



ProBioRefine 2021 - International workshop on system analysis and technologies for biorefineries

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ProBioRefine 2021

International workshop on system analysis and technologies for biorefineries



DTU Chemical Engineering
Department of Chemical and Biochemical Engineering

COWIfonden

Knowledge Hub Zealand

world-class insight and innovation

Online event

May 6th & 7th, 2021

Book of Abstracts

Organizing committee



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Abstracts

Session I - Global perspectives on bioeconomy



Prof. Christos T. Maravelias, Princeton University, USA

A systems engineering view of biofuels and the bioeconomy

We discuss how process systems engineering (PSE) studies can shed light on some critical questions concerning the development of a sustainable biofuels sector and, more broadly, the bioeconomy. We start with a discussion of the golden rule of “atom-economical” technologies and discuss the wider question of target biofuels and bioproduct selection. Second, we overview the challenges and major drivers in the design of efficient biofuel supply chains and present an integrated landscape-feedstock-biorefinery framework. Third, we discuss how future trends and development (e.g., electrification) are expected to impact the development of biofuels. Finally, we close with an overview of the options for and the role of carbon sequestration in biomass-to-energy strategies.



Prof. David Chiaramonti, Polytechnic of Turin, Italy

Biorefining in the context of the EU and International policies: opportunities and challenges

A wide number of scenarios for bioeconomy and biorefining have been elaborated and published by many International and EU Organizations, targeting 2030 and 2050. As regards the energy sector, the essential role of biobased and recycled carbon fuels emerges as a common element of these forecasts, complementary to renewable electricity use in transports: impacts have been estimated for all major end-use sectors, with special focus on Aviation, Maritime and Heavy-Duty sectors. The increased EU ambition on GHG reduction, which set a 55% target at 2030, combined with the post-pandemic need to recover the economy, creates unique conditions to rethink the ecological transition and amend current policies to boost the greening of economy. Innovative value chains will have to be deployed at full commercial scale, moving most advanced solutions through the Mountain of Death. The present work analyses the current and future scenarios, some of the key EU policies, identifying opportunities and challenges.



Prof. Solange I. Mussatto, Technical University of Denmark, Denmark

Sustainable solutions for advanced biorefineries

The development of advanced biorefineries, which aim at converting biomass (from agriculture, forestry, aquaculture) in a spectrum of products and bioenergy, is seen today as key to implement a sustainable biobased economy. Although important developments have been done in this area, further research and improvements are still required to obtain environmentally friendly and economically feasible commercial scale biorefineries. In this lecture, the most recent strategies and innovations able to support the implementation of advanced biorefineries will be presented. Focus will be given on the development of efficient bioprocessing systems.



Prof. Peter Fantke, Technical University of Denmark, Denmark

Assessing environmental sustainability to support a bio-based economy

Producing biochemicals from renewable resources is a key driver for developing a viable, bioeconomy, in support of progressing toward global sustainable development targets. Life cycle assessment (LCA) is a standardized tool to measure related progress by quantifying environmental sustainability performance of chemical products along entire life cycles. However, there are currently only few available studies that comprehensively and systematically assess environmental performance of biochemical products. These studies show inconsistencies in coverage of environmental impacts and life cycle stages, with varying conclusions. Claims of better sustainability performance of biochemicals over functionally equivalent fossil-based chemicals are often based on comparing global warming impacts, while ignoring other impacts from bio-feedstock production. To boost sustainable biochemicals, we recommend that LCA practitioners include the broader range of impact indicators and entire life cycles, follow standards and guidance, and address missing data. The biochemical industry should systematically use LCA to direct research, identify impact hotspots, and develop methods to estimate full-scale process performance. This will promote biotechnology as important contributor to solving existing sustainability challenges.



Prof. Suttchai Assambumrungrat, Chulalongkorn University, Thailand

Bio-Circular-Green Economy Model - Action in Thailand

Bio – Circular – Green (BCG) economy model has become a national agenda of Thailand to drive our economy for sustainable growth with less dependence on fossil-based resources, conforming with the UN Sustainable Development Goals (SDGs). Thailand has competitive advantages of immense wealth of natural and bio-resources. However, transforming the existing fossil-based economy to the BCG economy requires great effort, interaction and collaboration between different players on various levels. The BCG strategy consists of 4 drivers and 4 enablers, involving the government, industry, communities, academia and international organizations. The BCG drivers include sectoral development, talent & entrepreneur development, area-based development, and frontier research/knowledge. The enablers include regulatory framework, infrastructure & facility development, capacity building, and global network.



Dr. Morten Ambye-Jensen, Aarhus University, Denmark

Sustainable production of proteins from grass and legumes in a green biorefinery - development from pilot scale to commercial implementation

Research and development at industrially relevant scale is of critical importance for an efficient and persistent implementation of biorefining technologies within the circular bioeconomy. A new demonstration scale platform for green biorefining, producing a leaf protein concentrate, a fibre press cake and a process liquid rich in soluble organics and inorganic nutrients, has been established at Aarhus University. The facility was inaugurated July 2019 and has been serving a broad spectrum of ongoing R&D projects for optimizing processes and increasing value within green biorefining.

Green Biorefining holds vast potentials as a new source of proteins for a growing population. Furthermore, the environmental benefits of growing perennial grasses and legumes on arable soil, includes reduced nutrient leaching and -pesticide use as well as increased soil carbon. However, for large-scale implementation the technology needs to prove economically sustainable as well as practically- and industrially viable. The results have now paved the way for commercial implementation of the technology in Denmark.



Dr. Jesper Ahrenfeldt, Stiesdal Fuel Technologies, Denmark

Skyclean biorefinery concept



Dr. Ondřej Mašek, University of Edinburgh & UK Biochar Research Centre, UK

Integration of biomass pyrolysis and biochar in biorefineries

Attempts to reduce carbon emissions into the atmosphere and thus mitigate changes in climate have led to development and progressive deployment of a number of technologies that offer cleaner electricity, heat, transport fuels, and materials. Due to the perceived carbon neutral nature of biomass, bioenergy, biofuels and green chemicals are playing an important role in the climate change mitigation efforts.

The need for an increasing contribution of renewable energy sources has been recognised and highlighted in the IPCC 5th Assessment Report. However, this report also argues that to get GHG emissions on the trajectory required by some of the low-stabilisation scenarios, e.g. reaching atmospheric concentration levels of about 450 ppm CO_{2eq} by 2100 (consistent with a likely chance to keep temperature change below 2°C relative to pre-industrial levels), would require deployment of carbon-negative technologies, such as Bioenergy and CCS (BECCS). There are different ways how CO₂ can be removed from bioenergy and biofuels plants, one of which is capture of released CO₂ in the production process and its transport and sequestration. The option that will be discussed in this presentation is the use of pyrolysis technology and biochar, where part of the carbon contained in the biomass feedstock is stabilised in solid form before sequestration.

Research on biochar has been growing rapidly over the past decade and yielded a lot of new findings. At present first small-scale applications are starting to emerge, establishing first commercial ventures. In this presentation I will discuss the potential for integration of biochar as a carbon sequestration technology with different processes for conversion of biomass, and benefits as well as challenges that this may bring.



Prof. Irini Angelidaki, Technical University of Denmark, Denmark

Biotechnology as a tool for capturing and recycling of CO₂

The concentration of CO₂ has reached very high levels, which has tremendous negative impact on climate and threatens the environment. Although, much emphasis has been given on reducing GHG emissions, carbon capture and storage (CCS) are also needed. Several studies have shown that reduction of CO₂ emissions are not enough to stop serious global warming. Innovative methods are needed to store or recycle CO₂. However, the most of the proposed methods for CO₂ storage seem to be very expensive and technologically difficult. On the contrary, biotechnology can play an important role in capturing CO₂ in products and thereby recycle it. The biological capture of CO₂ in microbial cells, has emerged as a promising way of recycling CO₂. Indeed, binding of CO₂ to various high value products, such as proteins (e.g., microbial cells containing high content of proteins using methanotrophic bacteria), or functional foods containing high content of antioxidants, or biosuccinic acid using bacteria (e.g., *Actinobacillus succinogenes*) or biomethane using archaea, are some of the promising solutions for carbon capture and use (CCU). Recent techno-economic analyses and life cycle assessments have clearly shown that biotechnological processes that recycle and upgrade CO₂ into high-value end-products, and at the same time use all the individual components of the biomass in a cascade based approach show promising prospects for a sustainable use of the biomass resources. In this presentation, I will present results from various biotechnological approaches by which CO₂ is incorporated into biostimulants, biomethane, biosuccinic acid and single cell proteins for food/feed purposes.



Dr. Xavier Flores-Alsina, Technical University of Denmark, Denmark

Model-based assessment of carbon fluxes in a full-scale industrial water treatment system

In this study a model based approach is developed to support process engineers in how to optimize: 1) energy recovery, 2) chemical use, 3) operational procedures and 4) retrofitting equipment (=capacity liberation) at a full-scale industrial wastewater treatment system treating wastewater from the biotech industry. These models are coded and simulated in a single software platform and generate the holistic benchmarks and metrics to evaluate options prior to implementation. In this way, it is possible to answer the question, should I go for this option? Simulation results show that plant measurements and model predictions range up to 15 % difference. The proposed approach is capable of reproducing main streams neutralization, volatile fatty acid production, particulate removal and nitrate denitrification in the first units of the flow diagram (buffer tank, primary clarifier, pre-acidification tank). It also correctly predicts biogas composition as well COD recovery in the form of electricity and heat in the anaerobic granular sludge reactor and the scrubbing unit. Finally, it is

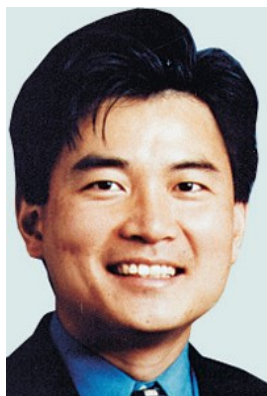
possible to describe N and P removal processes, energy consumption, use of chemicals and the quality of sludge after inactivation/dewatering. The final part of the study will show for the very first time a functional plant-wide model of the biggest industrial water plant in Northern Europe and the detailed discussion of different capacity liberation options discussing OPEX supported by simulations. The study shows the huge potential of water digitalization when optimizing water systems.



Dr. Aline Machado de Castro, Petrobras, Brasil

Increasing value of by-products from biodiesel and bioethanol industries through biotechnological routes

During the production of biodiesel from oleaginous plants and bioethanol (and its peer product, the edible sugar) from sugarcane, side streams such as glycerin, vinasse, molasses, and bagasse are, generally, not utilized to their full potential. They are carbon and nutrient-rich, offering valuable media for the exploitation of a biorefinery environment. In this speech, we will discuss the rationale behind the choice of target products and present some examples of our findings on biotechnological transformations of those streams to key (bio)chemical building blocks (alcohols, acids), solvents and biofuels.



Prof. Jay H Lee, Korea Advanced Institute for Technology (KAIST), Korea

Co – author: Seongwhan Kang

GIS-based Design and Evaluation of Biorefinery Supply Chain

This research suggests a three-stage model based framework for the design of an economic microalgae-based biofuel supply chain considering the geographic characteristics of a target area. First, the design stage decides the dimensions of each type of biorefineries, and economic analyses are done to estimate the processing costs for different design options. Using the spatial dimensions determined in the first stage, the second stage selects the candidate locations for the biorefineries using a geographic information system (GIS) based site evaluation. This stage screens the available land area for the biorefineries and also reduces the computational burden of the latter stage. In the mathematical optimization stage, a mixed-integer fractional programming optimization model is formulated to make multi-period strategic and tactical decisions of the supply chain under the unit supply cost minimization objective. The model framework is demonstrated through a case study in three distinct areas, Texas, the U.S., Northern Territory of Australia, and La Guajira, Colombia, selected through a global analysis of suitable land based on GIS.



Prof. Saeid Baroutian, University of Auckland, New Zealand

Recovery of flavour and bioactive compounds from New Zealand's native trees

Kānuka tree, *Kunzea ericoides*, is a native New Zealand plant that has a long history of a wide range of practical and medicinal uses. Despite its well-documented anti-microbial and anti-inflammatory properties, the use has primarily been limited to honey and essential oil production. There is a notable prolific and underutilised source of kānuka currently available on East Cape of New Zealand. By taking advantage of this abundance of trees in collaboration and engagement with the indigenous communities of East Cape (Māori) we have developed new high-value food additive products and bioactive ingredients. By integrating fast pyrolysis, spray drying and subcritical water extraction processes, we have developed a range of high-quality unique products. This project is looking at setting up a manufacturing plant in East Cape of New Zealand so that the whole indigenous Māori community can benefit from job opportunities.



Prof. Dehua Liu, Tsinghua University, China

A Commercial Demonstration of Biorefinery of Lipids----Coproduct of Biodiesel and 1,3-Propanediol

Lipase-catalyzed transesterification (also esterification) from lipids for biodiesel production has some advantages over chemical-catalyzed process, such as environmental friendship, lower energy consumption, widely suitable for low quality vegetable oils or animal fats. However, the low stability of the lipase due to alcohol has been being regarded as the main hurdle to the industrialization of lipase-catalyzed biodiesel production. Tsinghua University has developed a novel process to eliminate the inhibition of methanol on lipase, thus the operational life of the lipase could be improved by more than 300 cycles from several (1-5) cycles while traditional process applied. The patented novel process was successfully demonstrated in several commercial plants (20-100 thousand ton/year).

As a by-product, glycerol will be produced at about 10% of biodiesel during the process of biodiesel production. More and more concerns were pay on how to utilize the crude glycerol. It could be a promising way to produce 1, 3-propanediol (PDO) by fermentation with crude glycerol as feedstock. PDO is a valuable monomer to synthesize polytrimethylene terephthalate (PTT). PTT has excellent properties for textile fibre or engineering plastics, and it was found to have some better properties than other polyesters such as PET, PBT. Tsinghua University has developed a novel flexible process for PDO production by fermentation from glycerol or sugars, and it was also successfully commercialized.



Prof. Anker Degn Jensen, Technical University of Denmark, Denmark

Enhancing bio-oil quality and energy recovery by atmospheric hydrodeoxygenation of wheat straw pyrolysis vapors using Pt and Mo-based catalysts

Atmospheric hydrodeoxygenation (HDO) of wheat straw fast pyrolysis vapors was studied as a promising route for the production of renewable liquid transportation fuels. The performance of TiO₂-supported Pt (0.5 wt.%) and MoO₃ (10 wt.%) catalysts was compared to an industrial Mo-based catalyst using a bench scale reactor operated at atmospheric pressure and up to high biomass-to-catalyst ratios (B:C). Mass and energy balances were complemented by detailed bio-oil characterization including advanced methods such as GC×GC-ToF/MS or-FID and 13C NMR. At 50 vol.% H₂, all three HDO catalysts effectively reduced the oxygen content of the bio-oils to ~7-12 wt.% (dry basis) compared to a non-catalytic reference (23 wt.% O). MoO₃/TiO₂ was least efficient in conversion of acids (TAN = 28 mg/KOH), while Pt/TiO₂ and MoO₃/Al₂O₃ obtained oils with TAN ~13 mg KOH/g (non-catalytic = 66 mg KOH/g). Compared to the TiO₂-supported

catalysts, the industrial Mo/Al₂O₃ catalyst produced higher yields of coke at the expense of condensed bio-oil. MoO₃/TiO₂ performed similar to Pt/TiO₂ in terms of deoxygenation and energy recovery of condensed bio-oil, and by increasing the H₂ concentration to 90 vol.% the energy recovery of bio-oil increased to 39 and 42% at 8 and 10 wt.% O (d.b.), respectively. Pt/TiO₂ showed the highest selectivity to aliphatics and the lowest coke yields, e.g. the coke yield at B:C ~8 was only 0.6 wt.% of fed biomass. This study demonstrates that by using low-pressures of hydrogen and appropriate HDO catalysts, the quality of bio-oil can be improved without severely compromising its quantity (carbon yield) as observed under catalytic fast pyrolysis conditions using acidic catalysts in the absence of hydrogen.

Session V – Industry perspectives



Dr. Bent Sarup, Alfa Laval, Denmark

Pretreatment for Hydrotreated Vegetable Oil Production

There is currently a surge in demand for technology to produce renewable fuels such as diesel and jet fuels, from fats and oil. This has by some been named Hydrotreated Vegetable Oil (HVO) technology, although also a range of non-vegetable oils can and are being used. In order to secure the lifetime of the hydrotreating catalyst the fats and oils need to be pretreated to remove impurities negatively affecting catalyst lifetime. For this a subset of technologies from the edible oil industry can be applied when duly adapted to a service in HVO pretreatment. This presentation will provide an overview of common feedstocks, the requirements for the pretreated oil and a technology overview. It will further point towards future challenges and need for R&D to secure an increase in the available feedstock.



Hans-Martin Friis Møller, Kalundborg Forsyning A/S, Denmark

The Utility's role in the industrial symbiosis



Per Møller, Kalundborg Symbiosis, Denmark

Industrial and Urban Symbiosis – the new normal

Industrial Symbiosis is recognized by the EU to empower industry towards the realization of a circular economy. To succeed, this mindset needs to be understood, accepted, and integrated into organizations and business networks in order to unleash its full potential. Kalundborg Symbiosis has proven just this, becoming an award-winning example for industrial clusters around the world. In this presentation you will get a glance at its public-private cross-sectoral partnership model and value proposition. Industrial and Urban Symbiosis is already defining the "new" normal, where production is decoupled from resource consumption, and cities and industry inhabits a joined ecosystem.



Dr. Rofice Dickson, Lahore University of Management Sciences (LUMS), Pakistan

This work evaluates the economics, environmental impact, risk assessment, and optimal processing route of bio-SA production from multiple feedstocks (first, second, and third-generation), including (1) glucose, (2) corn stover, (3) glycerol, and (4) seaweed. A superstructure-based optimization model consisting of 39 processing alternatives with a technology readiness level of 7–9 is developed, and the optimal topology for bio-SA production by maximization of the net present value under deterministic and stochastic conditions is identified. Once optimization is completed, the framework provides clear guidance for multi-criteria analysis, including the technical, economical, and environmental aspects of the biorefinery.



Prof. Fernando Pellegrini Pessoa

Co – author: Dr. Ewerton Emmanuel da Silva Calixto

SENAI CIMATEC Competence Center in Chemical and Biochemical Process Intensification Engineering

Due to its biodiversity, Brazil has Industrial Biotechnology as the most promising vector for its economic and social development. It is evident the importance of Process Intensification, associated with the concept of industry 4.0, in the development of new products and processes, as well as in the improvement of existing and operating systems. The SENAI CIMATEC Competence for Chemical and Biochemical Process Intensification Engineering (CCEIPQB) has started in that direction in order to get a more sustainable production, with minimum cost and more modern and better systems. Therefore, the CCEIPQB aims to propose innovative and sustainable processes/products as solutions to various social dilemmas, contribute to the training of qualified personnel, attract new projects and services in modeling (kinetics, thermodynamics, etc.), simulation and optimization of chemical and biochemical processes, energy integration of processes and minimization in the disposal of aqueous effluents. Furthermore, the focus of this Competence Center lies on the application of engineering concepts in its broadest sense and the SENAI CIMATEC University Center with its undergraduate and graduate courses, together with all the infrastructure offered by CIMATEC PARK (technological park for the development of pilot plants), has the necessary expertise to train skills in this area of paramount importance.



Prof. Mauricio Sales-Cruz, Metropolitan Autonomous University (UAM), Mexico

Comprehensive assessment of a 2G bioethanol biorefinery: Process Intensification

Recently in Process Systems Engineering, process intensification techniques are being developed and implemented to obtain safer processes, with greater equipment efficiency, reduce their size and operating costs, incorporate retrofitting, consume a minimum of energy, generate the least possible amount of waste and obtain as many products with the least possible amount of raw material. Under this perspective, the second generation (2G) ethanol production process has not been extensively investigated. Generally, the studies reported on the design of 2G ethanol production plants have focused on: the determination of efficient pretreatments for lignin removal, the improvement of enzymes and strains to increase the efficiency of the saccharification and fermentation stages, respectively; and the recovery of waste such as lignin and fermentation residues. However, to achieve sustainable designs it is necessary to analyze aspects of energy integration, waste management and its environmental impact. Hence the objective of this work is to propose a methodology to evaluate alternatives for the synthesis of a 2G ethanol biorefinery from agroindustrial waste (or lignocellulosic raw material), with the incorporation of different processing technologies, to obtain data that support the eligibility of a sequence of most appropriate operation in technical, economic and environmental terms. The methodology is based on modeling, synthesis, design and simulation, where the heat integration in the 2G biorefinery is a key tool to evaluate the process in technical, economic and environmental terms. First, a conceptual design of the industrial scale production process is established, which consists of technological alternatives that may exist in the market or that may be created. In this stage the processing conditions are limited in terms of the availability of the raw material, installed capacity, processing cycle and other restrictions imposed. Then, a basic design is made to determine the operating conditions and the design of the equipment, criteria for cost evaluation and environmental impact are established to determine the viability of the process. Detailed process flow diagrams are used with various alternatives for the 2G biorefinery: (a) the first option corresponds to a standard design that includes traditional technologies for the pretreatment, saccharification, fermentation, separation and purification; (b) other options consider alternatives for the pretreatment (acid process or steam explosion) and the purification (molecular sieves or extractive distillation), and additionally options for wastewater treatment and energy cogeneration.

Sugarcane bagasse was considered as raw material, and the simulations were performed using process simulators (SuperPro Designer and Aspen). For the assessment and comparison of the biorefinery alternatives, the evaluation criteria were: unit production cost, waste emissions, and overall energy required. The results show which process alternatives can lead to higher sustainable ethanol production, supporting better decision making in the synthesis and design of biorefineries and pointing to where research should be directed to obtain integrated processes.



Prof. Mario Eden, Auburn University, USA

Process Intensification for Scalable Desulfurization of Biogas

Most distributed natural gas resources like shale gas, landfill gas, and biogas, contain significant amounts of sulfur (primarily as hydrogen sulfide). Before these carbon resources can be utilized, it is necessary to reduce the sulfur content (ranging from several hundred ppm to several percent) to acceptable levels for further processing (e.g. <1 ppm for certain catalytic conversion processes). Moreover, small-scale desulfurization technologies commonly use adsorbents to remove the sulfur, which is expensive and generates significant amounts of waste. At larger scales, catalytic processes like the Claus process, can be effective, but are too complex and capital-intensive for distributed applications, such as small biorefineries. In the absence of effective, low-cost solutions to desulfurize small-scale, distributed resources, the sour gas is either vented, flared, or simply capped, and thus not utilized. The estimated amount of methane vented/flared from landfills in the US alone is over 250 billion ft³ annually. The methane emissions associated with venting along with the CO₂ emissions resulting from flaring contribute significantly to the global greenhouse gas burden.

As part of an ongoing research project supported by the RAPID Institute for Process Intensification, we are evaluating the performance of a new modular, scalable catalytic desulfurization process, SourCat™, that was developed by our partner IntraMicron. The technology utilizes a patented oxidative sulfur removal (OSR) catalyst, which selectively oxidizes a range of sulfur compounds, i.e. H₂S, COS, and simple mercaptans to elemental sulfur.

Using experimental process data combined with literature information, we have developed process models for four different desulfurization technologies: 1) SourCat™, 2) iron-chelate systems (LO-CAT®), 3) Claus, and 4) Triazine scavenger. The processes are modeled at a range of processing rates (1 to 1,000 MMSCFD) and inlet H₂S concentrations ranging from 500 ppm to 2,500 ppm in order to evaluate the desulfurization cost.

This presentation will provide an overview of the scalable SourCat™ desulfurization process along with a discussion of the results of the process modeling and techno-economic analyses, which show that the SourCat™ process is a viable and cost-effective option for sweetening of distributed biogas resources, thus eliminating the need for traditional adsorbent beds.