exist to harvest and collect these residues in an economic and sustainable way, making their efficient usage a challenge.

[5] European Industrial Initiative on Bioenergy, SET-PLAN, technology roadmaps, SETIS-EC (extracted 2014).
[6] M. Szabo et al, Technical Assessment of the Renewable Energy Action Plans, JRC Reference Reports, ISSN 1831-9424 (2011).
[7] I. Pearson et al., Unconventional Gas: Potential Energy Market Impacts in the European Union, JRC Scientific and Policy Reports, ISSN 1831-9424 (2012).
[8] Deliverable 4.2, Strategic Research Agenda supporting the roadmap, FP7-project Sahyog (2014).

Moreover, roughly 5 ton waste per capita is generated, of which 17% can be considered partially or fully degradable.[9] Municipal solid waste, accounting for 10% of the total waste and being composed of approximately 38% biodegradable matter[10], represents the largest fraction. In addition, Europe produces > 220 M tonnes of food waste and 10 Mton sewage sludge (dry). Europe has one of the best waste management systems, and the EU Waste Framework Directive and landfill directive set binding targets for recycling municipal solid waste and diverting biodegradable municipal waste from landfill. Nevertheless, large differences are seen in the municipal waste management system between countries, whereby in some member states the majority of MSW is still landfilled. Moreover, as indicated in some studies, doubt exists about the consistency of the data reported by the different MS, since the amount of waste is not always reflected by the number of inhabitants.

The **market** will develop into a more bio-based molecules and materials one and especially to the development of new innovative molecules (polymers, resin, coatings, glues, plasticisers etc.). The full value chain development will strongly lead to process intensification. This means that more processes will turn from batch to continuous. Some of the processes can become micro- or milli-production based. Flexible, decentralised and robust, fast to market systems will be installed geographically where the market needs are, where the resources are or where some utilities as rest heat, steam, CO_2, H_2 or whatever is produced.

Legislation will be supportive of certification, turning waste legislation into material legislation and the needs for a legislation that will be less in favour of energy applications in the primary use. Markets will also develop further into recycling and re-use with strong efforts on energy reduction between the primary and the secondary (based on recycling) process. Recycling will be based on renewing the chemicals allowing making whatever is needed in the next cycling round.

2.2 Needs and challenges in India

The Indian **population** is so fast growing that the first concern is to feed more than 1.5 billion people by 2050. In the same period (2010 - 2021) there will be an increase in large cities (> 100.000 people) and small towns (< 100.000 people) from 377 to more than 540. At the same time, the rural population will remain more or less stable and only reduce from 833 million to 810 million people, indicating that growth will come in **urbanisation**. There will be a large increase in the need to access food in a proper way (processed) amongst those living in cities. Those living in the rural areas, many of whom are already suffering from malnutrition, will still have the same needs for food as they have now. Apart from food we see that 23.5% of the primary energy needs in India,[11] mostly related to household energy consumption, is currently coming from biomass (185 of 788 MTOE) and is expected to grow to 40%. It indicates that **food/feed** and **energy** will become the focus areas for India.

Indeed biomass can replace coal for energy production (2 GW to 30 GW), biogas can replace CNG/LPG (7.3 bill m^3 to 44 bill m^3), bioethanol can replace gasoline (1 Mton to 10 Mton) and biodiesel can replace diesel (0.05 MTon to 2 MTon). This all will mean that the share of biomass in renewable energy will presumably increase from 7% to 15%.

[9] EUROSTAT, section Waste statistics. (extracted 10/13)
[10] EEA, Managing municipal solid waste, a review of achievements in 32 European countries (2013).
[11] IAE, Statistics, India: balances for 2012. (accessed 10/14)

From the **feedstock availability** point, forests are covering 70 Mha, and agriculture crop land covers around 141 Mha + an extra 55 Mha lying fallow for more than 6 months. The grazing (grassland) surface is about 50 Mha. Lack of optimised seeds, lack of water or proper water management and lack of fertilizer makes that yields are decreasing whereas under proper management the yields can certainly increase by a factor 3 – 4. On top of that more than 50 Mton of rice straw is burned (especially in the Punjab) in the field leading to huge CO_2 emissions and particulates. This can be used as energy source. In addition, a lot of fruits and vegetables never reach the market due to improper storage and processing capacity. 283 million bovine animal produce more than 1250 Mton of manure (18%DS), and 500 million poultry birds produce an extra 10 Mton dry manure (75% DS).[12] Horticulture, nowadays at 210 Mton, but with a large planned expansion (target 350 Mton) in order to improve nutritional quality, is targeted to at least 350 Mton. The food processing waste of it will lead to an extra 80 up to 140 Mton of waste. Municipal solid waste is estimated at 150 Mton with more than 50% bio-waste. Nowadays on top of that it covers 60 thousand ha of landfills emitting landfill gas (greenhouse gases). Sewage is mounting from 40 billion litre/day to 50 billion litre/day at least. It will be responsible from more than 10 million extra sludge and more than 20 million ton CO_2-emissions. Moreover, a still non-explored possibility is the 7400 km long coastal area of India that can provide production sites for cultivation of large amounts of algae and especially macroalgae, rich in proteins, sugars, oils and lipids and many other compounds as well as energy source.

It is clear that the low hanging fruits are the use of all kinds of residues in a smart way. In the same time production and logistics and storage will increase the biomass (i.e. food amounts) and will later on generate an extra residue stream. The first biomass use can go to energy, but improved solutions must be developed to upgrade these waste streams by pre-treatment and fractionation (extraction) into added value compounds.

It is indeed seen that the production of biomass will be key in the whole process. Primarily the processing will focus on food processing in order to make better conservation processes. Indeed nowadays farmers tend to produce cereals because the storage of it is at least somewhat more reliable than the storage of vegetables or fruits. Later on India can go to the full integrated bio-refinery with the help and collaboration with Europe. As far as markets are concerned a strong food supply market will develop, accompanied by a bioenergy market as a side product. In the long-term India will be able to use its large biodiversity and develop high added value products from very special and added value plants leading to a fully needed market. The lower hanging fruits of biodiversity are based on the huge potential of varieties and species that can be investigated for instance in the field of algae, seaweeds, bamboo, jatropha etc. This is separate from the potential in fragrances, aromas, medicines producing plants.

From a **policy** point of view the right decisions must be taken to support the food production and increase in yield, to give higher value to bio-energy and to support not only the bio-energy but also the conversion into added value as chemicals and materials with the support from Europe. India has the strongest expertise on semi-arid and dry land agriculture (sorghum and millet) in the world. This expertise can be used for parts of the Indian agriculture intensification and can become standard for other similar regions in the world (especially in Africa).

[12] K. Krishan, India International Cleantech Summit 2013, Outlook for Cleantech in India (http://www.indiacleantechsummit.com/presentations/day3/ClosingSession/Kolluru_Krishan.pdf) (2013).

In fact the proper use and management of biomass will lead to a huge environmental effect. The burning of rice straw causes air quality problems up to in Delhi; in rural areas > 400 people per million capita per year[13] die due to poor indoor air quality (result of cooking on fresh wood); waste heaps and dumps are emitting greenhouse gases; and waste water is a big problem. We can calculate that proper municipal bio-waste and sewage handling would reduce the CO_{2eq} emissions by 150 million tonnes which is the equivalent of more than 25 large coal fired power plants and also the loss of the equivalent energy potential. Only the biodegradable municipal solid waste would be an equivalent of 2500 – 3750 Mm^3 biogas. So, these environmental managements, carried out in a smart way, can lead to a diverse group of energy production systems. In order to do so, a large political will and support will also be necessary in order to thrive towards the right decisions.

3 Designing the Roadmap

3.1 Vision

Biomass and Bio waste Feedstock

As mentioned earlier, the further development of the biobased society relies strongly on the availability and secure supply of suitable renewable feedstock from agriculture, forestry and/or waste. Europe and India, with a land area of respectively 418.2 Mha and 297.3 Mha, have differences in land use and therefore also availability of renewable resources. Whereas in Europe the agricultural area (41.7%) and forests (42.3%) have nearly equal shares, in India the agricultural area (60.5%) is dominating.[14] Moreover, significant differences exist in the exploitation of forests. The forests in Europe are largely available for wood supply, whereas in India they are largely protected and much less accessible for commercial exploitation. In India, significant amounts of wood come from trees outside the forest. This makes agriculture the dominating source of biomass in India, whereas both agriculture and forestry are important for Europe.

In **Europe**, a steady increase in the utilization of biomass from **agriculture** (energy and arable crops) for energy use from the year 2006 to 2010 has been observed from consulting National Renewable Energy Action Plans (NREAPs) reports. Thus, several issues must be considered to reduce the negative impact of these cultivations on natural ecosystems and the competition on land use for production of food, energy and biobased materials. Indeed, Europe, as an important food producer needs to develop strategies to efficiently **secure** and increase its **agricultural output for food**, also necessary to provide a stable of non-food uses and to open up new avenues for use of biomass for the sustainable bio-based economy chains and to face the instability of biomass supply. Smart approaches should be developed for the **better use of limited agriculture land** in Europe by **optimization of the agricultural practices** and to improve and secure soil quality, to counteract environmental threats such as erosion, salinization and contamination. Yield increase and stabilization has to come via

[13] World Health Organisation, Country Profiles of Environmental Burden of Disease, Fact sheet India, data 2004.
[14] Deliverable 4.2, Strategic Research Agenda supporting the roadmap, FP7-project Sahyog (2014).

selection and development of more **robust and resilient crops**, also aided by the **geno- and phenotyping** of plants. Efficient strategies should be developed to further decrease losses in the production chain, to **assess and reduce environmental impact of biomass production**, increase ecosystem services and enhance biodiversity. Moreover, the potential of highly productive biomass systems having a low land use footprint, minimum water and fertilizer inputs and able to grow on marginal lands .Also highly productive aquatic biomass, including in particular **macro- and microalgae**, should be fully explored. In order to facilitate the transition to the market, the technical improvements and their economical sustainability will need a demonstration through **pilot scale programs**.

In Europe, The SAHYOG biomass inventory indicates a major biomass potential in the form of **agricultural residues** (e.g. straw…) mainly available in the countries with a large agricultural sector and high agricultural production. In addition, livestock farming also generates significant amounts of wastes (e.g. manure, feathers….). However, there are some limitations for the use of these agricultural residues and wastes for the production of bioenergy or biochemical, or for the application in a bio-refinery approach. A number of issues must be considered, including the assessment of the **technical availability** potential of these agro-resources (quantity taking into account multi-annual variation, logistics, transportation distance) also aided by **GIS-based** analysis, new developments leading to a more cost effective **technological route** (stabilization and/or transformation), economical (costs of resources and cost of energy) and social issues (perception and attitude of farmers).

Forestry is a significant source of biomass in Europe, especially in the countries with a large **forestry** sector. Currently, roughly 337 Mm^3 of (mostly coniferous) roundwood is recovered for direct utilization in industrial applications such as construction and pulp and paper production.[15] However, increasing amounts of roundwood (mostly non-coniferous) are also used as **fuel wood** for renewable energy and its usage keeps on growing at a rate of 2-3% a year since 2006. Also, the NREAPs reports confirm a significant increase of the use of forest biomass for energy from the year 2006 to 2010.

In addition to energy, woody biomass can also be used as a renewable resource for other, currently **less-exploited sectors** of the biobased economy, such as for instance for the production of chemicals. It is therefore important to have a **detailed estimation** of the technical availability potential of the woody biomass, not only considering the actual wood reserves but also taking into account the **technical limits** in its exploitation, such as accessibility of the wood, logistics, collection…., also aided by **GIS-based analysis** of the geographical localization of wood and waste wood.

In the roundwood production and its transformation to the various industrial products, several **forestry residues** are generated. These include forest residues (small branches, top wood, bark), solid rest products from the industrial processing (dust, shavings chips…) as well as residues from the pulp and paper industry (black liquor…). These residues already find (partial) application for the production of bioenergy or materials application, but their **full utilization** in the various sectors of the bioeconomy should be considered. This will need a clear assessment of the availability and new, cost effective technologic routes for utilizing their full potential.

[15] FAOSTAT, section forestry and production data, data 2013. (extracted 6/2014)

In EU, the term “**waste**” and related “biodegradable waste” is defined by directives, and EU members are obliged to report data on waste amounts to Eurostat. These include 48 categories of waste, and a distinction is made between hazardous and non-hazardous. In total, the economic activities and households produce yearly roughly 5 ton waste per capita.[16] Nevertheless, as indicated in some studies, doubt exists about the consistency of the data reported by the different MS, since the amount of waste is not always reflected by the number of inhabitants. Therefore, further improvements on the **harmonization**, and the **waste collection system** enabling registration would be needed. From the reported wastes, roughly 500 kg per capita per year is municipal solid waste (MSW). It is estimated that MSW consists of roughly 38% and represents more or less half of the biodegradable wastes. The EU Waste Framework Directive and landfill directive set binding targets for recycling municipal solid waste and diverting biodegradable municipal waste from landfill. Nevertheless, large differences are seen in the municipal waste management system between countries, whereby in some member states the majority of MSW is still landfilled. Therefore, in Europe a more detailed **assessment** of the composition and further valorisation routes of the MSW are needed. Not all residues and side streams from economic activities and household are considered as waste. For instance biodegradable streams such as natural textiles, paper or processed wood are not considered as biowaste. The waste also excludes manure that is reused as fertilizer in agriculture, agricultural non-hazardous residues that remain at the site of generation as part of the biological cycles, as well as by-products of food production or wood-processing that never become waste and are for instance used in other sectors like feed or materials. (Some of) these “non-waste” residues and side streams have the potential to have an improved valorisation in for instance a cascade approach, requiring a detailed inventory and the development of suitable processes.

CO_2 is also a promising “waste” building block to produce chemicals, materials and (advanced) fuels. The conversion can be made by biological means in for instance autotrophic processes, or in catalytically or electrochemically induced processes. These processes are however still in their infancy and further research and development has to be performed to lower the cost and increase the performance of the process.

In **India**, biomass plays a vital role especially in rural areas, as it constitutes the **major energy source** to majority of **households**. Being an agriculture-based country, India derives most part of its potential biomass from agricultural crops and agricultural by-products. About 23.5% of the total primary energy used in the country is still derived from biomass and more than 70% of the country’s population depends upon it for its energy needs. For the production of agricultural produce and sustainable utilization, India should address some critical issues viz. Deployment of existing technologies in agriculture, and increasing research in agronomic sciences and breeding technologies, proper supply chain, adequate policy framework, and effective financing mechanisms, regulatory framework information and dissemination. In addition, considering the increasing demands of feedstock, India has to handle the feedstock competition on biomass for food, energy and industrial material use. Research on **improvements of agricultural practices** is needed to increase biomass production for food and non-food uses. The available leads from on-going projects on diversified agriculture, crop rotation practices, state-wise diversified germplasm demarcation, improved water and fertilizer management, phenotyping etc. will have to be taken into

[16] EUROSTAT, section Waste statistics. (extracted 10/13)

consideration. More specifically related to biofuel-production, a full development of existing energy crops on wastelands, such as the Jatropha cultivation, should be addressed. Moreover, there is need to increase the agricultural biomass potential by including opportunity of **high yields varieties**, energy plantation in the **unexploited waste land** and **regional solutions** diversified crop selection as per state geographical and agronomical conditions. The Sahyog database indicates a large biomass potential of underused and unutilized **crop residues** (Husk, Straw, and Stover). Nevertheless, a detailed assessment of their technical availability (including logistics) should be considered, and their options to include them in the bio-economy chain should be addressed taking into consideration also the marginal farmers at regular basis.

Also research is needed on **new crops/plants** having the potential of growing on marginal or waste land or having high productivities and low land use. India has a very **rich biodiversity**, with more than 45 000 species of plants representing 12.5% of the total world biodiversity.[17] However, only a small portion has currently been exploited. Bioprospecting of the biodiversity is expected to lead to new species having improved properties for biomass production, as well as species containing high added value active compounds for instance for medicinal application. Also still non-explored possibility is the 7400 km long coastal area of India that can provide production sites for cultivation of large amounts of **algae** and especially macroalgae, rich in proteins, sugars, oils and lipids and many other compounds as well as energy source. In addition, micro-algae can provide high productive systems with low land use.

Concerning biomass from **forestry** in India, the total growing stock of India's forest and tree outside forests is estimated as 6047 Mm^3 which comprises 4499 Mm^3 inside the forests and 1548 Mm^3 tree outside the forests (TOF).[18,19] Despite the larger growing stock in forests, more than 90% of the annual production of wood comes from TOF, and the commercial availability of biomass from Indian forest is not considerable due to policy matter. For forests very little information is available from authenticated sources, and also the data on trees outside forest are very limited stressing the need of a further assessment of the **technical availability** especially of **TOF**.

There is a recent interest in India is on cultivation of **Bamboo**. India is the second richest country in terms of Bamboo genetic diversity with a total of 136 species under 75 general.[18] The total bamboo bearing area has recently been mapped and estimates on the amount of culms have been made. Actions are taken in the national bamboo mission, to increase the coverage area in potential areas, with improved varieties to increase yield. The bamboo industry is stimulated and expected to grow significantly, stressing the need of research on the technical conversion processes allowing the utilization of bamboo in the various sectors of the bio-economy. Bamboo is traditionally applied in paper and pulp and handicrafts industry, but further implementation as wood substitute, timber replacement, energy feedstock…is envisaged.[20,21]

[17] India's 5th National Report to the convention on Biological Diversity, Ministry of Environment and Forests India (2014).
[18] Forest Survey of India, Ministry of Environment and Forests, India, India State of Forest report 2011 (2011).
[19] FAO, Global Forest Resources Assessment 2010 (FRA 2010), ISBN 978-92-5-106654-6, 340p (2010).
[20] National Mission on Bamboo Applications, Dept. Science & Technology India, press release 5/2010, http://dst.gov.in/whats_new/press-release10/pib_5-5-2010_3.htm. (extracted 11/2014).
[21] National Bamboo Mission; Dept. of Agriculture and Cooperation, Action plan (http://nbm.nic.in/actionplan.html). (extracted 11/2014)

In India, there is vast potential for energy generation from **waste**, as for instance municipal waste generated in the country comes from varying sources and disposed in a local landfill site. However, there were not proper record from authenticated sources from textiles, leather, food and fruit processing industries which may also account for the significant amount of bio wasted generated in the country. The rate of urbanization in India was 28.7% in 2005 and is expected to rise to 34.5 % by 2015. This situation demands an infallible waste management system to handle the large amount and diverse types of industrial, agro-industrial and municipal wastes. Efficient **segregation of waste**, **transportation** and **treatment** along with awareness and education amongst citizens and smooth functioning of an effective system, pave the way to the entire process of waste and waste water management.

Biorefinery

The replacement of oil with biomass as raw material for fuel and chemical production is an interesting option to reduce dependence on fossil fuels and is the driving force for the development of bio-refinery complexes. In our vision, Bio-refineries are highly energy-efficient and make use of mostly zero-waste production processes, and they allow industries to manufacture environmental friendly products with small carbon and water footprints. Therefore, a bio-refinery should be able to produce a gamut of marketable products and energy in a sustainable fashion. The products can be intermediates or final products, such as food, feed, materials, and chemicals; while energy includes fuels, power and heat. The design of a bio-refinery should be sustainable by taking into account possible unintended consequences such as the competition with food and biomass resources, water use, quality of the products, usage of land, emission of greenhouse gases and impact on biodiversity. Economic constraints dictate that bio-refineries need to be operated efficiently and at low cost. Due to the limited availability of biomass the raw materials should be used efficiently by developing multi-purpose bio-refineries. However, some have been established to exploit new value chains, such as aquatic/marine biomass.

The bio-refinery systems which will come into operation in the near future will have the production of biofuels (transportation sector) as the main focus [22]. These biofuels can be mixed with gasoline, diesel or natural gas to compensate the fuel scarcity in the transportation sector. The volume and the prices of these biofuels generated should be competitive with the fossil fuel prices in the future markets. Besides bio-refinery systems that are focused on producing energy carriers, in the longer term Bio-refineries will develop that are mainly producing biobased products and materials, with conversion of side streams to energy.

An open and collaborative approach creates synergies in education, research, development and innovation throughout the bio-refinery value chain. Integration of supply and manufacturing chains and increased collaboration between innovative players from traditional industries such as the chemical, energy, agriculture and forestry sectors combines the key strengths of each sector, creating the critical mass to attract investors, policymakers and young talent. Therefore a key factor for the development of a sustainable, highly efficient and cost effective bio-refinery is the integration of aforementioned parameters into the existing infrastructure. At national, regional and global levels there are three main drivers for

[22] IEA Bioenergy Task 42: Biorefinery (2010).

using biomass in bio-refinery for production of bioenergy, biofuels and biochemicals. These are *climate change, energy security and rural development*. The political motivation to support renewable sources of energy and chemicals arises from each individual driver or combinations. Policies designed to target one driver can be detrimental to another. For example, policies aimed at ensuring energy security may result in increased *Green House Gas* (GHG) emissions where local coal reserves are preferentially exploited at the expense of imported oil or gas. In addition, electricity and heat can be provided by a variety of renewable alternatives (wind, sun, water, biomass and so on), while biomass is very likely to be the only viable alternative to fossil resources for production of transportation fuels and chemicals, since it is the only C-rich material source available on the Earth, besides fossils. As a consequence, the sustainable biomass production is a crucial issue, especially concerning a possible fertile land competition with food and feed industries[23].

In conclusion, the development of bio-refineries should be steered towards development and implementation of bio-refineries that can deal with **multiple biomass feedstock streams** either via a single process or through a combination of several integrated ones: flexibility is very important. Furthermore, economic constraints dictate that bio-refineries need to be operated **efficiently and at low cost**, and (further) adoption of **sustainability criteria** will drive the continued development of Bio-refineries. The development of more flexible and sustainable bio-refineries in the future will only be possible if crucial bottlenecks along the value chain can be removed. In this strategic research agenda, a number of these bottlenecks will be identified, while listing solutions in order to overcome them. From a technological point of view, conversions with **anaerobic digestion** and **thermochemical systems** are considered to be important for energy production, especially on the short-term. From a resource point of view, **ligno-cellulosic streams** (mid-term) are considered to be significant input streams for the biorefinery. **Oils** and **fats**, already used for oleochemical products and biofuels, are expected to be further explored in a biorefinery whereby also the side products are valorised. On the mid- and long-term, new biorefinery approached based on new resources such as for instance proteins, lignin, furfural or CO_2, or processes leading to inorganics are expected to lead to new biobased products. To facilitate implementation and commercialization of the various processes, **demonstration** actions will be needed in the biomass pre-treatment as well as in the conversion processes.

3.2 Topics relevant for the EU-India collaboration

Based on the needs and challenges of both Europe and India, stakeholder consultation and the research and development needs identified in both Europe and India, several joint research and development interests have been identified. Altogether, following research and development recommendations were formulated, over three different categories, feedstock, waste and biorefinery. In addition policy recommendations were also defined.

A survey was made and sent to industrial, academic and governmental stakeholders, and active of the various sectors of the bioeconomy. In total 207 complete responses were received both from Europe and India. For Europe, responses were received from 19 from the 28 MS.

[23] Future Biorefineries in India: Challenges and Opportunities, World Economic Forum Report (2012).

Stakeholders from industry, academia as well as governmental institutes responded, as displayed in Figure 1. More or less equal responses were obtained from universities, research institutes and industry. For EU-28, the industrial participants were from large enterprises, SME and consultancy firms. In India, mostly large enterprises participated and less participation was noted for SMEs and consultancy firms.

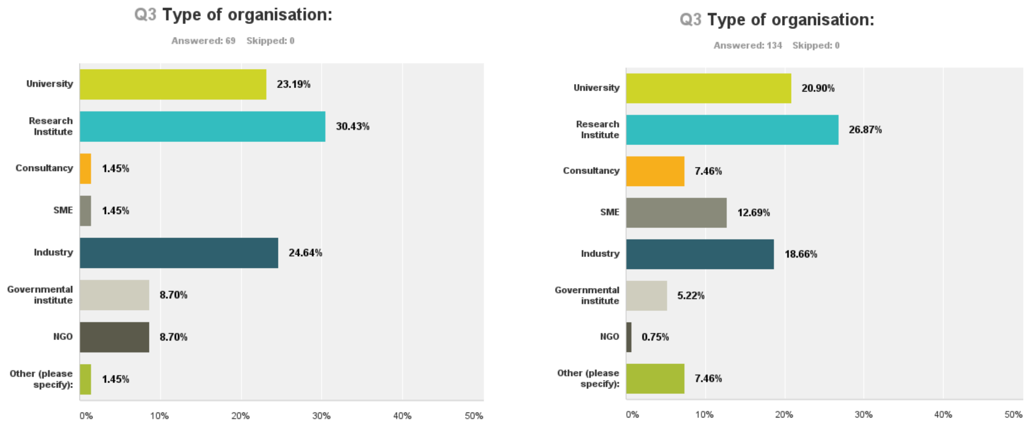

Figure 1: Type of organisation of the respondents (left: India, right: EU-27)

In addition, also stakeholders from the various sectors were addressed. For India, the responses were mostly from the energy, environmental and agricultural sector in almost equal amounts. For Europe, on the hand, a higher contribution from the chemistry/material sector and less from the environmental sector were collected. The other category mostly comprises stakeholders active in biotechnology with a cross-sectorial domain.

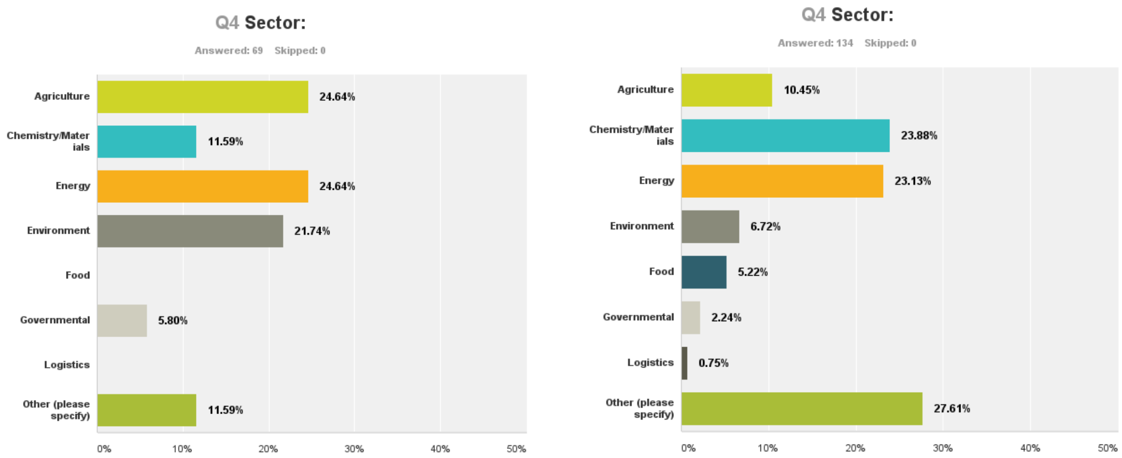

Figure 2: Sector of the respondents (left: India, right: EU-27)

For each of the three categories (+ a fourth related to policy and markets), the respondents had (maximum) three votes that could be given to the R&D recommendations that were considered to be the most important for the EU-India collaboration. The total results (cross-sectorial, and considering all organisations) are given in the tables below. From the tables, 7 main areas of interest can be derived:

Feedstock:

- Optimization of agricultural practices through breeding, modelling, monitoring. Providing regionalized solutions. Development of accurate biomass mapping methodology.
- Development of new (energy) crops, including phenotyping, suitable for marginal and abandoned lands and/or low nutrient/water supply and allowing agricultural intensification.
- Research and development on micro- and macro algae as future biomass source.

Waste and Byproducts

- Set up of surveys to monitor the amounts and compositions of the different types of residues and wastes (municipal, agricultural and process residues and waste). Proper databases on the available biomass potential allowing future predictions considering climate change. Improving the collection of municipal waste (segregation) and sustainable agricultural residues harvesting.
- Development of new technologies to convert the different types of solid wastes and residues (agro-forestry, municipal and industrial).

Biorefineries

- Development of biorefinery based on lignocellulosic biomass towards fuel and chemicals.
- Linked to waste: further development of anaerobic digestion to convert organic wastes into biogas (and in a later stage chemicals of biofuels).

Biomass production			
Answer Options	**INDIA**	**EU**	**average**
Exploring biodiversity	15.8%	12.8%	14.3%
Research on the bioprospecting and sustainable exploitation of the rich biodiversity of medicinal and /or	15.8%	12.8%	14.3%
Improved plant production by geno- and phenotyping	50.9%	30.8%	40.8%
Set-up of a genotypic and phenotypic inventory of seed bank material, landraces and wild plants.	8.8%	5.1%	6.9%
Research on the phenotyping of plants to obtain improved crop performance including marginal lands.	42.1%	25.6%	33.9%
Optimization of agricultural practices through breeding, modelling, monitoring	43.9%	76.1%	60.0%
Research on breeding and/or agricultural practices to increase/stabilise plant biomass production for	10.5%	17.9%	14.2%
Research to better understand the range of options for fine-tuning biomass quantity and quality.	12.3%	14.5%	13.4%
Research to provide regional solutions for optimized plant biomass production.	5.3%	17.9%	11.6%
Demonstrate (appropriate) remote monitoring and control systems (GIS) for plant production in rural	7.0%	5.1%	6.1%
Development of strategies to restore abandoned land with adapted crops and land management.	8.8%	20.5%	14.6%
Full development of existing energy crops (Jatropha cultivation)	5.3%	4.3%	4.8%
Full development of Jatropha cultivation.	5.3%	4.3%	4.8%
Development of new cops (high yielding/high straw, dedicated energy, resilient)	49.1%	56.4%	52.8%
Development of new crops (and biotechnology crops) allowing agricultural intensification.	7.0%	12.0%	9.5%
Development of high yielding crop varieties providing by-products of interest (e.g. higher-straw	7.0%	10.3%	8.6%
Development of high yielding dedicated bioenergy crops via optimized agriculture technologies with	22.8%	18.8%	20.8%
Development of more resilient crops (for instance against heat, salinity and draught), such as for instance	12.3%	15.4%	13.8%
Assessing and reducing environmental impact of biomass production	8.8%	24.8%	16.8%
Modelling of cropping scenarios and their environmental and socio-economic impact.	8.8%	4.3%	6.5%
Development of tools/methodologies to reduce the environmental impact of biomass production.	0.0%	20.5%	10.3%
Demonstration through pilot scale programs	24.6%	20.5%	22.5%
Demonstration and assessment of intermittent cropping and crop rotation through a pilot scale program.	0.0%	6.0%	3.0%
Pilot demonstration and assessment of the economical sustainability of improved micro- and macro	24.6%	14.5%	19.5%
Forestry	3.5%	9.4%	6.5%
Develop/set up (improved) forestry management systems for the sustainable procurement of forestry	3.5%	9.4%	6.5%
Development/Research on the application of algae	89.5%	56.4%	72.9%
Research on the exploiting the full potential of micro-algae in a biorefinery strategy.	17.5%	17.1%	17.3%
Development of concepts for closing the nutrient loop for aqueous based plant biomass production.	3.5%	5.1%	4.3%
Research on the phenotyping and selection of algae towards breeding of new organisms.	1.8%	1.7%	1.7%
Development of algae-based waste water treatment systems.	24.6%	14.5%	19.5%
Development of algae production systems for the sustainable production of renewable energy.	35.1%	15.4%	25.2%
Development of genetic toolboxes for algae.	7.0%	2.6%	4.8%
answered question	*57*	*117*	*174*
skipped question	*11*	*20*	*31*

Table 1: Overview of the importance of the different research recommendations for biomass production, expressed as the number of votes received.

By-products/Waste			
Answer Options	**India**	**EU**	**average**
Monitoring the amounts and composition of waste	45.6%	60.2%	52.9%
Set up of a survey to assess the amount and type of waste dumped at	1.8%	9.3%	5.5%
Assessment of the composition and the generation of MSW and the	14.0%	18.6%	16.3%
Set up of a survey of the generation and available agricultural and processing	29.8%	32.2%	31.0%
Improve collection and utilization of wastes	66.7%	69.5%	68.1%
Development of technologies/methods to harvest, collect and use agricultural	42.1%	40.7%	41.4%
Research to the better and maximum utilization of biowaste.	24.6%	28.8%	26.7%
Development of new Technologies to convert existing (solid) waste	77.2%	70.3%	73.8%
Development of technological routes to apply on existing agro-forestry waste,	29.8%	31.4%	30.6%
Development of technological routes to apply on existing municipal waste as	28.1%	20.3%	24.2%
Development of technological routes to apply on existing industrial waste as	19.3%	18.6%	19.0%
Research on wastewater treatment / bioremediation	36.9%	16.1%	26.5%
Research on plants suitable for waste treatment and conversion.	14.0%	8.5%	11.3%
Research on bioremediation, including bioremediation in sewage	22.8%	7.6%	15.2%
Conversion of CO2	28.1%	27.1%	27.6%
Development of new processes converting CO2 in bioenergy or biobased	28.1%	27.1%	27.6%
Development of routes to convert wastes to a platform system for bioenergy	26.3%	43.2%	34.8%
Development of improved and safer conversion processes of wastes	10.5%	22.0%	16.3%
Development of new routes for waste valorisation biobased products through	7.0%	6.8%	6.9%
Developing new routes for waste valorisation to biobased products and fuels	8.8%	14.4%	11.6%
answered question	*57*	*118*	*175*
skipped question	*11*	*19*	*30*

Table 2: Overview of the importance of the different research recommendations for by-products/waste, expressed as the number of votes received.

Biorefineries			
Answer Options	**INDIA**	**EU**	**Average**
Anaerobic digestion	76.4%	68.6%	72.5%
Research and developments to improve the overall efficiencies and	7.3%	6.8%	7.0%
Development of strategies for multi-feedstock anaerobic digestion of	27.3%	16.1%	21.7%
Development of a multiple-product approach for anaerobic digestion	7.3%	10.2%	8.7%
Development of easy-to-operate and inexpensive anaerobic digesters	5.5%	13.6%	9.5%
Research on the microbiology of AD for different feedstocks, including	7.3%	2.5%	4.9%
Research on the required upgrading, storage and logistics of biogas in	3.6%	4.2%	3.9%
Research on the use of digestate such as fertilizer substitute or fibres.	7.3%	8.5%	7.9%
Research on the pre-treatment of biomass for gasification.	10.9%	6.8%	8.8%
Thermochemical systems	23.6%	33.1%	28.3%
Creating more efficient approaches by combining thermochemcial and	14.6%	13.6%	14.1%
Development of a pyrolysis oil platform for producing advanced	7.3%	7.6%	7.4%
Development of a combined process based on pyrolysis and	1.8%	11.9%	6.8%
Biorefinery based on lignocellulosic resources towards fuels and	84.7%	90.7%	87.7%
Development and utilization of smart enzyme systems for	20.0%	13.6%	16.8%
Development, utilization and economical assessment of more active,	7.3%	10.2%	8.7%
Research and development of yeasts that can produce cellulases and	10.2%	10.2%	10.2%
Development of conversion methodologies for lignin towards	10.9%	11.9%	11.4%
Research and demonstration on process intensification to achieve	18.2%	21.2%	19.7%
Development of biorefinery systems based on fast growing and/or	18.2%	23.7%	21.0%
Biorefinery based on oils towards fuels and chemicals	5.5%	9.3%	7.4%
New methodologies for producing and refining non-food plant oils	5.5%	5.1%	5.3%
Development of a full oleochemistry platform, including phytosterols,	0.0%	4.2%	2.1%
New biorefinery systems	23.6%	22.0%	22.8%
Development of new routes for producing biochemicals based on	10.9%	9.3%	10.1%
Development of new routes for producing biochemicals from Protein-	7.3%	7.6%	7.4%
Development of a biorefinery leading to inorganics as silica, K, Ca,	5.5%	5.1%	5.3%
Biorefinery based on gases (CO2/methane) towards fuels and	7.3%	5.1%	6.2%
Research on fermentations using gas as a feedstock to produce	7.3%	5.1%	6.2%
Demonstration	50.9%	48.3%	49.6%
Set up of demo-biorefinery systems (low volume-high value/high	14.6%	8.5%	11.5%
Set up of integrated demo biorefinery systems (ethanol, sugar, power,	25.5%	22.0%	23.7%
Demonstration of small decentralized biomass densification	10.9%	17.8%	14.4%
Smart equipment	12.7%	11.0%	11.9%
Development of smart processing equipment.	12.7%	11.0%	11.9%
answered question	*55*	118	*173*
skipped question	*13*	*19*	*32*

Table 3: Overview of the importance of the different research recommendations for biorefinery, expressed as the number of votes received.

3.3 Roadmap

To develop towards a full bio-economy, research on various time-scales should be undertaken, i.e. short-term (2014-2020) to realize for instance the goals on renewable energy and further implementation in chemistry, mid-term (2020-2030) and finally long-term (2030-2050) to achieve a complete circular economy.

Recommendations leading to short-term implementation (2014-2020)

Several actions are already taken and should still be extended to reach the targets on renewable energy and to realize a further transition towards a more biobased chemistry, without compromising on the food supply necessary for a growing population. As far as biomass and biowaste feedstock is concerned, several research and development actions are needed on a short-term.

Several short-term actions are needed to secure the **feedstock** supply for food and energy. Research is needed to increase plant production, by optimizing the agricultural practices to increase biomass production for food and non-food applications, with optimal water, fertilizer and PPP management, while securing soil quality and avoiding environmental threats such as salination, erosion…This should be done a combined approach: soil quality determination, selection of a crop-appropriate variety and selection of the appropriate fertilizers (biofertilizer, biocontrole agents and chemical fertilizers). Moreover, improved practices on rain water harvesting and controlled water dosing are needed, for India to intensify agriculture and reduce water shortages, in Europe to reduce further the pressure of the agricultural sector on both surface and ground waters. Research should be performed to provide diversified and regional solutions for optimal biomass production, taking into account the various climatic zones and aided for instance by GIS remote motoring. Moreover, research on the phenotyping of plants should be performed to obtain more stress resistant varieties/seeds (abiotic and biotic stress) that will result in an improved crop performance on lands not suitable for food production, such as marginal, abandoned lands or contaminated land.

Moreover, developments are needed to further explore and demonstrate highly productive bioenergy crops, especially suited for cultivation on set-aside or marginal lands. On a short-term, the research should be concentrated on the already identified crops of common interest, such as sorghum and jathropha to explore their full potential on lands with a poor land quality. In addition, research is needed to assess the full potential of micro-and macro algae systems. Case studies should be developed which demonstrate a cost-competitive production of algae-based products, whereby the costs are reduced for instance by technical developments, applying a biorefinery approach, closing the nutrient loop or using waste streams in the production. These specific case studies, likely targeted to niche markets, will facilitate later commercialization of bulk products, such as oils and proteins. In addition, algae are considered by both to be very promising to remediate contaminated water and waste water, and by joint actions in this field, implementations are expected on a short-term.

With the area of **residues** and **wastes**, a harmonized survey is needed to monitor the various wastes and/or residues that are available. This includes the technical potential of agricultural wastes, as well as a harmonized overview of the amounts and composition of municipal solid waste. In Europe, wastes, such as municipal waste and common sludge, are already recorded in EUROSTAT, but a further harmonization between the MS on the methodology is needed. Moreover, only scattered information is available on the residual by-products and side streams that are not classified as waste, but could have an improved valorisation in a cascade approach. Also in India, the monitoring, cost effective segregation and collection of waste, is considered to be essential to reduce and utilize waste in the bioeconomy. Research is needed to improve the collection and logistics of residues and waste, especially for the agricultural by-products. Also technological conversion routes are requested for reducing and better using of the different types of wastes, especially municipal solid waste, residual agro wastes and biological-organic industrial waste. New conversion technologies are needed, but on a short-term, especially the full development of anaerobic systems (see biorefineries) is needed for biogas production. On a mid-term, the implementation of a more cascade approach with various valorisation outputs, as well as conversion to other, non-energetic products are expected. More specifically, anaerobic digestion (among others) could provide a platform for VFA production that could be used as platform molecule for chemicals or advanced fuels.

For biorefineries, research on the energetic valorisation of biomass and waste is expected to be further implemented on a short-term. Research on anaerobic digestion (linked to waste) is needed, mostly to reduce the overall costs, to be able to treat various feedstock and to have easy-to-operate systems for rural areas. The developments should be dedicated on closing the loop, like using the digestate, as well as on the microbiology to achieve very performant processes. Also the upgrading of the biogas, storage and logistics will be requested. Also the development of lignocellulosic biorefineries was indicated to be of joint interest. To achieve a more cost-competitive lignocellulosic biorefinery, more active and cheaper enzymes are needed, and new process intensification steps should be developed, especially to reduce the downstream processing costs. To facilitate implementation and commercialization, the demonstration of the densification of biomass, demo-biorefineries as well as integrated demo-biorefineries are important. These biorefineries can be built on locally interesting feedstock, including bamboo for India.

Feedstock

Improved agricultural practices

Improved plant production by geno- and phenotyping
Research on the phenotyping of plants to obtain improved crop performance including marginal lands, resource use efficiency, resilience, biomass composition, multi-purpose use potential.
Optimization of agricultural practices through breeding, modelling, monitoring
Research on breeding and/or agricultural practices to increase/stabilise plant biomass production for food and non-food uses by plant breeding improvements and/or improved agricultural practices.
Research to better understand the range of options for fine-tuning biomass quantity and quality.
Research to provide regional solutions for optimized plant biomass production.

Development of new (bioenergy) crops

Development of new cops (high yielding/high straw, dedicated energy, resilient)
Development of high yielding dedicated bioenergy crops via optimized agriculture technologies with minimum inputs in terms of nutrients, water and energy consumption for the set-aside and marginal lands.
Development of more resilient crops (for instance against heat, salinity and draught), such as for instance sorghum. Diversified agriculture crops for semi-arid, dry land and marginal land agriculture.

Micro- and macro algae

Demonstration through pilot scale programs
Pilot demonstration and assessment of the economical sustainability of improved micro- and macroalgae production processes.
Development/Research on the application of algae
Research on the exploiting the full potential of micro-algae in a biorefinery strategy.

Development of concepts for closing the nutrient loop for aqueous based plant biomass production.
Development of algae-based waste water treatment systems.

Residues and wastes

Survey and collection

Survey of residues/wastes
Set up of a survey to assess the amount and type of waste dumped at landfills.
Assessment of the composition and the generation of MSW and the development of new routes for the valorisation of the organic fraction.
Set up of a survey of the generation and available agricultural and processing by-products and wastes available for energy and biochemicals production.
Improved collection and utilization of wastes
Research to the better and maximum utilization of biowaste.

New technologies to convert organic-biological residues and waste from agro-forestry, municipal and industrial waste

Development of new Technologies to convert existing (solid) waste
Development of technological routes to apply on existing agro-forestry waste, including horticultural waste, for bioenergy or biobased products.
Development of technological routes to apply on existing municipal waste as feedstock for bioenergy or biobased products.
Development of technological routes to apply on existing industrial waste as feedstock for bioenergy or biobased products.

Biorefineries

Anaerobic digestion

Anaerobic digestion
Research and developments to improve the overall efficiencies and reduction of costs of anaerobic digestion (reduction of retention time, increase of process stability, improved pre-treatment, extraction of added value compounds, upgrade gas).
Development of strategies for multi-feedstock anaerobic digestion of various types of waste, including waste water, municipal solid waste, agricultural waste and industrial waste.
Development of easy-to-operate and inexpensive anaerobic digesters and their application demonstration in rural areas.
Research on the microbiology of AD for different feedstock, including pre-treatment (e.g. separate hydrolysis), mixed culture systems, use of enzymes and micro-nutrients.
Research on the required upgrading, storage and logistics of biogas in relation to its application, such as injection in the grid or use in transport, and its economical assessment

Research on the use of digestate such as fertilizer substitute or fibres.
Research on the pre-treatment of biomass for gasification.

Lignocellulosic biorefinery

Lignocellulosic Biorefinery
Development, utilization and economical assessment of more active, cheaper enzymes for hydrolysis of lignocellulosic biomass.
Research and demonstration on process intensification to achieve more cost-competitive lignocellulosic biorefineries.
Demonstration
Set up of demo-biorefinery systems (low volume-high value/high volume-low value).
Demonstration of small decentralized biomass densification programmes.

Recommendations leading to mid-term implementation (2020-2030)

Besides the earlier described short-term research lines, also research is needed that is expected to find implementation on a mid-term time-span, but which is essential to achieve the final goals of the biobased economy.

Within the area of **feedstock production,** it is to be expected that research on improving the agricultural practices and providing, diversified regional production will be continued. This will further focus on the yield increase, by further optimizing the water, PPP and nutrients balance and applying agricultural management techniques. Nevertheless, the focus will likely shift towards the restoring of abandoned land as well as developing and implementing new, higher productive (energy) crops suitable to grow on these lands. The latter includes new crops providing by-products of interest, allowing agricultural intensification, or being more resilient against heat, draught or salinity. To attain improved crop performance, the research on the phenotyping of plants should be continued.

After the successful demonstration of the first cost-competitive algae-based products, research and development will be needed to discover and select new commercially interesting algae, for instance by phenotyping and the development of genetic toolboxes. Moreover, a continuation of the technological developments on the production, harvesting, and further treatment of the micro- and macro algae will be needed to increase its competitiveness as a biomass source for bulk ingredients like for instance oils for biofuel production.

On the level of **residues and waste**, more research will be needed to be able to harvest and collect agricultural residues in a technical feasible and cost-competitive way. The amount of residues that can be harvested without affecting the soil quality should be addressed. Even if developments leading to an energetic valorisation of various agro-, industrial and municipal wastes will likely be implemented on a shorter-term, additional research and development will still be needed to achieve the highest possible valorisation of the various waste streams in a cascade approach, as well as using them for non-energetic products such as biobased materials and chemicals. This will need the further development of technological routes to apply on the various types of waste. Building further on the knowledge gathered on anaerobic digestion (see biorefinery), one of the promising techniques on a mid-term build concerns VFA production as building block for fuels and chemicals.

As far as **biorefineries** are concerned, it is expected that the research and developments will divert from energy towards the application in biobased products and towards combined processes. The research on anaerobic digestion will therefore be less focused on the energetic valorisation of the biomass and wastes, but rather on the implementation of platforms allowing a multiple-product implementation, such as VFA, H_2….. Within the lignocellulosic biorefinery, the development of combined processes is also foreseen, including for instance the simultaneous conversion/valorisation of lignin and a combined saccharification and conversion. Moreover, new feedstock, such as the fast growing resources (bamboo, energy crops...), will have to be investigated. To facilitate implementation and commercialization, the demonstration of the processes remains of utmost importance.

Feedstock

Improved agricultural practices

Improved plant production by geno- and phenotyping
Research on the phenotyping of plants to obtain improved crop performance including marginal lands, resource use efficiency, resilience, biomass composition, multi-purpose use potential.
Optimization of agricultural practices through breeding, modelling, monitoring
Development of strategies to restore abandoned land with adapted crops and land management.

Development of new (bioenergy) crops

Development of new cops (high yielding/high straw, dedicated energy, resilient)
Development of new crops (and biotechnology crops) allowing agricultural intensification.
Development of high yielding crop varieties providing by-products of interest (e.g. higher-straw varieties).
Development of more resilient crops (for instance against heat, salinity and draught), such as for instance sorghum. Diversified agriculture crops for semi-arid, dry land and marginal land agriculture.

Aquatic biomass

Development/Research on the application of algae
Research on the exploiting the full potential of micro-algae in a biorefinery strategy.
Research on the phenotyping and selection of algae towards breeding of new organisms.
Development of algae production systems for the sustainable production of renewable energy.

Residues and wastes

Survey and collection

Improved collection and utilization of wastes
Development of technologies/methods to harvest, collect and use agricultural by-products, including the assessment of the limits of biomass that can be removed from the fields.

New technologies to convert organic-biological residues and waste from agro-forestry, municipal and industrial waste

Development of new Technologies to convert existing (solid) waste
Development of technological routes to apply on existing agro-forestry waste, including horticultural waste, for bioenergy or biobased products.
Development of technological routes to apply on existing municipal waste as feedstock for bioenergy or biobased products.
Development of technological routes to apply on existing industrial waste as feedstock for bioenergy or biobased products.

Biorefineries

Anaerobic digestion

Anaerobic digestion
Development of a multiple-product approach for anaerobic digestion (hydrogen, VFA, digestate) for bioenergy, biochemical and biomaterials application.

Lignocellulosic biorefinery

Lignocellulosic biorefinery
Development and utilization of smart enzyme systems for simultaneously conversion of cellulose and lignin from lignocellulosic feedstock.
Research and development of yeasts that can produce cellulases and convert sugars in a range of biobased products and fuels (EtOH, Butanol etc.).
Development of conversion methodologies for lignin towards bioaromatics through biological, chemical and thermal catalysis.
Research and demonstration on process intensification to achieve more cost-competitive lignocellulosic biorefineries.
Development of biorefinery systems based on fast growing and/or easily available biomass resources (bamboo, short rotation coppice, dedicated energy crops ...).
Demonstration
Set up of demo-biorefinery systems (low volume-high value/high volume-low value).
Set up of integrated demo biorefinery systems (ethanol, sugar, power ...).

Recommendations leading to mid/long-term implementation (2020-2050)

On the mid- and long-term, further developments of the earlier mentioned processes will have to be performed, leading to the final goals of a biobased and circular economy and using all sources of waste as resource for the biobased economy. In time, on short-term, research will concentrate on the low hanging fruits, whereby on a long-term, important, but technologically more difficult waste streams will be tackled, such as the use of CO_2 as a resource. Even if currently already several developments exist to use CO_2 as a resource (biologically, chemically), further development are to be expected making it a significant resource. Moreover, new developments are expected from mimicking nature and synthetic biology. Also the development of new biorefinery systems based on other platform molecules, such as proteins or furfural, or providing other types of products such as inorganics, are expected to develop and could be the subject of research in the mid- and long-term. In India, the supply of biomass from forests is currently not considered due to policy matter, and woody biomass comes mostly from tree out of forests. On a long-term, also this biomass source may become important. All these topics were indicated in the survey as less priority, but are expected to increase in importance in the future and could therefore be the subject of common research in the future.

Forestry
Develop/set up (improved) forestry management systems for the sustainable procurement of forestry biomass (including residues).

Conversion of CO2
Development of new processes converting CO2 in bioenergy or biobased products.

Development of routes to convert wastes to a platform system for bioenergy and biobased products
Developing new routes for waste valorisation to biobased products and fuels using synthetic biology.

New Biorefinery systems: gases (CO2/methane)
Research on fermentations using gas as a feedstock to produce biofuels and biochemical.

New biorefinery systems
Development of new routes for producing biochemicals based on Furfural-based chemistry.
Development of new routes for producing biochemicals from Protein-based resources.
Development of a biorefinery leading to inorganics as silica, K, Ca, nutrients, …

Development/Research on the application of algae
Development of genetic toolboxes for algae.

4 Conclusions

This Upstream/Downstream Roadmap compiles the needs and challenges, and the shared vision for the EU and India on the latest developments in the bio-based economy in line with the SRA. Based on several stakeholders meetings, both in Europe and India, research recommendation have been formulated that are considered to be of importance for the EU-India collaboration. Through a survey, 250 stakeholders have been consulted, both from Europe and India, from academia, government and industry, and from the various sectors of the bioeconomy. In line with the results of this survey, the most important topics for the EU-India collaboration have been selected, which are:

Feedstock:

- Optimization of agricultural practices through breeding, modelling, monitoring. Providing regionalized solutions. Development of accurate biomass mapping methodology.
- Development of new (energy) crops, including phenotyping, suitable for marginal and abandoned lands and/or low nutrient/water supply and allowing agricultural intensification.
- Research and development on micro- and macro algae as future biomass source.

Waste and Byproducts

- Set up of surveys to monitor the amounts and compositions of the different types of residues and wastes (municipal, agricultural and process residues and waste). Proper databases on the available biomass potential allowing future predictions considering climate change. Improving the collection of municipal waste (segregation) and sustainable agricultural residues harvesting.
- Development of new technologies to convert the different types of solid wastes and residues (agro-forestry, municipal and industrial).

Biorefineries

- Development of biorefinery based on lignocellulosic biomass towards fuel and chemicals.
- Linked to waste: further development of anaerobic digestion to convert organic wastes into biogas (and in a later stage chemicals of biofuels).

In this deliverable the short-term, mid-term and long-term subjects for possible collaboration are discussed for these topics.

Besides the tackling of the R&D challenges, also a political framework and societal changes are needed to further fuel the bioeconomy and facilitate cooperation between EU-India in this field. More specifically, a cooperation framework between EU and India and a financial structure to realize joint R&D projects is essential. Moreover, the joint transition to a bioeconomy will also need societal changes in the different steps of the chain:

- Production: capacity building for farmers of improved agricultural practices.
- Conversion: joint industrial cooperation and demonstration and increased production of biobased products.
- Consumer: increased public awareness and societal support for biobased products
- Policy: creation of an enabling environment for the bioeconomy.