Welcome to the presentation of

MEMFO R&D group

Department of Chemical Engineering
at the
Norwegian University of Science and Technology;
Trondheim - Norway

Membrane Research in MEMFO

Main Fields of Research:

Membranes for (industrial) gas applications (ex: CO_2, CH_4, H_2,VOC, Cl_2, SF_6....)

Material technology – membrane development

Membranes for renewable energy (biogas, H_2)

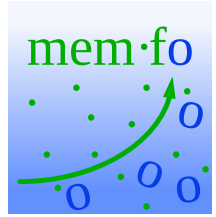
Design of environmental friendly processes

Simulation & optimization of (integrated) membrane processes

More Recent Fields of Research:

Membranes in bioprocessing; biodiesel & bioethanol

The Membrane Research Group



• Professor May-Britt Hägg	*Head of group*
• Post doc Arne Lindbråthen;	*glass membranes*
• Post doc t Jon A. Lie;	*carbon membranes*
• PhD-student David Grainger	*carbon membranes*
• PhD-student Tone Borge;	*mixed matrix membranes*
• PhD-student Lei Shao;	*mixed matrix membranes*
• PhD-student Marius Sandru	*polymeric FSC-membrane*
• PhD-student Liyuan Deng	*various polymeric membranes*
• Senior researcher Dr. Taek-Joong Kim;	*polymeric FSC-membranes*
• Senior researcher Tom-Nils Nilsen	*polymer synthesis*
Ass.member:	
• PhD-student Antti Tynys	*polymerization catalysis*
Joining in August 2006:	
• PhD-student NN	*modeling and simulations*
• Varying number MSc-students every year	

Membrane Research in MEMFO

Mission Statement:

- Our research shall always aim at economic and environmental friendly solutions with a potential of being useful to industry
- In our research we strive for a multidisiplinary approach and international cooperation
- Our research shall always be conducted in an ethical way and with the greatest precision

Guidelines for conducting research within the group:

- Be helpful and share your knowledge with your colleague – by lifting others, you lift yourself
- Stimulate interaction with group members and a have positive attitude to voluntary work
- Cleanliness and order are keys to success
- Think practical feasibility and possible scale-up, with theory in mind

Brief history of MEMFO

MEMFO was established in 1994 at HiT / Tel-Tek in Porsgrunn

MEMFO moved to NTNU, Trondheim, in August 2001

Most of the research conducted over the years has been done in cooperation with industry.

Among the partners have been: Norsk Hydro, Statoil, Borealis, Bioscan, Shell, Kværner, ABB, Alstom, various SMB-partners and others

MEMFO

- has a large international network & co-operation
- is partner in Sintef / NTNU / Statoil Gas Center
- has several projects running funded through the Norwegian Research Council
- participates in several international projects (EU, USA, Japan)
- was responsible for European Membrane Summer School (EMS) held in Trondheim August 2003

Selected projects of special importance 1998 - 2006

Period 1998 - 2004

- Recovery of Cl_2 by membranes (NFR-Norsk Hydro Mg)
- FSC-membranes for CO_2 recovery (Brite EU-Ram)
- Dehydration and dewpointing of natural gas (EU-4FWP)
- VOC-recovery during filling of oil tankers (ITP-Venturie; SMB)
- Feasibility study on subsea membrane separation (Shell)
- Renewable energy; (Nordic council, co-operation Denmark & Russia)

Projects initiated 2004 or later; running

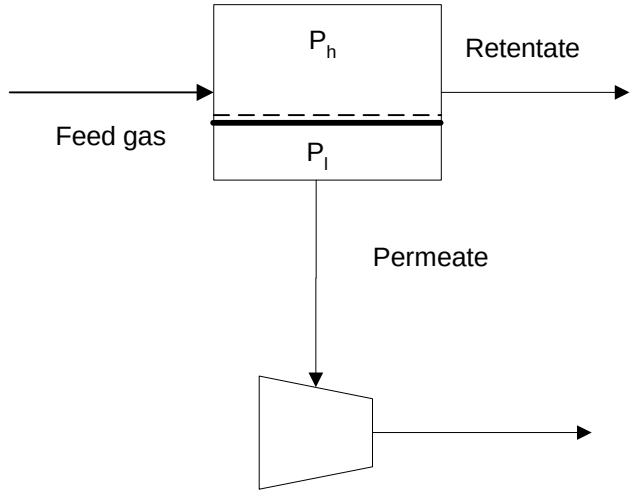
- Recovery of hydrogen with membranes; (NaturalHy, EU)
- Gas Management Research Structure NTNU/Sintef (Engas; EU)
- Recovery of CO_2 from flue gas (ULCOS, EU)
- Development of nanocomposite materials (Sintef - NCSU; 2 projects)
- Development of FSC membrane for CO_2 capture (NFR -Statoil - Alstom)
- Membranes against global warming (NanoGloWa – EU)

Focus for the gas membrane research

1. Capture of greenhouse gases (CO_2, VOC, SF_6..)
2. Renewable energy (upgrading of biogas)
3. Recovery of hydrogen from gas streams
4. Purification of aggressive gases (Cl_2, HCl, SO_2…)
5. Simulation of (integrated) membrane processes (for energy optimization)

- Focus for the research 1-4 is:

  MATERIAL DEVELOPMENT & TRANSPORT PROCESSES of GASES through the MEMBRANE



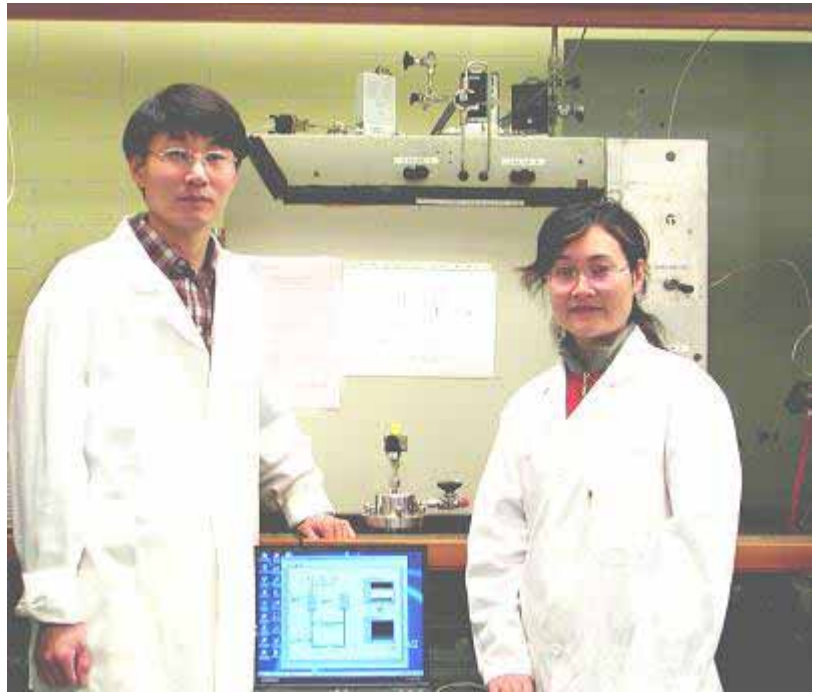
1. Capture of greenhouse gases

1A) Development of a Fixed-Site-Carrier-membrane

A polymeric "Fixed-Site-Carrier" (FSC) poly-vinylamine membrane for selective CO_2 capture is being developed (now patented). Very promising results have been obtained. The project currently running is funded by Statoil, Alstom & NFR

Picture:

- Senior researcher; Dr. Taek-Joong Kim obtained his PhD from TIPS/RAS, Moscow (left)
- PhD-student Liyuan Deng from Hunan Univ. of Science & Techn., China (right)



PhD-student Marius Sandru joined the project in 2005

1A) Development of the FSC-membrane

- Principal objective: To develop a low cost membrane for CO_2 removal from gas streams
- Subgoals: To document
  - selectivity > 500 for CO_2/N_2
  - CO_2-flux> 0.1 $m^3(STP)/m^2 \cdot bar \cdot h$

Even higher values have now been documented for single gases, while selectivity for mixed gas (10vol% CO_2) is currently documented around 200

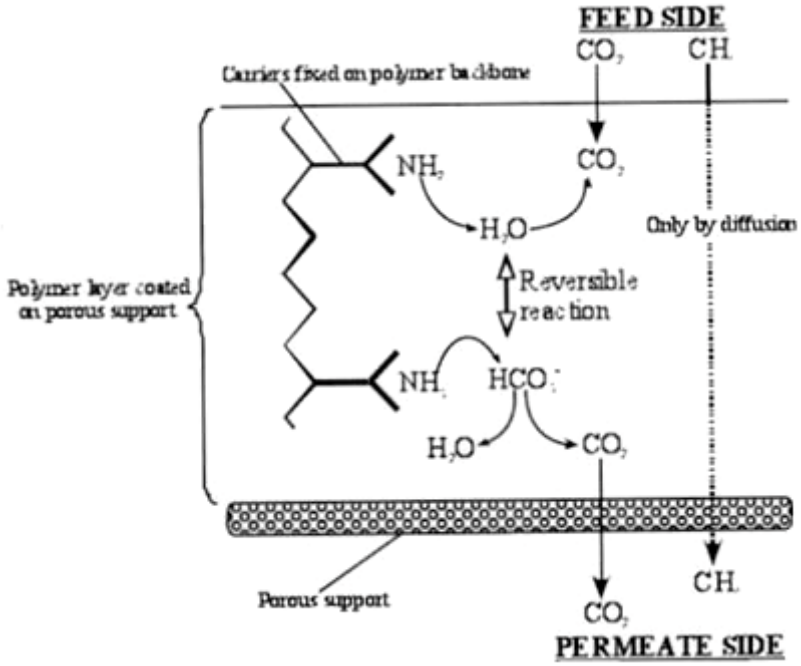
- Important variables to control:

  -type of support structure

  -method of crosslinking

  -polymeric molecular weight

  -swelling of membrane (hence CO_2 is removed as HCO_3^-)



Proposed mechanism for CO_2 transport through the membrane

Patent: PCT, WO 2005/08997 A1

Article: T-J Kim, B. Li, M-B Hägg; ***Novel fixed-site-carrier polyvinylamine membrane for CO2 capture;*** in J.Polymer Sci. Part B: Polymer Physics, accepted for publication August 2004

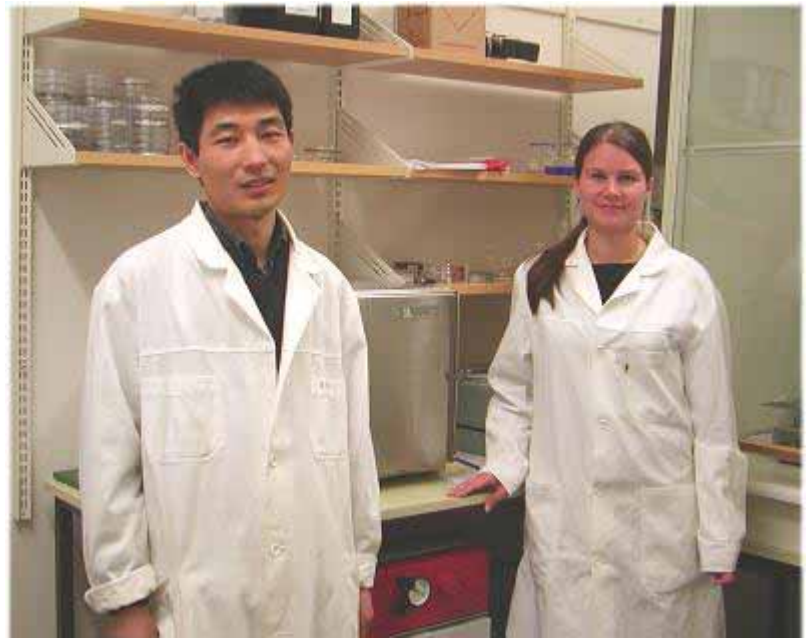
1. Capture of greenhouse gases

1B) Studies of mixed matrix membrane materials

- Studies of mixed matrix membrane materials ((hybride polymer nanocomposite materials) for optimization of flux and selectivities)

Picture:

- PhD-student Lei Shao; financed by NFR /NANOMAT program (left)
- Project with Sintef and North Carolina State Univ. (prof. R. Spontak). Industrial experience. MSc. from Beijing Inst. of Techn., China



PhD-student Tone Borge; financed by NTNU; strategic area: Nanostructured Materials. MSc. from NTNU (right) Tone will spend some time at NCSU with prof. Spontak as part of her PhD

1B) Studies of mixed matrix membrane materials

- Principal objective: To prepare and study various types of MM and polymer nanocomposite membranes for 1) selective capture of greenhouse gases and 2) separation from gas streams containing H_2
- The MM-membranes have been documented to show increased flux and selectivity for selected gases

  The MM membranes are prepared in two different ways; with nanostructured fillers or

  with carbon molecular sieves as the inorganic phase in a polymeric continuous phase

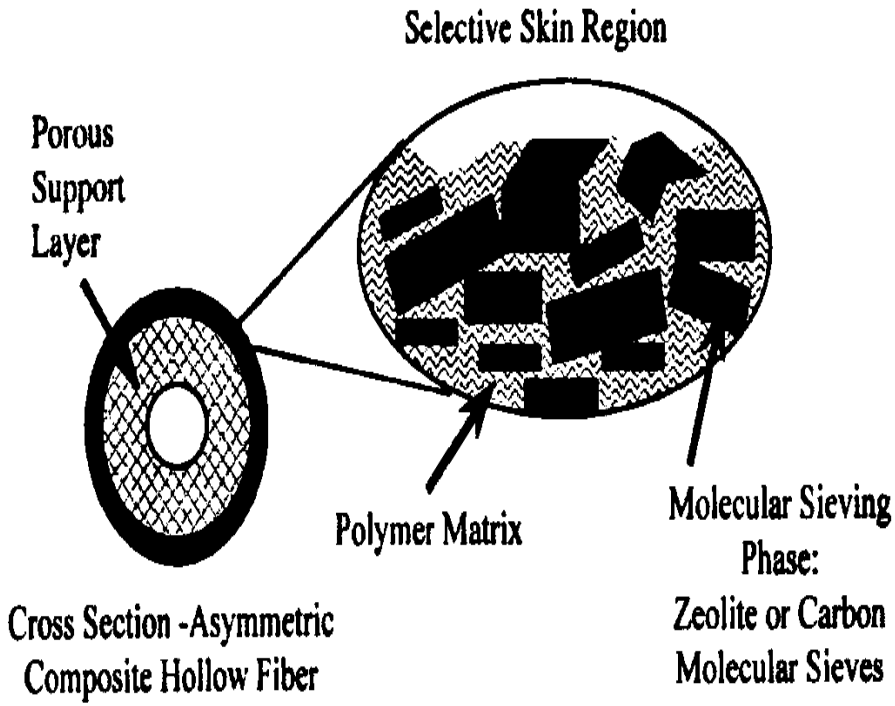
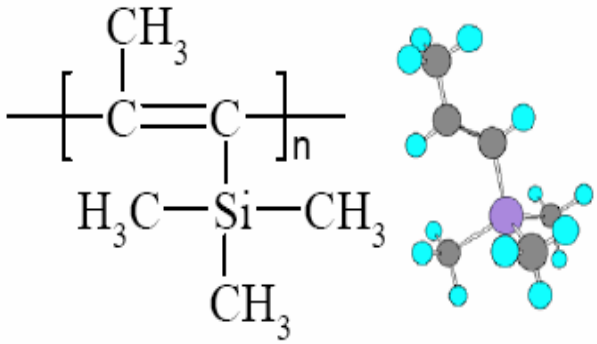
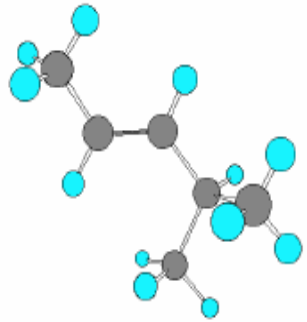
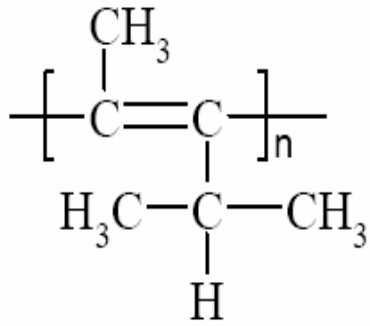


Fig. 5. Schematic of a mixed matrix membrane.

For the reverse selective MM-membrane, we work with PMP with fillers (silica, carbon)







PTMSP

$T_g > 250°C$

FFV = 0.29

$P_{n\text{-}C_4H_{10}} = 87{,}000$ Barrer

$\alpha_{n\text{-}C_4H_{10}/CH_4} = 47$

PMP

$T_g > 250°C$

FFV = 0.28

$P_{n\text{-}C_4H_{10}} = 5{,}800$ Barrer

$\alpha_{n\text{-}C_4H_{10}/CH_4} = 13.2$

1 Barrer = 10^{-10} cm^3(STP) cm/(cm^2 s cmHg)

2. Carbon membranes for renewable energy and CO_2 capture

- Carbon membranes are prepared by tailoring the pore size for selected gas separations by controlling variables like choice of precursor and carbonization conditions. ***Amazing results achieved!***

- Post doc Jon Arvid Lie is preparing membranes for CO_2 capture and H_2 recovery
- He obtained his PhD in 2005, at MEMFO/NTNU on upgrading of biogas

  Spent 4 months in 2003 with Prof. Koros' group at Georgia Tech. studying pyrolysis techniques

  Pilot tests at sites have been performed



Jon is now a post doc on the EU-NATURALHY project, and is also involved in ULCOS and ENGAS, and engaged in everything related to renewable energy

3. Carbon membranes for hydrogen recovery

- Carbon membranes are prepared by tailoring the pore size for selected gas separations by controlling variables like choice of precursor and carbonization conditions. Recently started.
- Principal objective: To recover H_2 from various gas mixtures.

- PhD-sudent David Grainger is sponsored by The Gas Center at NTNU/Sintef

  David is connected to the EU-project NATURALHY as well.

  Industrial experience, SASOL

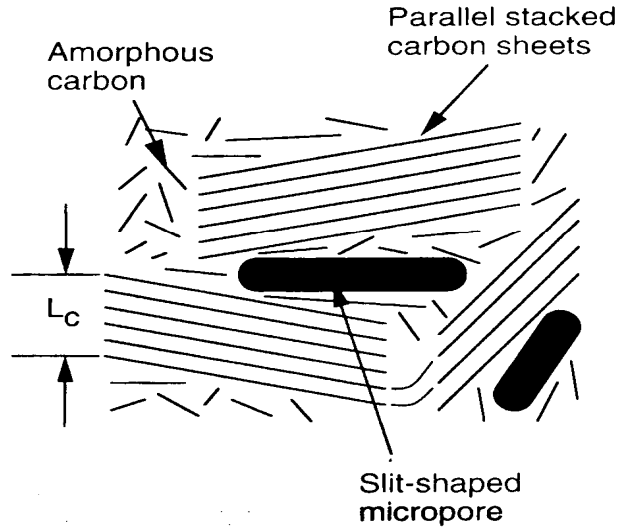
  MSc. From Univ. of Twente

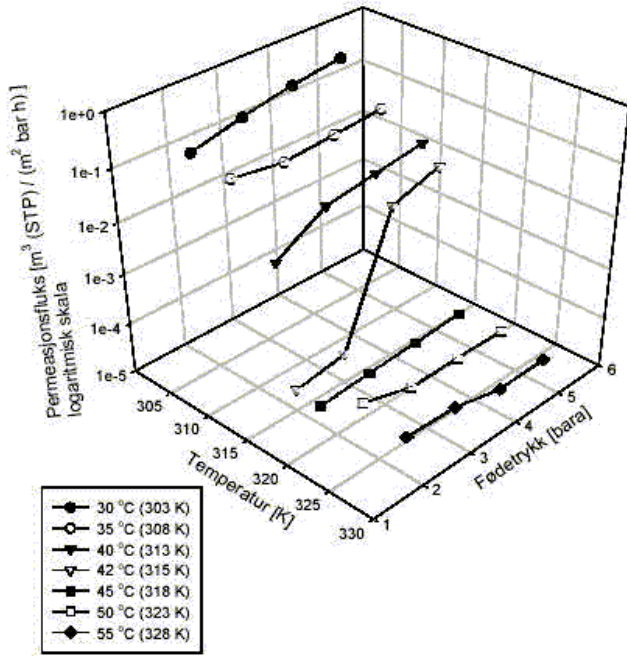


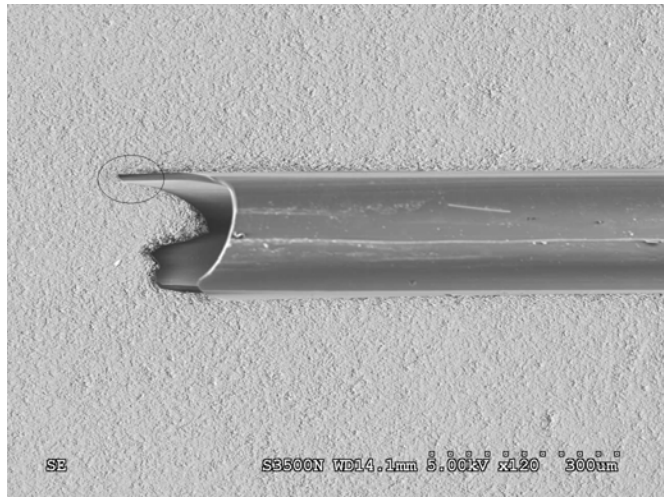
David is also our wizard on the computer; doing work on modelling and simulations and thereby involved in many of the projects

Carbon membranes have been studied for recovery of various gases; also hydrocarbons besides CO_2 and H_2

- Preparation of CMS-membranes is an important part of the research; studying effect on performance by varying pyrolysis conditions (tailoring of pore size)
- Transport mechanisms are essential to understand for the separation







4. Purification of aggressive gases; Cl_2, HCl

- Project for purification of aggressive gases using membranes has been a major focus for Memfo in many years. Initiated by Norsk Hydro in 1994, later project through NFR. Today the fundamental studies are done in a post doc project.
- Interest from industry world wide is very big. A major break-through is expected if further financing can be found; promising results have been obtained.

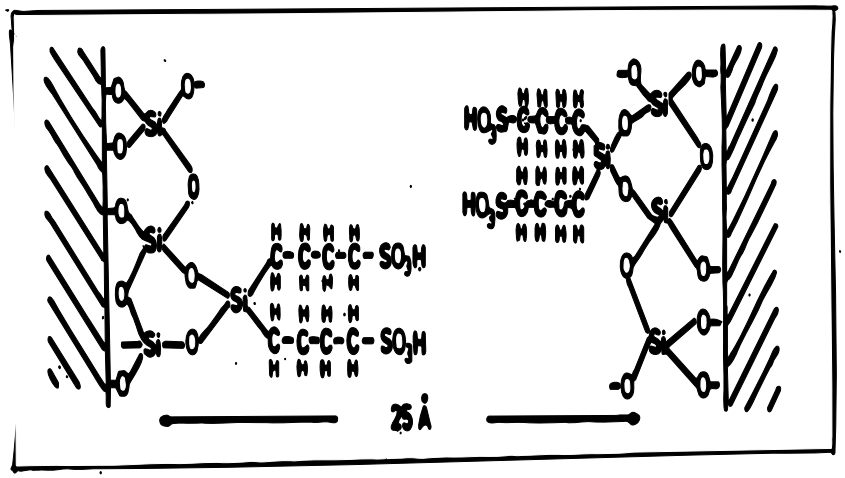
- The project has cooperation with Japan (Prof. T. Yazawa) on preparing the glass membrane
- Arne spent 4 months at the Japanese institute for studying glass membranes.



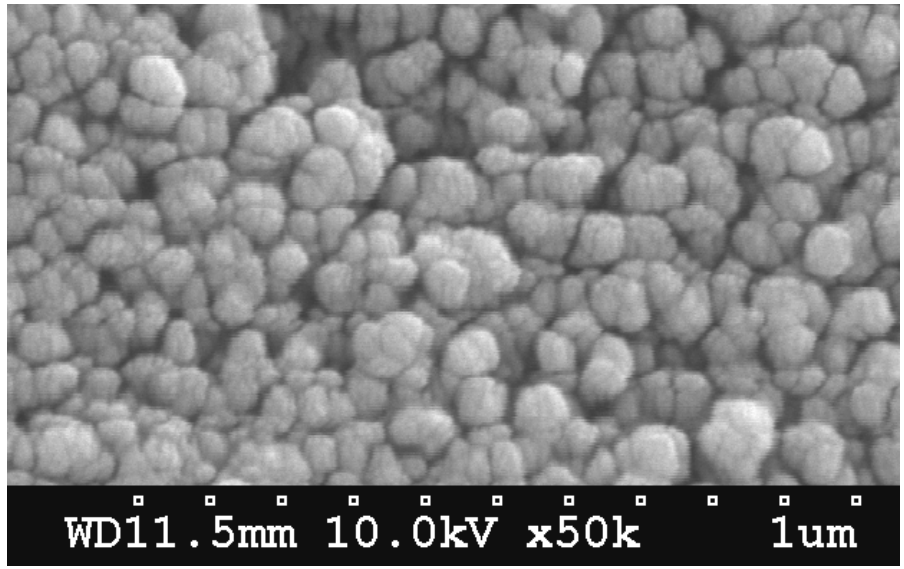
Arne Lindbråthen obtained his doctoral degree (PhD) with MEMFO/NTNU in February2005. He is currently a post doc with valuable competence in the lab. on instrumentation

Purification of aggressive gases cont.

Principal objective: To develop a stable surface modified glass membrane for separation of gases like Cl_2, HCl, SO_2



- The membrane development is extremely challenging with respect to material durability.
- Perfluorinated compounds are being used to modify the glass surface (pore tailoring) for optimised flux and selectivity.
- Special mixed matrix materials are also being tested



Some information on running EU-projects

EU - 6th FW; **NATURALHY**

(Natural gas & Hydrogen)



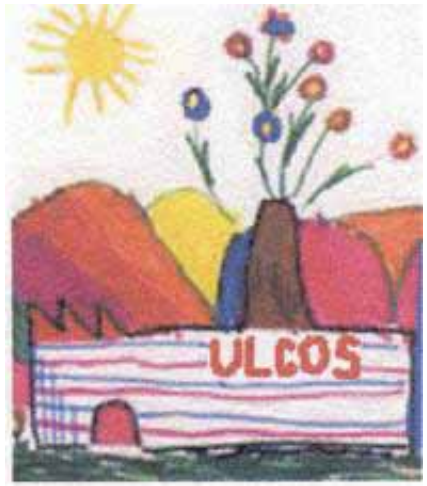
EU- 6th FW; NanoGloWa

Nanomaterials against Global Warming)



EU; **ULCOS**

(**U**ltra **L**ow **CO_2** **S**teelmaking)



EU 6th FW; ENGAS

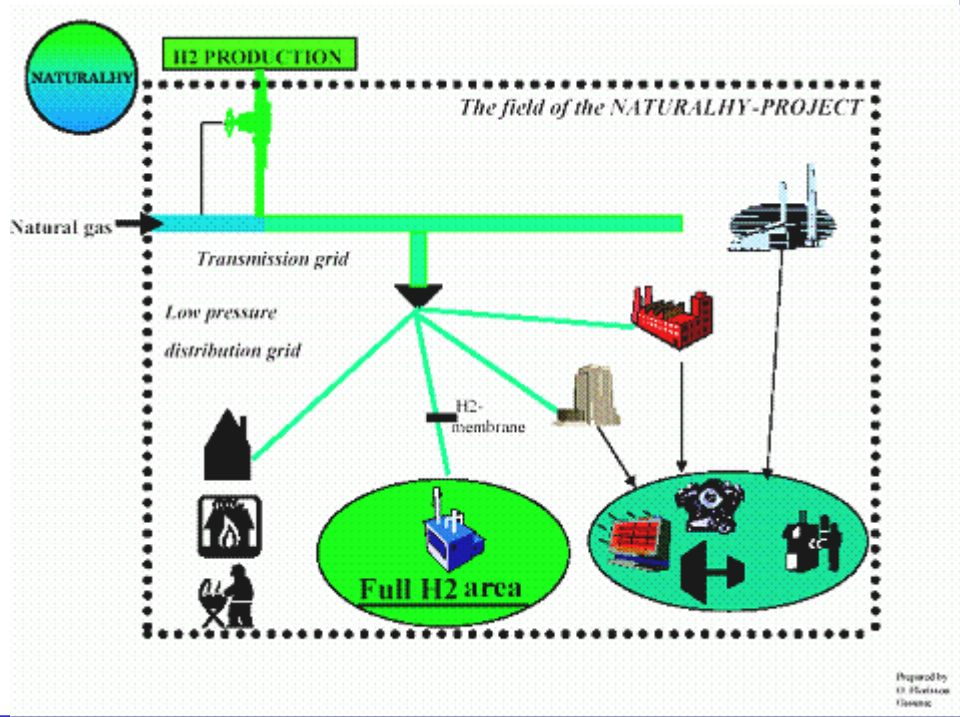
(The Environmental Gas Management)



The NaturalHy project

- Preparation for the hydrogen economy (EU 6th FWP project)
  - To test the use of existing natural gas networks in Europe for hydrogen distribution
  - Project will test all critical components in a NG network
  - 39 partners

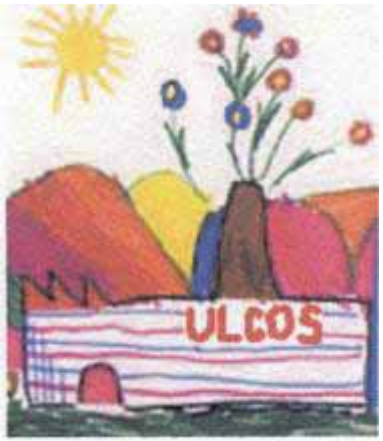
- MEMFO is developing carbon and MM membranes for recovery of H_2 from a H_2-natural gas mixture in a pipeline

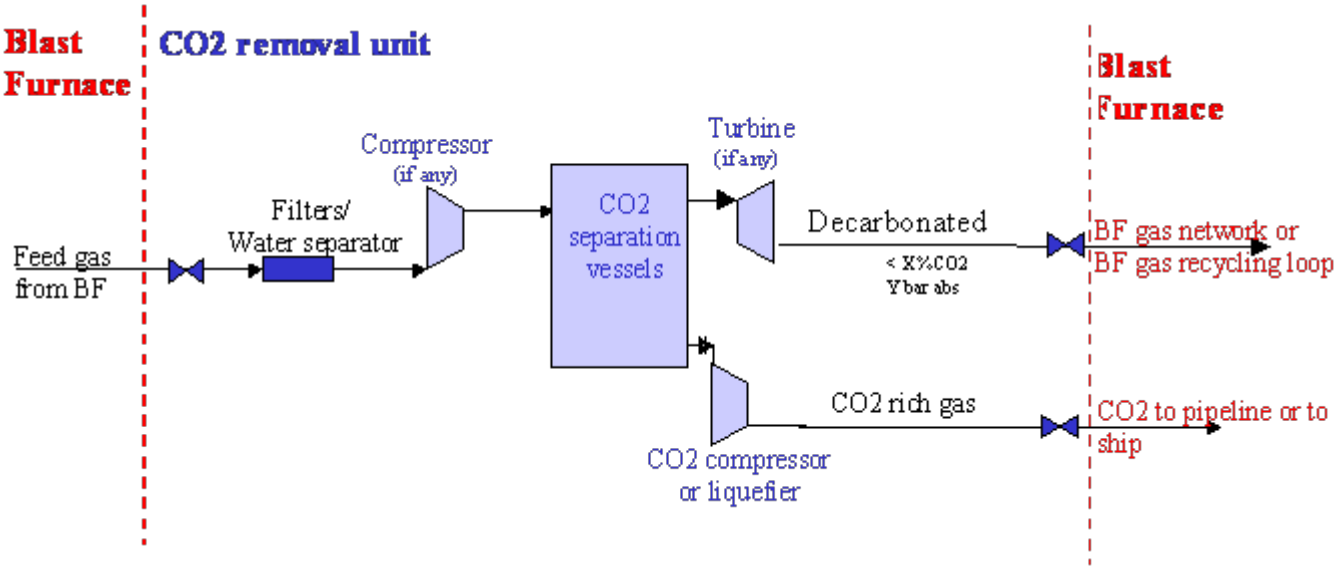


ULCOS (Ultra Low CO_2 Steelmaking)

- Initiated by the steel industry in Europe
- To develop new production technologies to drastically cut greenhouse gas emmisions by 2030

- **MEMFO's involvement**: Prepare suitable membranes for CO_2 capture from the flue gas - very high CO_2 concentration
- Recommended membranes: Fixed Site Carrier (FSC) membranes; various materials have been tested





Location of the CO_2 removal unit in the steel production process

NanoGloWa (Nanomaterials against Global Warming)

Objective: To develop optimal nanostructured membranes and installations for different applications in CO_2 capture from powerplants

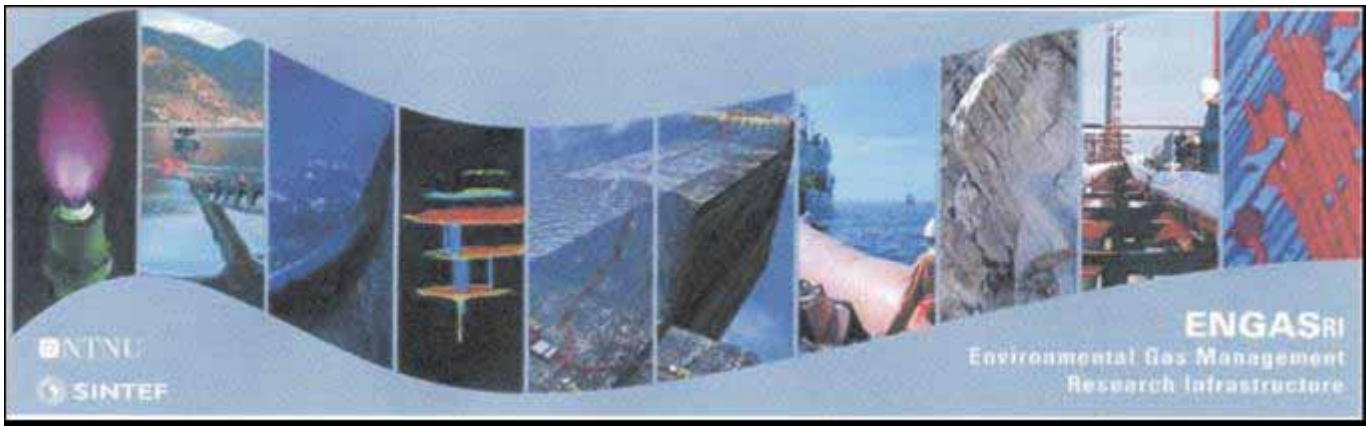
MEMFO's involvement:

- To develop for further upscaling the CO_2-selective FSC-membrane as well as the CMS membrane.
- Process design through modeling and simulation



ENGAS (EU project FP6)

- A group of lab. facilities at NTNU/SINTEF have been recognized as **Research Infrastructure** by the EU commission, i.e. a multidisciplinary and internationalized reasearch environment.
- The combined fields of expertise at **ENGAS** are linked to processes for cleaning up CO_2, NOx, SOx and other green house gases (more info on www.ntnu.no/engas).
- Researchers linked to European projects can apply for joining the laboratories to learn and collaborate.
- MEMFO is contributing with membrane expertise on materials and gas separation, as well as available equipment for membrane formation and characterization





Thank you for visiting us at
MEMFO at NTNU Trondheim - Norway