OPEN DAYS, European Week of Regions and Cities
Brussels, October 5-8, 2009
Growth and Competitiveness through Renewable Energy Resources

Sustainable Energy – Biofuels and Biorefinery Concept

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Mitigating the Environmental Impacts of Energy Generation
- CO_2 Related Research and Fuels Production

SkyPro Oulu – Science into Products and Processes
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Contact Information

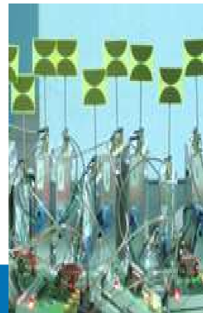
University of Oulu 2008

Founded in 1958
6 faculties
16 000 students
3 000 employees
Total funding EUR 208 million in 2008
Among the largest universities in Finland with an exceptionally wide scientific base

- First degrees 1340
- Doctoral degrees 134
- Publications 3640
  - Scientific publications 2254
- 63 invention disclosures, 6 patent applications

New University law in 2009:

The University of Oulu will be developed as an international science university in collabortion with research institutes and companies.



Structure for the New Collaboration at the University of Oulu

High quality, interdisciplinary, international, focused research and educational activities

Development of Science University

Graduate Schools
Centre of Excellence (SA)
Research Center(s)
Research Programmes
Doctoral Programme(s)
Master's Programme(s)

Interdisciplinary Graduate Schools

GS for Environment, Energy and Natural Resources

Co-operation with industry and society

Oulu Innovation Centers of Excellence

Centers of Expertise in Energy, Water and Air Industry Clusters (CEWIC, SkyPro)

Co-operation with research institutes

Interdisciplinary Research Centers

Center for Environment and Natural Resources

Vision: Sustainable energy

Environmental Engineering Research at the University of Oulu - Spearhead Sectors

- **Resource efficiency**
  - Waste minimization and resources use optimization
  - Process control and automation
  - Recycling technologies
- **Water**
  - Drinking and industrial water purification
  - Mechanical, chemical and biological wastewater treatment technologies
- **Air**
  - Catalytic air purification technologies
  - CO_2 utilization
- **Energy**
  - **Biorefineries**
  - **Biofuels, biogas, bio-H_2, fuel cells**
  - **Power plant automation**
  - **Energy efficiency**

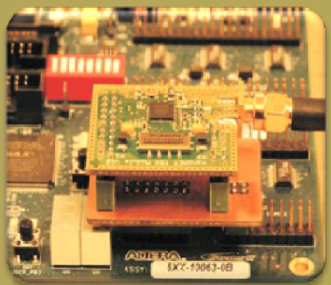
Sustainable Energy Research at the University of Oulu

Energy generation and renewable energy sources

- Modelling and Control of a Solar Thermal Power Plant
- Hydrogen Fuel Cell Electrochemical Model
- Hydrogen Production by Bio-ethanol Reforming
- Anaerobic Bioreactor for Biobutanol Production
- Bio-ethanol Production from Potatoes

Environmental impacts of energy production

- Control of Biomass Combustion for Emission Reduction
- Health impacts of particulates originating from engines
- Wood Ash – a Potential Forest Fertilizer
- Chemical utilization of carbon dioxide
- Socio-ecological impacts of energy generation (hydropower) in the North

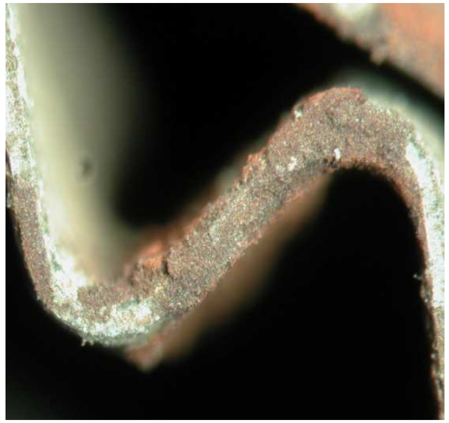


Energy-efficient products and processes

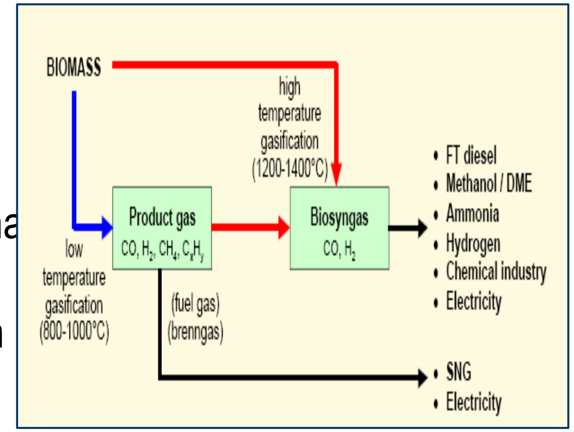
- Piezoelectric Energy Harvesting, Low Power Electronics
- Study of fouling on heat exchanger surfaces, effect on energy-efficiency
- Improved control of the cooking process in Kraft pulping
- Energy-efficiency in steel manufacture
- Improved measurement technologies

Catalysis Research by the Oulu Group - Pollution control, Sustainable energy and production, Fuels, Chemicals, Catalysts for biorefineries

- Catalytic oxidation of VOCs, CVOCs, malodorous compounds
- Catalytic oxidation and reduction of flue and exhaust gases
- **Catalytic routes in CO_2 utilization (methanol, DMC, carbonic esters)**
- **Reforming (CO_2) and Water gas shift reaction (H_2 production)**
- Catalytic wet oxidation and **Photocatalysis** (oxidation, non-fouling surfaces, **H_2 production**)
- **Catalytic routes from biomass to fuels (biohydrogen, methanol, ethanol, biobutanol, biopentanol)**
- Formaldehyde production from contaminated methanol
- Deactivation of catalysts, Control of the surface poisoning phenomena
- Catalytic materials and their characterization
- **Catalytic nanotubes and membranes in e.g. bio-fuels production**
- Catalysis in supercritical CO_2, microwave and plasma activation
- Abatement and health effects of fine particulates
- **Heterogeneous, homogeneous and biocatalysis - Combining the best features e.g. in bio-fuels production**



Catalytic converters in exhaust gas purification



Biomass to biogas and synthetic fuels

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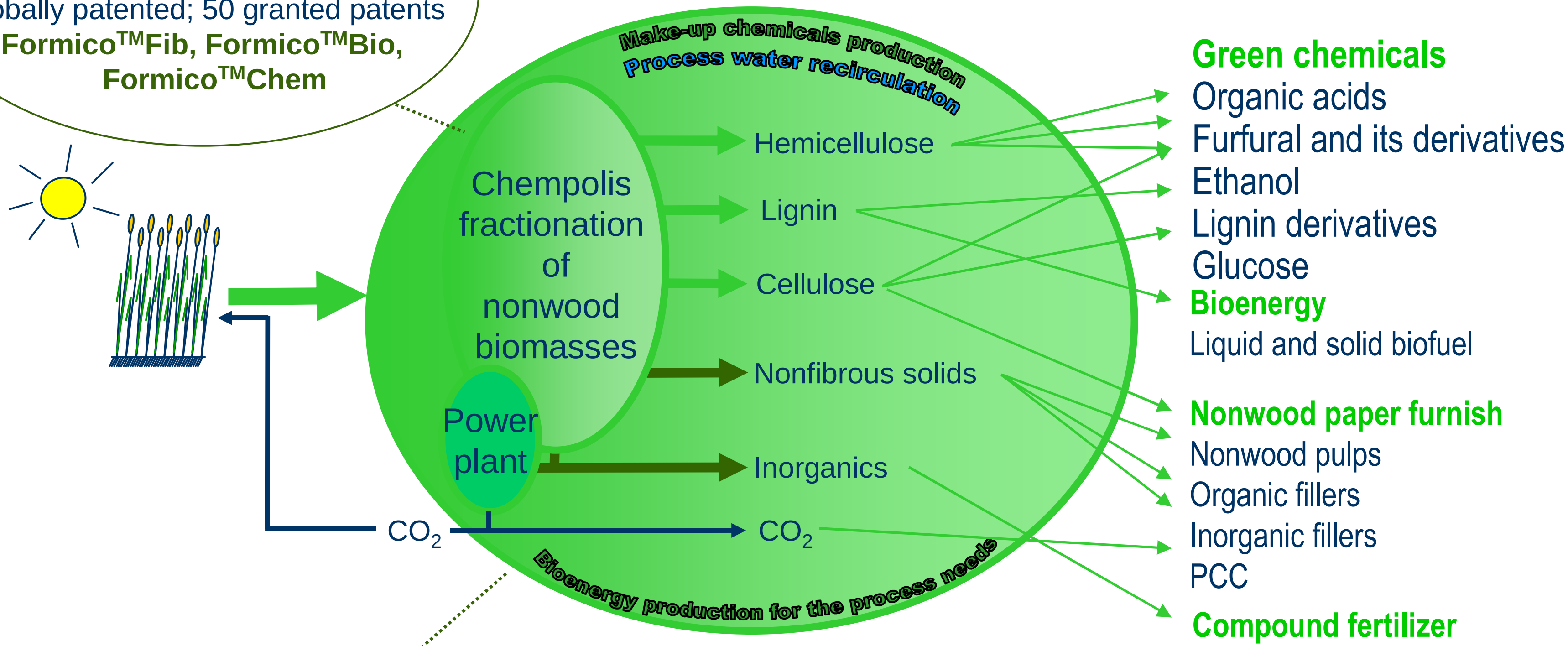
Development of a Nonwood (lignocellulosic) Biorefinery

chempolis
Creative Fibre Innovations

www.chempolis.com
Globally patented; 50 granted patents
Formico™Fib, Formico™Bio, Formico™Chem



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Chemical Process Engineering Lab

2 PhD theses
5 PhD students
10 Diploma theses
3 Diploma workers

Cooperation with
- Lappeenranta University of Technology
- **Fibre and Particle Engineering Lab (Univ. Of Oulu)**
- UPM
- South China University of Technology, China
- Shandong Light Industry Design Institute, China
- BASF

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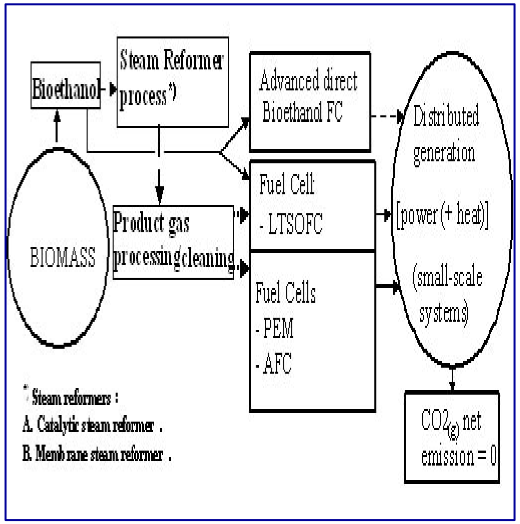
Renewable Energy - Biofuels

Bioethanol reforming to H_2 for e.g. fuel cells

- Focuses on developing new technologies for bioethanol - ethanol produced from lignocellulose materials - to be used effectively in **small-scale fuel cell systems of electric power output between 0.5 to 10 kW.**
- The technologies will cover **low temperature bioethanol reforming in hydrogen selective membrane reactors and cleaning methods as well as their combinations with any type of low-temperature fuel cells (200-390ºC)**
- In addition, the bioethanol driven fuel cells could be an intermediate step towards **glucose driven fuel cells**.
- **Catalytic microreactor concept, catalytic membranes**
- **CNTs as catalyst supports for fuel cells and reforming units**
- **Bio-ethanol reforming is potential technology for hydrogen production**
  - Ethanol is non-toxic, easily deliverable substance with relatively high H_2 content
  - Can be produced from renewable sources, e.g. biomass
  - Group VIII metals (Ni, Co, Pt, Rh) are found effective reforming catalysts



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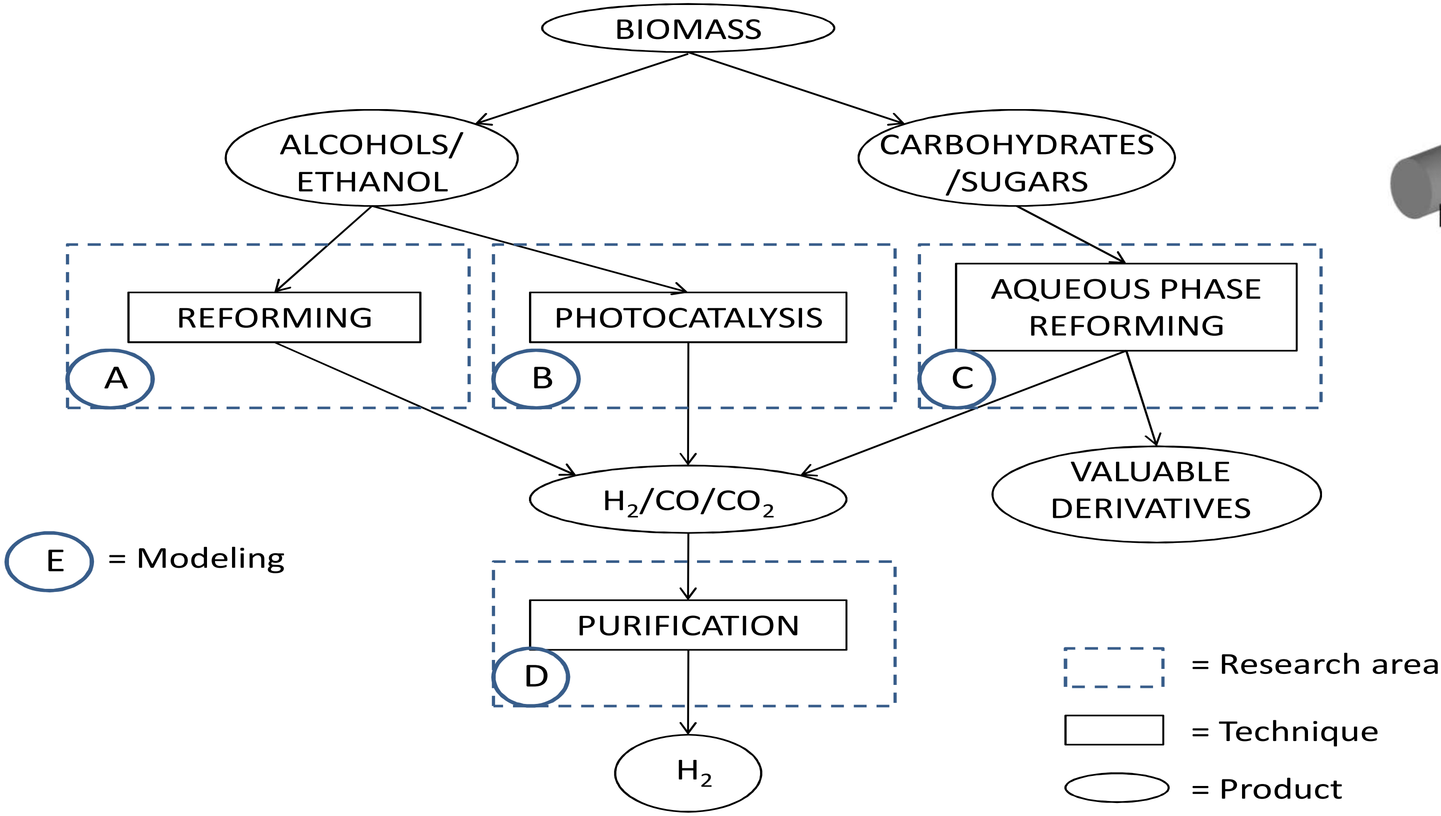
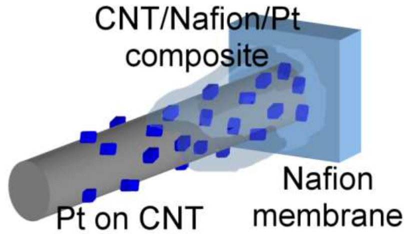
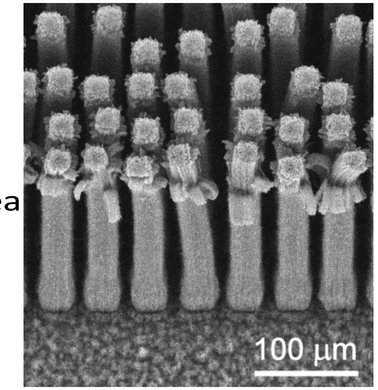
Photocatalysis, sustainability and hydrogen production

Our research approach: Microreactor concept, H_2-selective membranes, CNTs







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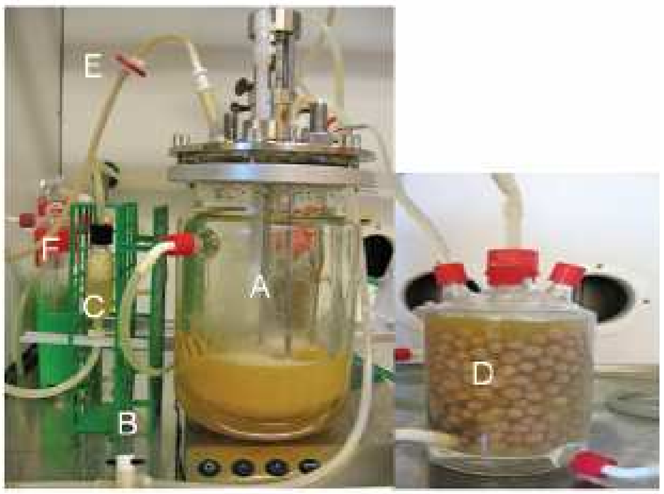
Renewable Energy - Biofuels

Biobutanol and biopentanol

- Microbiological production of **biobutanol, higher alcohols and oxygenates as fuel substitutes** (efficient processes)
- An anaerobic reactor system with temperature control and pH monitoring, cell immobilization unit, and circulation of fermentation medium was developed.
- Butanol was produced from whey supplemented with yeast extract
- Involves developing and optimize catalytic materials and chemical (catalytic) reaction pathways in the production of bioalcohols and other bio-derived compounds



Anaerobic reactor system
A: Reactor
B: Three-way valve
C: Pre-filter
D: Cell immobilization unit,
E: Filter used with gas-inlet and water lock tubings
F: Water lock

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Renewable Energy - Biobutanol and biopentanol

Technological challenges and opportunities in bio-alcohols production

- **Digestion of the raw material** (e.g., by-products of food or paper/pulp industry) to fermentable sugars
- **Inhibition caused by high solvent content**, decomposition of solvent and the loss in microbiological activity
- **Separation of butanol** is a challenge due to its water solubility (Butanol forms a separate phase only after the concentration exceeds 7%)
- **Novel catalysts and catalytic processes** for chemical synthesis (from glycerol)
- Several species of anaerobic, spore-forming ***Clostridia*** are capable of metabolizing different carbon sources to **butanol, ethanol and acetone** (ABE-fermentation)
- Butanol yield can be increased with **genetic manipulation of the micro-organisms**, **continuous fermentation process, bacterial cell immobilization and in-situ product recovery**
- **Opportunities:**
  These technologies are expected to be applicable for the conversion of glycerol (a higher alcohol) and lower (bio)alcohols into high-value liquid fuels.

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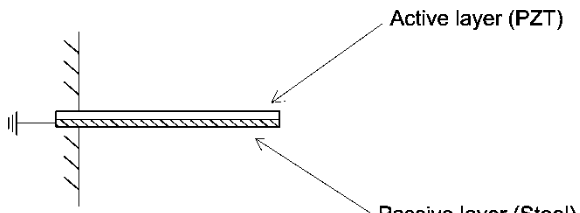
Energy-efficient products and processes

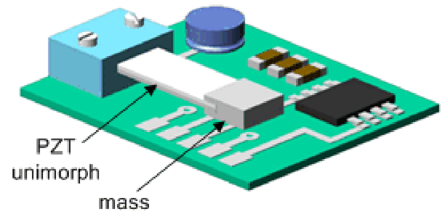
Piezoelectric energy harvesting for powering low power electronics

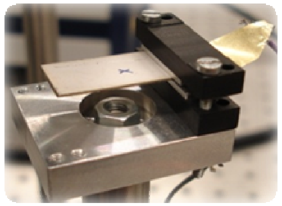
- Wireless data transmission techniques need wires for the power supply or batteries
- The development of energy harvesters would reduce the need for batteries and wires - cost-effective solutions for
  - autonomous wireless sensor networks
  - powering portable electronics
  - maintenance-free systems
- One of the most promising techniques is mechanical energy harvesting e.g. by piezoelectric components
  - deformations produced by different means is directly converted to electrical charge via direct piezoelectric effect
- The obtained results prove that piezoelectric energy harvesters are a viable option when powering low power electronics in vibrating environments.

(a)



(b)





Schematics of **(a)** unimorph type piezo structure **(b)** energy harvester system with the harvester and accompanying electronics

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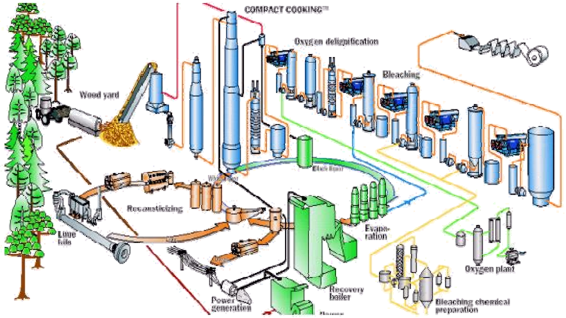
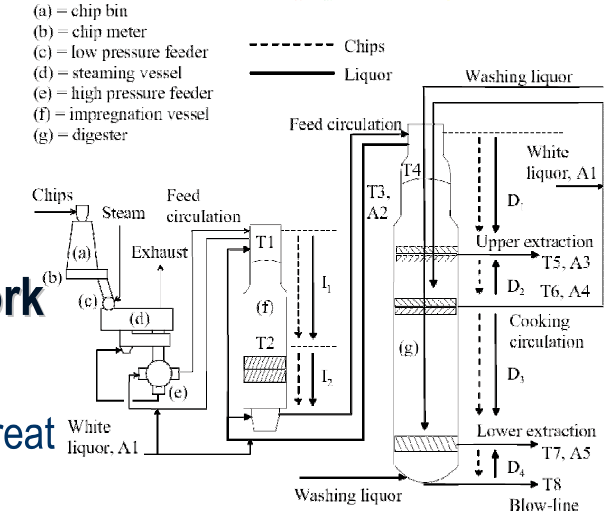
Energy-efficient products and processes

Improved control of the cooking process in Kraft pulping

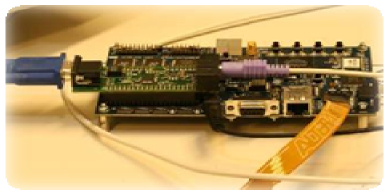
- The control of the impregnation vessel and digester in a cooking process of the chemical pulping plant has a great influence on energy and raw material savings
- If the quality control variations can be eliminated in the cooking process, the energy and raw material saving are significant
- The quality change in cooking process affects the fibre line's energy consumption e.g. in oxygen delignification and raw material consumption e.g. bleaching chemicals.





Managing the energy efficiency of a process sensor network

- Energy consumption is the main limitation of wireless sensor networks (WSN) and Deployment of WSNs in difficult environments or at high great data transfer speeds is especially challenging
- In this research the possibilities of saving energy & producing energy of a wireless process measurement system is studied
- The main focus areas of the project are saving and producing energy at the network nodes to reduce power dissipation as much as possible.



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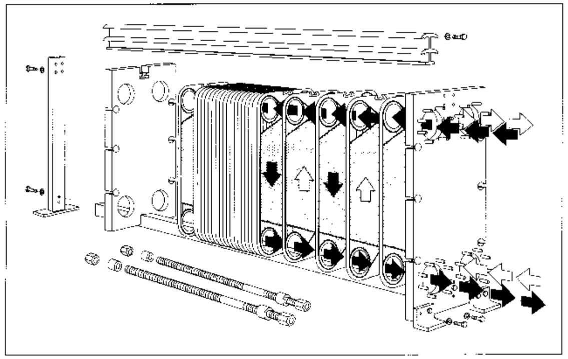
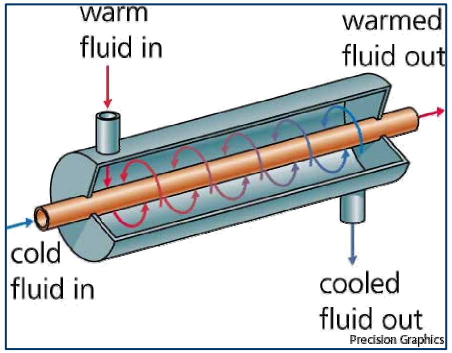
Kajaani University Consortium, Measurement and Sensor Laboratory

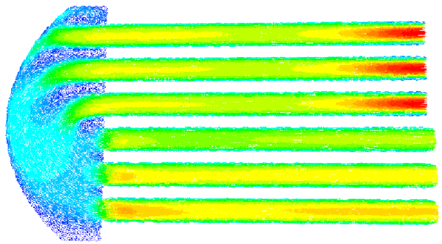
Energy-efficient products and processes

Control of fouling of heat exchangers

Energy efficiency of heat exchangers may be diminished by fouling







- **<u>Fouling</u>:** unwanted material deposits on the heat transfer surface
  - Reduces heat transfer
  - Increases the pressure drop of the system
- **It is estimated that fouling costs are about 0.2% of the countries Gross National Product**
  - Cost of fouling to industry is about 30 milliard €/yr in EC
- **Mechanical methods are expensive and not very efficient**
- **Chemical detergents may damage the product and negative environmental effects**
- **Research need:**
  - Understanding fouling phenomena
  - Develop new design methods and coatings to decrease fouling
- **Tested: non-fouling surfaces, verified in industrial scale testing in the connection with an industrial process**

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Mitigating the environmental impacts of energy generation

Chemical utilisation of CO_2

- Recovered CO_2 can be used for the production of chemicals, fuels and other useful products.
- Motivations to producing chemicals from CO_2:
  - CO_2 is cheap, non-toxic feedstock that can replace toxic chemicals
  - Production of chemicals from CO_2 can lead to totally new materials
    - **Examples:** syngas, methanol, dimethyl carbonate (DMC), carbonic esters, DME
  - New routes to existing chemical intermediates and products could be safer, more efficient and economical than current methods
  - The production of chemicals from CO_2 could have a minor (Mt scale) but positive impact on the global carbon balance

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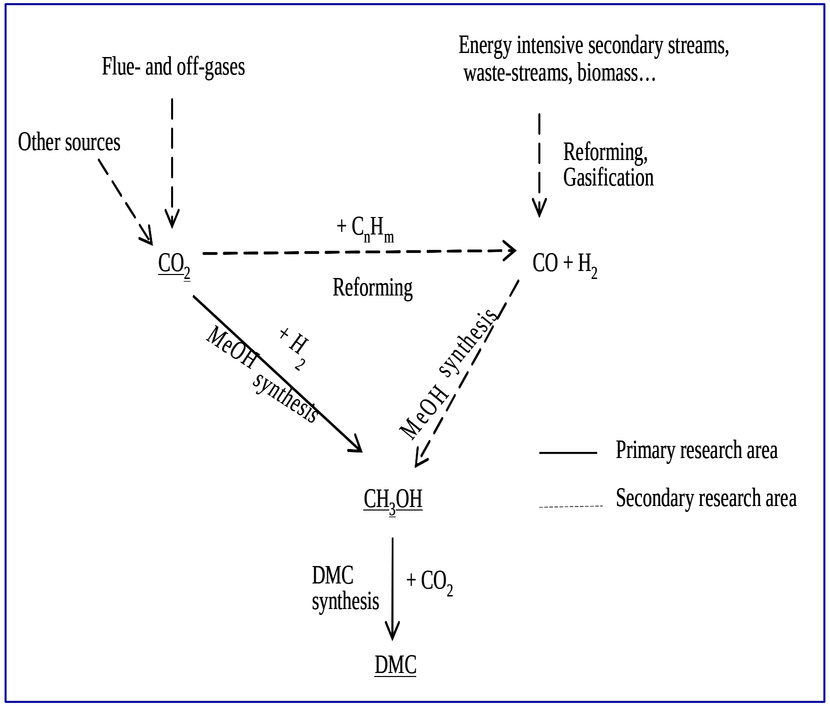
Chemical utilisation of CO_2
On-going and earlier research

- **CO2-USE**
  - CO_2 as a raw material for fuels and petrochemical components
- **CO2H2 and ReGenGas**
  - Reforming of CO_2 to syngas, CO_2 recycling
- **CO2UTIL, SuSe**
  - Sustainable production of methanol, dimethyl carbonate (DMC) and carbonic esters from carbon dioxide by green chemistry principles



Our target:

Secondary CO_2 as a raw material for valuable chemicals/products inside the company that produces CO_2, e.g. oil, chemical, power, pulp and paper, and metallurgical industry

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CO2UTIL, Towards utilization of CO_2 as a green and versatile commodity chemical - Clean synthesis of Methanol and Dimethyl Carbonate

KETJU
KESTÄVÄ TUOTANTO JA TUOTTEET
2006-2010

DMC selectivity 100 %, Better activity
- Under one phase reaction conditions
- Recycling of Catalytic Species
- Water trapping

Future activities
- Catalyst Design for Continuous Flow Reactors
- Heterogenization of the catalyst
- New catalytic materials

- Developing **green chemicals via a sustainable process in accordance with Green Chemistry principles**
- **Value enhancement of a secondary resource, CO_2**
- The conventional method for methanol production is based on fossil feedstock and the production of DMC involves the use of toxic phosgene or CO
  - Reduction of the hazard from solvents and chemicals
  - Explore safe and environmentally sound reaction routes and energy-efficient processes
  - Identify new, effective catalysts for methanol and DMC syntheses
- Develop a **dynamic simulation system** that can be used in studying the realization of different process routes from process control viewpoint

ÅBO AKADEMI PROCESS CHEMISTRY CENTRE
ÅBO AKADEMI
UNIVERSITE DE BOURGOGNE
CNRS

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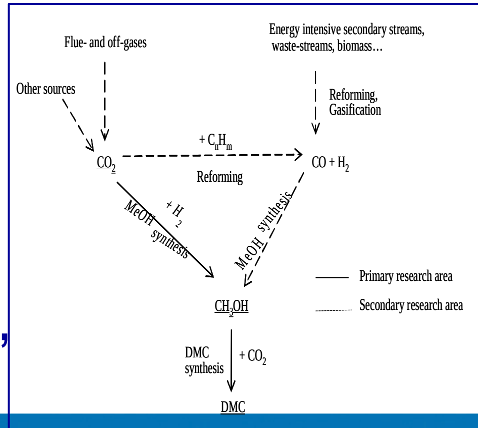
Reforming

- Process for producing synthesis gas (H_2 + CO)
- Synthesis gas is an important raw material e.g. in methanol synthesis, hydrocarbons production)
- Synthesis gas can be produced from almost any carbon source ranging from natural gas to biomass
- CO_2 as a feedstock in **dry reforming: $CO_2 + CH_4 \rightarrow 2H_2 + 2CO$**

- **Bioethanol reforming** (COST Action 543, REFORMH2)
- **Other biomass based materials** (COST Action 543, REFORMH2)
- **Challenges:**
  - Sufficient conversion $\rightarrow$ high temperature is needed
  - Carbon formation problem $\rightarrow$ catalyst resistive of carbon or regeneration is needed
- **Research focus:**
  - Catalyst development and optimization, Reaction conditions optimization
  - **Miniaturization, microreactor concept**
  - **Catalytic membranes, phenomena integration**
  - Industry specific solutions
- **Dynamic simulations will be done for the whole reaction chain, from secondary CO_2 to different products such as synthesis gas, methanol and DMC**.



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Methanol synthesis

- Methanol is an important product and feedstock in chemical industry
- Commercially methanol is produced from synthesis gas

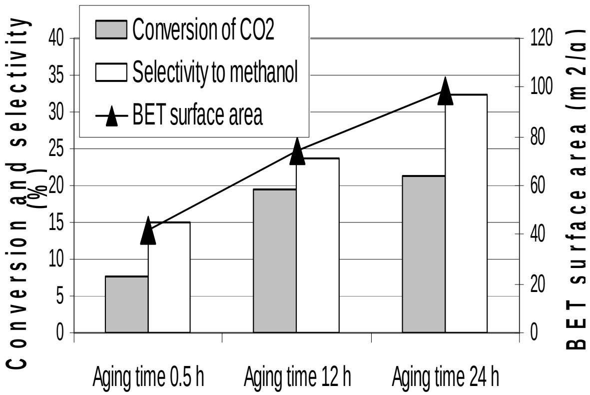
$$CO + 2H_2 \leftrightarrow CH_3OH$$

- It is possible to use CO_2 as a feedstock in methanol synthesis

$$\mathbf{CO_2 + 3H_2 \leftrightarrow CH_3OH + H_2O}$$

- **Challenges**
  - Reaction is thermodynamically unfavorable
  - More active and selective catalysts are needed
    - » **Catalyst development and optimization**
    - » **Zr-based catalysts selective** (**$Cu/ZnO/ZrO_2$**)
    - » Proper preparation, **phase structure important**

KETJU KESTÄVÄ TUOTANTO JA TUOTTEET 2006-2010



Example of our results: co-precipitated $Cu/ZnO/ZrO_2$; activity tests: T = 250°C, p = 30 bar and H_2/CO_2 = 3.

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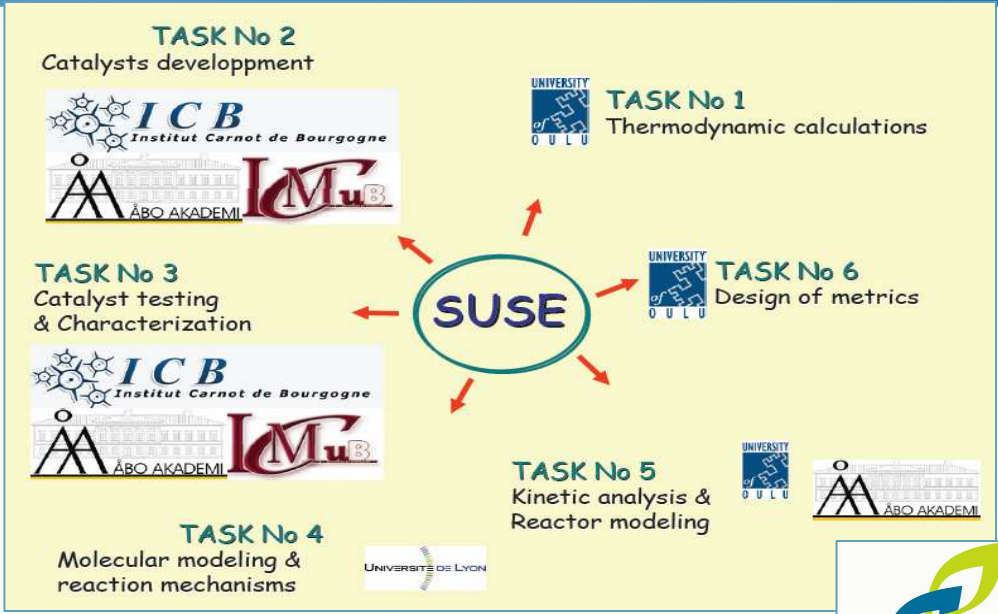
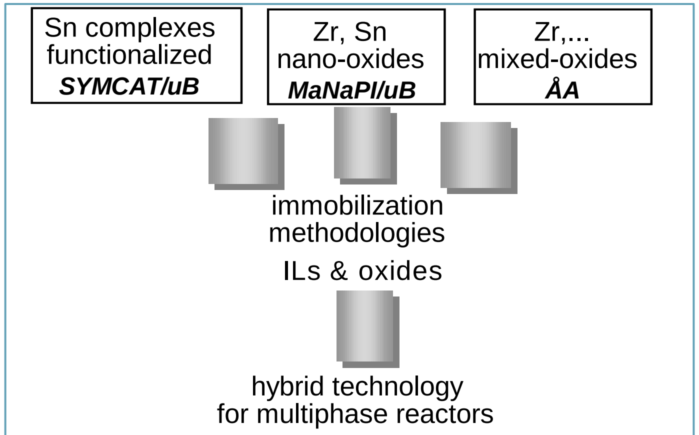


Sustaining carbonic esters synthesis with carbon dioxide feedstock, SUSE

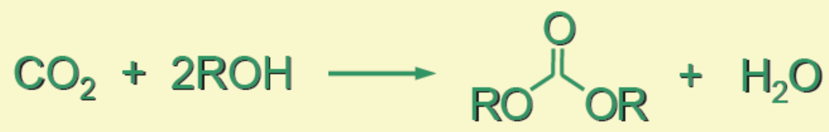


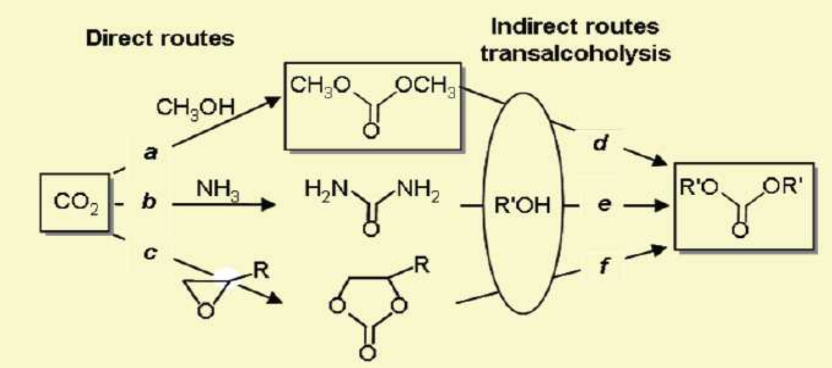
Scheme 3. Flow-chart of catalyst processing

Flow-chart of catalyst processing.

The objectives of the project are

- To design hybrid catalysts for carbonic esters synthesis via employing the best features of homogeneous and heterogeneous catalysis,
- **To use CO_2 + bio-alcohols in carbonic esters synthesis**,
- To design catalyst recovery and recycling for the best process performance, e.g. catalyst immobilization, use of ionic liquids, continuous operation,
- To design metrics for assessing the benign by design approach, to perform environmental assessment analysis.





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www.cleantechoulu.fi/air/skypro-oulu/
Science into products and production technologies
SkyPro Oulu
CLEAN AIR CLUSTER
Leverage from
the EU
2007–2013
European Union
European Regional Development Fund
OULU

SkyPro Oulu
Science into products and production technologies

- The main goal is to establish a research centre on air-related technology in the Oulu Region.
- SkyPro Oulu is launched by the project Science into Products and Production Technologies 2008-2011 with two main activities:
  1) building up the SkyPro Oulu (Clean Air Cluster) – collaboration net
  2) executing a research project to demonstrate the collaboration
- The budget of the launching project: 650 000 €
  (ERDF and Finnish Government 572 000 €, City of Oulu 58 000 €, Micropolis technology centre 20 000 €)
- The lead partner of the launching project: University of Oulu
- Co-partner: Micropolis Technology Centre

European Union
European Regional Development Fund

Leverage from the EU 2007–2013

Incorporating science to products and production technologies

- Transmitting information
- Improving the visibility of Oulu region in the air pollution control branch
- Boosting innovations
- Continued development of clean air know-how in Oulu Region

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COST Action 543 Training School

June 2-6, 2008, University of Oulu, Finland

Training School: Sustainable Production and Energy:

Catalysis by Nanomaterials, Catalytic Microstructures

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Financed by COST Action 543, Graduate School for Energy Science and Technology, Graduate School in Chemical Engineering, University of Oulu

COST Action 543, 540, P19 Training School

May 4-8, 2009, University of Oulu, Finland

Collaboration between
COST Actions
543, 540, P19

Training School: Environmental Applications of TiO_2 Photocatalysis

COST Action P19: Multiscale modelling of materials

COST Action 540 »PHONASUM«

SkyPro Oulu
CLEAN AIR CLUSTER

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Financed by ESF/COST Action, University of Oulu (CEWIC and SkyPro Oulu), Graduate School for Energy Science and Technology (EST) and Graduate School in Chemical Engineering (GSCE)

G S C E

EST Graduate School

Cewic
Centre of Expertise in the Water Industry Cluster

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Vice-head of the Department
Vice-rector of the University

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