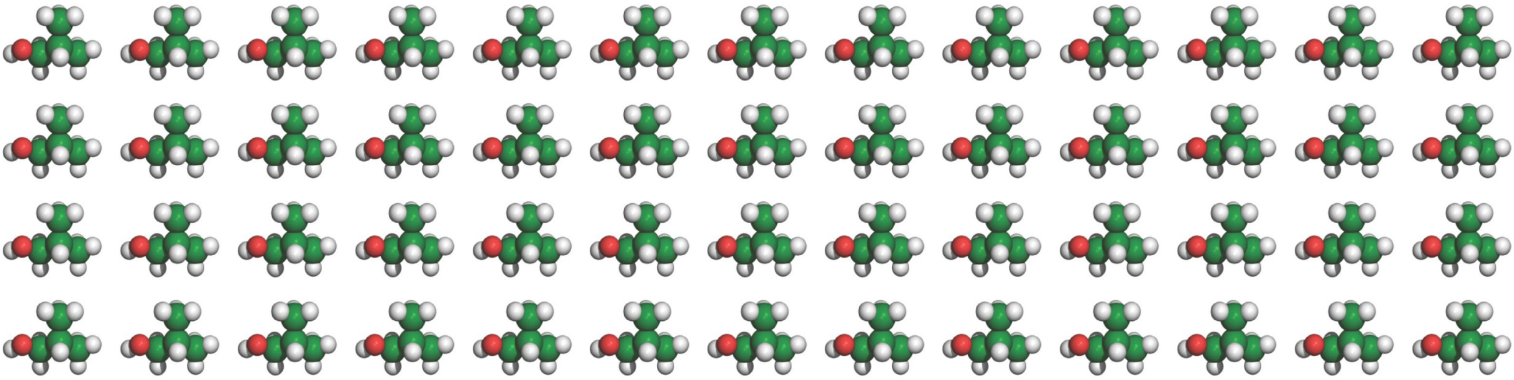
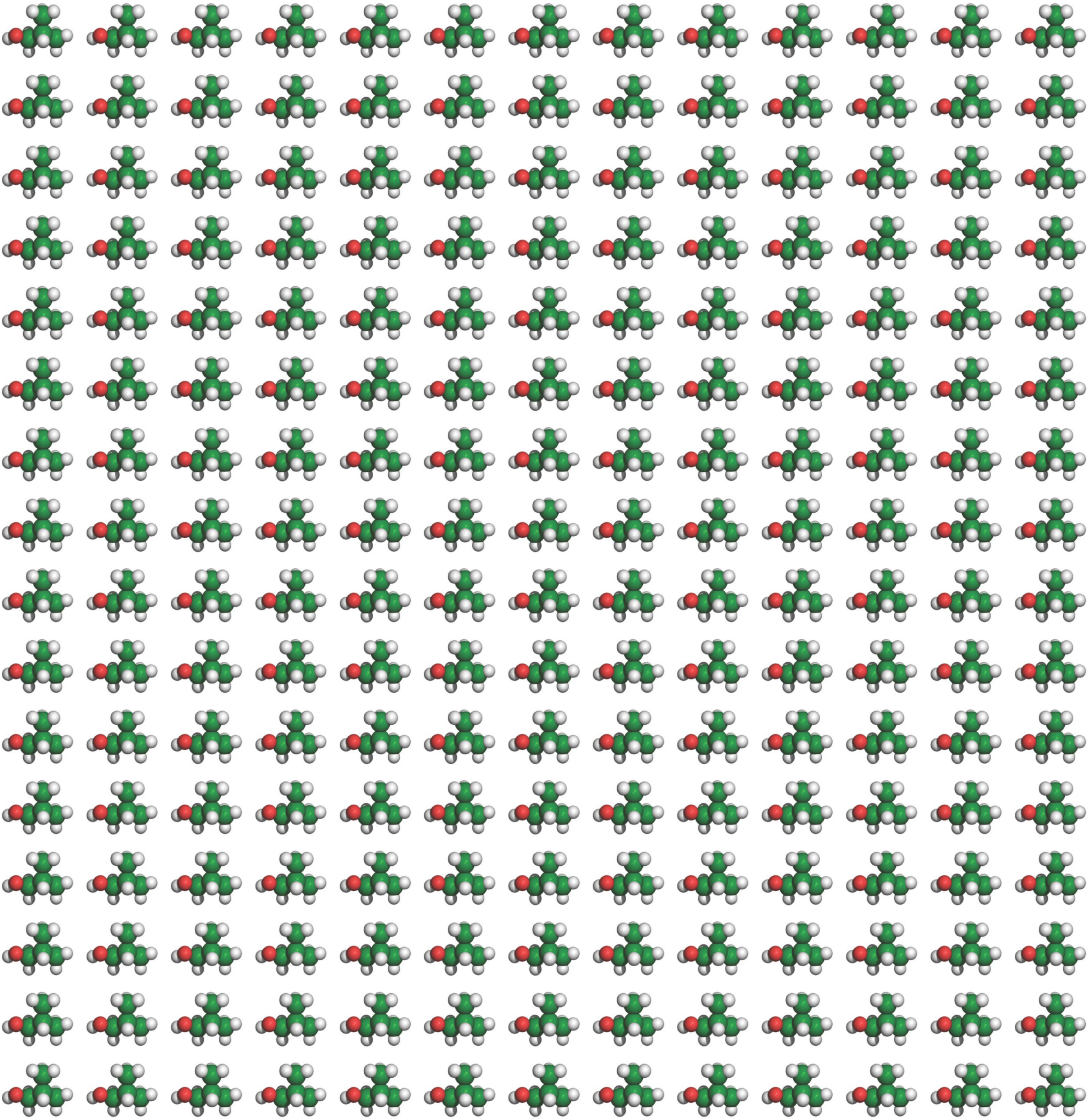
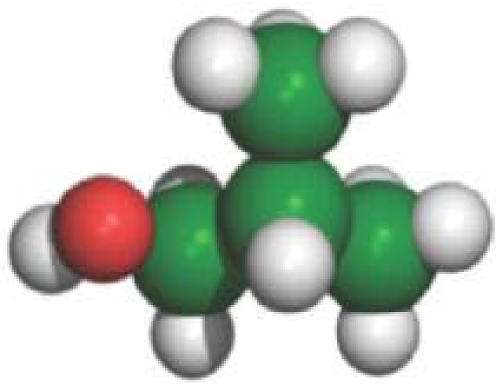


Iso-Butanol Platform Rotterdam (IBPR)



Iso-Butanol Platform Rotterdam (IBPR)

Public summary



Isobutanol

Investing in your future
The IBPR project is partly financed
by the European Development Fund of the
European Union

Management summary

The IPBR consortium demonstrated the technical feasibility of a bio-refinery in the Rotterdam area based on the platform molecule isobutanol. The project encompassed the entire value chain from lignocellulosic biomass up to and including the high value end-products striving for entire biomass valorisation.

The feedstock of the envisioned full scale bio-refinery is lignocellulosic biomass consuming 1,000,000 ton/year (dry weight) of it. The bio-refinery is envisioned to operate 8,000 hours per year, a common practise in the petro-chemical industry (the remaining time there is no production, to allow for maintenance).

In the process, the biomass is fractionated into three main fractions: cellulose pulp, hemicellulose, and lignin. Isobutanol is produced by fermentation from the carbohydrate containing fractions. The end-products that are studied in the project are:

- **Glycerol tertiary butyl ether (GTBE),** a high value biofuel that can be blended in diesel with proven soot emission reduction for EURO4 and older engine types
- **Isobutanol-acetone condensate (IAc)**, a product which after hydrogenation is a high value diesel blending product that can be added to jet fuels
- **Isobutyl acetate (IBAc)**, a colourless solvent, that presents good solvency characteristics for polymers, resins, oils and cellulose nitrate and is miscible with all common organic solvents.
- **Purified lignin from the acetone organosolv**, a component suitable for bio-based resins, polyurethanes or other polymers; it can also be used in bunker fuels

In this project all individual process steps of the full value chain of the bio-refinery have been proven on lab scale. Furthermore, information is generated as part of the technical, economical and sustainability assessment.

Pretreatment

- Spruce and poplar were effectively fractionated using ECN patented ketone based Organosolv fractionation technology resulting in near native pure lignins as well as hydrolysable cellulose pulps.
- Two 10 kg batches of cellulose were produced which after mild activation were shown suitable to produce sugars.
- Mild bleaching treatment significantly increased the rate of glucose formation yielding fermentable sugars within 48 hours corresponding to roughly half the reaction time

Hydrolyses

- Using a commercial cellulase cocktail 90 g/l resp. 60 g/l glucose was obtained for spruce and poplar.

Isobutanol production

- Hydrolysates were sucessfully used as substrate for isobutanol production.
- Including acetate in the fermentation reduces the number of by-products.

- Dewatering using commercial ceramic hybrid sylica membranes (with high stability towards acidity) decreases membrane costs significantly.

Isobutyl Acetate and Isobutanol-acetone condensate production

- Production of Green Isobutylacetate (IBAc) is feasible at high conversions using esterification and trans esterification reactions and a combination thereof.
- Cross condensation of Isobutanol and acetone followed by hydrotreatment give excellent products for drop in fuels for diesel and Jet fuel.

Istobutene production

- Isobutanol was converted to iso-butene was obtained at commercially viable productivities (WHSV > 10) at high selectivities using commercial catalysts.
- 150 mL of isobutanol produced in the project was succesfully converted to isobutene, isolated and used for the production of GTBE.

Production of GTBE

- GTBE has been successfully produced; production of GTBE is profitable on designed scale of 156 kton/year (even though depending on raw material cost price).
- Mixing GTBE in diesel influences fuel hose properties well within maximum range.

Lignin

- Lignin was demonstrated to be suitable for resins used in plywood and showed promise for the production of asphalt.
- The lignin produced is highly reactive as demonstrated by combustion and explosion test. It is therefore less suitable as fuel, but likely more suitable as raw material in the chemical industry.

The economics of the full scale bio-refinery were calculated in detail based on a dedicated process design. A feasible plant design has been developed for producing IBAc, GTBE and lignin from wood, with a best-case pay-out time of 6 years. The CAPEX of the various cases ranges between 310 - 400 M€. The OPEX ranges between 530 - 690 M€.
The life cycle assessment shows advantages of the bio-based isobutanol platform in comparison to the petrochemical platform. The ‘non-renewable energy use’ is approximately 45% lower in comparison to the petrochemical counterpart. The GHG emissions are up 25% lower for the bio-refinery in comparison to their equivalent fossil systems. For fresh water depletion, savings can be up to 58% in contrast to their petrochemical counterparts.
It is recommended to demonstrate the full chain of the bio-refinery at pilot scale. The estimated investment costs for a pilot plant are estimated to be 6.4 M€.

This report contains an overview of all results. The underlying full scientific reports are available on request.

Table of Contents

1. Introduction

The IPBR consortium investigated the feasibility of developing and realizing a bio-refinery in the Rotterdam area. The consortium focussed on a biomass value chain with isobutanol as the platform molecule. Isobutanol could be used as a raw material to produce jet fuels, aromatics, isobutylene and other derivatives used for additives for gasoline or diesel fuels.

The final report of the preliminary feasibility study of the IBPR-project as published in February 2014, indicated that the economic feasibility to produce p-xylene and jet fuels from beet sugar or beet sugar pulp via isobutanol was low. As a consequence, it was decided to shift to lignocellulosic biomass, and search for new applications of using bio-isobutanol at a scale more modest than p-xylene and jet fuels, so that:

- The price of hydrolysis enzymes would no longer be a showstopper;
- The scale of availability of biomass (and consequently isobutanol) would better match the demand of the final products;
- There would be a possibility to valorise lignin, generating extra revenues.

A scheme of the project is shown in the figure below.

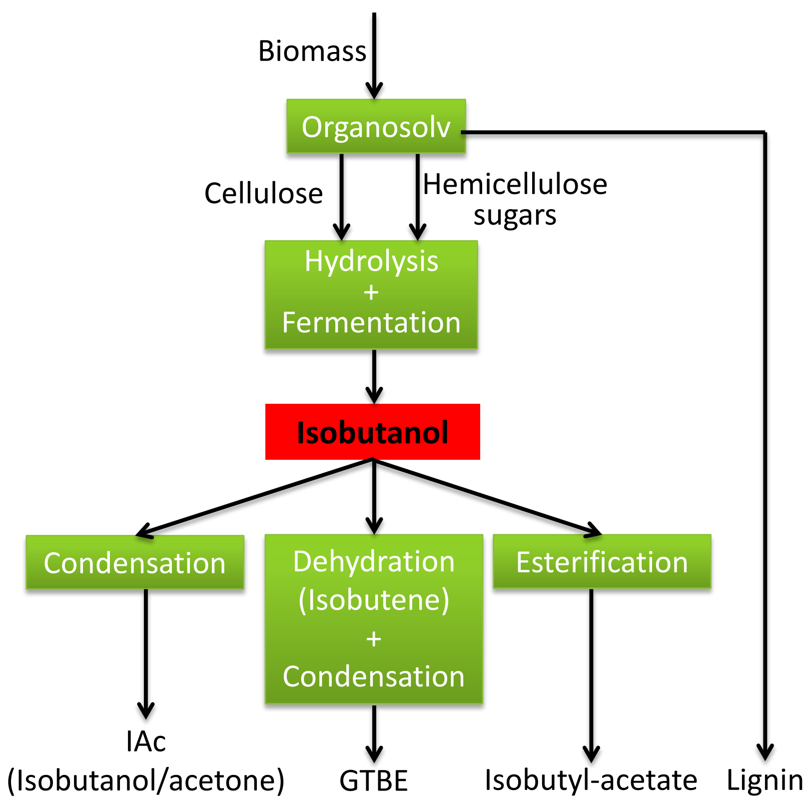


Figure 1. Schematic representation of the project

The aim of this phase of the project was to demonstrate and qualify the technical feasibility of all steps of the current envisioned cascading valorisation of lignocellulosic biomass via isobutanol to high value products.
Although all steps are more or less known (at minimum at the lab scale) or even commercially practised, the entire chain needed to be demonstrated, and some of the crucial steps needed to be independently verified, qualified or even developed. Other steps needed to be demonstrated with the technology envisioned, for instance the use of membranes for the reactive esterification.

This project experimentally determined the critical parameters of the entire chain and the results were used for a technical economic and sustainability analysis of the platform. Furthermore, the cost of a pilot plant, the next envisioned step of the full development process, were estimated and reviewed.

In this report a summary of the main results of the project is presented. The results are structured as follows:

- Process development
    - Biomass feedstock selection and pre-treatment
    - Production and upgrading of isobutanol
    - Production of end products from isobutanol
    - Production of end products from lignin
- Process design and evaluation
    - Process design
    - Technical and economical evaluation
    - Sustainability assessment
- Pilot plant design

2. Process Development

2.1 Biomass feedstock selection and pre-treatment

Based on feedstock availability, processability etc., the consortium has selected spruce (as member of the soft-wood feedstock spectrum) and poplar (hardwood) for demonstrating the technical feasibility of the entire envisioned value chain.

Spruce and poplar were effectively fractionated using the ECN patented ketone based Organosolv fractionation technology. Near native, pure lignins were obtained which were used for further product developments. Two 10 kg batches of cellulose were produced, which after mild activation, were shown to be suitable to produce sugars for fermentation to isobutanol in the subsequent work packages.

ECN has evaluated mild bleaching treatments of the pulp obtained from poplar and spruce to enhance the hydrolisability of the pulp. It was found that a very mild bleaching treatment significantly increased the rate of glucose formation. This was successfully scaled up by WUR.
Using a commercial cellulase cocktail from Dyadic, the hydrolysis of biomass was optimized to obtain fermentable hydrolysates with high sugar concentrations for isobutanol production. Hydrolysates containing up to 90 g/L glucose were obtained for spruce and 60 g/L glucose for poplar feedstocks.

2.2 Production and upgrading of isobutanol

2.2.1 Production of isobutanol by fermentation

WUR studied the production of isobutanol from spruce and poplar wood pulp hydrolysates prepared from organosolv-derived fractions. The fermentation was studied using proprietary technology from Gevo inc.

Hydrolysates were successfully used as substrate for isobutanol production. The effect on the isobutanol production of an acetate buffer in the hydrolysate was assessed. When acetate was present in the medium the isobutanol production was not affected but the strain produced less by-products.
Scaling-up of the fermentation process highlighted the importance of an efficient system for the *in-situ* extraction of the isobutanol to reach high fermentation performances.

Figure 2. Isobutanol by fermentation (labscale on the left and pilot on the right)

2.2.2 Isobutanol upgrading

The dewatering of isobutanol is a critical intermediate process step both from a technical and an economic perspective.

The dewatering of isobutanol has been studied by Zirk©Technology using a process called pervaporation, which has significant energy efficiency advantages over conventional processes such as azeotropic distillation.

The pervaporative dewatering of isobutanol was evaluated with commercial ceramic membrane as hybrid silica (Hybsi) from Pervatech at two temperatures (100°C and 130°C). Compared to other ceramic membranes, hybrid silica (Hybsi) gives an ability to perform dewatering at high temperatures. The water flux in dewatering by pervaporation increases exponentially with the increase of temperature due to an increase in driving force whereas the organics flux remains small. This means that the membrane surface area required
for hybrid silica membranes can be reduced by applying higher feed temperatures. Furthermore, the reduction of water content from 20 wt.% to 1 wt.% was observed to be much
faster than from 1 wt.% to 0.1 wt.%.

The high prices of hybrid silica membranes is no limiting factor any more for commercial use, since ceramic pervaporation membranes have much higher fluxes and selectivities than commercially available polymeric membranes. The fact that the Pervatech membranes also possess a high stability towards acidity makes pervaporation a suitable method for the dewatering of isobutanol.

2.3 Production of end products from isobutanol

The IBPR consortium focusses on the development of a value chain for isobutanol in the Rotterdam region. Biomass is converted to isobutanol, which can be used as a building block for the production of various chemicals. The project aims to convert isobutanol, produced via organosolv and fermentation into the following three different products:

- Isobutyl Acetate (IBAc), a renewable solvent
- Glycerol Tertiary Butyl Ether (GTBE), an biofuel/additive for diesel
- Isobutanol-acetone condensate (IAc), to produce so called green precursors for fuels and chemicals, such as diesel, gasoline, jetfuel and bionaphta

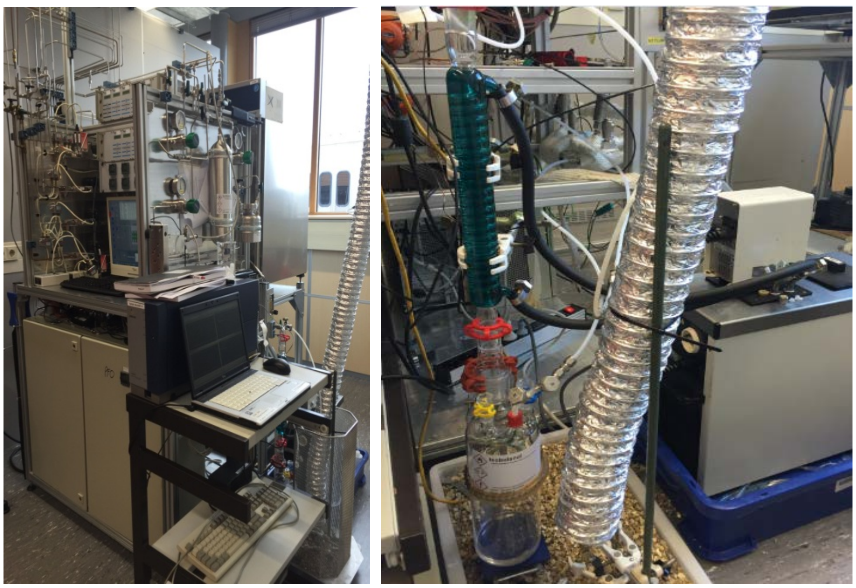


Figure 3. multi-reactor test rig (left) and isobutene condensor (right)

2.3.1 Isobutyl Acetate (IBAc)

Bio-based downstream processes may use isobutanol in order to produce so called green solvents, which are esters or acetates. In this study the conversion of isobutanol towards isobutyl acetate utilizing a combined reaction/separation approach has been conducted by Zirk©Technology.

Isobutyl acetate from Isobutanol can be produced via three routes

1. Esterification: isobutanol and acetic acid gives isobutyl acetate and water
2. Trans estherification: isobutanol and methyl acetate gives isobutyl acetate and methanol
3. Combination of 1 and 2: The so-called “methyl acetate induced esterification”

The reactions are equilibrium reactions with relatively slow kinetics and require cost intensive separation unit operation as azeotropic distillation, which has a relative high energy usage.
Membranes as separation aid show a clear potential as an alternative to distillation processes since it allows simultaneously reaction/separation concepts (tuning the reaction equilibrium to the favored position), hence lowering residence time, which could result in lower operational costs.

In this study, the performance of a commercial available silica membrane has been used as separation module in the esterification and transesterification reactions with isobutanol, as well as the methyl acetate induced esterification at various conditions. The esterification of methanol and acetic acid to methyl acetate has been evaluated as well because methanol-water mixtures and methyl acetate are available on the recycle market for relatively low prices.

The results in this study clearly show the potential of the hybrid silica (Hybsi) membrane from Pervatech in these reaction/separation systems. All reactions reached conversion between 80-100%. The esterification reaction with isobutanol showed fast reaction rates, where the transesterification reaction with isobutanol showed lower reaction rates. Surprisingly, the "methyl acetate induced esterification" showed the fastest reaction rates leading towards the highest conversion, and is very worthwhile to explore in more detail.

The economic evaluation shows that an energy reduction of approximately 40% is feasible, leading to lower operational costs.
This promising perspective should be tested in a pilot plant configuration.

2.3.2 Glycerol Tertiary Butyl Ether (GTBE)

2.3.2.1 Isobutanol dehydration

First step in producing GTBE from isobutanol is to convert it into isobutene. In this part of the project, ECN has demonstrated the technical feasibility of converting isobutanol to isobutene.

Five catalysts from three different vendors were found to be highly effective for the dehydration of isobutanol to isobutene. All five catalysts showed higher productivities than reported in patent literature. Thus the basis of the economic analysis was conservative.

A 150 ml batch of isobutanol was successfully converted to isobutene, thus demonstrating one more step of the chain.

2.3.2.2 GTBE production and use

One of the end-products is GTBE, a biofuel that can be added to diesel. Isobutanol is converted into isobutene, which in turn is one of the raw materials for the production of the biofuel GTBE that can be added to diesel.

GTBE was successfully produced by Procede from renewable isobutene produced by ECN from isobutanol produced by WUR, demonstrating the full chain from lignocellulosic biomass to GTBE.

The GTBE production plant designed in the IBPR project has a capacity of 156 kton/y. For this production capacity 123 kton/y isobutanol and 71 kton/y glycerol are required.
Since GTBE is a new chemical, it needs to be registered with REACH, when produced above 1 tonne per year. In order to complete a registration with REACH, animal tests have to be performed.

When new fuels or new fuel additives are developed and introduced to the automotive industry they are tested for material compatibility with common automotive fuel systems. It is important that such new fuels or additives do not cause additional degradation of materials, such as plastics, elastomers, composites or metals.

A literature survey and study were performed to determine what type of material compatibility testing is usually performed in the automotive industry. A widely used method of experimentation for testing the compatibility of fuel systems is immersing materials in fuels or fuel mixtures.

Sufficient amounts of GTBE were produced at lab scale and immersion experiments have been performed. After immersion experiments, the change in material appearance was determined, as well as the change in volume and mass of the hose and the burst pressure of the hose.
Rubber hoses with inner reinforcement, a rubber hose without reinforcement and a polyamide hose were tested respectively in diesel and a diesel/GTBE mixture. Maximum swelling of the hoses was +12 vol%, which is well within the maximum range of +20 vol%. Furthermore, burst pressure tests indicated there were minor differences in burst pressure between hoses from diesel and diesel/GTBE immersion tests.

A techno-economic evaluation was performed on the designed 156 kton/y GTBE production plant. It was concluded that the total production cost of GTBE is highly dependent on the raw material cost price. Based on the renewable isobutene (i.e. isobutanol) cost price determined within the consortium it was concluded that the production of GTBE is profitable.

2.3.3 Isobutanol-acetone condensate (IAc)

Biobased downstream processes may use isobutanol in order to produce so called green precursors for fuels and chemicals, such as diesel, gasoline, jetfuel and bionaphta. In this study the downstream processing of isobutanol to these precursors by cross condensation of isobutanol with acetone and subsequent hydrotreatment have been evaluated by Zirk©Technology.

The heterogeneous-catalytic gas-phase process makes it possible to condense isobutanol and ketones (acetone) to larger hydrocarbon molecules containing only one atom of oxygen per molecule. After an optional oxygen-removing step such as hydrotreatment, fuel-identical hydrocarbons including jet fuel can be obtained.
A tailor-made carbon chain distribution and additionally carbon-chain branching can be achieved, which determines the cold flow properties of the product to a large extent.

The choice of raw materials, the process conditions and the recycling of intermediate products are tuning factors. The crude or partially distilled product can be used as drop-in fuel for diesel. The intermediates – longer ketones, primary and secondary alcohols – also serve as value-added raw materials and intermediates for many chemical applications, i.e. plasticizers, surfactants, alkenes, solvents, fatty alcohols, and lubricants.

The presented process offers an attractive alternative to other competing processes producing long-chain hydrocarbons, like Fischer-Tropsch or hydrotreatment of fats and oils. Being based on inexpensive, long-term stable and commercially available catalysts and designed for a wide range of possible raw materials optionally stemming from residues, the suggested route is ready for scale-up.

The results of this study show that the cross condensation of isobutanol and acetone reveals two main reactions products, ie a C7-reaction product which can be recycled and a C11 and C15 mixture. This mixture has been submitted to hydrotreatment under different temperatures (360-270 ^{o}C) and pressures (15-80 barg). The results of this hydrotreatment indicate that under relatively mild reaction conditions the obtained products show excellent low temperature properties (freezing point -60 ^{o}C and lower) and superior oxidation stability characteristics.

2.4 Production of end products from lignin

As shown, spruce and poplar were effectively fractionated using the ECN patented ketone based Organosolv fractionation technology. Near native, pure lignins were obtained which were used by ECN for further product developments. Developments were conducted in the field of lignin application as chemical and as fuel.

2.4.1 Chemicals

The screening on the Organosolv lignin applications provided clear insight in the commercial applicability from literature and experiments.
The lignin's market potential regarding its application for bunker biofuel, biobitumen, rubber tyres, bio-additive for paints, bio-polyurethanes and bio-resins was identified. The suitability of Organosolv lignin for all applications studied, is strongly dependent on its blending behavior and its chemical reactivity.

Experimental proof was provided that both Kraft and Organosolv lignin are well suited as replacement for phenol in phenol formaldehyde (PF)-thermosetting resins and that the suitability of Organosolv lignin for bunker fuel and biobitumen strongly depends on miscibility.

2.4.2 Fuel

Organosolv lignins are potentially very high quality bio-based solid fuels. The deployment of such materials in pulverized-fuel systems is possible and should not lead to significant operational problems.The tested lignins pulverize well and burn efficiently, with little undesired combustion by-products.

However, there are a few points requiring additional attention, to rule out potential safety issues. This is particularly true for handling of the pulverized lignins. The measured explosivity parameter indicate that even at a relatively coarse milling, both tested materials require very little energy to spark up an explosion. Also, the molten and sticky material resulting from such explosion and ejected onto the surrounding surfaces, continues burning in the open air. This might eventually also lead to a secondary explosion and/or fire in the handling/storage area. Therefore, only appropriately ATEX certified/equipped installations should be used to grind and handle the pulverized lignins.

Furthermore, as the lignins contain quite a lot of dust already at the production stage, care must be taken during handling prior to pulverization to avoid dust dispersion. Also, since the lignins are relatively low melting and pumpable materials, one could also consider using liquid- instead of solid injection system for feeding lignins in thermal applications. This would circumvent the dust explosivity issue altogether.

3. Process design and evaluation

3.1 Technical and economical evaluation

The various technologies studied should ultimately be combined into a large bio-refinery in the port of Rotterdam. ECN and TUD made a conceptual design of this bio-refinery, with the aim to get a first design of the complete bio-refinery, to investigate the technical and economic feasibility of the various technologies as well as the complete bio-refinery and to provide input to the LCA.

The system boundaries of the bio-refinery (the parts that are included in this study) are shown in Figure 4 below.

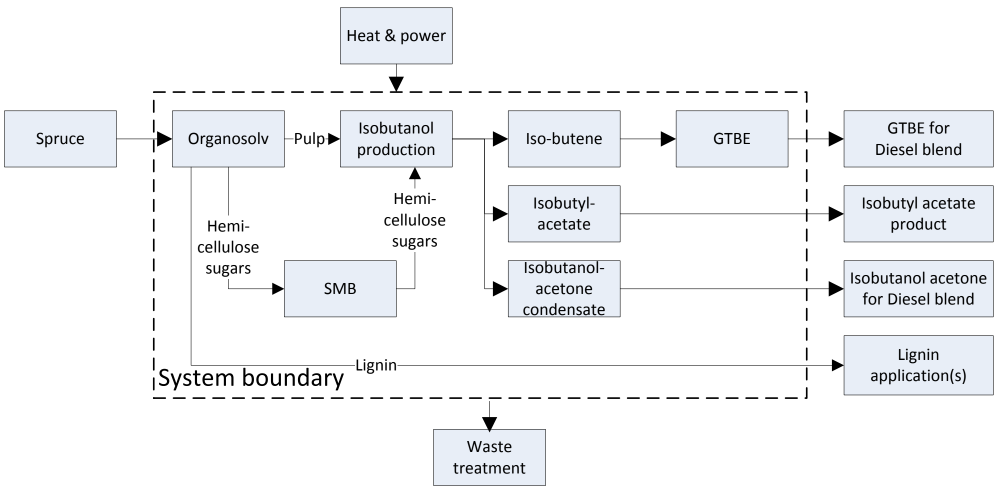


Figure 4. System boundaries of the bio-refinery

The selected feedstock of the conceptual full scale bio-refinery is spruce, and the bio-refinery will consume 1,000,000 ton/year (dry weight) of it. The bio-refinery is envisioned to operate 8,000 hours per year (the remaining time there is no production, to allow for maintenance).

In the Organosolv process, the spruce is fractionated into 3 main fractions: cellulose pulp, hemicellulose, and lignin. The cellulose pulp, and optionally also the hemicellulose, is used to produce three different end products. Lignin is also an end-product of the bio-refinery.

The end-products that are studied in the project are:

- **Glycerol tertiary butyl ether (GTBE),** a high value biofuel that can be blended in diesel with proven soot emission reduction for EURO4 and older engine types
- **Isobutanol-acetone condensate (IAc)**, a product which after hydrogenation is a high value diesel blending product that can be added to jet fuels
- **Isobutyl acetate (IBAc)**, a colourless solvent, that presents good solvency characteristics for polymers, resins, oils and cellulose nitrate and is miscible with all common organic solvents.

- **Purified lignin from the acetone organosolv**, a component in bio-based resins, polyurethanes or other polymers; can also be used in bunker fuels

The Organosolv section is the most profitable section, even when a relatively high feedstock price and competitive product prices are assumed.

The fermentation seems to be the process section that has the largest economic challenges as it never achieves a Pay Out Time shorter than the project life time. It requires isobutanol transfer prices that are significantly higher than assumed in this study to achieve a Net Present Value of zero, with the assumed project lifetime.
Three options for the fermentation step have been evaluated for impact on plant capital investments and operating margin. Fermentation of the cellulose fraction only to iso-butanol is possible, but economics can be significantly improved by co-fermentation of the hemicellulosic sugars. This requires a fermentation process that is resistant against potential inhibitors that might be present in the sugar stream. An alternative option investigated is purification of the sugars stream before fermentation, but the investments in the required simulating bed reactor are too high to make this a feasible option.

The economics of all the cases were calculated in detail. The CAPEX of the various cases ranges between 310 - 400 M€. The OPEX ranges between 530 - 690 M€.

A feasible plant design has been developed for producing IBAc, GTBE and lignin from wood, with a best-case pay-out time of 6 years.

3.2 Sustainability assessment

Utrecht University carried-out an early sustainability assessment and a life cycle assessment of the isobutanol platform Rotterdam bio-refinery. The results are compared to an equivalent oil-based platform (*i.e.,* with the same products distribution).

3.2.1 Early stage sustainability assessment

The early-stage sustainability assessment is carried out by using a method that aims to compare bio-based systems against dominant conventional systems (*e.g.,* a petrochemical route). The method considers three main indicators namely, economic constraint, energy related impacts of raw materials and process complexity. For both systems, the bio-based and the fossil-based systems, the indicators are aggregated into a *single score* (after normalization and using weighting factors). An *index ratio* is defined as the ratio between the single score of the bio-based process and the single score of the reference (conventional) system. An *index ratio below 0.9* indicates that the bio-based alternative shows a potentially better performance and thus is classified as *favorable.* Index ratios above 1.2, indicate that the bio-based system has potentially lower performance than the conventional counterpart and thus classified as *unfavorable.*

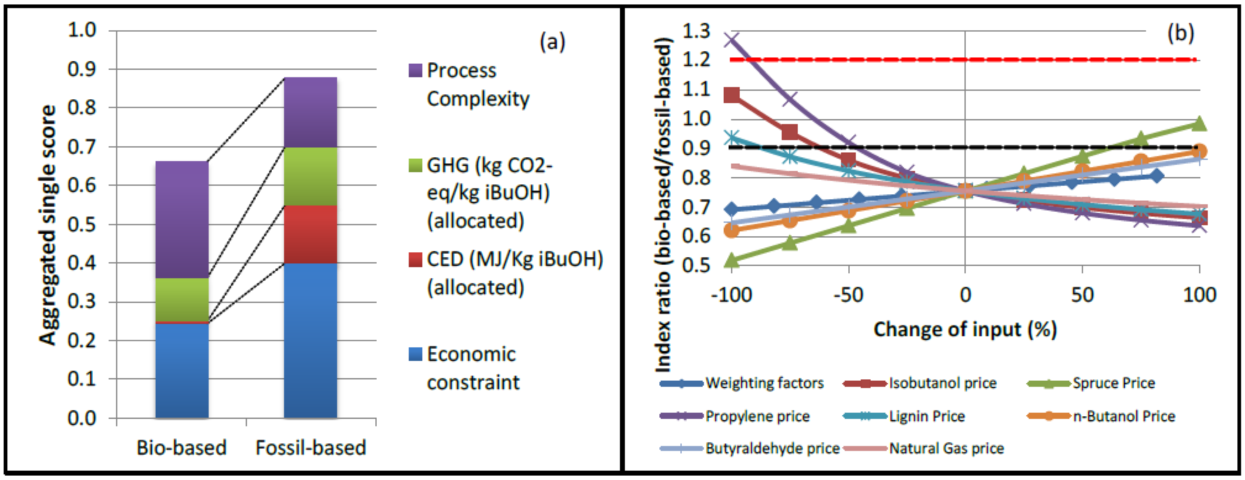


Figure 5. Comparison of bio-based isobutanol against fossil-based isobutanol, including sensitivity analysis

The index ratio is 0.76, thus reflecting a potential advantage of bio-based over fossil-based isobutanol. The results of a sensitivity analysis on the index ratio of isobutanol production indicates that even at drastic changes on data inputs (± 100%) the result is robust.

Figure 6 shows the ranking of isobutanol in comparison with other bio-based products (assessed using the same method, and derived from sugars from lignocellulosic biomass), highlighting the potential of isobutanol.

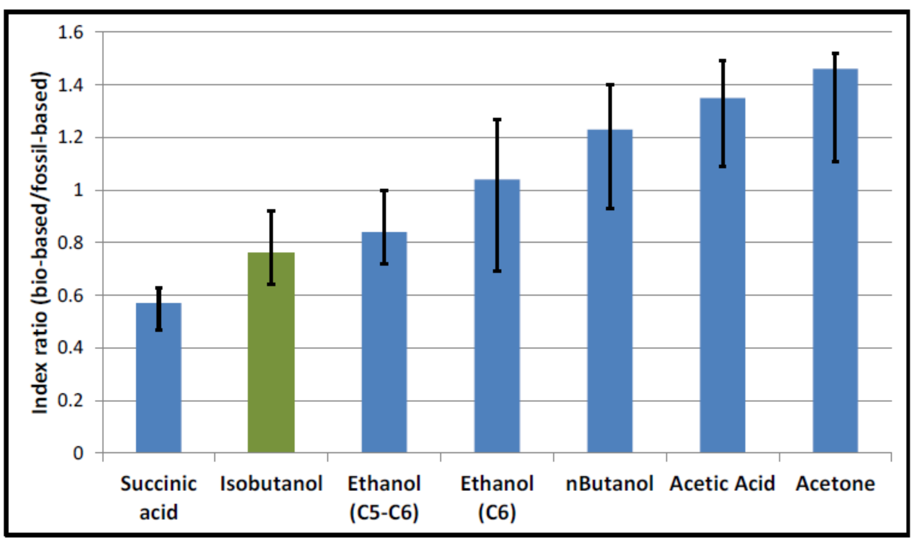


Figure 6. Ranking of isobutanol in comparison to other bio-based derivatives.

3.2.2 Life Cycle Assessment

The life cycle assessment conducted by Utrecht University departs from the techno-economic assessment developed by ECN and was used to assess the potential environmental impacts of the Isobutanol Platform. The assessment follows a cradle-to-gate analysis for four impact categories: Non-renewable energy use (NREU), Climate change/Greenhouse Gases (GHG), Fresh water depletion (WD), and agricultural land occupation (ALO).

Based on the results from the life cycle assessment, the bio-based isobutanol platform shows advantages in comparison to the petrochemical platform.

The approaches used for allocating the environmental impacts have an important effect on the outcome of the LCA. When the most conservative approach is used, reductions in the environmental impacts (in comparison to the petrochemical counterparts) are lower than those obtained when a fraction of the impacts are allocated to lignin. Nevertheless, the direction of the impacts (*e.g.,* decrease of GHG, NREU, WD and increase of ALO) does not change with the allocation method.

Based on the results from allocation approach allocating a fraction of the impacts to lignin, the NREU is approximately 45% lower in comparison to their petrochemical counterparts. The GHG emissions are up to 25% lower for biorefinery in comparison to their equivalent fossil systems. For fresh water depletion, savings can be up to 58% in contrast to their petrochemical counterparts.

The results of the sensitivity analyses of the LCA indicate that the distribution of isobutanol to isobutyl acetate and GTBE or condensation products show a significant effect on NREU, GHG emissions and fresh water depletion. The results suggest that GTBE is potentially an environmentally friendlier product than condensation products and isobutyl acetate, and that condensation products are potentially environmentally friendlier than isobutyl acetate.

Reductions on consumption of utilities of the bio-based systems have an important effect on the potential reductions of the environmental impacts over the fossil-based systems.

4. Pilot plant design

A feasible plant design has been developed for producing IBAc, GTBE and lignin from wood, with a best-case pay-out time of 6 years. Next phase in developing the bio-refinery is demonstration of the full chain at pilot scale. For this purpose TUD developed a pilot plant design.

The pilot plant will be split up into several sections. The Organosolv, SMB/hydrolyses (Simulated Moving Bed) and Fermentation sections are coupled (but not integrated). The Isobutene & GTBE, IBAc and IAc sections are not coupled.
The results are presented in Table 1.

Table 1. Pilot plant conceptual design, main results

	CAPEX Pilot (M€)	Location	Operation time	Main feedstock	Scale
Organosolv	2.3	BPF [1]	8 weeks	Spruce	100 kg/h
SMB/hydrolyses	1.2	BPF	8 weeks	Hemicell. Hydrolysate	160 kg/h
Fermentation	0.7	BPF	8 weeks	Cellulose	37 kg/h
Isobutene & GTBE	0.7	PlantOne	2 weeks	Isobutanol	65 kg/h
IBAc	0.2	PlantOne	2 weeks	Isobutanol	1.6 kg/h
IAc	1.4	PlantOne	30 days	Isobutanol	84 kg/h
Total	**6.4**	**-**	**-**	**-**	**-**

The total investment costs to demonstrate the full chain of the isobutanol bio-refinery at minimum pilot scale is estimated to be 6.4 M€.

[1] BPF: Bioprocess Pilot Facility, in Delft

Contacts

Project management

Coordinator:	Bram Brouwer	BE-Basic
Technical Manager:	Sjaak van Loo	ECN
Project leader	George Brouwer	BE-Basic
Financial Manager:	Yvette van Scheppingen	BE-Basic
Executive Secretary:	Sandra Ransdorp	BE-Basic

Consortium members

AVR	Simon Frans de Vries
BE-Basic	Bram Brouwer
Corbion	Peter Baets
Deltalinqs	Hans van 't Noordende
ECN	Jaap Kiel
GEVO	Chris Ryan
Grontmij	Jaap Drost
Port of Rotterdam	Bas Hennissen
Procede	Geert Versteeg
Technical University Delft	Adrie Straathof
Utrecht University	Andrea Ramirez
Wageningen University	Ana Lopez-Contreras
Zirk©Technology	Hennie Zirkzee

Investing in your future
The IBPR project is partly financed
by the European Development Fund of the
European Union

7 april 2016