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THE ROLE OF PERVAPORATION IN BIOREFINERIES AND SOME CONCLUDING REMARKS

FRENCH-NORDIC RESEARCH DAY – PARIS, MARCH 10–11, 2016

BIOMASS CONVERSION: GREEN CHEMISTRY & INNOVATIVE PROCESSES

Riitta L. Keiski, Professor, Dean
University of Oulu, Faculty of Technology
Environmental and Chemical Engineering Research Unit
riitta.keiski@oulu.fi; www.oulu.fi/pyolam

14.3.2016

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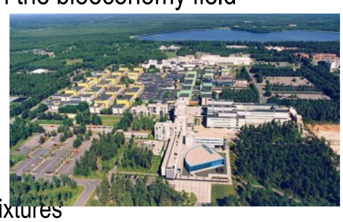
OUTLINE OF THE PRESENTATION

- Information about my home university's activities in the bioeconomy field
- Introduction
- Sustainability
- Pervaporation
- Pervaporation cases
  - Butanol recovery from aqueous multicomponent mixtures
  - Dehydration of ethanol
  - Dehydration of ionic liquids
- Conclusions
- Counclusions concerning the networking event



PERVAPORATION - separation process in which liquid mixture is separated by a partial vaporization through the membrane.

During pervaporation, the feed mixture is in a direct contact with one side of the liophilic membrane whereas the permeate is removed in a vapor state from the opposite side into a vacuum or sweeping gas and then condense.

By Wojciech Kujawski, 2010

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Our strategy is based on five thematic, internationally significant research focus areas

University of Oulu

- Multidisciplinary university with 10 faculties from humanities and medicine to economics and technology

Creating sustainability by materials and systems

Molecular and environmental basis of life-long health

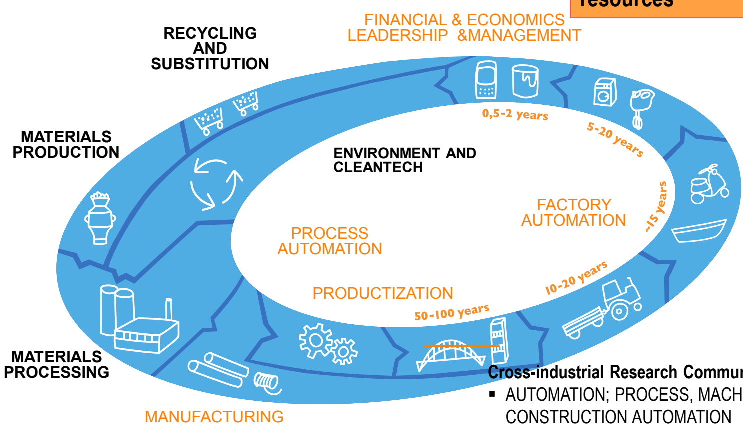
Digital solutions in sensing and interactions

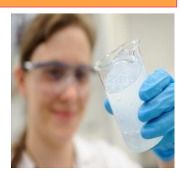
Earth and near-space system and environmental change

Understanding humans in change

FACULTY OF TECHNOLOGY
Material Life cycle

Faculty of Technology focuses its education and research activities on **sustainable utilisation and industrial value addition of natural resources**





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Cross-industrial Research Communities
- AUTOMATION; PROCESS, MACHINE AND CONSTRUCTION AUTOMATION
- ENVIRONMENT, SUSTAINABLE PRODUCTION AND CLEANTECH INNOVATIONS
- PLANNING AND PRODUCTISATION

Value Chain Research Communities
- STEEL PRODUCTION, FABRICATION AND APPLICATIONS
- NOVEL INORGANIC MATERIALS AND CIRCULAR ECONOMY
- BIOECONOMY; BIOMATERIALS AND BIOCHEMICALS

RESEARCH COMMUNITIES - New research organization structure

Reason: Science is increasingly a group effort, universities must build structures to support that

Goal: To improve knowledge flows, enable collaboration, support ESRs careers and enhance multidisciplinarity and possibilities for new research openings and funding

Faculty of Technology: 13 Research Units, 250 employees, 22 professors

FACULTY OF TECHNOLOGY
Dean Riitta Keiski

Value Chain Research Communities:
- STEEL PRODUCTION, FABRICATION AND APPLICATIONS
- NOVEL INORGANIC MATERIALS AND CIRCULAR ECONOMY
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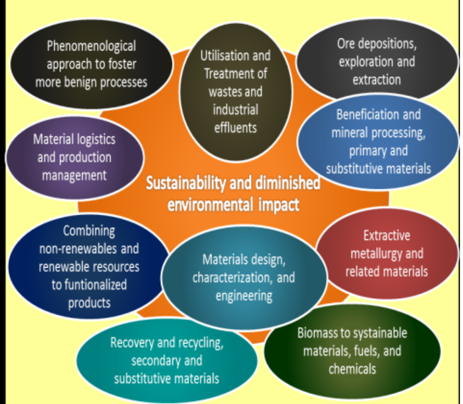
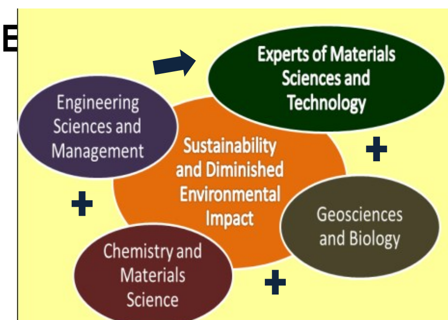
Cross-industrial Research Communities:
- AUTOMATION; PROCESS, MACHINE AND CONSTRUCTION AUTOMATION
- ENVIRONMENT, SUSTAINABLE PRODUCTION AND CLEANTECH INNOVATIONS
- PLANNING AND PRODUCTISATION

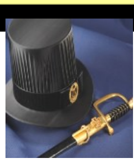
WORKSHOPS AND LABORATORIES

ADMA-DOCTORAL PROGRAMME

www.oulu.fi/adma/





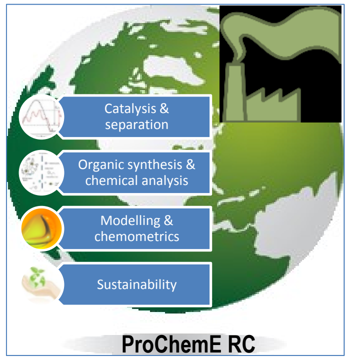


ADMA-DP

- A high-quality, international & multidisciplinary doctoral training, research on **natural and man-made materials and technologies for sustainable products, production processes and environmental applications**
- 26 Research groups from 4 Faculties at UOulu
- **11 salary-based positions** for 4 years each, coordination and management funding (**~1 950 000 €**)
- **Marie Curie ITN funding**: 3 positions (**~800 000 €**), Mathematics and Materials Science for Steel Production and Manufacturing
- EIT Raw Materials ADMA KAVA 2016-2018

SUSTAINABLE SOLUTIONS FOR PRODUCTION PROCESSES AND ENVIRONMENTAL APPLICATIONS, ProChemE RC

- **Consortium between:**
  - Environmental and Chemical Engineering (ECE)
  - Synthetic Organic Chemistry (OChem)
  - Inorganic Analytical Chemistry (AChem)
- **The main objective**
  - To develop sustainable and innovative technologies for production processes and environmental applications with a highly positive and significant societal impact and
  - To increase collaboration between RC partners as well as with partners in the RC's national and international networks
- **The concept of *'Science into products and production technologies'* will bring value both to academia and industry**



ProChemE RC provides scientific knowledge to design sustainable technologies for production processes & environmental applications

Cleantech innovations

www.oulu.fi/procheme/

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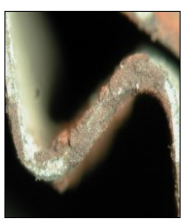
FACULTY OF TECHNOLOGY

ENVIRONMENTAL AND CHEMICAL ENGINEERING RESEARCH UNIT (ECE)

Catalysis for the Support of Sustainability

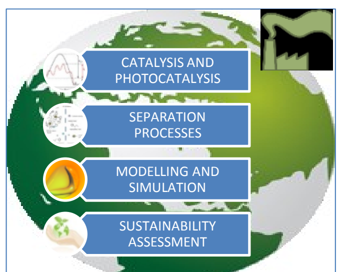
Separation Processes for the Support of Sustainability



Bioeconomy – Circular Economy Biomass, Secondary materials

Focus on Sustainable Production and CleanTech Innovations

www.oulu.fi/pyolam/



CATALYSIS AND SEPARAT-ION TO HYBRID STRUCTURES - Use of modelling & sustainability assessment

Development of sustainability assessment tools and criteria, Presently, for social impact evaluation, toxicity, and health effects of emissions

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MAIN RESEARCH TOPICS

‘Development and use of catalysts and membranes for biorefineries and in industry at large’

- CATALYSIS
  - **Catalysis and photocatalysis in fuels and chemicals** production from **biomass based and waste streams**
    - **Production of H_2**: Photocatalysis (a patent) and catalytic reforming (e.g. biogas/methane, C1-C4 alcohols, glycerol as H_2 carriers) (**conventional, CNT- and metal nanowire-based catalysts**)
    - **Biobutanol (ABE) production** from lignocellulosic materials and product purification; combining biochemical and chemical approaches
    - **Formaldehyde** from contaminated methanol (S), in pulp and paper industry
  - **Catalysis and photocatalysis in flue and exhaust gas purification, VOC abatement** (VOCs, CVOCs, malodorous and toxic compounds, NO_x, CO, HC, PM), and water purification
    - **Novel and poison resistant catalysts and methodology development for accelerated deactivation**
    - **Photocatalytic wastewater stream purification**
    - **Novel catalysts for environmental applications;** use of primary/secondary/substitutive materials
    - Catalytic **utilization of compounds** in emission streams
  - **CO_2 utilization**
    - Use of e.g. VOCs, CO_2 **in chemicals and fuels production and parallel to biomass utilization**
    - CO_2 as a **solvent in catalytic reactions**
    - Use of CO_2 in **mining industry beneficiation processes** (grinding and flotation)

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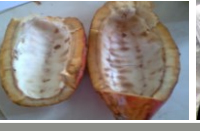
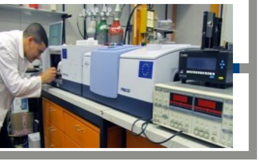
Main Research Topics

- SEPARATION PROCESSES
  - **Separation, purification, recovery, recycling**
    - Hydrogen, biogas, biofuels, nutrients, heavy metals, metalloids separation and purification
    - Membranes, adsorption materials, photocatalysis, chromatography, supercritical extraction
  - **Membrane technologies**
    - **Pervaporation: solvent recovery, ionic liquids purification/dewatering**
    - **Gas membranes**: biogas purification, separation of small gas molecules
    - **Nano- and ultrafiltration (MEUF and SEUF)**: phosphorus and other nutrients recovery, heavy metal and metalloids separation, anion and cation removal and concentration
    - **Reverse osmosis and UF**: recovery of valuable compounds from berries (flavonoids and antocyanides)
  - **Adsorption and photocatalysis**
    - Use of wastes or side products in materials development
    - Nanomaterials, activated carbons, iron and titanium based for water and gas stream purification
  - **Chromatography and supercritical extraction**
    - Protein separation
    - Seed oil refining, peat extraction

Cocoa (***Theobroma cacao***) pod husk (CPH)





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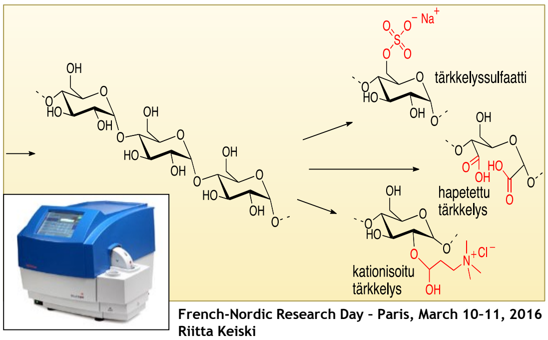
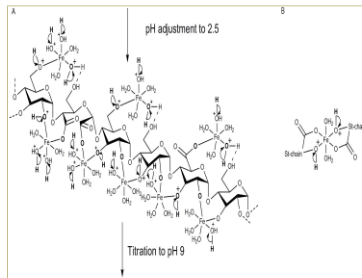
MODIFICATION OF STARCH AND ITS USE IN SEPARATION OF NUTRIENTS AND HEAVY METAL IONS

- Hydrolysis
- Oxidation
- Cationization
- Sulphonylation

- Polymer enhanced ultrafiltration
  - Starch derivatives as complexation agent
  - Metallic ions of Fe, Ni, Zn, Cu, Cr
  - Nutrients (P, N, S)

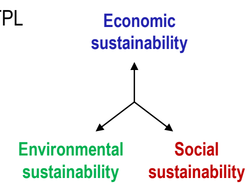


By Marja Lajunen, 2015



CROSS-CUTTING RESEARCH TOPICS

- **SUSTAINABILITY ASSESSMENT**
  - Research related to CO_2 utilization, biobutanol production, air purification and water treatment
  - For the technologies, processes, raw materials and products studied in MHTPL
  - Impacts on human health, environment, economy, society
  - Development of **sustainability assessment tools and criteria**
  - **Social impact evaluation, toxicity, health effects of emissions**

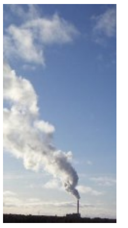


- **MODELLING AND SIMULATION**
  - In process and unit operation design: membranes, catalytic reactors, processes; combining modelling and experimental approaches
  - Fouling of heat exchange surfaces; combining modelling and experimental approaches
  - CFD, DEM, thermodynamics, kinetics
  - Energy efficiency, energy optimization models for real estates
  - Systematic/Statistical experimental design, DoE

- **COMBINING CATALYSIS AND SEPARATION TO HYBRID TECHNOLOGIES**
  - Utilization of modelling and sustainability assessment

APPLICATION AREAS

- **Development and use of unit operations for biorefineries**, chemical, mining and metallurgical industry, and SMEs and industry at large
- Cleantech applications
- Sustainable environmental and process technologies especially for mining/metallurgical and pharmaceutical/food/chemical industry, and **biorefineries**
- Use of renewable materials, recycled materials, and waste streams
- Use of primary, secondary and substitutive materials in materials development



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NETWORKING

- **SkyPro Oulu clean air cluster*** (part of CEE/OIA),
- National and University of Oulu collaboration: OMS, CASR, CSTIs (Cleen Ltd., FIBIC Ltd., FIMECC Ltd.)
- **International networks** (Marie Curie/NO-WASTE*, ERA-NET, New Indigo/Greentech*, COST Actions), and **international projects**
- **ADMA* and Thule DPs, and ProChemE*, Luminous and MtM RCs**

* coordination

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INTRODUCTION

- Increasing demand to produce fuels and chemicals from renewable resources
  - Biodiesel, bioethanol, biobutanol, biogas, hydrogen etc.
- Production processes should be
  - Technically feasible, economic, sustainable
- Separation processes have an important role in these processes
  - Adsorption, distillation, filtration, gas stripping, liquid-liquid extraction, perstraction, pervaporation, reverse osmosis, vapour permeation

By Johanna Niemistö, 2014

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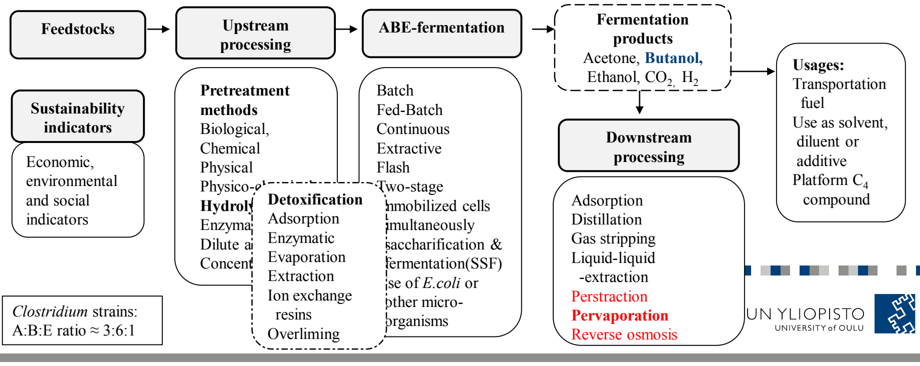


PROCESS INTENSIFICATION

- **Challenges**
  - Product inhibition
    - Low product concentrations, low yield
  - Cost of substrates and unit processes
    - Final cost of a product depends usually strongly on the efficiencies of the separation and purification steps
  - Complex process chains

- **Solutions**
  - Novel processing techniques
  - Hybrid processes
  - Biorefineries: combined production of fuels, value-added chemicals, power, heat, etc.

García V., Päkkilä J., Ojamo H., Muurinen E. & Keiski R.L. (2011), Challenges in biobutanol production: How to improve the efficiency? Renewable and Sustainable Energy Reviews 15(2): 964-980.
Niemistö J., Saavalainen P., Isomäki R., Kolli T., Huuhtanen M .& Keiski R.L. (2013), Biobutanol production from biomass. In: Gupta V.K. & Tuohy M.G. (eds) Biofuel Technologies: Recent developments. Berlin-Heidelberg, Springer-Verlag: 443-470.

SUSTAINABILITY

Niemistö J., Saavalainen P., Pongrácz E. & Keiski R.L.(2013), Biobutanol as a potential sustainable biofuel - Assessment of lignocellulosic and waste-based feedstocks. Journal of Sustainable Development of Energy, Water and Environment Systems 1(1) 27-45.

- Sustainability assessment focuses mainly in land use and GHG emissions ⟶ All sustainability aspects should be taken into account
- ”Triple bottom line” concept aiming to
  - Environmental responsibility
  - Economic return (wealth creation)
  - Social development

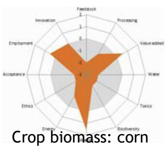
Figure:http://www.sustainability.umd.edu/content/about/what_is_sustainability.php

- Selection of proper indicators and measurement tools for impact evaluation is challenging
  - Harmonization and common criteria are needed

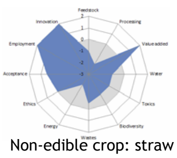
Economic	Environmental	Social
Feedstock price	Biodiversity and land use change	Customer acceptance and social dialog
Processing costs	Hazardous and toxic material usage	Ethicality and competing demand of raw materials
Value added	Emissions (e.g. GHG)	Employment effects
	Energy	Health and safety issues
	Wastes vs. by-products	Innovation and education potential
	Water consumption	

Food by-product: whey

Wood-based biomass: saw dust



Crop biomass: corn



Non-edible crop: straw

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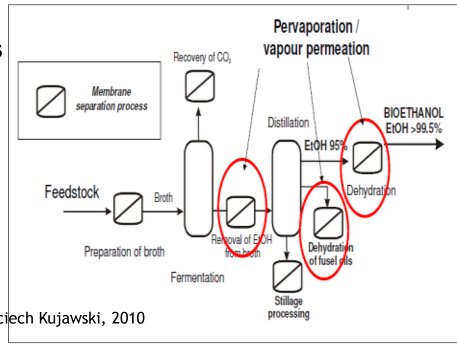
SUSTAINABILITY OF SEPARATION PROCESSES

- **Sustainability indicators:**
  - Operational conditions (temperature, pressure, heat sensitive compounds)
  - Energy efficiency
  - Material efficiency (need of chemical aids, recovery and reuse of them)
  - Separation efficiency: e.g. flux, selectivity, enrichment factor, stability
  - Health and safety issues
- **Distillation:** an energy intensive method
  - High enviromental and economic impacts
- **Liquid-liquid extraction and adsorption**:
  - Need of an extractant
  - Wnergy savings vs. separating agent
- **Membranes:**
  - Energy savings vs. membrane materials

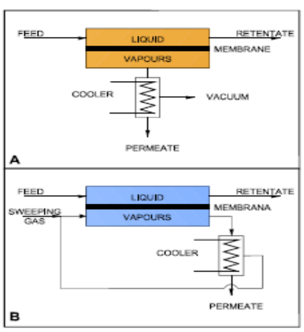
Membranes in ethanol production



By Wojciech Kujawski, 2010

PERVAPORATION

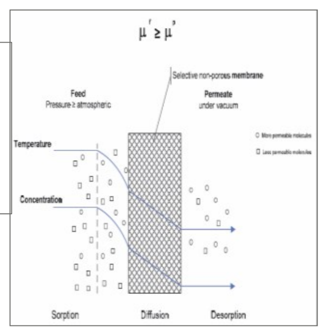
- Selective transport of component(s) through the membrane
  - Difference in chemical potential as the driving force, pressure driven mass transfer
  - Solution-diffusion mechanism through dense membranes
- Only permeate is evaporating → energy savings
- Mild processing conditions, can be combined together with the fermentation unit



A. Vacuum pervaporation

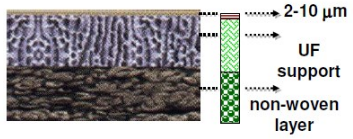
B. Sweeping gas pervaporation

Schematic diagram of the principle of the pervaporation (García 2009, Reclamation of VOCs, n-butanol and dicholormethane, from sodium chloride containing mixtures by pervaporation. Towards efficient use of resources in the chemical industry. PhD Thesis, University of Oulu).



By Wojciech Kujawski, 2010

ADVANTAGES OF PERVAPORATION



By Wojciech Kujawski, 2010, Johanna Niemistö, 2014

- Pervaporation is a superior technique in
  - Separation of azeotropic mixtures, heat sensitive compounds, mixtures including close-boiling point mixtures, or recovery of VOCs or impurities with minor concentrations in the feed solution (Shao & Huang 2007, Chapman *et al.* 2008)
  - When mild operating conditions are needed (biocompounds)
  - When there is no need for inserting any additional compounds into the process
  - No emissions to the environment (Shao & Huang 2007).
  - Possibility to obtain hybrid processes, *e.g.* by integrating a fermentor with a pervaporation unit or by combining other separation methods together with pervaporation makes increased product yields and efficiency possible

Advantages	Disadvantages
+ No additional chemicals needed	- Membrane **swelling**
+ More energy efficient than conventional distillation	- Temperature and concentration **polarization**
+ Simple, compact, flexible and versatile	- More or less **tailor-made** membranes needed for different applications
+ High selectivity also in lower operating conditions	- **Industrial scale** applications may be difficult to achieve
+ Can be combined to hybrid systems	

USE OF PERVAPORATION

Some potential applications:

- Removal of organic compounds from aqueous systems (separation of products/inhibitors/ valuable compounds from fermentation broths)
- Dehydration of organic solvents (azeotropic mixtures), ILs
- **Case-specific selection** of the best techniques for each process

separation of water from aqueous/organic mixtures	separation and/or dehydration of water-organic azeotropes (water-ethanol, water-isopropanol, water-pyridine, fusel oils); dehydration of organic solvents; shifting of the reaction equilibrium (e.g.esterification)
removal of volatile organic compounds (VOCs) from aqueous and gas streams	removal of chlorinated hydrocarbons removal of VOCs from water/air separation of aroma compounds continuous fermentation
separation of organic/organic mixtures	separation of azeotropes (e.g. ethanol-cyklohexane, methanol-MTBE, ethanol-ETBE), separation of isomers (e.g. xylenes).

By Wojciech Kujawski, 2010

- Pervaporation is used mainly in three different applications:
  - Dehydration of organic solvents (*e.g.* alcohols, ethers, esters, acids)
  - Removal of dilute organic compounds (*e.g.* VOCs, aroma compounds, biofuels from fermentation broths) from aqueous streams
  - Separation of organic–organic mixtures (*e.g.* methyl *tert*-butyl ether (MTBE) and methanol separation or dimethyl carbonate (DMC) and methanol separation).
- At the moment, dehydration of ethanol or isopropanol is the most important industrial application area of pervaporation and **the water removal from bioethanol is seen to have the greatest commercial potential** in the near future. (Baker 2012)

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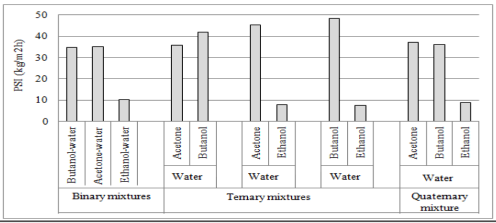
OUR RESEARCH: BUTANOL RECOVERY

- Membrane permselectivity followed the order of acetone ≈ butanol > ethanol
- Separation of ethanol was much lower as compared to acetone and butanol
- Permeation of n-butanol is preferable in solutions containing several organic compounds, indicating that the tested PDMS-membrane has a potential to be used in the ABE fermentation process.

- PDMS–PAN composite membrane
- Various binary, ternary and quaternary water–acetone-butanol-ethanol(ABE)-solutions at 42°C
- Permeation fluxes (J_i), membrane permeances (PM_i), separation factors (α_i) and pervaporation separation indices (PSI) determined



Niemistö J., Kujawski W., Keiski R.L. (2013), Pervaporation performance of composite poly(dimethyl siloxane) membrane for butanol recovery from model solutions. Journal of Membrane Science, 434:55-64.

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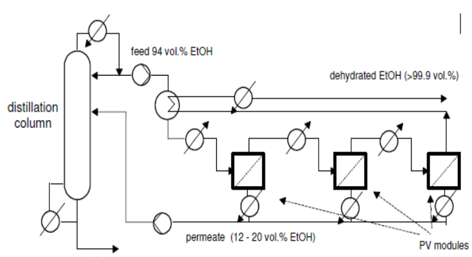
OUR RESEARCH: DEHYDRATION OF BIOETHANOL

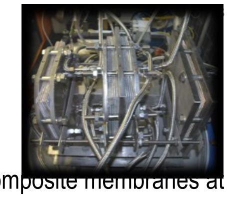
Run	Water permeance Q_{H2O} [g/m²hkPa]	Ethanol permeance Q_{EtOH} [g/m²hkPa]	Water/Ethanol selectivity α
1	10.8	0.08	248.5
2	10.8	0.07	161.5
3	20.3	0.08	261.4
4	15.5	0.08	232.8

- Tested membranes provided adequate selectivity, not only for the retentate (ethanol), but also for the permeate (water)
- Low ethanol concentration in the permeate favors intense integration of energy flows and energy savings



Niemistö J., Pasanen A., Hirvelä K., Myllykoski L., Muurinen E., Keiski R.L. (2013), Pilot study of bioethanol dehydration with polyvinyl alcohol membranes (**Submitted to Journal of Membrane Science**).

DEHYDRATION OF BIOETHANOL



- Feed pretreatment by charcoal filtration
  - An efficient and up-scalable method
- Pervap(r) based, hydrophilic crosslinked polyvinyl alcohol (PVA) composite membranes at 98 °C

Run	Feed EtOH conc. [wt%]	Final EtOH conc. [wt%]	Feed [kg]	Operation time [h]	Membrane area [m²]	Notifications
1	90.0	99.6	70	28	2	Retentate was circulated continuously back to the feed tank.
2	87.8	99.6	70	44 (10+18+16)	2	Both permeate and retentate were circulated back to the feed tank during the steady state stage.
3	85.1	99.6	35	18	1	Membrane 1
4	84.9	99.6	35	18	1	Membrane 2

- Permeation fluxes (J_i), membrane permeances (PM_i), separation factors (α_i) and pervaporation separation indices (PSI) were determined

Niemistö J., Pasanen A., Hirvelä K., Myllykoski L., Muurinen E., Keiski R.L. (2013), Pilot study of bioethanol dehydration with polyvinyl alcohol membranes (**Submitted to Journal of Membrane Science**).

J. Niemistö, Towards production of more sustainable and efficient biofuels – use of pervaporation in product recovery and purification. PhD thesis. Oulu 2014, ACTA Universitatis Ouluensis, C 485.

The aims of the research:

1) to obtain new knowledge of the transportation biofuel (biobutanol and bioethanol) production processes utilizing different kinds of biomasses

2) to develop more sustainable and more efficient production steps for these production processes

Biofuel/biobutanol production

Niemistö J., Saavalainen P., Isomäki R., Kolli T., Huuhtanen M., Keiski R.L. (2013) Biobutanol production from biomass. In: Gupta V.K., Tuohy M.G. (eds). Biofuel Technologies: Recent developments. Springer. Springer-Verlag, Berlin-Heidelberg (2013), Chapter 17. pp. 443-470.

García V., Päkkilä J., Ojamo H., Muurinen E., Keiski R.L. (2011). Challenges in biobutanol production: How to improve the efficiency? Renewable and Sustainable Energy Reviews 15(2011), pp. 964 - 980.

EXAMPLE of A PhD THESIS: Johanna Niemistö, PhD thesis, 2014
Towards production of more sustainable and efficient biofuels – use of pervaporation in product recovery and purification

Pervaporation studies

Niemistö J., Kujawski W., Keiski R.L., Pervaporation performance of composite poly(dimethyl siloxane) membrane for butanol recovery from model solutions. Journal of Membrane Science, 434 (2013) 55–64.

Niemistö J., Pasanen A., Hirvelä K., Myllykoski L., Muurinen E., Keiski R.L. (2013), Pilot study of bioethanol dehydration with polyvinyl acetate membranes. Journal of Membrane Science, 447 (2013) 119-127.

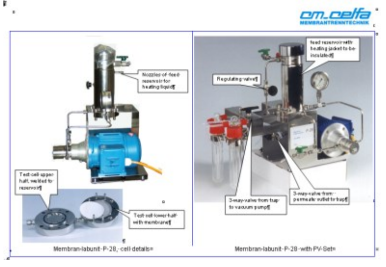
Sustainability

Niemistö J., Saavalainen P., Pongrácz E., Keiski R.L. (2013), Biobutanol as a potential sustainable biofuel - Assessment of lignocellulosic and waste-based feedstocks. Journal of Sustainable Development of Energy. Water and Environment Systems 1(2) 1–19.

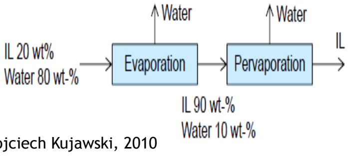
OUR RESEARCH: WATER REMOVAL FROM IONIC LIQUIDS

The aim of the research at the University of Oulu:

- To study the potential of pervaporation in the recovery of ionic liquids (IL) (modelling, technoeconomical evaluation)
- To find suitable membranes for the water recovery
- To achieve optimal operation conditions for the efficient (>99.5%) separation of water from IL
- PVA-TiO_2 membranes can be used to dehydrate [AMIM]Cl at moderate temperatures and thus allows a possible recovery method for [AMIM]Cl



García V., Valkama H., Sliz R., King A.W.T., Myllylä R., Kilpeläinen I., Keiski R.L. (2013), Pervaporation recovery of [AMIM]Cl during wood dissolution; effect of [AMIM]Cl properties on the membrane performance. **Journal of Membrane Science** 444 (2013) 9-15.

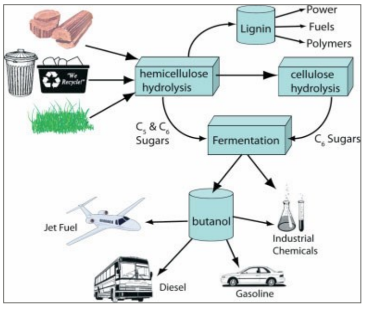


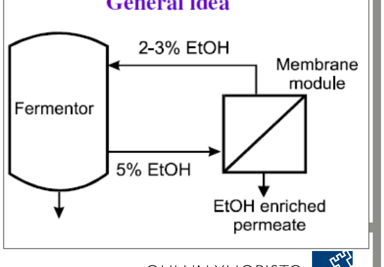
By Wojciech Kujawski, 2010

CONCLUSIONS

- Need to develop novel, superior and sustainable biofuel production processes and biorefinery concepts
  - Better yield
  - Industrial scale
  - How to combine biomass routes to waste and side product streams (gaseous, liquid, solid)
- Especially separation techniques have an important role in chemical industry and in biorefineries
- Pervaporation can be an excellent technique in certain separation applications
  - e.g. decentralized small-scale biofuel production

Figure: Harvey B.G. & Meylemans H.A. (2011), *J. Chem. Technol. Biotechnol. 86: 2-9*



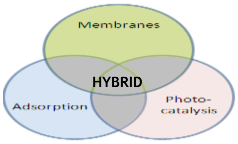


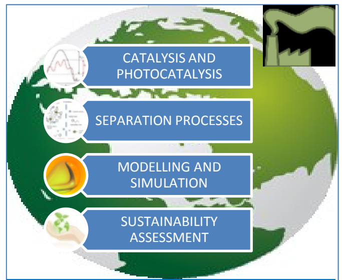
Membrane bioreactors, by Wojciech Kujawski, 2010

CONCLUSIONS

Target: To bring sustainable solutions to industry and cleantech area based on separation processes (e.g. pervaporation) and catalysis:

- Process and environmental catalysis – heterogeneous, homogeneous, biocatalysis
- Novel materials and materials development
- Wise use of primary, secondary and substitutive materials → improved materials recovery, substitutes for scarce natural resources, use of industrial side streams
- Hybrid methods combining membranes, adsorption and catalysis, and structures (e.g. new ideas in unit operation structures)





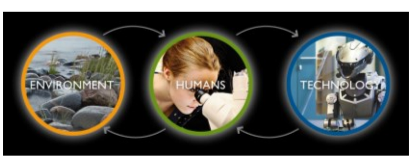
CATALYSIS AND SEPARATION TO HYBRID STRUCTURES - Use of modelling & sustainability assessment

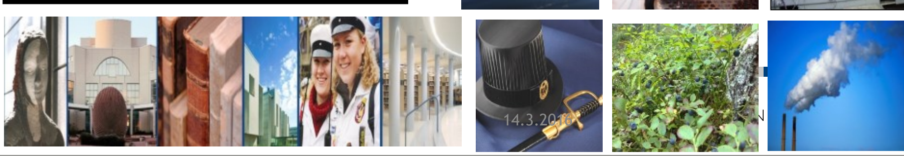
- **Assessing sustainability in an early stage of the technology to be developed**
- **Addressing key societal issues, e.g. CO_2 minimization, sustainable energy and production, catalysis**

Dean, Prof. Riitta Keiski
Faculty of Technology University of Oulu
+358 40 726 3018
riitta.keiski@oulu.fi; www.oulu.fi/pyolam

Many thanks to Prof. Wojciech Kujawski, Dr. Johanna Niemistö, Ms. Paula Saavalainen, and the ECE Research team

Thanks to the Audience!





NETWORKING EVENT: CONCLUSIONS

Norway: Moving from black to green: development of biorefinery processes and products in NO, Karin Øyaas, PFI

- Forest and wood sector can triple their turnover → Biomaterials, biochemicals, bioenergy (Biocomposites, mechanical pulping (fibre & paper), nanocellulose, carbohydrate polymers, biorefining and bioenergy)
- Renewable wood-based biofuels for shipping (low-S transportation fuel from upgraded fast pyrolysis oil)
- Norwegian Biorefinery Laboratory (Norwegian Research Council (4 M€): sugar, biogas, syngas and pyrolysis oil platforms
- Great possibilities for value creation, low price materials for energy products

France: Biorefineries: The central role of catalysis, Fredrik Dumeignil, UCCS

- Biomass → Chemicals + waste → …
- New approach for catalysis and new concepts of catalysis: robustness, H_2O tolerance (biomass releases/contains water), selectivity, activity, avoid over-reaction (yearly variation of biomass quality)
- Innovative catalysts and processes for oxidation reactions: applying new solids to biomass valorization: methanol to formaldehyde and DMM (FeMo catalyst, air as oxidant); ethanol to hydrogen
- From fundamental research to industrial applications
- Hybrid catalysts: multiprocesses, integrating two worlds: new reactors, new strategies for catalytically active phases,…

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14.3.2016

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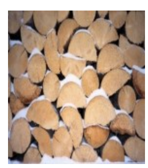
NETWORKING EVENT: CONCLUSIONS

- **Finland: Switchable ionic liquids in biorefining: from fractionation and pretreatment to catalysis and nanocellulose, Jyri-Pekka Mikkola, Umeå University**
  - New types of ILs, ILs in biorefineries: Simple SIL structures, enzyme friendly (aqueous)
  - Not interacting or bound to the active sites where reactions take place
  - Biomass pretreatment: application of new ILs
  - Superior process for cellulose nanofibers, IL pretreated wood chips
  - Energy savings

- **France: 2nd generation biofuels and bio-products: an overview of recent projects at IFPEN, Nadege Charon, IFPEN**
  - Biomass pretreatment, feedstock preparation
  - Life Cycle and multi-criteria Analysis (validation of sustainability criteria)
  - R&D, Technology licensors, Fuels producers
  - Catalyst development, process development, hydrotreating
  - Demonstration plants important
  - Importance of analysis: traceable, accurate; bidimensional (GC & GC), several analysis techniques need development and are important



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NETWORKING EVENT: CONCLUSIONS

- **Denmark: Biocatalytic enzyme processes for CO_2 conversion and lignin modification, Anne S. Meyer, Technical University of Denmark**
  - Biocatalytic conversion of CO_2 to methanol and Enzymatic upgrading of lignin
  - CO_2 emissions 35.7 bill. tons/year
  - Carbon cycle within the 'Methanol economy'
  - CO_2 conversion at exhaust site
  - Model compounds as a basic for building mechanisms

- **France: From different biomasses to new macromolecular architectures, Luc Averous, Univ. of Strasbourg**
  - Integration: from biomass to final products
  - Bioplastics, biomaterials
  - Taking advantages of the existing structures, examples lignin & fatty acids
  - Avoiding harmful process steps, solvent and catalyst free synthesis
  - A huge potential of chemical pathways
  - Innovative macromolecular architectures possible

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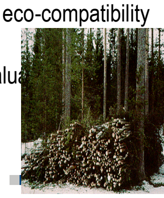
- **Finland: Low temperature transformation of biomass: challenge for chemical reaction engineering, Tapio Salmi, Åbo Akademi**
  - Kinetics, thermodynamics, heat and mass transfer, fluid dynamics/Reaction engineering
  - Hemicellulose an interesting starting compound for bioproducts, reaction engineering plays a role, cascade reactors; Kinetics: T and chip size important, Independent of pH
  - Low T important
- **France: Design of biobased solvents, Sophie Thiebaud-Roux, INP-ENSIACET**
  - Worldwide consumption of solvents in 2012: 28 million metric tons (6 million in Europe)
  - Biosolvents are already on the market
  - Criteria: technical specifications, environmental and health properties, eco-compatibility and efficiency of the process, cost
  - Substitution methodology, systhesis of the molecule, experimental evalua targeted application



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CONCLUSIONS

1. **The forest-based sector in a biobased society**(*
   - 1.1. Barriers and policy instruments in forest-based bioeconomy
2. **Responsible management of forest resources**(*
   - 2.1. Enhanced biomass production and new inventory systems (Forest Big Data)
   - 2.2. Forests and well-being
3. **Creating industrial leadership**(*
   - 3.1. Novel fractionation and modification technologies
   - 3.2. BioIT
   - 3.3. Distributed bioeconomy
   - 3.4. Circular economy based on renewables
   - 3.5. Bioenergy, biofuels and bioenergy carriers
   - 3.6. Business models and service concepts for bioeconomy
4. **Fulfilling consumer needs**(*
   - 4.1. Building with wood (including interior solutions)
   - 4.2. From wood to textiles (including demo-platforms)
   - 4.3. From wood and forests to food and feed
   - 4.4. Biochemicals and biomaterials
   - 4.5. New biobased products

Forest bioeconomy NRA

Recommendations for the Finnish forest-based bioeconomy R&D
By the Finnish National Support Group to the Forest-based Sector Technology Platform

NETWORKING EVENT: CONCLUSIONS

Tekes ACADEMY OF FINLAND

- **Academy of Finland:**
  - BioFuture 2025 Bioeconomy programme: All Research Councils are taking part in this call
- **Tekes, Nordic funding, H2020**
- **Science is increasingly a group effort; Universities, research institutes and research funding organisations must build structures to support that**
  - Improves knowledge flows, enables collaboration and enhances multidisciplinarity

NETWORKING EVENT: CONCLUSIONS

- **General observations:**
  - Forest and wood sector can triple their turnover; **News: European Bioeconomy worth € 2.1 trillion turnover and 18.3 million employees** – brings possibilities and motivation
    - **Food, feed and beverages industries** 50 % of that
    - **Biobased industries**: chemicals and plastics, pharmaceuticals, paper and paper products, forest-based industries, textile sector, biofuels and bioenergy; 600 billion **€**
  - Biocatalysts, heterogeneous catalysts, homogeneous catalysts - essential
  - Separation processes, membranes, pervaporation - essential
  - New catalytic materials and structures, combining reaction and separation, hybrid materials and structures – completely new ideas
  - ILs' multiple role in biorefineries – brings possibilities
  - Pretreatment of biomass – essential in some cases
  - Aqueous environment – brings challenges
  - Wise use of the biomass; Combining bioeconomy and circular economy concepts – needs information based on assessment
  - Brings different disciplines closer to each other – application areas, a necessity
  - Sustainability – a must

French-Nordic Research Day - Paris, March 10-11, 2016; Riitta Keiski

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