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ERIFORE

European Research Infrastructure for Circular Forest Bioeconomy

Deliverable 4.2
Report on other main European and global players in the field of separation and downstream processing

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SUMMARY

Special expertise in separation technologies and downstreaming are heavily concentrated in locations where there are strong chemical, petrochemical, and pulp and paper industries. Research infrastructures in separation technology can be found at pilot facilities and at smaller scale at numerous universities. This report focuses on analysing large scale piloting facilities.

Universities in separation technologies are developing separation and downstream processes mainly in laboratory scale and by utilizing computational methods. Universities do also valuable research in measuring physical properties of new materials and storing the information in different data bases (TRL 1-4). Universities have unique competencies and they are developing new technologies, for example hybrid separations. Data on available competence and equipment at universities can be found in the Attachments.

The number of players which are able to operate at the scale of larger than 10 kg/h is small in research and development. However, the availability of these units and facilities was reported to be good. Many piloting facilities are not researching or developing downstream processes as a distinct or separated field, they rather test or study feasibilities of separation of the produced bio based materials. Typically piloting facilities use state-of-the-art downstreaming tools in scale-up to purify and concentrate the final product (TRL 5-7). Most of the identified integrated piloting facilities which focus on biorefinery processes rely on separation unit operations which are commercially used in other applications and well tested on a commercial scale. These unit operations are typically used in scale-up projects where well-functioning separation and purification steps can be critical for the whole process.

It can be well argumented that more special separation tools should be installed into these piloting plants. However, the risk of investments in special tools is easily higher due to limited flexibility of special tools and lower availability expertise. On the other hand, it is seen that special tools are essential in order to improve biorefinery processes and to decrease the production costs which are related to downstream process. It can also be concluded, that there is clear need to improve awareness and utilization of the current piloting facilities.

In total 10 different piloting facilities were recognized which have integrated tools and experience in processing of bio based materials in downstreaming:

1. Fraunhofer CBP (DE)
2. Bio Base Europe Pilot Plant (BE)
3. Bioprocess Pilot Facility B.V. (ND)
4. CPI – Industrial Biotechnology and Biorefining (UK)
5. NREL Bioprocessing Pilot Plant (US)
6. Inventia (SWE)
7. SP Biorefinery Demo Plant / SP Processum (SWE)
8. VTT - Bioruukki (FI)
9. NGP2 (DE) - Under construction
10. NREL – Biomass Conversion Pilot Plants (US)

Industrial companies (e.g. Sulzer) have commercial piloting units for different separation units. These plants do not fall within the scope of this report since focus was on open access pilot facilities.

1 Introduction

The aim of the ERIFORE is to **establish a globally competitive European research infrastructure** in the field of **Forest based Bioeconomy**. The approach of ERIFORE is to facilitate through **research infrastructure co-operation** the development and commercialization of **novel, industrially adaptable and techno-economically viable solutions** that can be derived from a **Circular Forest Bioeconomy**. These solutions are founded on value chains ranging from sustainable biomass management, harvesting and efficient biomass utilization producing the most value added products, enhanced recycling, and reuse of material through the whole lifecycle. Thus, the future infrastructure shall comprise **shared knowledge platform** and educational services, centralized information management environment, **research laboratories with up-to-date equipment**, **versatile characterisation and analytical equipment, modelling and simulation tools, and extensive selection of pilot plants in the field of biorefinery**.

Partners of ERIFORE have complementary research infrastructure for development of processes for production of chemicals, fuels, fibre products and materials from renewable biomass utilizing biotechnological, chemical and thermal processing technologies.

The scope and technical content of research areas and infrastructures in circular forest biorefinery field can be described in many ways. In ERIFORE project the dividing is based on steps in the development chain: raw material sourcing and availability, primary processing of the forest biomass, secondary processing of the biomass components and downstream processing technologies (Figure 1).

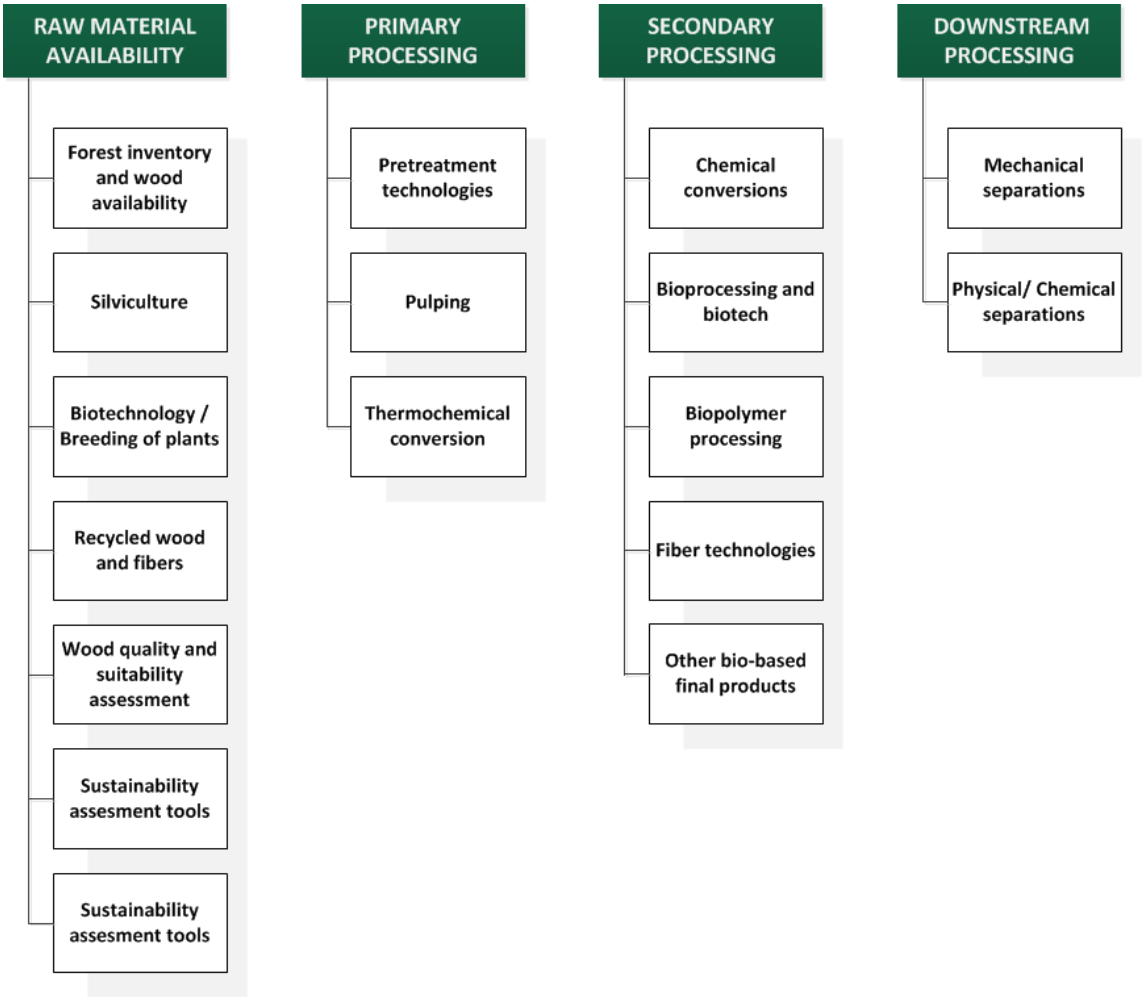

Figure 1. The technology areas included in ERIFORE action.

The work in the project has been divided in 3 tasks:

- the capabilities, facilities, networking and funding sources of the consortium partners
- the other main European and global research providers in the field of forest based bio economy
- the main R&D needs, drivers and trends in forest based bio economy

This report (D4.2) covers the **other main European and global research providers** in the field of **forest biomass downstream processing**.

1.1 Scope and Objectives

The objective of this study is to evaluate the capabilities, facilities, networking and funding sources of the main European partners in the downstream processing. Global players are studied on a level that it is possible to compare European facilities and skills to other main global players.

The field of downstream processing technologies means processes and unit operations needed in purification and recovery of side streams and products (Figure 2). Purification is the physical separation or enrichment of a substance of interest from one or from a mixture of other contaminating substance(s). Separations are carried out based on differences in

chemical or physical properties such as size, shape, mass, density, or chemical affinity, between the substances in the mixture. For most efficient purification of complex mixtures a stepwise combination of different separation techniques can be used. Separation techniques allow retrieval of valuable components from biomass streams such as intermediate components for chemicals and fuel components or other organic compounds. Depending on the desired product the choice of a particular separation technique is important and in many cases multiple separation steps are necessary. Parameters such as higher temperatures, solvents or acids can result in loss of functionality or breakdown of desired molecules. Products may be biomass components, separated after controlled biomass deconstruction steps or chemicals which are produced in biotechnology processes. Technologies include advanced solid-liquid separation, extraction, centrifugation, precipitation and crystallisation, membrane filtration technologies as well as more traditional unit operations like evaporators. Downstreaming technologies are described in detail in the ERIFORE deliverables D4.1.

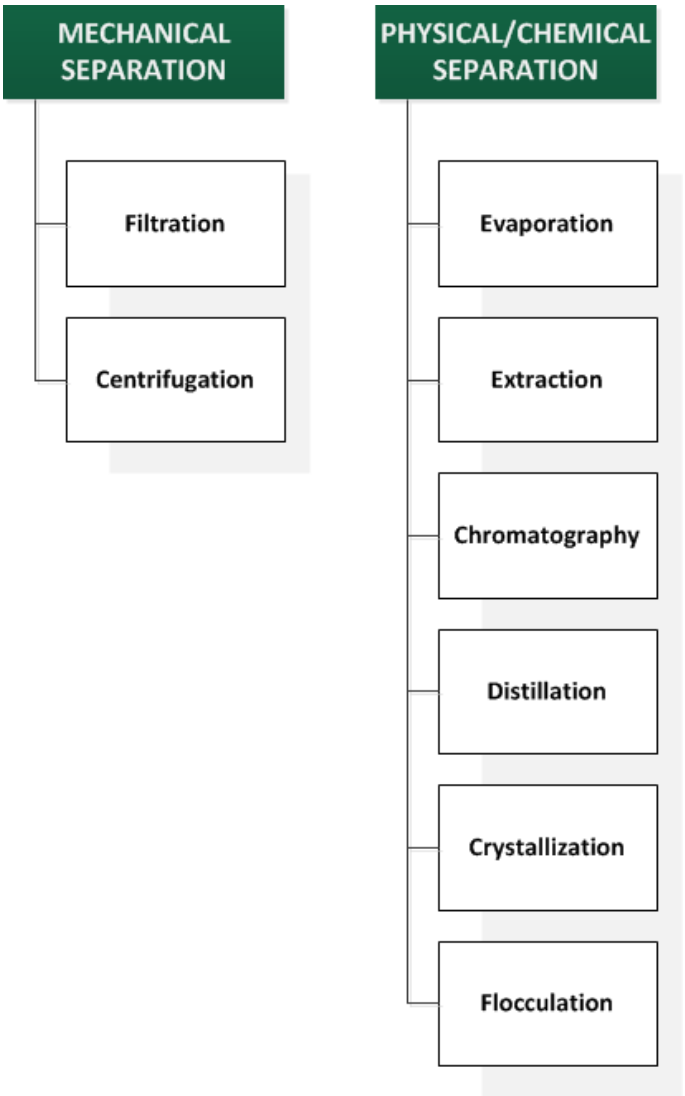

Figure 2. Scope of ERIFORE downstream processing.

The data collection of European and global main players focused on the main players, which have enough capacity and knowledge to do world leading research. The work is divided in two categories:

1. Downstreaming demonstration facilities which are integrated with different biorefinery processes (scale > 10 kg/h)
2. Unique separation technologies which can be expected to be scaled up in the near future for biorefinery applications (scale > 1kg/h)

2 Methods

The task to identify national downstreaming capabilities, research topics, facilities and networks were distributed to different partners. Later analysis of the inputs was done by identified experts. National downstreaming networks were not seen relevant for ERIFORE project. European and global networks were identified by internal experts and asked by survey.

In addition, a survey was distributed to identified European experts in the field of downstreaming and biorefineries. The results of the survey was analysed by experts. The survey had around 95 responses of which 70 reported to have some tools in downstream processing. Only 3 respondents reported to have pilot or demonstration scale tools in downstreaming. Semi-pilot scale tools were reported by 26 respondents.

The data collection of European and global main players focused only on the main players, which have enough capacity and knowledge to do world leading research. The main focus of the work was in European organisations and for example of the survey respondents 11 were did not belong to EU and only 4 were outside Europe (Canada, USA, New Zealand).

3 The capabilities, facilities, networking and funding sources of the ERIFORE consortium partners

All ERIFORE partners carry out research where the forest biomass is a key starting material. Downstream processing expertise is extensive and includes techniques: filtration, centrifugation, evaporation, extraction, chromatography, distillation, crystallisation and flocculation. A few organisations also have ATEX classified laboratories and possibilities to do reactive distillations as well as preparative chromatography and crystallography. Within the consortium there is expertise and facilities from laboratory scale up to ton scales for some partners and some techniques.

The project partners have extensive networks and are frequently part of consortiums for various bio-process development projects. However, there are few networks and projects dedicated to downstream processing only. The downstream processes are merely a part of other processes and projects i.e. primary and secondary processing.
In the first D4.1 it was found that the most basic equipment are demonstrated well and in large scale.

- Coarse filters (10 000 dm^3/h)
- Centrifugation (10 000 dm^3/h)
- Membranes filtration (4 000 dm^3/h)
- Falling-film evaporation (5 000 dm^3/h)

- Distillation (500 dm^3/h)
- Vacuum filtration (250 dm^3/h)
- Liquid-Liquid extraction (85 dm^3/h)
- Spray dying (50 dm^3/h)
- Ion exchange (1 200 dm^3 batch)
- Precipitation and crystallization (1 200 dm^3 batch)

More unique and special separation tools which aim to decrease processing costs by e.g. combining different process units together or processing at demanding environment, were not reported at large scale (> 10 kg/h).

- Extractive distillation (10 dm^3/h)
- Reactive extraction (10 dm^3/h)
- High-pressure extraction (10 dm^3/h)
- Freeze dryer / Lyophilizer (10 dm^3 batch)
- Electrodialysis (0.15 dm^3/h)
- Pervaporation (no scale reported)

A few organisations has ATEX set ups and possibilities. In-situ separation capabilities were not reported at any scale.

4 Expertise areas and capabilities of external organisations

This chapter describes the identified main organisations outside the ERIFORE consortium. In order to limit the amount of relevant organisations, only those with downstreaming units at piloting scale (> 10 kg/h) were included. Especially organisations which are integrated with biorefinery processes were studied. Organisations which are working below the chosen thresholds are described in the attachment due to the excessive number of these players. This list is not exhaustive. Some downstream pilot facilities were probably not identified during the process, but the main organisations with biorefinery downstream facilities are described.

4.1 Bioprocess Pilot Facility – BPF (ND)

The Bioprocess Pilot Facility is situated in Delft by a consortium of industrial partners and knowledge institutions led by Delft University of Technology. Small and large companies and knowledge institutions from the agro, paper and chemical industrial sectors have already expressed interest in using the facility.

As funded by TU Delft, the corporate sector, the European Union, the Dutch Ministry of Economic Affairs, the Province of South Holland and the Municipalities of Rotterdam, Delft and The Hague, BPF pre-eminently is the organization to enable cooperation.
Users themselves select the process to be investigated from the available modules, ranging from various methods of biomass pretreatment, fermentation, recycling and purification to third-generation bioprocesses. Separation process units are integrated in these facilities and are used in scale-up research work to purify and concentrate different material streams.

As such, the facility is flexible and geared towards the needs of researchers from universities, knowledge institutions and industries, large and small, from the chemical industry to equipment

manufacturing. The Bioprocess Pilot Facility is a centre of bioprocessing expertise. Training opportunities will be available for students, researchers and technologists.
Services:

- Reduce risks for up-scaling from lab-scale to factory
- Produce product (100s kilograms) to run pre-marketing/application tests or pre-clinical/tox trials
- Test/validate new technical designs
- Enhance the bio-processing competence in your team/organization (both down- and up-scaling know-how)
- Proven experience with working under GMP- and food quality regimes, resulting in reliable engineering as well as process/product data;
- Perfect embedding in a strong (knowledge) infrastructure and perfect fit with regional developments: the Biotech Campus Delft;
- Open access, confidentiality & IP remains with client.

4.2 Centre for Process Innovation – CPI (UK)

CPI's facilities often offer the option of small scale pilot production allowing their customers to produce a volume of product for investment and demonstration purposes. CPI offers proof of concept programmes resulting in small scale production, along with economic assessment and scale up packages. Separation process units are integrated in these facilities and are used in scale-up research work to purify and concentrate different material streams.

The expert team at CPI can help guide from concept to finished product. They have experienced scientists, engineers, scale up experts, process operators and commercialisation specialists to take projects from early concepts through to robust manufacturing process packages and/or products.

Services:

- Technology landscaping and technical due diligence
- Process guidance for relevant targeted host-strain development
- Process modelling and optimisation
- Techno-economic process benchmarking and plant build cost estimation
- Process scale-up and demonstration

4.3 Biorenewables Development Centre – BDC (UK)

The BDC bridges the gap between the science base at the University of York and the needs of industry to develop and scale-up new greener processes and products.

Biorenewables Development Centre (BDC) offers a broad variety of services in the fields of chemistry and biology to help businesses convert plants, microbes and biowastes into profitable green products. They can help at many points in the biorenewables supply chain, e.g. use for waste tomato leaves, new fuels for your biomass boilers, or a plant-based source of chemicals for fertilisers or cosmetics. All their facilities are open-access.

Biorefining and chemical processing inevitably requires separations at some point in the process. BDC also has novel demonstration equipment, including spinning cone columns, supercritical CO_2 and microwave heating technologies.

4.4 NREL – Biomass Conversion Pilot Plants (US)

Bio-based conversion of lignocellulosic biomass to fuels and chemicals employing various pretreatment techniques, enzymatic hydrolysis, aerobic and anaerobic microbial conversion processes and downstream conversion and recovery technologies. Work performed at bench scale to 1 tonne/d pilot scale. Pilot scale systems can be operated in batch mode or integrated continuous operation.

Thermochemical conversion of lignocellulosic biomass to fuels and chemicals employing various gasification, fast pyrolysis, and catalytic pyrolysis conversion technologies; gas cleanup; and downstream catalytic conversion reactors. Work performed at bench scale and in a 0.5 tonne/d continuous pilot scale conversion system.

Biochemical: Pilot scale equipment includes three 1 tonne/d continuous feed trains and pretreatment reactor systems; four 4,000-L high solids enzymatic hydrolysis reactors; numerous bioreactors including two 160 L, two 1,500 L, and four 9,000 L vessels; and separation systems (centrifuges, tangential flow filtration, evaporation and distillation). Instrumentation and analytical sample analysis for calculation of yields and mass balances. Space is available for integrating client equipment into the process flow trains. Separation process units are integrated in these facilities and are used in scale-up research work to purify and concentrate different material streams.

4.5 MoRe Research Örnsködsvik AB (SWE)

MoRe Research Örnsköldsvik AB is a neutral and independent research and development company in the field of products and processes for e.g. the forest industry. The company used to be a part of the MoDo group, a large paper and pulp company, founded more than one hundred years ago. The focus areas of MoRe Research are All the way (Hela vägen®), Analytical services, Biorefinery, Process Emergency and Education.

MoRe Research is experienced in membrane filtration. Together with Domsjö mills MoRe have built a pilot plant for ceramic membranes which can withstand high temperatures, up to ca. 140°C today. Full size membranes are used, hence data can reliably be transferred to full-scale. MoRe also have a pilot plant for plastic membranes, where the temperature is limited to 40 – 80°C depending on membrane material, making them less suitable for hot process streams.

The unit for continuous liquid-liquid extraction can be used for continuous separation of chemicals between/out of two non-mixable liquids. High value organic compounds e.g. may be extracted from water based residual industry streams.

4.6 Innventia (SWE)

Innventia is a world-leading research institute that works with innovations based on forest raw materials. The majority of operations are carried out in project form via research programmes involving many partners but Innventia also carries out a large number of direct commissions in

the form of analyses, testing and demonstrations in labs and pilots. A wood-based biorefinery requires effective process technology for separating different derivatives from process streams. One overall objective of Innventia's operations is to develop effective processes for all wood derivatives, which can be integrated into the pulp mill and result in unique products.

Innventia are working on several interesting applications, both for lignin and for hemicellulose and cellulose. LignoBoost is one of the technologies available and ready for use to develop your biorefinery concept. The LignoBoost demonstration plant in Bäckhammar opened in 2007. The demonstration plant is owned and operated by a subsidiary to Innventia, LignoBoost Demo AB, which was established with the aim of proving the LignoBoost process concept on a near-commercial scale. There is a daily production of high quality lignin in the plant.

A new initiative, called LignoCity, will now further develop the demonstration plant and make it an open test bed for companies who want to evaluate and validate new refining concepts in the lignin area. Innventia has equipment for filtration, centrifugation, distillation, precipitation and extraction.

Examples:

- The patented LignoBoost process for the extraction of lignin from black liquor.
- High-temperature membrane separation of e.g. hemicelluloses from process liquids.
- Leaching of inorganic and/or organic compounds from wood chips.
- Upgrading of hemicelluloses through precipitation and washing processes to high purities.
- Separation of suberin and betulin from hardwood bark using a water-based method (patent pending).

Separation process units are integrated in these facilities and are used in scale-up research work to purify and concentrate different material streams.

4.7 TNO - Netherlands Organisation for Applied Scientific Research (ND)

TNO does not possess integrated pilot facilities for downstreaming, but they have research groups and facilities which are focusing on downstreaming. TNO focuses chiefly on separation processes which have a high selectivity and low energy consumption. To manufacture chemicals more efficiently the number of separation steps in downstream processing has to be decreased. This can be realized by integrating and intensifying separation processes so that energy consumption and costs will decrease and quality improves.

TNO applies innovative technologies in converting 'classical chemistry' to 'new chemistry' and has a track record in the following technologies:

- Crystallization: TNO has developed the Hydraulic Wash Column (HWC). In combination with melt crystallization this can achieve 99% purity in a single step. The energy saving compared with current technologies is a minimum of 20% and can be as much as 90%.
- Extraction: A second highly selective separation technique on which TNO is concentrating in this respect is extraction. Reaction mixtures seldom only consist of the product but also of solvents, by-products and raw materials which have not reacted. You do not want to have to separate these components one by one using different techniques, but to separate the product, very selectively and in a single step, from all the other components. Extraction has the potential to do just this.

- Membrane-technology: TNO is also working on the combination of extraction and membrane technology, whereby the membrane provides a large and stable contact area so that the reaction mixture and the extractant stay separated. Membrane extraction has already been successfully applied in water treatment, and the step towards using this technique for chemical processes is the next milestone.

4.8 VITO – Separation processes (BE)

VITO does not possess integrated pilot facilities for downstreaming, but they have research groups and facilities which are focusing on downstreaming.

Increase in efficiency of (bio) chemical processes by combining reaction and membrane technology. Sustainable operations and a circular economy require higher-performing separation processes. VITO is working on solutions to the treatment of process streams and integrates technologies to form an efficient whole.

Their separation processes are suitable for isolating reaction products, purifying and reusing solvents and recovering valuable components from waste and secondary streams. They combine their process expertise (filtration, extraction, adsorption) with application expertise from different sectors of industry (chemistry, pharmacy, food, textiles, metal, surface treatment, etc.).

VITO is capable of selecting the best separation technology and test its feasibility in laboratory scale or directly in the production environment. VITO has a wide selection of specialised equipment available on a lab and pilot scale.

Apart from linking separation steps, they also specialise in the integration of separation processes with chemical and biological conversion processes (fermentation, enzymatic) for in-situ recovery of products from reaction mixtures. Furthermore, by integrating membrane technology, certain reactions suddenly become possible or much more efficient than before.

4.9 Summary

4.9.1 Universities

The number of research teams which are active in separation technologies and downstream processing is large and are located normally in technical universities. These organisations do more basic research and detailed information of separation units is scarcely available. Universities are normally very active in model development of different separation technologies. Universities are also active in measurements of basic data (e.g. vapour-liquid equilibrium data), which is used in simulations. The challenge for biorefinery concepts is that the amount of possible molecules is large and the physical and chemical data is still largely missing which leads to strong need of experimental work and high risks in scale-up operations.

4.9.2 Piloting facilities

The number of organisations which are active in biorefinery downstreaming in pilot scale is limited. These piloting facilities are normally part of national research institutions (e.g. Fraunhofer, VTT, SP, TNO, VITO) or then they are individual organisations (e.g. Bio Base Europe Pilot Plant, Bio Processing Facility, CPI, Biorenewables Development Centre).

The most common services of these organisations in downstreaming and separation technologies are:

- Scale-up
- Process development
- Custom manufacturing
- Techno-economic assessments
- Process modelling and simulation
- Process Intensification

The most relevant organisations for ERIFORE in downstreaming seem to be located in countries which have a dedicated bioeconomy strategy (DE, SWE, FI, ND, BE, DN, US). Relevant research equipment for separation technologies are also available in other countries, but the focus of these organisations is more in petrochemical and fossil based separations or these organisation have not clearly identified which materials they are separating.

5 Research facilities in Europe

The data collection of European and Global main players focused on the main players, which have enough capacity and knowledge to do world leading research. The work is divided in two categories:

1. Downstream demonstration facilities which are integrated with different biorefinery processes (scale > 10 kg/h)
2. Unique separation technologies which can be expected to be scaled-up in the near future for biorefinery applications (scale > 1kg/h)

In laboratory scale, many European RTOs have interesting technologies. Listing and describing all relevant organisations and technologies in one report is difficult and probably unnecessary in this report. The report tries to identify the main special or novel technologies which are currently operating between 1 kg/h – 10 kg/h scale (TRL4-5) and which are expected to be up-scale in the near future.

A detailed list of analysed organisations and countries can be found from the attachment part of the report. It was omitted from the main part as it is not within the scope of this report.

The following sub-chapters will describe the main facilities of ERIFORE consortium and external organisation and make comparable analysis. Some technology areas were left out due to lack of data.

5.1 Filtration

5.1.1 Solid-liquid separation

ERIFORE consortium has good competencies and tools in pilot scale solid-liquid separation. VTT (FI) and BBEPP (BE) have excellent facilities for pressure and vacuum assisted filtrations up to pilot scale. FhG (DE) has screw presses, drum presses and filter presses for pilot scale filtrations and SP (SWE) has pilot scale filter presses, decanter centrifuges and filters for bench scale filtrations.

From external members interviewed Lappeenranta University of Technology (FI) has good pilot facilities for solid–liquid separations. On the grounds of ERIFORE web-survey Innventia (SWE), Bioprocess Pilot Facility (ND), Netherlands Organisation for Applied Scientific Research, (ND), CTP (FR), Bioeconomy Science Center (BioSC) and Forschungszentrum Jülich (DE) and National Renewable Energy Laboratory (USA) have pilot scale facilities for filtrations.

In addition to the abovementioned facilities filtration equipment at pilot –and commercial scale are supplied by numerous expert suppliers (e.g. Outotec Filters). It is common that the suppliers provide complete services all the way from laboratory tests, through to pilot plant tests and commercial design. It is also common that these companies hire out pilot plant facilities for tests on site.

Table 1. Special infrastructure in solid-liquid filtration.

Country	Organisation	Equipment/facility
BE	BBEPP	Pressure and vacuum assisted filtrations up to pilot scale
DE	FhG	Screw presses, drum presses and filter presses up to pilot scale
FIN	VTT	Pressure and vacuum assisted filtrations up to pilot scale
LT	LSIWC	Facilities for screw press filtrations
SE	SP PD	Filters for bench scale filtrations
SE	SP Processum	Filters for pilot scale filtrations, filter press, nutsche filter

5.1.2 Membranes

ERIFORE consortium has excellent competencies and tools in pilot scale membrane separation. VTT (FI) has facilities for MF, UF, NF and RO filtrations up to pilot scale. BBEPP (BE) has pilot facilities for MF and UF filtrations. FhG (DE) has equipment for MF and UF up to pilot scale. SP PD (SWE) has pilot facilities for NF and Wood K plus (AUT) facilities for NF, but in the case of Wood K plus only 1 l/h scale.

Outside the ERIFORE family interviews proved that Lappeenranta University of Technology (FI) has good facilities for MF, UF and NF filtrations up to pilot scale. Interviews showed also that VITO (ND) has their own membrane technology for separation of aromatic oligomers and monomers derived from lignin. At the moment scale is 200 L/h but it can be easily brought to larger scale. ENSIACET (FR) has fractioning capacity up to 1 T/h. NOFIMA (NOR) has various units for separation and purification up to feed rate 500 kg/h and Lund University (SWE) has large scale membrane pilot facilities for MF, NF, UF and RO up to 1m3 feed-volume.

On the grounds of ERIFORE web-survey Inventia (Sweden), Bioprocess Pilot Facility (ND), Netherlands Organisation for Applied Scientific Research (ND), CTP (FR) and National Renewable Energy Laboratory (USA) has pilot scale facilities for membrane filtrations. Outside the ERIFORE family and ERIFORE web-survey there are still many other membrane experts like Membrane Science, Engineering and Technology Centre (US), which is focused on advance membrane technology in separation processes through research and development.

There are "conventional" membrane facilities at pilot –and commercial scale available by numerous suppliers (for example Valmet and Alfa Laval). It is common that the suppliers provide complete services all the way from laboratory tests, through to pilot plant tests and commercial design. It is also common that these companies hire out pilot plant facilities for tests on site

Membrane techniques that could be of special interest in forest biomass-based processes are forward osmosis (FO), electrodialysis (ED) and membrane distillation (MD). From ERIFORE partners Fraunhofer IGB has pilot scale (10 dm^3/h) electrodialysis unit. VTT has lab scale facilities for FO filtrations as well as for ED trials and in the near future also for MD trials. Outside the ERIFORE family, Bioprocess Pilot Facility has facilities for ED. Added to FO and ED research infra there are facilities available at pilot –and commercial scale supplied by expert suppliers (for FO e.g. Modern Water and Oasys and for ED e.g. Fumatec). It is common that the suppliers provide complete services all the way from laboratory tests, through to pilot plant tests and commercial design. It is also common that these companies hire out pilot plant facilities for tests on site.

Table 2. Special infrastructure in membrane technologies

Country	Organisation	Equipment/facility
AT	Wood K Plus	Facilities for NF, but only 1 l/h scale
BE	BBEPP	Pilot facilities for MF and UF filtrations
DE	FhG	Equipment for MF and UF up to pilot scale
FIN	VTT	Facilities for MF, UF, NF and RO up to pilot scale. FO and ED in lab scale
SE	SP PD	Pilot facilities for MF, UF and NF
FIN	LUT	Facilities for MF, UF and NF filtrations up to pilot scale
FR	ENSIACET	Fractioning capacity up to 1 tonne/h
NL	VITO	Membranes for aromatic oligomers and monomers (200 L/h)
NL	TNO	Pilot scale membrane facilities
NO	NOFIMA	Various units for separation and purification up to feed rate 500 kg/h
SE	Lund University	Pilot facilities for MF, NF, UF and RO up to 1m^3 feed-volume
SE	MoRe Research AB	Pilot/full scale facilities for MF, UF and NF (ceramic, plastic)

5.2 Evaporation

ERIFORE consortium has good tools for evaporation. Bulk evaporation tasks such as falling film evaporation can be used in demonstration scale (1 000 dm^3/h) to dry or concentrate different materials. ERIFORE consortium has also special tools such as short path evaporators in pilot scale. These short path evaporates are used to concentrate or recover materials which are heat prone. ERIFORE members did not report any research in evaporation, and the tools are mainly used just to dry and concentrate final products.

The identified external piloting partners have similar tools for evaporation in pilot scale. These evaporation tools are necessary to produce concentrated final products. Evaporation was not a research topic in any identified piloting organization. Evaporation is only a tool to concentrate materials and not an individual research topic. Some universities e.g. Wageningen UR is researching more energy efficient technologies to dry and dewater different streams by optimizing mass-transfer and minimizing energy consumption of mixing.

Evaporation is commercial technology and widely used in many different sectors. The development work of evaporation is highly commercial and out of scope of ERIFORE research topics. The main challenges are evaporation processes are normally to minimize energy consumption, and also to minimize operational problems, such as fouling, during concentrating of difficult materials.

5.3 Extraction

ERIFORE consortium has good tools and expertise in extraction processes. ERIFORE consortium has pilot scale tools (up to 100 kg/h) for conventional Liquid-Liquid extractions (LLE). This LLE process is used to separate molecules which are prone to high temperature, and to separate mixtures which cannot be separated with distillation due to e.g. similar boiling points or azeotropes of mixtures.

ERIFORE consortium has special extraction tools such hybrid extractive distillation units or high-pressure extraction units in the semi-pilot scale (10 dm^3/h). Reactive extractions were reported in pilot scale (100 dm^3/h). Extractive distillation aims to separate difficult mixtures and also decrease cost by combining different processes. In high-pressure extractions, ERIFORE consortium has good competencies and ERIFORE consortium is capable to extract materials e.g. in super-critical CO_2 in the scale of 10 dm^3/h.

Extraction tools which would have additional technical value to ERIFORE consortium were not identified. Tools at similar scale were reported e.g. at Inventia. Several university report research in different extraction processes. The main tasks for universities are to measure different equilibrium concentrations for model development and simulations. Universities have also special hybrid extraction tools in laboratory scale which could have scale-up potential in the future. Universities have also good analysis tools and competency for model development-

Conventional extraction is a relatively commercial technology and for example Sulzer company have piloting units to test different extraction processes in pilot and semi-industrial scale. This information is normally restricted for commercial use and is therefore irrelevant for ERIFORE project.

5.4 Distillation

ERIFORE consortium has a good competencies and tools in distillation. ERIFORE consortium has equipment in conventional distillation up to demonstration scale (500 dm3/h) which is used e.g. in lignocellulosic ethanol process to concentrate the ethanol stream.

More special distillation tools are also quite well covered in ERIFORE consortium e.g. extractive and reactive distillation units are available in semi-pilot scale (10 dm3/h) at Fraunhofer CBP and SP Processum.

External members have good expertise and analysis tools and they are maintaining data bases and developing models and simulation tools especially at university level. This research is done mainly in laboratory scale and only few organizations have strong focus on bio based materials.

Biorenewables Development Center have a multi-stage spinning cone column (1 000 dm3/h) which is able to process high viscose slurries. This tool can minimize preprocessing and filtering before distillation. Other additional value piloting scale distillation units were not identified.

TU Dortmund is a strong organization in distillation and they have unique expertise in bio based distillation. They have reactive, enzymatic and extractive distillation units in pilot scale (DN50). TU Oldenburg has a reactive distillation unit in pilot scale (DN50). These special hybrid distillation units could possibly decrease costs of some biorefinery processes.

Distillation is commercial technology and is widely used in petrochemical industry and in separation of ethanol and water mixtures. Several commercial demonstration units for lignocellulosic ethanol are built which uses conventional distillation to concentrate ethanol water mixture. Some commercial organisations have also azeotropic distillation units to concentrate the ethanol-water mixture to water free fuel grade ethanol.

Table 3. Special infrastructures in distillation technology.

Country	Organisation	Equipment/facility
SWE	SP	Large demonstration scale distillation unit (500 dm3/h) for ethanol water
DE	TU Dortmund	Pilot scale (~10 dm3/h) reactive distillation unit for hybrid separations. The
DE	TU Oldenburg	Pilot scale (10 dm3/h) reactive distillation unit with 10 sampling points and

5.5 Chromatography

ERIFORE consortium has a good competencies and tools in chromatography. BBEPP, Belgium has a bench scale preparative chromatography unit with columns up to 500 L for batch chromatography. WoodKPlus, Austria has pilot chromatography columns for normal phase, reversed phase or biochromatography with a bed height between 100-400 mm and a volume up to 3 l, suitable for organic solvents.

External members have chromatography equipment mainly at laboratory scale, but even at pilot plant scale. External members that have responded that they have chromatography capabilities but that have not specified at which scale include Bio Industrial Pilot Plant at the Department of Biotechnology in Austria, LUT (FI), LSIWC (LT), Institute of Biotechnology (LT), Lund University (SWE), Bioproduce / KTH (Sweden) and ETH Zürich (CH).

External members that have pilot capabilities within chromatography include Biorenewables Development Centre, York, UK that has two chromatography systems where different solid media can be utilised. The Bio-Rad chromatography station is designed for the small-scale production/purification of pharmaceuticals or proteins. It has a column diameter of 100 mm and flow rates of between 5-120 L/hr. The Biotage Isolera LS system is a flash purification system designed for the separation of complex organic mixtures. It has cartridges instead of a column which are typically pre-packed. The flow rate of the Isolera system is 5-400 mL/min. One more

external member is the Bioprocess Pilot Facility (BPF) in the Netherlands that has columns up to 170 litre.

In addition to the abovementioned facilities chromatography equipment at commercial scale are supplied by numerous expert suppliers (for example Novasep). It is common that the suppliers provide complete services all the way from laboratory tests, through to pilot plant tests and commercial design. It is also common that these companies hire out pilot plant facilities for tests on site.

Of particular interest is Simulated Moving Bed (SMB) equipment. It does not seem as if this equipment is available within the ERIFORE consortium, or other institutes/universities investigated. The SMB is suitable for continuous production.
One other technique that could be of special interest is Counter Current Chromatography (CCC). The Brunel Institute, UK is experts within CCC.

Table 4. Special infrastructures in chromatography technology.

Country	Organisation	Equipment/facility
BE	BBEPP	GRACE bench scale preparative chromatography unit, Columns up to 500 L
AT	Wood K Plus	Pilot chromatography column for normal phase, reversed phase or
UK	BDC	Bio-Rad chromatography station: column diameter of 100 mm and flow
ND	BPF	170 litre columns

5.6 Crystallization

The ERIFORE consortium has valuable expertise and competency in the complex field of crystallization. Although this technique is commonly implemented in industry, there are few (open-access) places where crystallization can be tested on a larger scale.

Within the consortium crystallizations can be performed at CBP on a semi-pilot scale and at BBEPP on a full pilot-scale. CBP has a batch crystallizer with a working volume of 800 liters and is installed together with a filter drying unit. BBEPP operates a complete crystallization line that consists of a crystallization vessel of 4 m^3, an inverted basket centrifuge (40 kg/cycle), and a Louvre crystal dryer (10 kg water/h removal). Per crystallization cycle (cool -or evaporative crystallization), up to 800 kg of crystals can be harvested and processed.

An external partner with crystallization expertise on semi-pilot scale is BPF (Netherlands). They operate various glass-lined vessels (ranging from 300 dm3 to 600 dm3) the vessels are equipped with a jacket for cooling and heating (-30°C to 160°C), pH-control and vacuum distillation units.

5.7 Summary

The main tools were collected to two tables below. Clear overlapping of different tools can be recognized. At demonstration scale (> 100 kg/h) overlapping is less significant. European partners are able to operate all chosen separation methods at least at semi-pilot scale. More detailed distribution could have revealed some unique equipment.

Table 5. Summary table for downstreaming: L < 1 kg/h, 1kg/h < s > 10 kg/h, P > 10 kg/h, D > 100 kg/h

Name of the organisation (Country) / Technology	Filtration and membranes	Evaporation	Pervaporation	Extraction	Reactive extraction	High pressure extraction	Distillation	Azeotropic distillation	Extractive distillation	Reactive distillation	Adsorption	Absoprtion	Chromatography	Crystallization	Flocculation	Electrodialysis	Freeze drying	In-situ product recovery (ISPP)
All identified organisations	D	D	S	P	P	P	D	P	S	D	P	P	P	P	P	P	P	D
VTT (FI)	D	P		S	S	S					L	L		S	P	L	P	
Fraunhofer IGB (DE)												P				P		
Fraunhofer ICT (DE)	P	S		S		P	S							L				
Fraunhofer CBP (DE)	D	P		P	S	P	P	S	S	S	L	L	P	P			L	D
TU Dortmund (DE)	L		L	L						P		P						
Universität Oldenburg (DE)										P								
SP (SWE)	D	D					D											
SP Processum (SWE)	P	S		P	L	L	P	P	S	S	S	S		L				S
BBEPP (BE)	D	D	S	P	P					D	P		P	P	L		L	
BPF (ND)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CPI (UK)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Innventia (SWE)	L	L		P			L				L	L	L	L	P			
SP Process Development (SWE)	L	P		L		L	L	L	L	L	L	L	L	S	L		L	
MoRe Research (SWE)	P	S									L	L			L			
Lund University (SWE)	P						P											
TNO (ND)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
VITO (BE)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

6 Co-operation networks in Downstreaming

It was concluded in D4.1, that ERIFORE project partners have extensive networks and are frequently part of consortiums for various bio-process development projects. However, there are few networks and projects, which are dedicated solely to downstream processing since this is often an integral part of other processes and projects.

This part of the report aimed to identify other downstreaming networks on European and global level. Only three international downstreaming networks were identified. These networks are dedicated to downstreaming in general or process technologies. Bio-process related downstream networks were not identified.

6.1 ISTP – Institute for Sustainable Process Technology

ISPT connects stakeholders from different sectors and disciplines to process technologies whereby process innovation is strengthened and expedited and The Netherlands distinguishes itself in the International innovation landscape.

ISPT's mission is to realize and maintain an active and open innovation platform for sustainable process technology where all stakeholders can optimally work together within an inspirational and trusted environment thereby maximizing the contribution to (break through) innovations.

ISPT aims to build and maintain a trusted based network in which all relevant partners collaborate on break through innovations. This is achieved by the innovative way of working and by the open and active character of the knowledge infrastructure.

ISPT focuses on the following areas:

- Research, because collaborative innovations advance the process industry
- Europe, because the scope of our work transcends the Dutch borders
- Education, because people drive innovations

ISPT has the following clusters:

- Energy Efficient Bulk Liquid Separation
- Drying and Dewatering
- Utilities and Optimal Use of Heat
- Process Intensification, Process System Engineering and Advanced Process Control
- Water Processing
- Gas Separation and Treatment
- Mild Fractionation for Food
- Bio Fast Track to Bulk
- Sustainable Business Models
- Deep Eutective solvents
- System Integration

6.2 EFCE – Fluid separations

The Fluid Separations Working Party of EFCE aims to bring together people involved with different aspects of fluid separation processes to discuss common problems, latest advances, and future needs, and to improve the relevance and quality of research and promote its application.
The Working Party aims to:

- Be a European forum for separation practitioners & researchers & encourage collaboration.
- Facilitate debate around research and education and provide guidance for industrial practice & public policy where appropriate.

6.3 The UNIFAC Consortium

The UNIFAC Consortium has been founded at the Carl von Ossietzky University of Oldenburg at the chair of industrial chemistry of Prof. Gmehling to invite private companies to support the further development of the group contribution methods UNIFAC and its successor modified UNIFAC (Dortmund). Both models are used for the prediction of thermodynamic properties, especially the estimation of phase equilibria.
The UNIFAC consortium is a successful example of private sponsorship of a public university in Germany.

The consortium was founded in 1997 when the public financing of the further development of the models became unlikely. The models UNIFAC and mod. UNIFAC (Dortmund) have already been used widely in software for the simulation and synthesis of chemical processes. Many companies doing process development in the field of chemical engineering had announced their support for a new way to subsidize the further development. This is facilitated through the support of over 40 companies, and is particularly aided by the DDBST GmbH, which supplies the complete Dortmund Data Bank (DDB) and several software tools for free. The DDB, a factual data bank for thermodynamic data, especially phase equilibrium data, is the main source for the work of the consortium.

The normal work of the consortium includes

- the creation of new and the improvement of older model parameters
- the measurement of experimental data (partly own work, partly given to contractors)
- holding annual member meetings

The consortium has e. g. added or modified 404 interaction parameters in the original UNIFAC matrix compared to the 635 parameters from the latest publication.

The major goals are to

- improve the quality of the predictions
- extend the range of applicability of the models. This includes the support for further component types with new functional groups.
- supply the parameters to process simulation and DDB software (for consortium members only)

The model parameters are confidential and only accessible to consortium members for at least two and a half year after the first delivery. After this time the university can publish the model parameters.

6.4 Summary

The number of downstreaming networks is small and they are either focused purely in separation technologies or model development. Biorefinery related downstreaming networks were not identified. Downstreaming is normally just a part of other biorefinery related networks.

7 Funding

Downstreaming specific funding sources were not identified. Organisations which are active in downstreaming get their funding from other sources and normally downstreaming is a part of either biorefinery or chemistry related projects at higher TRL level.

8 Conclusions

Special expertise in separation technologies and downstreaming are heavily concentrated in locations where strong chemical, petrochemical, and pulp and paper industries are located.

Universities, which are active in separation technologies, are developing separation and downstream processes mainly in laboratory scale and by utilizing computational methods. Universities also do valuable work in measuring physical properties of new materials and storing the information in different data bases which are used further in simulation tools. The number of university organisation is large, and deeper analysis of these organisations and their specialty skills was not done due to very scattered information.

The number of organisations able to operate at the scale of larger than 10 dm^3/h is small in research and development. In total 10 different organisations having integrated pilot scale facilities and experience in processing of bio based materials in downstreaming were recognized:

1. Fraunhofer CBP (DE)
2. Bio Base Europe Pilot Plant (BE)
3. Bioprocess Pilot Facility B.V. (ND)
4. CPI – Industrial Biotechnology and Biorefining (UK)
5. NREL Bioprocessing Pilot Plant (US)
6. Inventia (SWE)
7. SP Biorefinery Demo Plant / SP Processum (SWE)
8. VTT - Bioruukki (FI)
9. NGP2 (DE) - Under construction
10. NREL – Biomass Conversion Pilot Plants (US)

These facilities have in most cases conventional separation tools in pilot scale. These unit operations are typically used in scale-up projects where well-functioning separation and purification steps can be critical for the whole process. Based on received data very specific downstreaming capabilities were not identified.

From the collected data, it can be concluded that the studied organisations have unique equipment at national level, but at European level, the research tools and capabilities are so similar that clear distinction of specialness of different organisations is difficult recognize.

Overlapping of tools were seen (Table 5) in all chosen downstreaming technologies. More detailed scope could have revealed unique tools in these chosen organisations.

Clear conclusion of the received data can be just drawn from the size of the equipment. Clear added value in scale was not identified from the identified external organisations. External organisations have either similar or smaller scale units than ERIFORE consortium possesses.

Table 6 summaries the operational scale of different separation tools. It can be seen that all chosen separation technologies can be operated at the scale above 10 kg/h in Europe and in ERIFORE consortium. Special tools are available in smaller scale than the more conventional tools. Hybrid separation tools which are seen necessary to decrease operating costs of some biorefinery processes, are operating currently at semi-pilot or pilot scale. Based on the received material it cannot be concluded, if investing in larger scale of these hybrid separation tools would be beneficial for the research infrastructure.

From a global perspective Europe seems to have special facilities for open-access research in biorefinery related downstreaming processes. Only comparable open-access facility outside Europe was found from USA where National Renewable Energy Laboratory (NREL) possesses a bioprocess facility.

Table 6. Summary table of all identified organisations for downstreaming: L < 1 kg/h, 1kg/h < s > 10 kg/h, P > 10 kg/h, D > 100 kg/h

	Filtration and membranes	Evaporation	Pervaporation	Extraction	Reactive extraction	High pressure extraction	Distillation	Azeotropic distillation	Extractive distillation	Reactive distillation	Adsorption	Absoprtion	Chromatography	Crystallization	Flocculation	Electrodialysis	Freeze drying	In-situ product recovery (ISPP)
All identified organisations	D	D	S	P	P	P	D	P	S	D	S	P	D	P	D	P	P	D

Universities have special scientific capabilities for example in model development and tools for analysis of these different technologies. Going deeper into data of analysis tools, would beneficial in order to identify special competencies of universities, but this was not done in this report, because the amount of organisations which should had been studied, would had been too large. Few universities which have special tools and competencies were identified during the report, such as TU Dortmund, TU Oldenburg, Lund University and Technical University of Lappeenranta, but this short list of universities is not comprehensive.

From the analysis of the survey, it can be concluded that the availability of different pilot scale tools is good and that there is not a lack of equipment in Europe. On the other hand, many organisations which do not have close contacts to piloting facilities, reported to have very limited access or financial resources to do piloting operations. This is probably caused by poor awareness of available open-access piloting facilities. If the awareness of these piloting facilities is improved in Europe, then different organisations have better resources and capabilities to scale-up their processes. On the other hand, piloting facilities could increase their utilization rate of their equipment and possibly improve their scientific results if special knowledge of universities is utilized better. Collaboration and networking was seen as the main

solutions to improve utilisation of current research infrastructure. “ESFRI” and “European joint laboratory” were also suggested to improve the current situation.

In order to improve techno-economic impact of the current European research infrastructure, it would be necessary that smaller research groups with new ideas are more aware of open-access piloting scale facilities in Europe. In order to improve scientific results, piloting facilities should have better access and motivation to utilize special knowledge and competencies of scientific research groups e.g. in modelling.

European network, which is dedicated to downstream processes of biorefineries could be beneficial in order to improve the awareness of available piloting tools, and on other hand improve utilization of specific competencies of scientific research groups in downstreaming.

Appendix. Information on other main European and global players in the field of separation and downstream processing

Austria

Management Center of Innsbruck – Process Technology
The Research Group Process Technology has expertise on membrane technology and Downstream-Processing. The research field of membrane technology deals with the production and optimization of membranes and membrane materials. The focus of the field of Downstream-Processing is on the processing of microalgae and reaction mixtures of physico-chemical conversion processes, such as fractionation of lignocellulose. To lead to an optimization of these processes, this is supported by specific chemical and thermodynamic considerations. Concerning the tools and equipment no details are provided in the internet.

A relevant project with regard to ERIFORE is “the production of composite multichannel capillary membranes for nano-filtration”.

Link to webpage:	https://www.mci.edu/en/research-development/research-fields-units/technology-life-sciences/process-technology
Main contact:	michael.kraxner@mci.edu

University of Life Science Vienna – Institute of Biotechnology
The University of Life Science Vienna has expertise on bioseparation engineering, biophysical properties of Proteins & other Macromolecules, Chromatographic Modeling and Basics, Continous Bioseparation Processes, prediction of Bioseparation of Bioseparation Processes and steroid/ thyroid Hormone Receptors as Drug Targets.

The University of Life Science possesses processes and tools such as a BioIndustrial Pilot Plant (multi-purpose plant for fermentation and downstream processing of biomolecules under GMP-like conditions) at a scale of 30-1600 L including bioreactors, separators, homogenizer, filtration equipment, ultra- and diafiltration, chromatographic systems, reaction vessels. Moreover the University posseses capabilities in precipitation, flocculation and crystallization, nanomembranes, molecular modeling and surface scattering techniques. It has capabilities in chromatography such as a preparative High Performance Liquid Chromatography (prepHPCL), Analytical High Performance Liquid Chromatography (HPCL) and a liquid chromatography-high resolution mass spectrometry (LC-HRMS; LTQ Orbitrap XL).

Relevant ERIFORE projects of University of Life Sciences Vienna are “Gaining productivity, cost efficiency and sustainabilty in the downstreaming processing of bio products by novel integration and intensification strategies (EU-Intensio)”, ”BASF biorefinery”, ”Future Lignin and Pulp Processing Research (FLIPPR)” and ”Automation of process development in up and downstream of bioprocesses”.

Link to webpage:	http://www.biotec.boku.ac.at/arbeitsgruppenresearch-groups/pilot-plant/ http://www.biotec.boku.ac.at/arbeitsgruppenresearch-groups/research-group-jungbauer/research/
Main contact:	alois.jungbauer(at)boku.ac.at

University of Technology Vienna – Chemical Engineering
The Research Group Chemical Engineering of Vienna University of Technology has experience in thermal process engineering such as membrane processes, adsorption, absorption and drying as well as in chemical, biotechnological and environmental applications of thermal separation process

They possess equipment and tools such as basic engineering based on experiments (lab tests 50 mL – 1 L, pilot tests 30 – 50 L) and gas permeation test equipment (measurement of pure gas permeabilities using Mass Flow Meters).

Relevant ERIFORE projects of Vienna University of Technology are "Bio(FLEX)Net - Development of a concept for flexible power generation in biogas plants", "Biorefinery - Pretreatment with liquid hot water and organosolv treatment", "Biorefinery - Concentration and purification with membranes and In-Situ product recovery during ABE-fermentation".

Link to webpage:	http://www.vt.tuwien.ac.at/thermal_process_engineering_and_simulation/sustainable_process_engineering_chemometrics/EN/ http://thvt.at/?q=node/35
Main contact:	angela.miltner@tuwien.ac.at

University of Technology Graz – Insitute of Chemical Engineering and Environmental Technology (CEET)
The Research Group at the Institute of Chemical Engineering and Environmental Technology of Graz University of Technology has experience in downstream processes.

They possess equipment and tools such as filtration in lab scale, centrifugation in lab scale and semi pilot (3-50L, 1-5kg), evaporation in Lab scale;Semi pilot (3-50L, 1-5kg), Extraction in Lab scale and Semi pilot (3-50L, 1-5kg), Distillation in Lab scale and Semi pilot (3-50L, 1-5kg), precipitation in Lab scale and Semi pilot (3-50L, 1-5kg) and Flocculation in Lab scale.

Graz University of Technology provides no information about relevant research projects with regard to ERIFORE on the homepage.

Link to webpage:	https://www.tugraz.at/en/institute/ceet/home/
Main contact:	marlene.kienberger@tugraz.at

Belgium (BBEPP)

Flemish institute for technological research (VITO)
VITO has unique expertise in separation techniques to increase the efficiency of (bio) chemical processes by combining reaction and membrane technology. Three different modules are designed:

- Membrane filtrations: innovative research into industrial applications of membranes for the separation of incoming and outgoing streams and for improving production processes.
- Electro separations: research into electro-driven separation as a more robust and greener method for recuperation of valuable elements and desalination.
- Integration of separation technology in (bio) chemical processes for process intensification.

Currently, 3 pilot lines for membrane filtrations have been built and fine tuned which can treat acidic, solvent based hydrolysates with a capacity of up to 200 L/h. The membranes are able to selectively separate aromatic molecules with the same molecular mass.

Link to webpage:	https://vito.be/en/chemistry/separation-processes
Main contact:	Bert Bouwman, bert.bouwman@vito.be

In addition to these multi-disciplinary institutes also KU Leuven and UCL Leuven are active in separation technologies and downstreaming.

Denmark

Technical University of Denmark, Department of Chemical and Biochemical Engineering

The PILOT PLANT - Centre for Experimental Process - and Equipment Design focus on unit operations, reaction engineering, process control, process and plant design, instrumentation, automation and industrial measuring technology, but also topics such as scale-up and scale-down and batch versus continuous processes. Special focus areas are fermentation mainly from a process point-of-view, but also innovative technology and particle technology. PILOT Plant consists of 700 m2 pilot plants, laboratories and workshop. PILOT PLANT test work combines theory and practice, and simulates full scale behaviour. Facilities include:

- Distillation (batch and continuous)
- Absorption, stripping and flow in columns
- Drying: spray drying, fluid bed and tunnel drying
- Filtration and membrane processes
- Pump, liquid flow and gas flow systems
- Liquid agitation (mixing) and aeration
- Centrifugation
- Solid and liquid extraction
- Evaporation
- Crystallization
- Transport and separation of solids

- CO_2 absorber (simulated flue gas cleaning, CCS)
- Process control experiments
- Various mobile equipment

Link to webpage:	http://www.kt.dtu.dk/english/Research/PILOT-PLANT
Main contact:	lgk@kt.dtu.dk

Other Danish partners, such as Aarhus University, Aalborg University and Copenhagen University own lab scale separation equipment.

Estonia

TUT Faculty of Chemical and Materials Technology
Fields of Competence of the Faculty include:

- The thermal processing of oil shale and other materials
- The chemical-technical analysis and improvement of the liquid fuels
- Physiochemical properties of substances
- Purification technologies of waste water and natural water processing and research
- Implementation of photocatalytic processes in environmental technology
- Thin-film and nanostructured materials by chemical methods
- Modelling of carbon dioxide mineralisation processes
- Sustainable polymer materials for sustainable future: cellulose derivatives and wood-polymer composites
- Thermoplastic polymers with novel ingredients constituents and their composites: the effect of the ingredients on the crystallisation, rheology, and mechanical properties Functional textiles made of nanofibers
- New technologies for thermochemical processing of oil shale and fuel blends blended fuels
- Oil shale maximum refining bases Fundamentals for oil shale maximum upgrading
- The Liquefaction of dictyonema oil shale organic matter with supercritical solvents and reagents
- The development of wood preservatives-emulsions, aqueous solutions, and impregnation technology
- Testing wood polymer composites (PPKM) and developing improved and sustainable materials

Centre for Materials Research of the Faculty provide interdisciplinary research activity on the fields of science and technology, process technology and materials science (metals, semi-conductor materials, carbides, thin films, wooden and wood-based material properties, indoor

climate and humidity, biodegradation, using materials together, re-use materials, metal and stone material properties).

Link to webpage:	http://www.ttu.ee/faculty-of-chemical-and-materials-technology/faculty-of-chemical-and-materials-technology-1/about-faculty-3/
Main contact:	vahur.oja@ttu.ee

Estonian University of Life Science (EULS)
According to QS World University Rankings, the Estonian University of Life Sciences belongs to top 100 universities in the world in the field of Agriculture and Forestry. Thomson Reuters Essential Science Indicators database places the Estonian University of Life Sciences into the top 1% most cited research facilities in the world in the field on plant and animal science as well as environment and ecology.
Some of responsibility areas of academic activities and their content in EULS include:

- Biosystems engineering: Agricultural engineering and processing of agricultural products, farm engineering, biofuels, ergonomics
- Forest and wood processing technology: Wood science; technology of logging and forest machinery; wood processing; technology of wooden products; wood chemistry and technology; resources, properties and production technology of wood(en) fuel; forest logistics

Link to webpage:	http://mi.emu.ee/
Main contact:	info@emu.ee

Finland

Lappeenranta University of Technology - Downsteraming
The importance of refining bio-based materials has increased worldwide. The utilisation of raw materials is often hindered by their nonhomogeneous nature or the impurities they contain. The LUT School of Engineering Science is particularly focused on the development of products achieved through biorefining separation and purification, either as a finished product or for further processing. In recent years the school has carried out research particularly in the development and improvement of forest biorefinery processes. LUT examines separation processes in aqueous solutions, organic solvents, and ionic liquids. LUT also examines the further processing of biorefinery products into final products, such as packaging coatings or membranes, as well as the development of analytical methods for chemical compounds. LUT has good facilities in membrane filtration and chromatographic separation in Forest based Bioeconomy Downstream Processing (DSP)

Link to webpage:	www.lut.fi
Main contact:	mika.manttari@luti.fi

France

LRGP

LRGP has pioneered mass transport phenomenon in porous media like chromatographic stationary phases and has developed advanced methodology for dynamic optimization as well as undertaken researches on various field of bioseparations for biorefinery, especially concerning peptides (from enzymatic proteolysis) and carbohydrate polymers for years.
Strategic targets proposed by LRGP:

- Modeling and design of separation processes (membranes, chromatography, electrochemical technologies)
- Fast cartography of peptide mixtures (hydrolysates) by liquid chromatography- and capillary electrophoresis-mass spectrometry
- Methodology development for predicting separation performances (yield, enrichment and productivity) of complex protein hydrolysates in a peptide of interest by membrane or chromatographic separation
- Development of hybrid techniques combining ion exchange and bipolar membrane electrodialysis (zero effluent/continuous ion exchange processes)

They have tools such as:

- A bioprocessing platform with batch reactor from mL to 70 L.
- Membrane and chromatographic tools to separate bio-products, proteins, polyphenols, peptides, and enzymes.

Link to webpage:	http://lrgp-nancy.cnrs.fr/spip.php?rubrique44
Main contact:	Romain.Kapel@univ-lorraine.fr

IFPEn

With its globally recognized expertise, IFPEn is involved in some major international and European research projects. IFPEn has expertise in development, scale-up and demonstration of gasification and biochemical plant. In downstreaming processing, IFPEn researches gas cleaning technologies (Syngas cleaning and conditioning, cleaning with physical or chemical solvents, guard beds (chemisorption), development of special high-performance catalysts). IFPEn develops as well analytical methods for chemical compounds.

Relevant ERIFORE projects of IFPEn are:

- Futurol
- BioTfuel

Link to webpage:	http://www.ifpenergiesnouvelles.com/
Main contact:	alain.quignard@ifp.fr

CEA

CEA is a French public government-funded research organisation in the areas of energy, defence and security, information technologies and health technologies. Some research units at CEA are focused on the development of gas cleaning systems and the development of analytical methods for chemical compounds.

A relevant ERIFORE project of CEA is:

- GAYA

Link to webpage:	http://english.cea.fr/english-portal
Main contact:	Isabelle.PAMART@cea.fr

ARD

A stakeholder in the Bazancourt-Pomacle biorefinery, near Reims in France, ARD is a mutualised private research structure, owned by major players in French agribusiness as well as regional farming cooperatives. It was created in 1989 to find new opportunities for creating value from its shareholders' produce (cereals, sugar beet, alfafa, oilseeds, etc.). ARD has developed expertise in:

- plant fractionation and biorefining,
- white (industrial) biotechnology,
- bio-based chemistry and agro-materials,
- the environment.

With B.R.I., ARD is becoming a platform for open innovation. Having signed an agreement with the French Ministry for Industry in December 2009, B.R.I. (Biorafinerie Recherche et Innovation) is an open technological platform for industrial scale-up of biotechnology processes. This platform boasts laboratory equipment, pilot installations and an industrial demonstration unit (BioDémo).

Biodémo enjoyed financial support from the General Council of the Marne Département (€1.25 million), the Champagne-Ardenne Region (€1.25 million) and the ERDF (€2.5 million), making B.R.I. the European benchmark in terms of biorefinery. Apart from laboratory equipment ARD has also top-level pilot-scale equipment. Downstream pilot equipment includes:

- Rectification column for azeotropic distillation
- Sedimentation tanks
- Thin layer evaporator
- Forced flow evaporator

Link to webpage:	http://www.a-r-d.fr/en/
Main contact:	Alain LE FLOCH, President of ARD

Germany

TU Dortmund – Fluid separations
TU Dortmund has extensive in fluid separations including capabilities in bioseparations, reactive separations, hybrid separations, membrane separations, process intensification and in simulation of bioseparation processes. They have tools such ash:

- Non-reactive, reactive and hybrid membrane separations
- Membrane adsorption for purification of bioproducts
- Lab and pilot-scale columns for distillation and absorption (catalytic and non-catalytic internals)
- Lab and pilot-scale membrane plants (PV, VP, OSN)
- Mixer-settler devices for solvent screening
- Rotating packed bed (HIGEE) for reactive distillation

Relevant ERIFORE projects of TU Dortmund are:

- EuroBioRef

Link to webpage:	www.fvt.bci.tu-dortmund.de
Main contact:	andrzej.gorak@bci.tu-dortmund.de

RWTH Aachen – AVT.FVT – Department of Chemical Engineering, Fluid Separation processes
Thermal unit operations with focus on solvent and reactive extraction, distillation and liquid-liquid phase separation. Further research includes mass-transfer, interfaces and the development of thermodynamic models and molecular simulations.

At AVT - Fluid Separation Processes we are working on research and development with respect to thermal unit operations and the bases of their accurate description. The research topics can be divided into

Process and Apparatus:

- Design of thermal separation equipment based on results of lab-scale measuring cells
- Modelling of liquid-liquid and reactive extraction based on lab experiments with the ReDrop-Model
- Extraction of alcoholic components from aqueous solutions
- Recycling of phosphorus from sewage sludge ash
- Separation of dispersions in highly viscous systems under the influence of fine solid particles
- Solid extraction of plant-based material
- Distillation of aqueous systems

Link to webpage:	https://www.maschinenbau.rwth-aachen.de/go/id/xib/lidx/1
Main contact:	andreas.jupke@avt.rwth-aachen.de

Institute of Polymer Research
Focus of the research at the Institute of Polymer Research are membranes for applications in separation. Due to the interdisciplinary integration of material sciences and engineering, our research covers the full spectrum from basic research to industrial application. The latest equipment and methods for the synthesis, characterization and processing of polymers, as well as for membrane preparation, module development and design, and modelling of separation processes substantiate our competence in the field of polymer science and membranes.

The Institute has about 50 employees, of which a quarter are Ph.D. and Master students training in collaboration with various universities.

The majority of our research activities is part of the "Advanced Engineering Materials" programme which is integrated in the Helmholtz research area "Key Technologies".

Link to webpage:	http://www.hzg.de/
Main contact:	volker.abetz@hzg.de

Greece

The General Secretariat for Research and Technology of the Ministry of Development is responsible for designing, implementing and supervising national research and technological policy.

Because of its strategic location, qualified workforce and political and economic stability, many multinational companies such as Ericsson, Siemens, Motorola and Coca-Cola have their regional research and development headquarters in Greece.

Concerning the topics of downstreaming technologies, no relevant pilot facilities have been identified but 3 organizations can be referenced for the ERIFORE activities:

Chemical Engineering Sciences (ICE-HT) FORTH Foundation for Research and Technology

Chemical Process & Energy Resources Institute (CPERI)

Research Institute - Aristotle University of Thessaloniki

Hungary

Natural Resources Research Center
Natural Resources Research Center from University of West Hungary has experience in wood processing, as well as in wood components valorization. Also, topics related to pulp and paper

technologies energetic utilization of wood biomass are of interest. They found that the combined electron-beam methods have potentiality to upgrade bio-oil intermediates or to perform the direct conversion of a biomass to stable fuel. The main equipment used in the processing of wood to obtain composite materials are chippers, defibrators, fraction screens, drying and blending equipment, as well as hot presses.
The most important R&D services are supported by the Material and Product Testing Laboratory, Timber Structures Testing Laboratory, Testing Laboratory for Forestry and Wood Industries, Non-destructive Wood Testing Laboratory, Mechatronics Laboratory, Wood Protection Laboratory.

Link to webpage:	http://nrrc.nyme.hu/en/institute-of-wood-science/
Main contact:	Dr. Tamás Hofmann, email**:** hofmannt@emk.nyme.hu

Ireland

Technology Centre Biorefining & Bioenergy
Ireland's national Technology Centre for Biorefining and Bioenergy (TCBB) is one of a number of centres established and led by industry, and initially funded by Enterprise Ireland and the IDA Ireland. The TCBB is co-hosted by 4 Irish universities, NUI Galway, University College Dublin, University of Limerick and Trinity College Dublin to enable it to expand its expertise and resources to serve the broad bioeconomy audience. TCBB has been established to provide industry members with the ability to leverage the extensive expertise, knowledge, research skills and facilities available in Irish third-level institutions in order to create energy and valuable industrial materials from sustainable sources of biomass.

Through the TCBB industry members, can access academic research expertise, can access government agencies to inform and influence policy development and can access funding from national research programmes or from European Framework (Horizon 2020) programmes to pursue their aims. The principal objective of the Research Programme is to identify and develop those biorefining and bioenergy activities that hold the greatest commercial promise, and to develop them into commercial reality as quickly as possible.

TCBB is working to optimising the downstream separation technologies such as micro/nano filtration and adsorption to enable the efficient separation and extraction of valuable products or fractions from their biological processes.

The Technology Centre participates with a number of funding agencies to deliver its programme, including Horizon 2020, INTERREG, Science Foundation Ireland, The Higher Education Authority and other private research initiatives.

Link to webpage:	http://www.tcbb.ie/ http://www.biorefinery.ie/
Main contact:	bart.bonsall@tcbb.ie

Italy

Concerning the R&D expertise of ERIFORE topics, several universities and institutes can be highlighted and they are part of the CNR (The National Research Council of Italy aims to the cooperation with the industrial system. Actions include joint research programmes, research contracts, consulting, licensing and patent releases, foundation of research consortia and spin off companies, and many other initiatives aimed at enhancing the technology transfer processes to companies and business sectors.

The Institute on Membrane Technology
The Institute on Membrane Technology (ITM - Instituto per la Tecnologia delle Membrane) is a research structure created by the National Research Council of Italy (CNR - Consiglio Nazionale delle Ricerche), on 1993, for the development, at a national and international level, of membrane science and technology.

Link to webpage:	http://www.itm.cnr.it/index.php/en/
Main contact:	l.giorno@itm.cnr.it

Latvia

Latvian Institute of Organic Chmistry (LIOS)

The mission of LIOS aims to successfully merge achievements of innovative academic research in organic chemistry and pharmacology with competence in applied research of medicinal chemistry, thus, contributing to the development of science in Latvia and quality of life of society.

LIOS has defined two strategic tasks:

- to become an European-level research centre of excellence in organic and medicinal chemistry,
- to provide a full cycle of research necessary for drug discovery and development.

The process chemists of LIOS also develop general synthetic procedures applicable to a number of compounds which are of interest for pharmaceutical research and development.

LIOS has established cooperation with partners capable to produce necessary compounds in kilogram scale according to the procedures developed by the Institute.The highly skilled staff of LIOS possessing equipment for parallel synthesis, powerful analytical support and on-line access to the literature databases can solve the most complicated tasks in a short time period.

All synthesized compounds are supported with necessary analytical data (NMR, HPLC, LC-MS or microanalysis etc.). The custom synthesis products based on LIOS know-how are listed in web-based search engines – CHEMCATS®, ChemExper and Molport.

The current research topics LIOS are:

- Interdisciplinary Training Network for Validation of Gram-Negative Antibacterial Targets
- Developing new therapies for baten disease
- Peptidomimetics with photocontrolled biological activity

Link to webpage:	http://www.osi.lv/en/
Main contact:	sinta@osi.lv

Lithuania

Institute of Biotechnology
Scientific activity courses of the Institute are chemical, biological and technologic researches of proteins of various purposes, function of genes in yeast, molecular - gene researches of restriction and modification phenomenon.

Example of the Research: Plum scab virus coat protein coding gene cloning and protein synthesis in *E. coli* cells.

Link to webpage:	http://www.ibt.lt/en/title.html
Main contact:	office@bti.vu.lt

ASU Centre of Biosystems Engineering, Biomass Energetics and Water engineering
The Centre has expertise in dealing with renewable materials and these research capabilities:

- biofuel production technologies;
- second generation bioethanol and biodiesel;
- biofuel and biomass quality characteristics;
- utilization of biological wastes and side-stream products.

The Centre facilities consist of:

- high efficiency fluid chromatography;
- gas chromatography with mass detector;
- material quality and quantity analysis;
- fuel composition analysis (CHNS/O);
- automatic extractive distillation;
- materials purification;
- identification of mixture substances.

The team implement ERIFORE relevant project Distributed, integrated and harmonised Forest information for bioeconomy outlooks (DIABOLO, 2015-2019).

Link to webpage:	https://asu.lt/language/en/university/research/research-areas/strategic-scientific-action-lines-of-aleksandras-stulginskis-university/

Main contact:	Ernestas.Zaleckas@asu.lt

KTU Food Research and Technology Competence Centre (KTU FRTCC)

KTU FRTCC is an integral part of Integrated Science, Studies and Business Centre (valley) “Nemunas”. This is the first centre in the Baltic States, equipped with unique pilot equipment for food industry. New food products and recipes are created for food industry, basic and applied research is carried out, and exclusive attention is paid on business orders there.

There are five specialized production laboratories in the centre: Milk, Meat and Fish, Bakery/confectionary products, Fermentation and General tests laboratory, as well as Microbiology, Rheology, Chromatography and mass spectrometry, Chemical analysis with such capabilities as:

- automated vacuum tanning and devices with a full moisture and temperature control during ripening;
- selection and testing of raw materials for new dairy products;
- creation of new dairy products;
- texture of products is modelled, mellowed by changing and testing the intensity of salting;
- preparation of recipe compositions and emulsions;
- craetion and analysis of production processes of kvass, cider, beer and spirits;
- creation of natural food additives;
- application of sustainable technologies (thermal processing at low temperatures, vacuuming of semi-finished products);
- new food products are created, production descriptions and documentation are prepared;
- optimization of technological processes and recipes is performed;

The professionals of this centre:

- provide professional consultations on technical issues of food production and processing;
- constantly analyze EU directives, advise on their implementation;
- simulate real food production conditions with small amounts of raw materials;
- produce and demonstrate new product prototypes and samples;
- provide various trainings on the issues of food chemical composition, production, and quality.

Research, carried out in “Nemunas” valley, and laboratory equipment rent services can be ordered in information system of open-access centre (OAC): apcis.ktu.edu.

Link to webpage:	http://nivc.ktu.edu/en-about_us-15.htm#mm18
Main contact:	reda.aleksandraviciene@ktu.lt

The Netherlands

Bioprocess Pilot Facility (BPF)

In the Bioprocess Pilot Facility (BPF) companies and knowledge institutions can develop novel, sustainable and environmentally friendly production processes based on biological materials. DSP equipment includes (membrane) filtration, centrifugation, homogenization, (bio)chemical conversions, chromatography (up to 170 L), crystallization, electrodialysis, extraction, evaporation (up to 250 L/h), formulation and various drying methods. Numerous vessels (ranging from 60 l to 4 m3, with different material properties and capabilities) are available for a variety of process steps. The designated ATEX zones (T3) allow the use of flammable materials such as solvents throughout the downstream processing plant.

Link to webpage:	www.bpf.eu
Main contact:	Arno Van de Kant

Netherlands Organisation for Applied Scientific Research (TNO)

To manufacture chemicals more efficient the number of separation steps in downstream processing has to be decreased. This can be realized by integrating and intensifying separation processes so that energy consumption and costs will decrease and quality improves. TNO therefore focuses chiefly on separation processes which have a high selectivity and low energy consumption.

TNO applies innovative technologies in converting 'classical chemistry' to 'new chemistry' and has a track record in the following technologies:

- Crystallization: TNO has developed the Hydraulic Wash Column (HWC). In combination with melt crystallization this can achieve 99% purity in a single step. The energy saving compared with current technologies is a minimum of 20% and can be as much as 90%.
- Extraction
- Membrane-technology: TNO is also working on the combination of extraction and membrane technology, whereby the membrane provides a large and stable contact area so that the reaction mixture and the extractant stay separated. Membrane extraction has already been successfully applied in water treatment, and the step towards using this technique for chemical processes is the next milestone.

Link to webpage:	www.tno.nl https://www.tno.nl/en/focus-area/industry/sustainable-chemical-industry
Main contact:	Johan van Groenestijn

The European membrane institute Twente

The European Membrane Institute Twente (EMI Twente) performs confidential contract research directly with industry in the field of membrane science and technology. It acts as an interface between academic research and industrial needs. The EMI Twente is strongly linked to the Membrane Science and Technology group, representing a cluster of membrane related

research groups. Research areas the EMI Twente is active in covers a diverse set of expertise's, including polymeric, inorganic and hybrid membranes, transport phenomena, and process design.

Link to webpage:	https://www.utwente.nl/tnw/emi/
Main contact:	info-tnw-emi@utwente.nl

In addition to these multi-disciplinary organizations also TU Delft, TU Eindhove, Tilburg University and Universiteit Twente are active in separation technologies. In addition to these, ECN is active in thermochemical pathway.

Norway

In Norway most large scale separation equipment is industrially owned. Open-access pilot scale downstream processing equipment is very limited limited at this stage. NOFIMA offers pilot scale services in their 2013 established BIOTEP lab which includes:

The Biotep facilities include:

- Handling of a large variety of biomass
- Reactors for hydrolysis
- Separators, two/three phase
- Liquid phase separation
- Purification of lipids
- Water filtration (ultra/micro, nano, reverse osmosis)
- Concentrators, evaporators
- Mill dryer, hot air
- Spray dryer
- Powder handling
- Packaging

Link to webpage:	http://nofima.no/en/research-facilities/biotep/
Main contact:	ragnhild.whitaker@nofima.no

Poland

LUT Institute of Technical Biochemistry (ITB)
Currently, researchers from ITB conduct studies in the field of biotechnology, focusing on the development of novel processes or improvement of existing technologies in food, pharmaceutical, and chemical industries and in environment protection. Modernization of ITB in years 2012-2014 and purchasing of newest laboratory equipment gave rise to advanced

studies in the fields of industrial biotechnology, molecular biotechnology, biomaterials engineering (mainly bionanocellulose modifications), proteomics/structural biology, food biochemistry and nutrigenomics.

Some of the ITB facilities:

- 150 L fermenterChemap 150
- SIXFORS fermenter with 6 individual fermenters 750 mL each (INFORS AG)
- Liophilizator Alpha 1-4 LSC
- Apparatus for water content determination by Karl-Fisher method
- Pulsed-field gel electrophoresis apparatus (BIO-RAD)
- Fully equipped HPLC liquid and GC-MS gas chromatography sets
- Rigaku Oxford Diffraction Supernowamonocrystals diffractometer with CCD detector and two radiation microfocus sources (Mo and Cu).
- PCR thermal cyclers (BIO-RAD)
- 1D and 2D electrophoresis set (Protean i12 IEF Cell + Densitometer)
- MicroDoc gel documentation system MicroDoc(transilluminator + digital camera)
- Ultracentrifugation systems
- Filtration sets

Team 1 has had ERIFORE relevant project such as Application of biomass for production of polymeric and environmentally-friendly materials.

Link to webpage:	http://www.binoz.p.lodz.pl/en/institute-of-technical-biochemistry/about-institute
Main contact:	biochem@info.p.lodz.pl

PULS Institute of Wood Chemical Technology

The Institute research activities include:

- chemistry, ultrastructure and reactions of wood,
- physico-chemical modification of wood,
- glueing and refining technologies,
- chemical and physico-chemical conversion of wood and other lignocellulose materials,
- cellulose and paper technology,
- active fibrous carbon materials from cellulose and lignocellulose materials,
- technological and ecological aspects of utilisation and disposal of wood waste products.
- pyrolysis and activation surface carbon obtained from lignocellulosic materials and modeling their porous structure,

Link to webpage:	http://wtd.up.poznan.pl/en/Institut-of-Wood-Chemical-Technology/Contact
Main contact:	ichtd@up.poznan.pl

Portugal

Forestry plays an important economic role among the rural communities and industry (namely paper industry that includes Portucel Soporcel Group, engineered wood that includes Sonae Indústria, and furniture that includes several manufacturing plants in and around Paços de Ferreira, the core of Portugal's major industrial operations of IKEA). In 2001, the gross agricultural product accounted for 4 per cent of the national GDP.

The main player identified in Portugal in pilot scale for downstreaming technologies is a private non-profit research institute, RAIZ, whose partners are the Portucel Soporcel group and the Universities of Aveiro, Coimbra and Lisboa. Prof Carlos de Pascoal Neto is its Director.

RAIZ is committed to support the competitiveness of the Portuguese Pulp and Paper Industry, through research, technology transfer and training. RAIZ was officially formed in September 1995 and initiated its activity in January 1996.

Link to webpage:	raiz@portucelsoporcel.com
Main contact:	Carlos.Neto@thenavigatorcompany.com

Slovakia

Slovak University of Technology
Slovak University of Technology in Bratislava, Laboratory of complex utilisation of biomass has expertise in biomass processing; physico-chemical characterization of biomass; analysis of biomass to be used as energy source.

The identified equipment for the processing and characterization tools related to downstream processes are extraction units accelerated Solvent Extraction (ASE) 350 DIONEX and supercritical CO2 extractor.

Link to webpage:	www.sjf.stuba.sk
Main contact:	igor.surina@stuba.sk

Slovenia

Maribor University
The main research capabilities existing in the Faculty of Chemistry and Chemical Engineering, and other laboratories of Maribor University related to WP4 topics are:

- High pressure extraction vessels at laboratory and pilot scale
- Rectification column
- Instruments for high performance liquid chromatography (HPLC)
- Freeze-dryer
- Porosymeter (N_2 adsorption/desorption measurements)
- Supercritical CO_2 extractor;
- electrophoresis (CE-3D, SDS-PAGE-2D)

Its expertise is related to the design and optimization of conventional and high pressure processes such as extraction and adsorption processes for isolation and concentration of active ingredients from natural materials; *in vitro* testings of antimicrobial and antioxidative activities of extracts from natural materials.

Link to webpage:	http://www.fkkt.um.si
Main contact:	Prof. Z. Knez, email: zeljko.knez@um.si

Sweden

Sweden has a number of institutions performing downstream processing of forest biomass. The following organisations have been chosen due to their excellence and the degree of openness.

Lund University- Process Development Unit
The Process Development Unit (PDU) at Lund University is financed mainly by the Swedish Energy Agency and used for research. The PDU group has a long and successful tradition within the lignocellulose-to-bioethanol, but also in biorefinery applications. The PDU is located at the department of Chemical Engineering at Lund University, one the most well-known universities in Europe.
The PDU is staffed with personnel with long-time experience of pretreatment, hydrolysis and fermentation, as well as the analytical skills required to perform state-of-the-art research in the field of bioethanol and biorefinery.

The Process Development Unit (PDU) is a collection of unit operations in bench and pilot scale for bioethanol and biorefinery research. The PDU have capability for pretreatment of biomass, enzymatic hydrolysis and fermentation. The main difference between the research done in laboratory scale (typically 25-400 g dry matter) and the PDU research (typically 2-20 kg dry matter) is the possibility to scale the results obtained in the PDU to pilot plant scale (typically 1 ton/day). The facility includes filtration, membrane filtration, chromatography and distillation capabilities in batch and pilot scale to support the PDU.

Researchers at the Department of Chemical Engineering, Lund University, have been working with membrane technology, biomass produced chemicals and process design for more than 30

years and are thus some of the most experienced researchers in the field in the world. The Membrane Group at the department has experience from both fundamental and applied membrane research projects. The cooperation with industry has resulted in the realisation of several full-scale commercial membrane plants. The work in the Biomass Group is focused on biochemical engineering for production of fuels, chemicals and polymers from renewable raw materials and on process design. The Department of Chemical Engineering at Lund University has a wide variety of downstream equipment such as filter presses, centrifuges, membrane filtration equipment in sizes from laboratory scale to pilot plants and biomass characterization instruments, as for example, HPAEC-PAD, HPLC and SEC.

Link to webpage:	http://www.chemeng.lth.se/pdu/
Main contact:	Mats.Galbe@chemeng.lth.se

Bioproduce / KTH

Bioproduce is a pilot plant and contract manufacturing facilities for biological production located at KTH Royal Institute of Technology, Stockholm. The facility is in other words adapted for biotechnological processes, which could be of interest to the forest bioeconomy, e.g., for fermentation processes of forest biomass.

Bioproduce is active in three main areas where bioproduction plays a key role:

• early development stages of new therapeutics
• development of protein drugs
• bioproducts in other industrial sectors

A number of unit operations for downstream processing are available for concentration and recovery of both partially to highly purified products produced in bioreactor cultivations. For intracellular products the cells are harvested prior to disruption to release the product. After the cell and cell debris removal chromatography on packed bed follows. Bioproduce has large experience of continuous centrifugation, cell disintegration, cross-flow membrane filtration and partitioning in aqueous two-phase systems. For extracellular products the cells are removed by centrifugation, cross-flow membrane filtration or expanded bed adsorption. In the last case cell removal is integrated with concentration and initial product purification.

The BTPX 205 is a solids ejecting, continuously operating disk stack centrifuge for liquid /solid as well as liquid/liquid/solid separation. The bowl speed is variable between 7200 - 9630 rpm (max RCF 12800). Typical harvest capacity for *E. coli* is 100 - 200 litres/h. The separator system is automated in large parts and process parameters can be logged. A smaller solids ejecting, continuously operating disk-stack centrifuge for liquid /solid and liquid/liquid/solid separation is the LAPX 202. The bowl speed is variable between 3500 - 10000 rpm (max RCF 8200). Typical harvest capacity for *E. coli* is 20 - 30 litres/h. Except the motor control, the centrifuge is manually operated without any data logging.

Sartoflow Beta is a system for cross-flow membrane filtration with data logging. The filter holder Sartocon 2 plus can be fitted with up to 10 cassettes be mounted (maximum filter area 5m^2) that allows that batch volumes up to 1000 liter can be handled.

A smaller system for cross-flow membrane filtration (0.1 – 0.5 m2 filter area) can be used for scale up and scale down experiments.

The Gaulin-Homogeniser APV LAB 40 is a high-pressure pump with three pistons and a capacity of 30 l/h at the maximal pressure 1200 bar.

For expanded bed adsorption Bioproduce has both a Streamline and a Streamline Direct system both with a diameter of 2.5 cm.

Link to webpage:	http://www.bioproduce.se
Main contact:	info@bioproduce.se

MoRe Research Örnsködsvik AB

MoRe Research Örnsköldsvik AB is a neutral and independent research and development company in the field of products and processes for e.g. the forest industry. The company used to be a part of the MoDo group, a large paper and pulp company, founded more than one hundred years ago. The focus areas of MoRe Research are All the way (Hela vägen®), Analytical services, Biorefinery, Process Emergency and Education.

MoRe Research is experienced in membrane filtration. Together with Domsjö MoRe have built a pilot plant for ceramic membranes which can withstand high temperatures, up to ca. 140°C today. Full size membranes are used, so data can be transferred to full-scale. MoRe also have a pilot plant for plastic membranes, but here the temperature is limited to 40 – 80°C depending on membrane material, making them less suitable for hot process streams.

MoRe is a member company of SP Processum and have access to downstream equipment described below.

The *decanter centrifuge* separates solid material and salts from liquid in a continuous process. It has a wide range of possible usages, e.g. dewatering different types of sludge or hydrolyzates. It can also be used when harvesting algae. the centrifuge is primarily to be used for water based samples and in acidic as well as in alkaline conditions. The decanter centrifuge can process up to 100 l/hour of suspensions with a high fluid content. The higher the solid content of the sample, the smaller sample volumes per hour can be centrifuged. All parts resemble a full size centrifuge and the pilot results can therefore be translated into a full size decanter centrifuge for industrial use.

The unit for *continuous liquid-liquid extraction* can be used for continuous separation of chemicals between/out of two non-mixable liquids. High value organic compounds e.g. may be extracted from water based residual industry streams.

The *filter press* separates solid material from a water based slurry. With a special filter it can filter particles down to the diameter size of 0.5 µm. Tests have been done on hydrolysed fibre reject with very good results. The filter press consists of ten chambers, each with two filters. Each chamber can hold 1.2 litres of solid filtered material. Cellulose filters as well as those made of synthetic material can be used and filtration aids can also be used in order to facilitate filtration. This pilot also has a peristaltic pump which can handle slurries with solid particles. It has a pumping capacity of 130 litres of liquid per hour. Both filter press and pump are made of durable materials such as acid proof steel and polypropylene.

The *high speed centrifuge* separates microbial cells from liquids in a continuous process. Also liquids with different density may be separated from each other. It is continuous and able to centrifuge 30 litres of suspension/hour, whether it is a solid material to be separated from a fluid phase or if there are two solutions with different density to be separated from each other. The centrifuge is a good complement to the bio reactor. After fermentation in the bio reactor, the cells may be separated from the fluid phase in the high speed centrifuge. The combination of these two pilots is therefore a good tool to use in ethanol production development projects.

The *grinder* can beat a wide range of materials, biomasses or residuals from other processes. It has two sets of grinders, one for harder materials like bark, chips and dry sludge and one for softer materials like cellulose. The grinder has five screening rings, from the finest for particles up to a maximum diameter of 0.1 mm to the largest for particles up to 3 mm. The energy used when grinding can be measured.

Link to webpage:	http://www.more.se/en/
Main contact:	lars.sundvall@more.se

Biofuel Technology Centre

Biofuel technology center (BTC) is a research pilot plant park at the Swedish University for Agricultural Sciences, under the department of Forest Biomaterials and Technology. It is located in Umeå, Sweden. The pilot equipment is designed for refining solid biomass and is also used as resource for education. Focus is on handling, upgrading and combustion of a wide spectrum of solid biomass feedstock. Sampling followed by chemical and physical characterization is used to quantify different quality parameters. The batch size of handled biomass is from a few kilograms to several tons. BTC has pilot scale downstream processing equipement such as centrifuges.

Link to webpage:	http://www.slu.se/en/departments/forest-biomaterials-technology/btc/
Main contact:	sylvia.larsson@slu.se

Karlstad University

Karlstad University is one of the youngest universities in Sweden. Much research at the university is multidisciplinary, and the ambition is to further develop its leading research fields, notably communication and services, pulp, paper and surface treatment, printing technology, packaging, the environment, tool materials, education, working life science, tourism and leisure, and gender relations.

The university has pilot scale downstream processing equipment in the areas of evaporation and distillation. Research centres include, among others, the centres for Characterization and modelling of materials (with extensive equipment for analysis and testing of materials) and the paper surface centre. Research in chemical engineering is focused on pulp and paper processes and mainly conducted in four areas: Pulp Technology, Paper Technology, Surface Treatment Technology and Graphic Technology.

Link to webpage:	www.kau.se/
Main contact:	ulf.germgard@kau.se

Chalmers University of Technology
Chalmers University of Technology is a foundation university. Teaching and research is carried out in 18 departments. At Chalmers there are six national competence centres financed by national public funds Vinnova and the Swedish Energy Agency. There are also a number of centres cooperating across traditional departmental boundaries. There are eight horizontal "areas of advance": Built Environment, Energy, Information and Communication Technology, Life Science, Materials Science, Nanoscience and Nanotechnology, Production, Transport. Downstream equipment at Chalmers includes semi-pilot scale units for filtration, precipitation and flocculation. Chemical engineering design comprises research areas within, for example, transport operations and processes in particulate and porous media (including filtration, dewatering, washing, drying, coating and gas/fibre flow); Mixing in two- and three-phase systems (including solids suspension, pulp fibre suspensions, bubble columns, flocculation and liquid/liquid); Physico-chemical data for engineering processes.

Link to webpage:	http://www.chalmers.se/en/Pages/default.aspx
Main contact:	hanst@chalmers.se

Innventia
Innventia is a world-leading research institute that works with innovations based on forest raw materials. The majority of operations are carried out in project form via research programmes involving many partners, such as the three-year Innventia Research Programme, or in development projects with individual customer companies. Innventia also carries out a large number of direct commissions in the form of analyses, testing and demonstrations in labs and pilots.

A wood-based biorefinery requires effective process technology for separating different derivatives from process streams. One overall objective of Innventias operations is to develop effective processes for all wood derivatives, which can be integrated into the pulp mill and result in unique products. Innventia are working on several interesting applications, both for lignin and for hemicellulose and cellulose. LignoBoost is one of the technologies available and ready for use to develop your biorefinery concept.

The LignoBoost demonstration plant in Bäckhammar opened in 2007. The demonstration plant is owned and operated by a subsidiary to Innventia, LignoBoost Demo AB, which was established with the aim of proving the LignoBoost process concept on a near-commercial scale.

There is a daily production of high quality lignin in the plant. Innventia carries out assignments for clients wishing to evaluate their own black liquor or the lignin product from it. It is also possible to perform large-scale product- and process development at the LignoBoost Demo plant.

A new initiative, called LignoCity, will now further develop the demonstration plant and make it an open test bed for companies who want to evaluate and validate new refining concepts in the lignin area.

Innventia has equipment for filtration, centrifugation, distillation, precipitation and extraction.

Link to webpage:	http://www.innventia.com/en/

Switzerland

ETH Zürich – Separation Process Laboratory
SPL research deals with adsorption-based separations and chromatography, and with crystallization processes. Applications are in the purification of biopharmaceuticals and in carbon dioxide capture and storage systems.

- Crystallization and precipitation
- Adsorption and chromatography
- CO_2 capture and storage

In all research areas there is a tight synergy among theory, modelling, and experiments and our activities span all the relevant aspects of a separation process from fundamentals to an integrated process.
Experimental research can be conducted in cutting edge facilities featuring automated lab-pilot units for PSA/TSA processes, mineral carbonation, supercritical fluid assisted precipitation, SMB processes (with online controller). Characterization techniques are available for particle size and shape distributions, adsorption isotherms, as well as spectroscopic instruments for online process monitoring.

Link to webpage:	http://www.spl.ethz.ch/research.html

United Kingdom

Centre for Process Innovation (CPI)
CPI's facilities often offer the option of small scale pilot production allowing our customers to produce a volume of product for investment and demonstration purposes. CPI offers proof of concept programmes resulting in small scale production, along with economic assessment and scale up packages.

Current equipment and technology include:

- 10000 L & 4000 L DSP reactors
- 2000 L glass lined vessel
- Centrifugation technology (S/L)
- Homogeniser
- Filter dryer
- Solvent extraction and distillation capability

Link to webpage:	https://www.uk-cpi.com/

Biorenewables Development Centre

The Biorenewables Development Centre (BDC) offers a broad variety of services in the fields of chemistry and biology to help businesses convert plants, microbes and biowastes into profitable green products. Biorefining and chemical processing inevitably requires separations at some point in the process. BDC also has novel demonstration equipment, including spinning cone columns, supercritical CO_2 and microwave heating technologies.

- Glass reactor suite: Located in a zoned, mechanically vented area the system can be operated safely using solvents with an autoignition temperature of below 200 °C (T3). The 65 L jacketed vessel has a temperature range of -30 °C to 200°C controlled by a heater chiller unit. The setup can also be used for distillation and crystallization purposes.
- Distillation units: The BDC has a variety of distillation and evaporation technology at its disposal. This ranges from a standard packed column to a single-stage thin-film evaporator and a multi-stage thin-film spinning cone column. This allows the BDC to process a wide range of materials including heat-sensitive natural products found in high-value biomass streams. All the systems operate under vacuum, with the lowest achievable vacuum ranging from 10 – 70 mbar depending upon the system in operation.
    - Flavourtech centritherm (50 kg/h) – ATEX rated short path distillation
    - Flavourtech spinning cone (1000 kg/h) – ATEX rated multi-stage distillation column
- SC CO_2: This system comprises two extraction vessels with a combined working volume of 10 litres and it is capable of running at pressures up to 600 bar.
- A Filter drier is used for separating solids and liquids from each other, before drying the products. The system is a 50 litre batch system made from 316 stainless steel with an ATEX rated motor/stirrer to aid in product washing, smoothing, drying/cooling and discharging. Vacuum, heat and pressure can be applied to assist in the filtering and drying process.
- Two chromatography systems where different solid media can be utilised. The Bio-Rad chromatography station is designed for the small-scale production/purification of pharmaceuticals or proteins. It has a column diameter of 100 mm and flow rates of between 5-120 L/hr. The Biotage Isolera LS system is a flash purification system designed for the separation of complex organic mixtures. It has cartridges instead of a column which are typically pre-packed. The flow rate of the Isolera system is 5-400 mL/min.

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