NTNU & SINTEF

who are we

and

what are we doing

NTNU & SINTEF

NTNU : ***Norwegian University of Science and Technology***

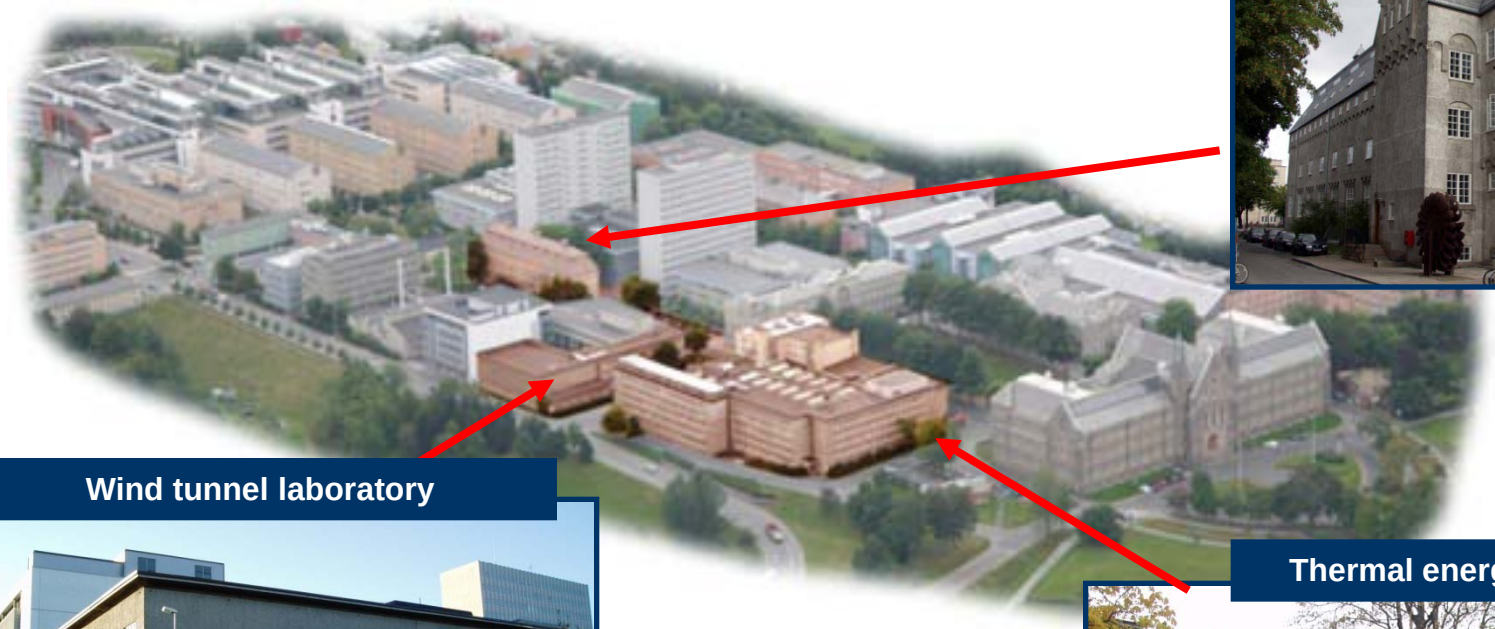
SINTEF: ***The Foundation for Scientific and Industrial Research at NTNU***

NTNU	4.000
SINTEF	2.000
Students	20.000

- NTNU 3,5 Bill NOK
- SINTEF 1,6 Bill NOK

Department of Energy and Process Engineering

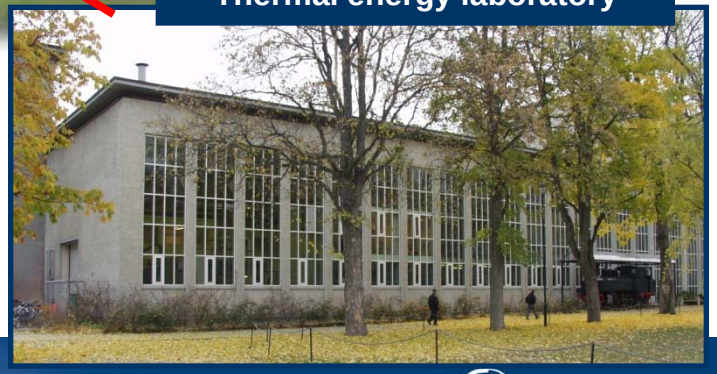
Faculty of Engineering Science and Technology



Water power laboratory

Wind tunnel laboratory

Thermal energy laboratory



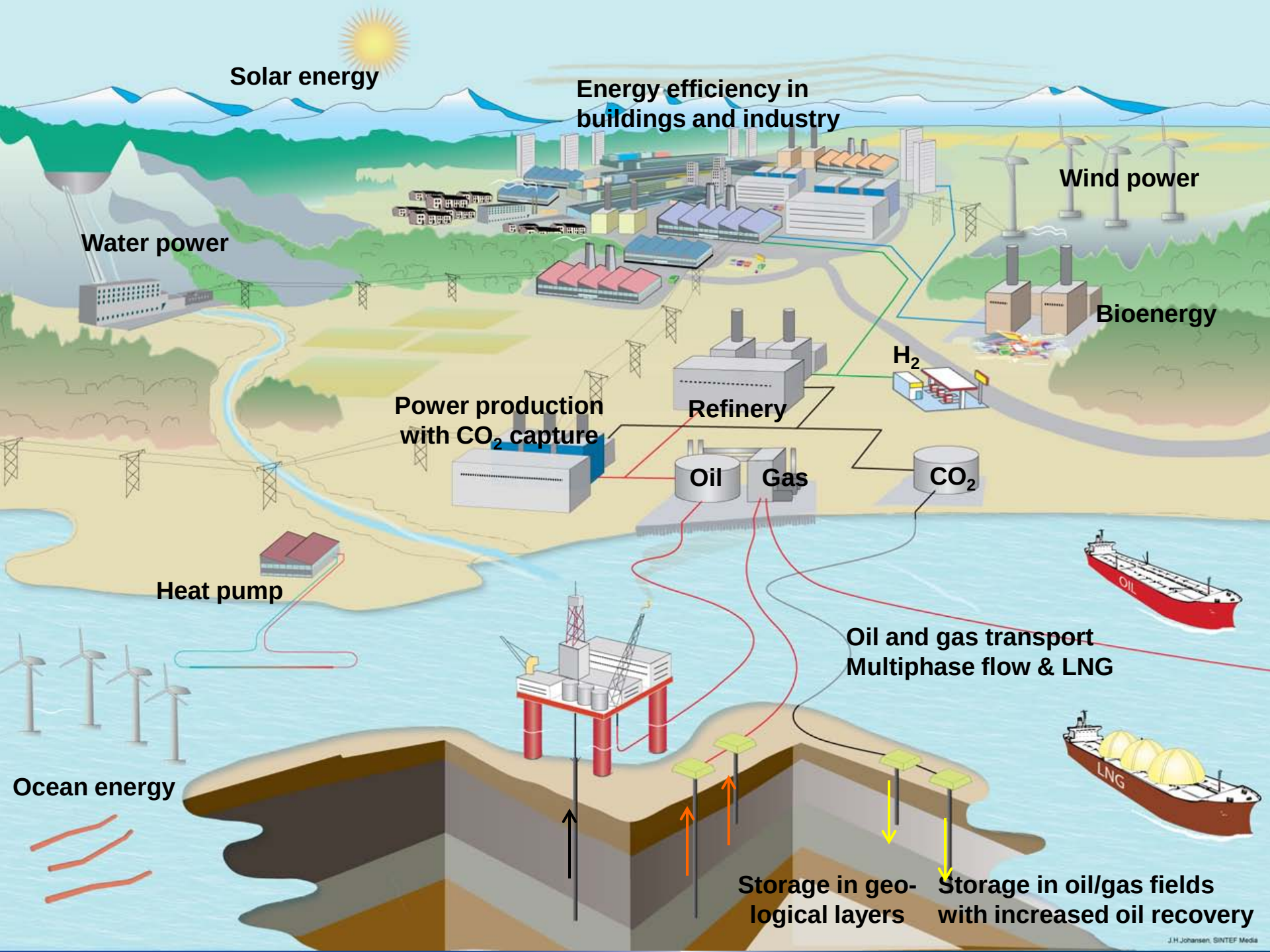
Department of Energy and Process Engineering

FACTS

- **130 employees within 4 specialist groups**
  - Thermal energy
  - Industrial process technology
  - Energy and indoor environment
  - Fluids engeneering
- **80-90 Ph.D. students**
- **70-100 M.Sc. students**

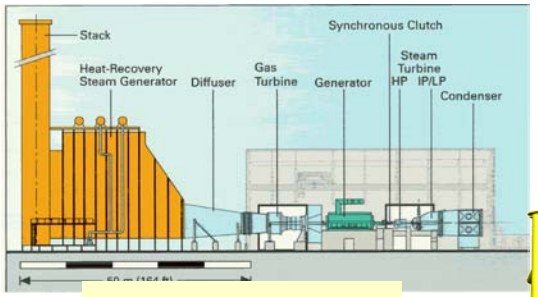
LAB

- **6000 m^2 of laboratories in 3 buildings**
- **20 employees in laboratory/workshop**

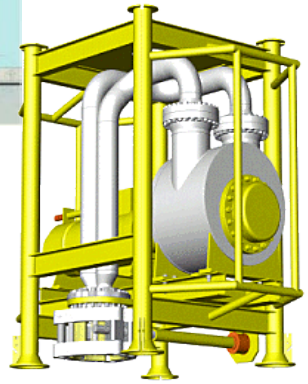

Solar energy
Energy efficiency in buildings and industry
Wind power
Water power
Bioenergy
H_2
Refinery
Power production with CO_2 capture
Oil
Gas
CO_2
Heat pump
OIL
Oil and gas transport Multiphase flow & LNG
LNG
Ocean energy
Storage in geo-logical layers
Storage in oil/gas fields with increased oil recovery
J.H.Johansen, SINTEF Media

Department of Energy and Process Engineering

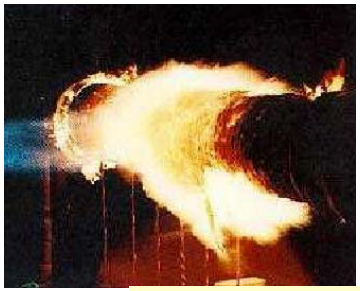
Thermal Energy Group



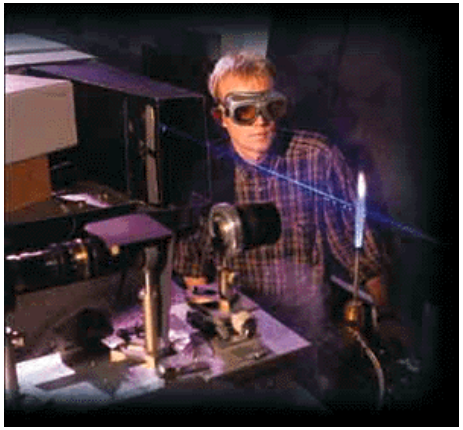
NG power plant with CO_2 capture

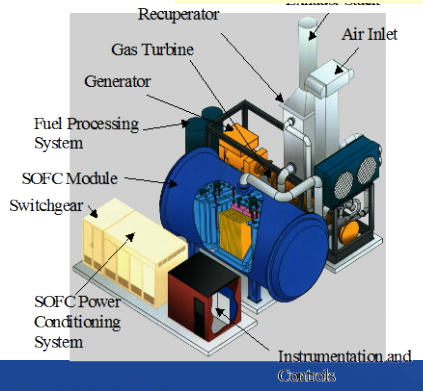


Multiphase pumps



Combustion

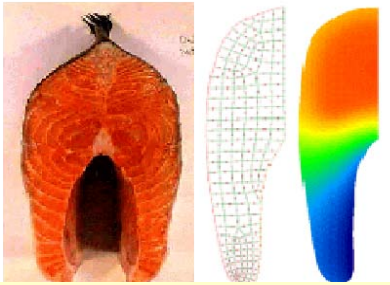




- **Combustion**
  - Combustion, including processes and equipment
  - Bio-energy
  - Waste combustion
  - Air pollution and gas cleaning
- **Turbo machinery and power generation**
  - Thermal turbo machinery, including gas turbines, multiphase- and NG compressors
  - Thermal power cycles including. CO_2 capture
  - High-temperature fuel cells
- **LCA og industrial ecology**
  - LCA – Life Cycle Analysis
  - Value Chain Analysis
  - Energy and Environment in developing countries
  - Systems engineering

Department of Energy and Process Engineering

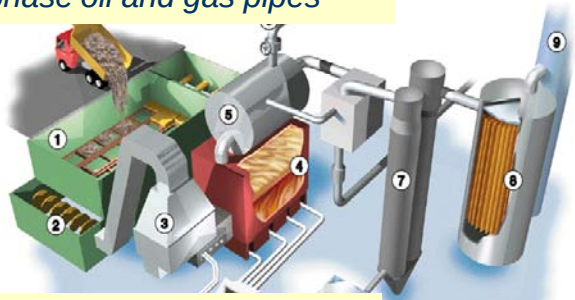
Industrial Process Technology Group



Cooling/freezing/dewatering

Refrigeration and heating in cars

Multiphase oil and gas pipes



Components to industrial heating and cooling systems

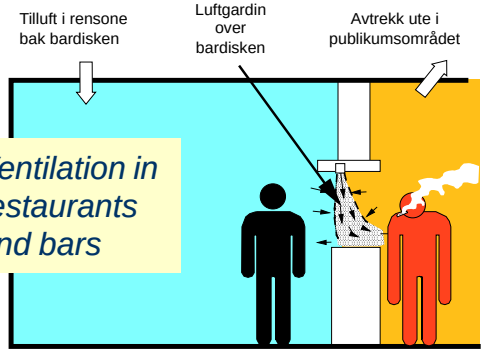
Offshore LNG

- **Heating and cooling technology**
  - Systems and components
  - Energy analysis
  - Process integration
  - Heat pumping systems
- **NG and Multiphase transport**
  - Multiphase transport
  - NG processing
  - Low temperature processes
- **Food engineering**
  - Dewatering and drying
  - Cooling, freezing and defrosting
  - Fluidized systems

Department of Energy and Process Engineering

Energy and Indoor Environment Group

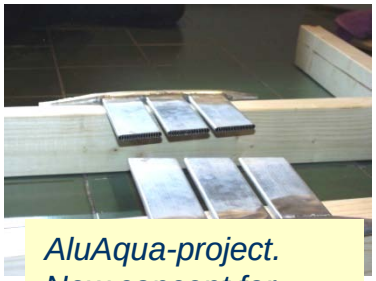
Indoor environment in schools



Ventilation in restaurants and bars

Fire safety and ventialtion in rock halls

50 kW CO_2 hot water heat pump, prototype



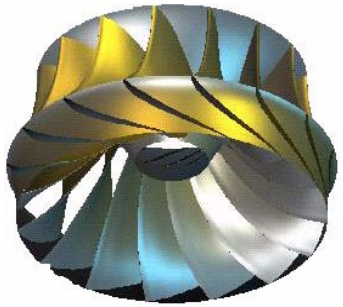
AluAqua-project. New concept for floor heating

- **Energy use and supply**
  - heating systems
  - energy use and planning
  - district heating
- **Building automation**
  - system simulations
  - facility management
  - O&M
- **Indoor environement**
  - building climatization
  - sanitation and recidential hygiene
  - applied heat pump engineering
- **Ventilation engineering**
  - HVAC systems
  - industrial ventilation
  - fire safety

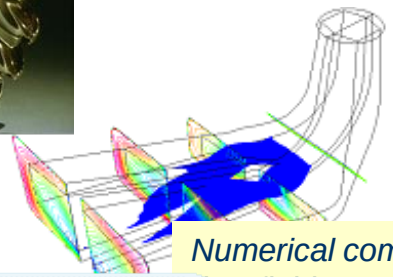
Department of Energy and Process Engineering

Fluid Engineering Group

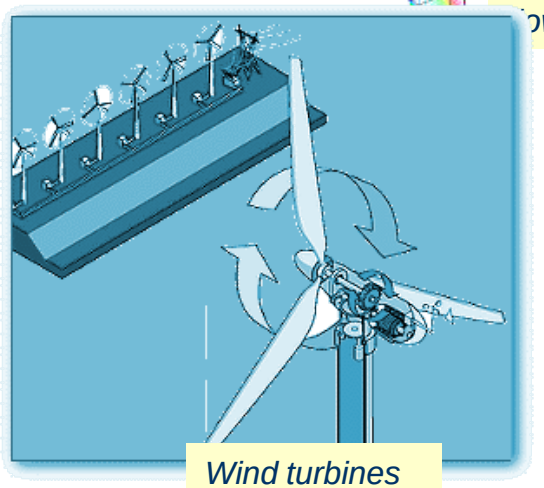
Pelton turbine



Francis turbine



Numerical computations of flow fields



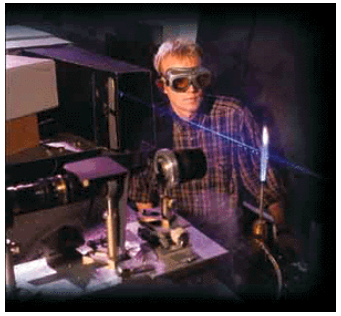
Wind turbines

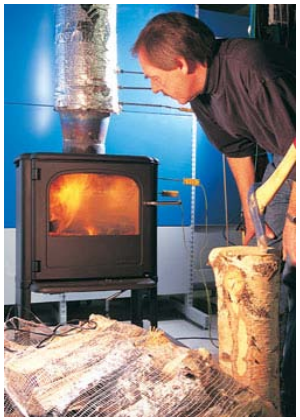
Aero dynamics

- **Fluid power and pneumatics**
  - Turbine and pump design
  - System analysis
  - Cavitation
- **Hydraulic fluid machines**
  - Components
  - Control
  - Power-assisted mechanisms
- **Fluid flow engineering**
  - Turbulence physics
  - Numeric fluid flow calculations
  - Fluid flow in micro media
  - Mulitphase flow
  - Aero and hydro dynamics

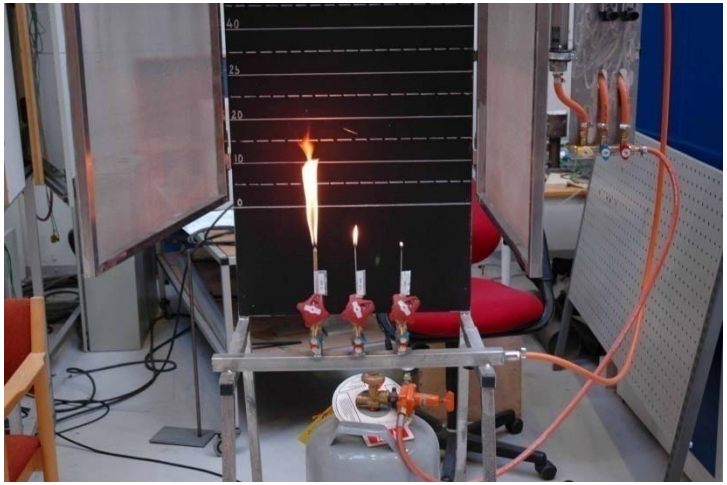
Laboratories

1. Combustion lab
2. Thermal energy Lab
3. Refrigeration lab
4. Multiphase flow lab
5. Indor environment lab
6. Dewatering and food egineering lab
7. Water power lab
8. Wind tunnell lab



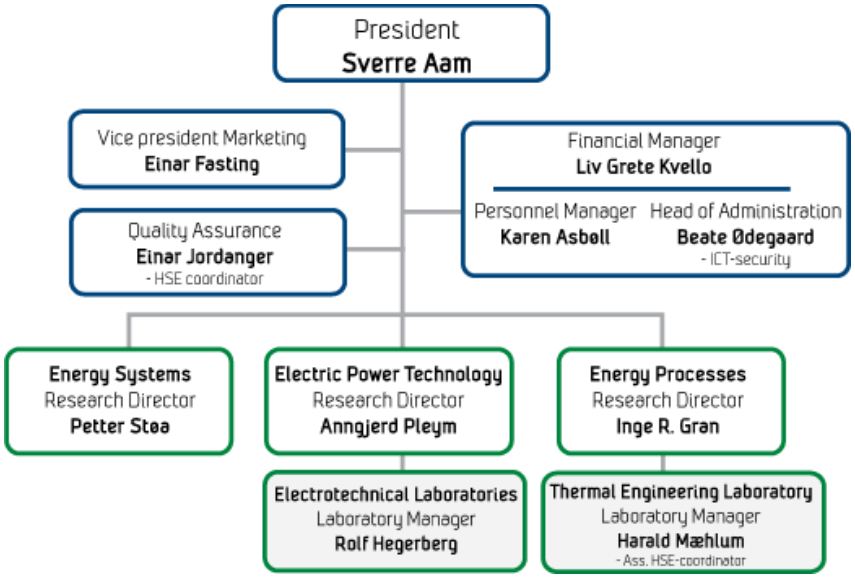


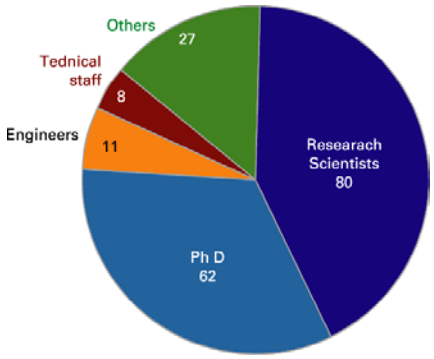
Laboratory based training



…….. and communication

SINTEF Energy Research



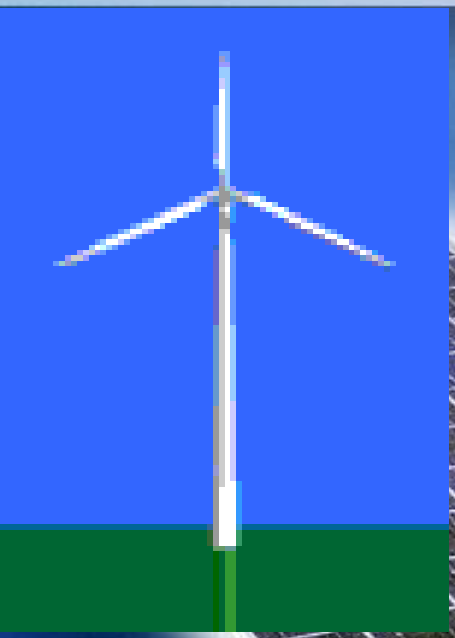


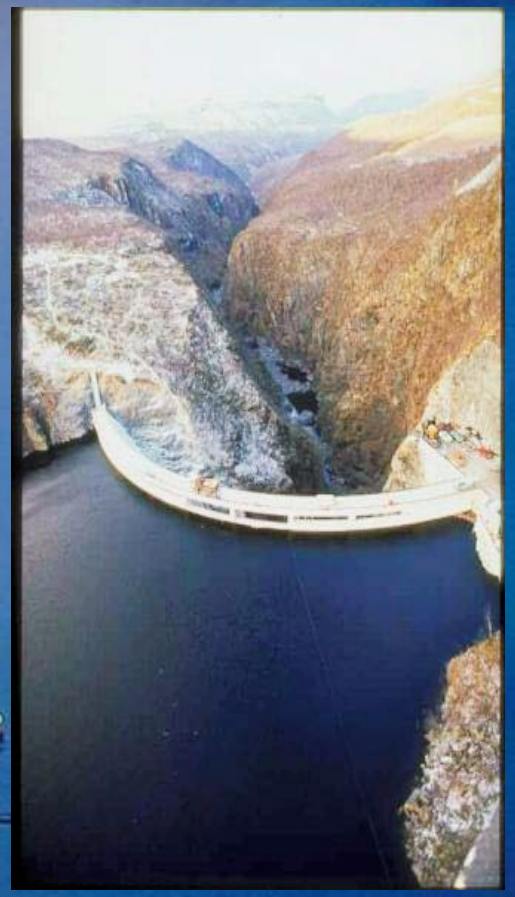
Number of employees: 188

Energy Processes:

- Ventilation and air conditioning in commercial and industrial premises
- Chilling, freezing and thawing of food
- CO_2 as a refrigerant in refrigeration and heat pump units
- Gas technology, LNG, production, storage and transport
- Power generation with “zero CO_2 emissions” , including CO_2 capture and transport
- **Thermal energy production from biomass and refuse**
- Drying and dewatering
- Energy saving in buildings and all types of industry
- Hydrogen: LH_2, gasification, combustion, safety, value chains
- Subsea technology oil/gas
- Hydronic heating systems, district heating and cooling
- Particle technology and multiphase transport
- Indoor climate and the work environment

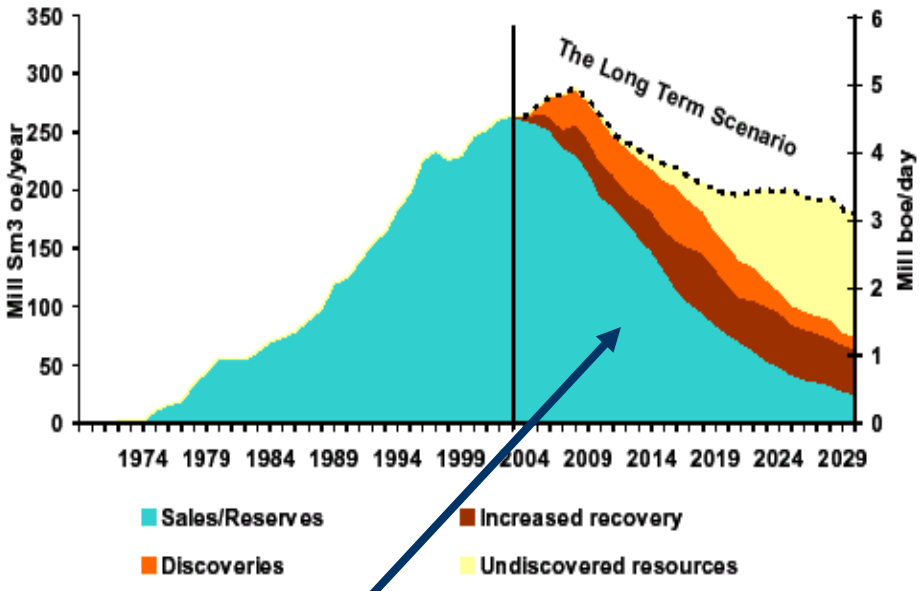
Norway - an energy nation……



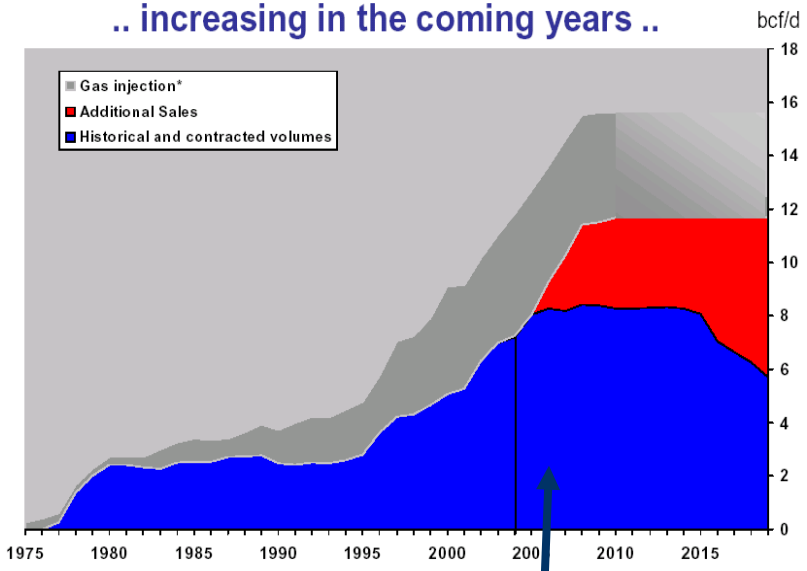


3 generations of energy development: Hydro Power, Petroleum, Renewables

Petroleum Production on the Norwegian Continental Shelf



.. increasing in the coming years ..



Declining Oil Production

Norway is the 3rd largest oil and 2nd largest gas exporter in the world

Increasing Gas Production

/NPD/

Norwegian Continental Shelf 1965 - 2005

Northern Areas
Artic conditions

Barents Sea
Snøhvit +++

Norwegian Sea
Deep waters

(Mature)

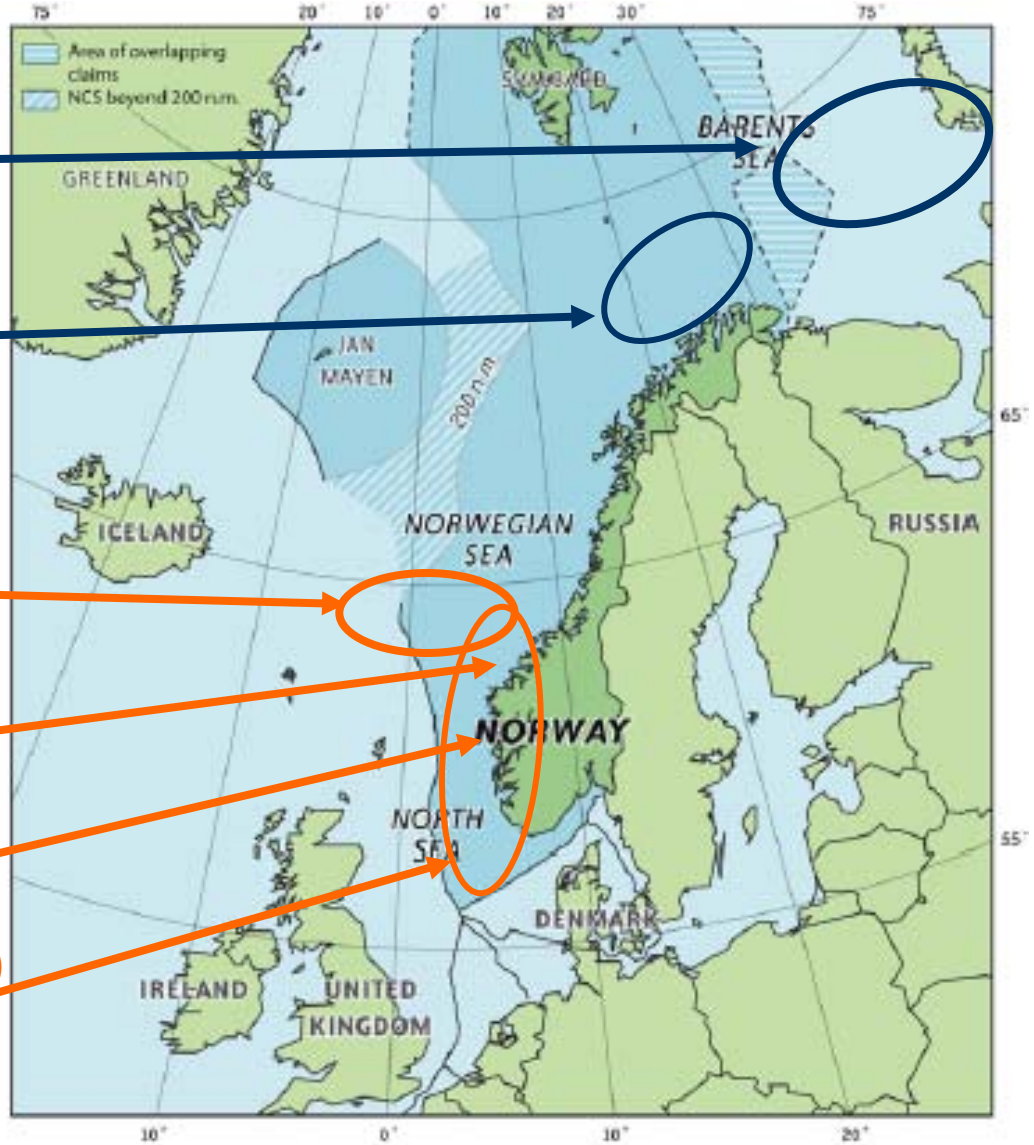
Haltenbanken

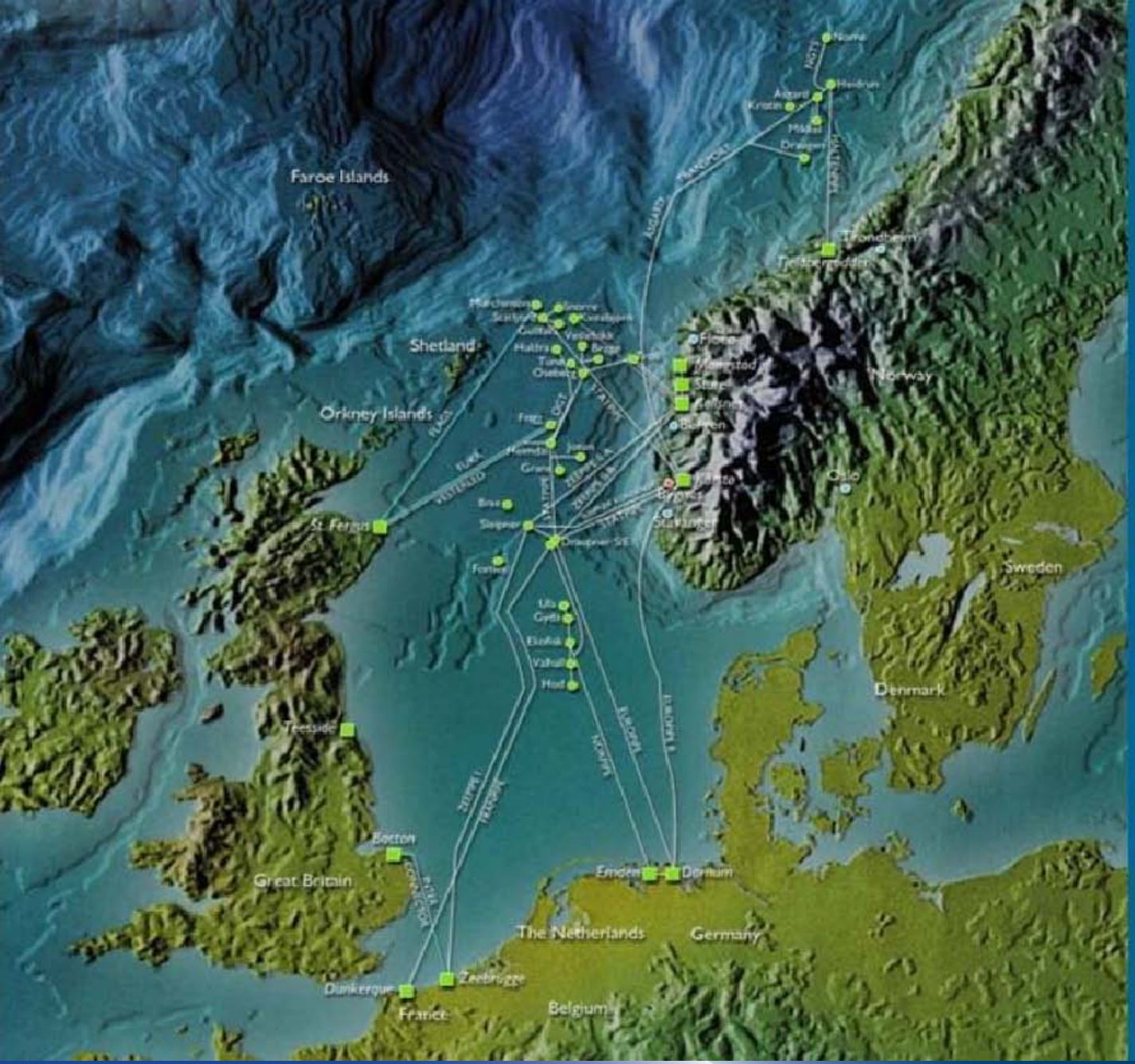
(Mature)

Northern North Sea
Tampen Oseberg +++

(Mature)

Southern North Sea
Ekofisk Valhall +++





GASSCO OPERATED SYSTEMS

[as of 1st August 2002]

Pipelines
- Franpipe
- Zeepipe I
- Zeepipe IIA + IIB
- Europipe
- Europipe II
- Haltenpipe
- Statpipe
- Åsgard transport
- Norne Gas Transportation System
- Vesterled
- Oseberg Gas Transport

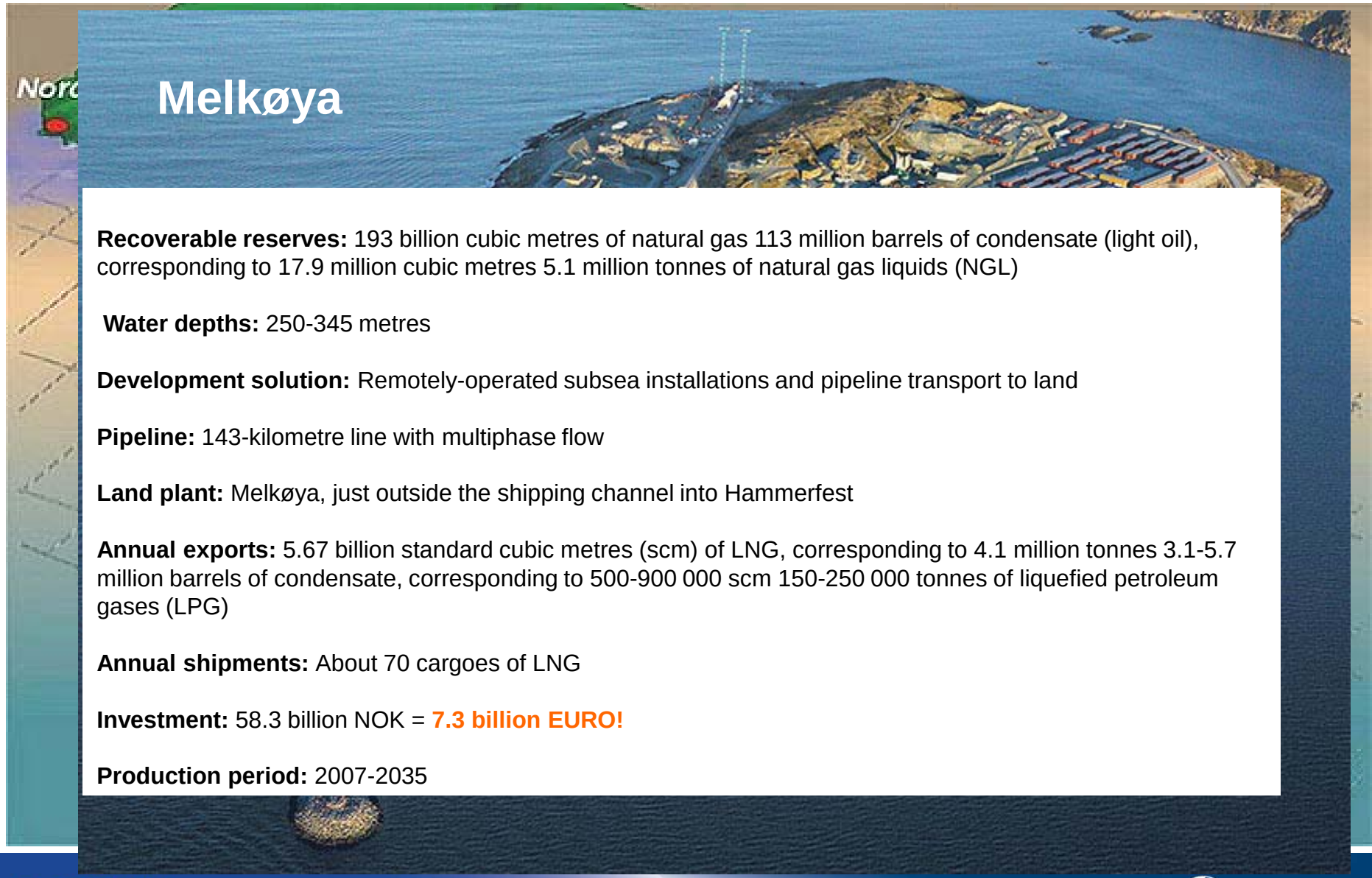
Different Systems, different ownership

Onshore facilities
- Kårstø, Norway
- Zeebrugge, Belgium
- Emden/Dornum, Germany
- Dunkerque, France
- St. Fergus, Scotland

Riser platforms
- Draupner S/E
- Sleipner Riser
- Heimdal Riser

...is now one unitised ownership structure with consistent ownership through the entire system

Snøhvit



Melkøya

Recoverable reserves: 193 billion cubic metres of natural gas 113 million barrels of condensate (light oil), corresponding to 17.9 million cubic metres 5.1 million tonnes of natural gas liquids (NGL)

Water depths: 250-345 metres

Development solution: Remotely-operated subsea installations and pipeline transport to land

Pipeline: 143-kilometre line with multiphase flow

Land plant: Melkøya, just outside the shipping channel into Hammerfest

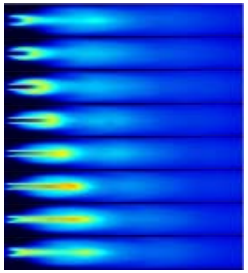
Annual exports: 5.67 billion standard cubic metres (scm) of LNG, corresponding to 4.1 million tonnes 3.1-5.7 million barrels of condensate, corresponding to 500-900 000 scm 150-250 000 tonnes of liquefied petroleum gases (LPG)

Annual shipments: About 70 cargoes of LNG

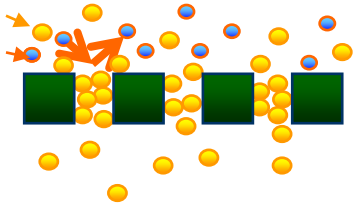
Investment: 58.3 billion NOK = **7.3 billion EURO!**

Production period: 2007-2035

The Gas Technology Centre
NTNU-SINTEF

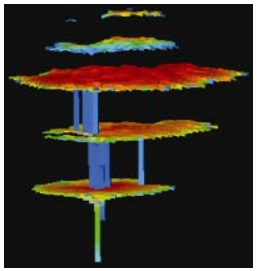


- Assembles the scientific resources and infrastructure for gas technologies in SINTEF and NTNU
- Strategic research partner Statoil, open for new entrants

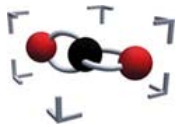


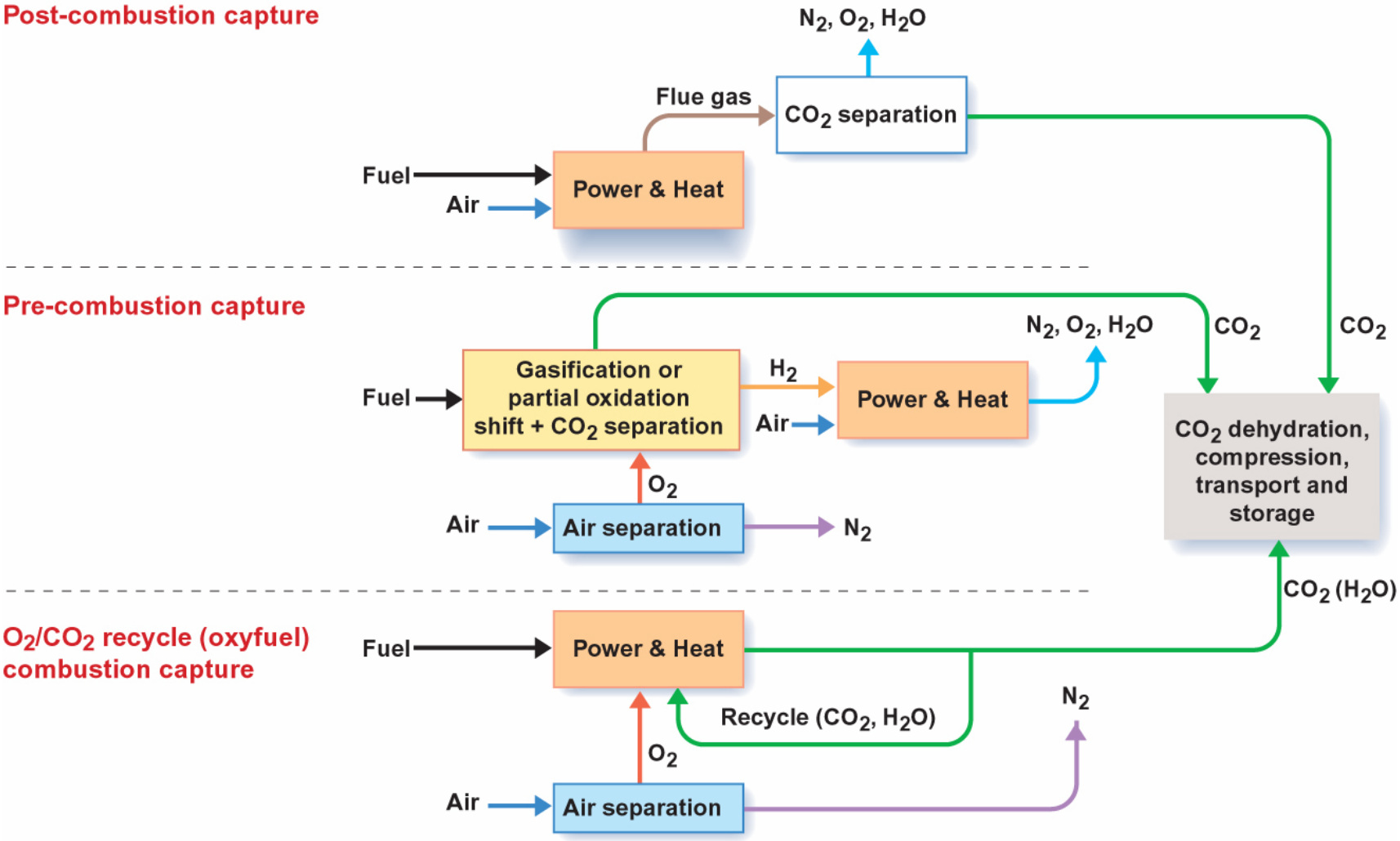
Mission:

- Secure world class education – gas technology
  - Awards ~75% of national MSc's within gas technology
  - ~30 PhD students each year within the topic
- Frontier research – gas technology
  - About 250 researchers in total (NTNU and SINTEF)
- Initiate large(r) research platforms:
  - In co-operation with the Research Council of Norway
  - EU-projects (6th & 7th Framework programmes)
  - Strategic industrial research contracts



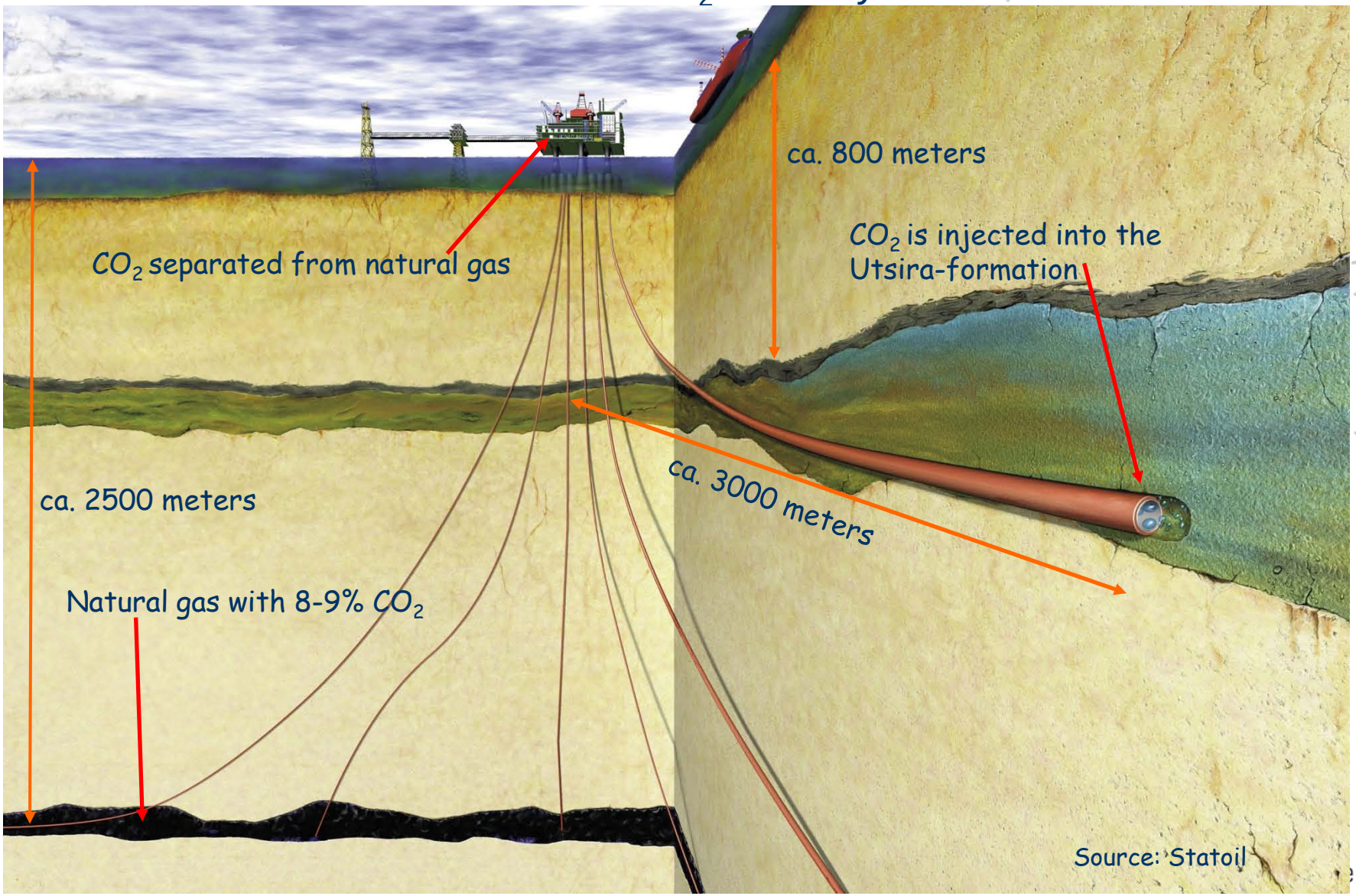
CO_2 - Capture




Post-combustion capture
N2, O2, H2O
Flue gas
CO2 separation
Fuel
Air
Power & Heat
Pre-combustion capture
N2, O2, H2O
CO2
CO2
Gasification or partial oxidation shift + CO2 separation
H2
Fuel
Power & Heat
Air
CO2 dehydration, compression, transport and storage
O2
Air
Air separation
N2
CO2 (H2O)
O2/CO2 recycle (oxyfuel) combustion capture
Fuel
Power & Heat
Recycle (CO2, H2O)
N2
O2
Air
Air separation

Sleipner gas field – CO_2 storage

ca. 1 million tonnes CO_2 annually since 1996



Centre for Renewable Energy

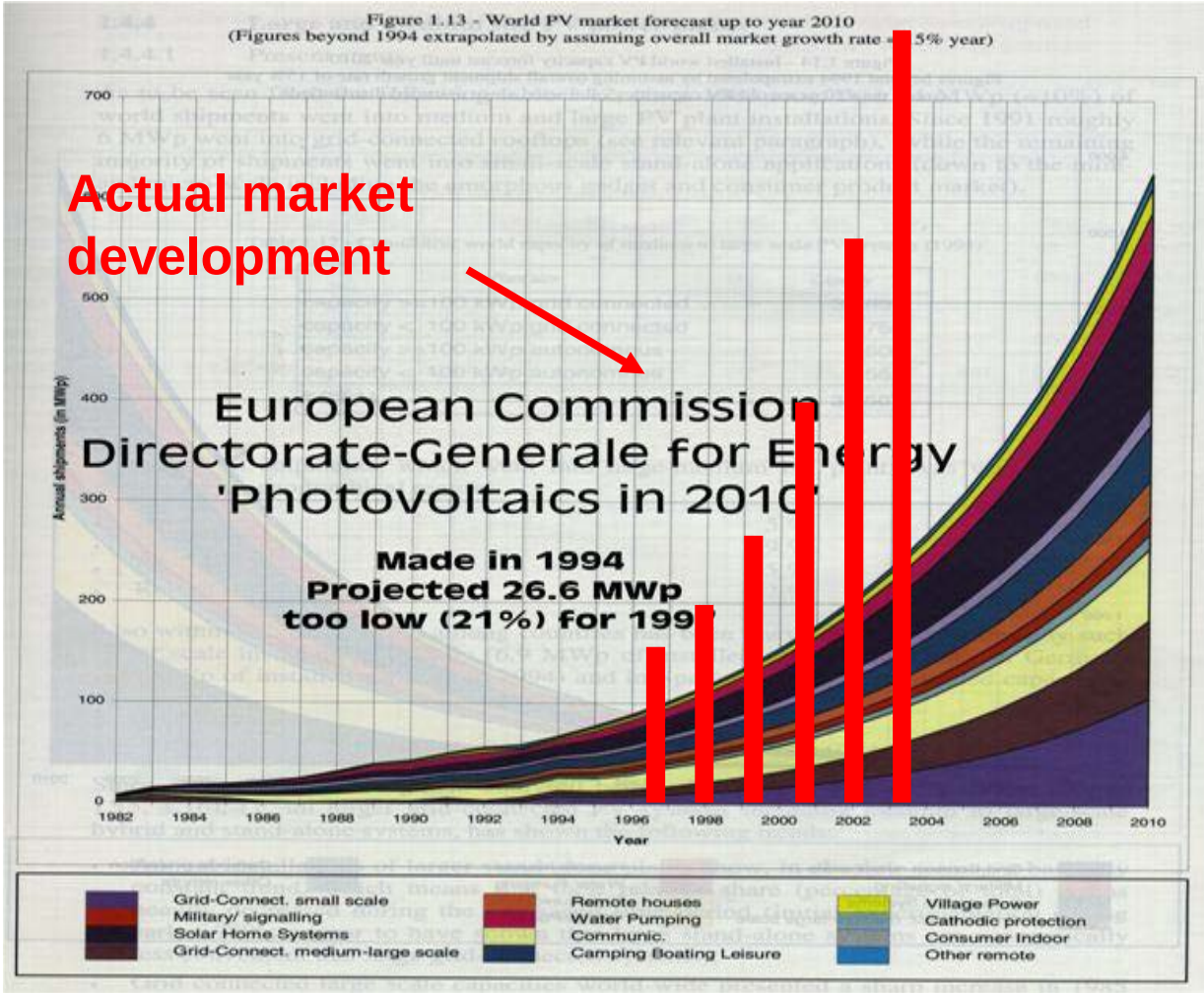
NTNU – SINTEF – IFE

- Wind power
- Solar power
- Small scale hydro power
- Bioenergy
- Hydrogen
- Wave, ocean energy
- Renewable energy systems
- Renewables and society
- Energy economising

Solar Cells

– The market grows faster than anticipated…

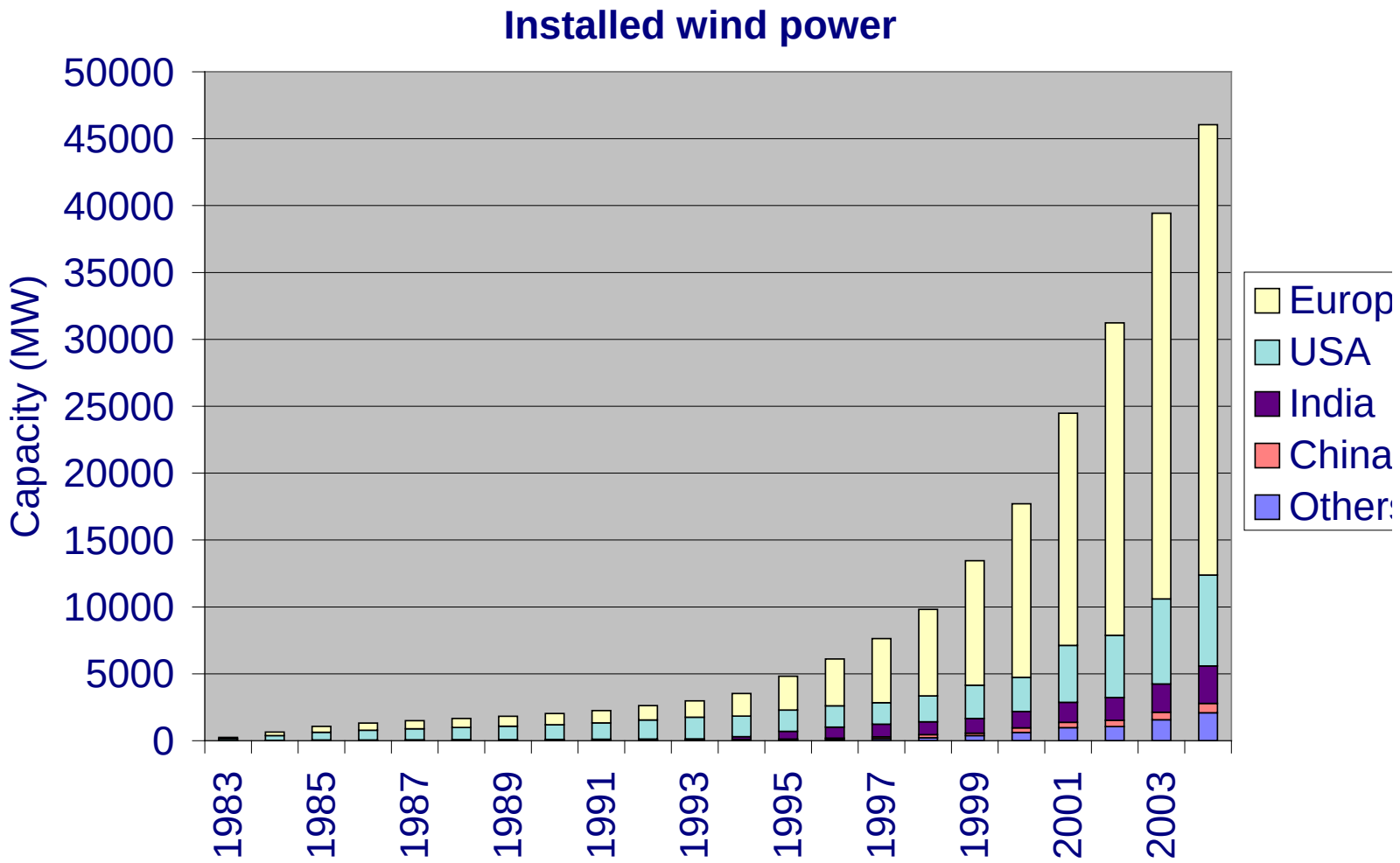
- solar
- hydro
- wind
- bio
- …



Wind energy

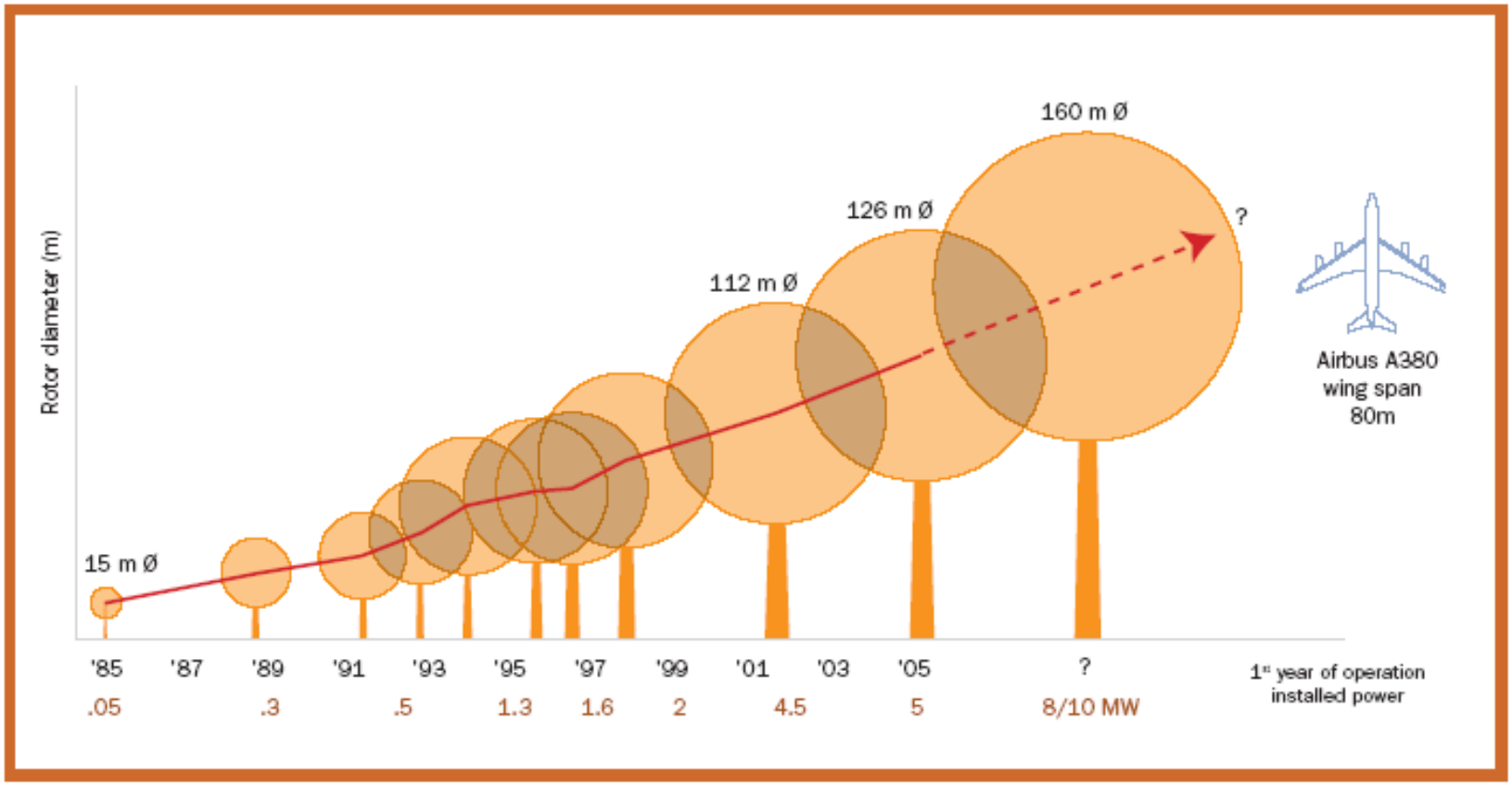
– The fastest growing energy technology

- solar
- hydro
- wind
- bio
- ...



Rapid technology development

- solar
- hydro
- wind
- bio
- ...

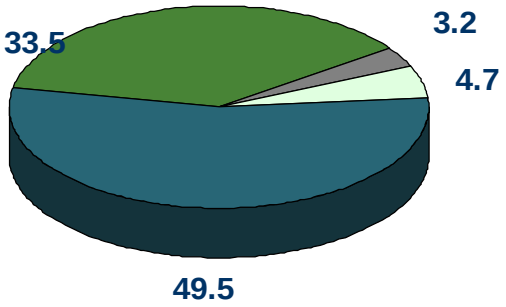


Source: Jos Beurskens, ECN

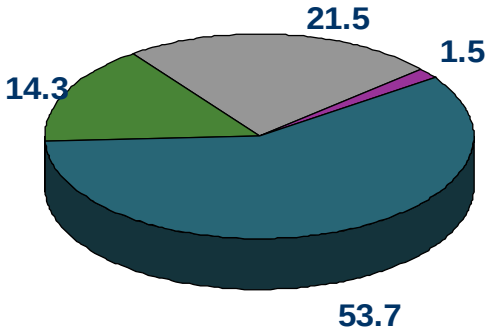
Bioenergy in the Nordic: 213 TWh

- 5% power og 95% heat

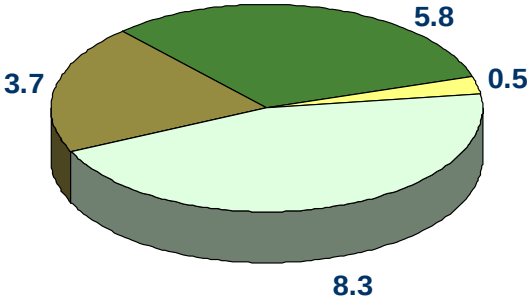
Sweden (91 TWh)



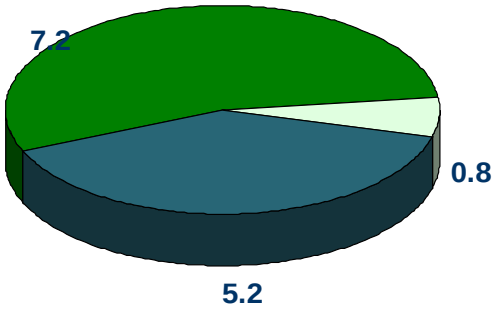
Finland (91 TWh)



Denmark (18 TWh)



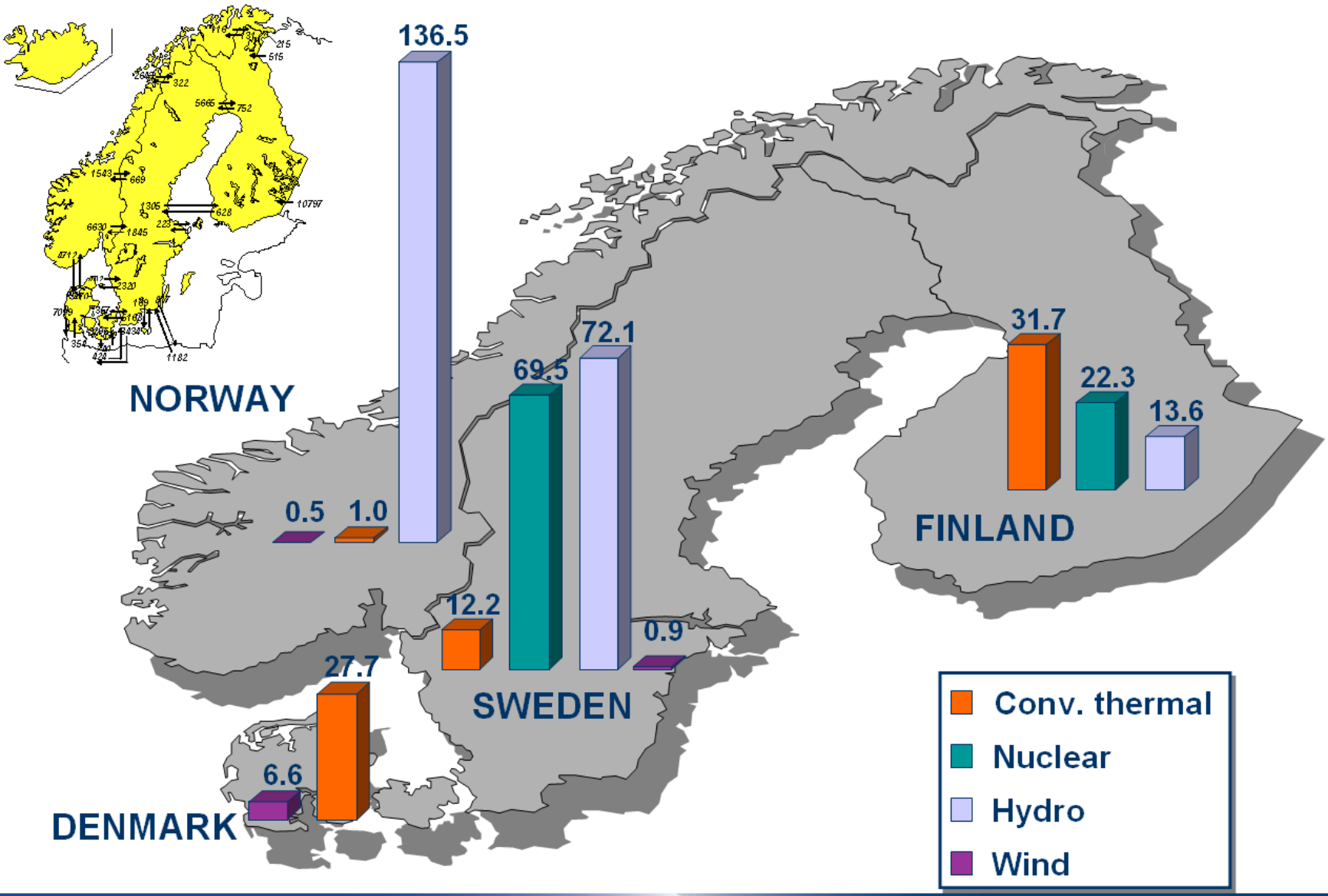
Norway (15 TWh)



- By-products forest industry
- Wood Fuel
- Waste
- Straw
- Peat
- Biogas

Ref: Norsk Bioenergiforening

Electricity Generation in Nordel 2005 (TWh)

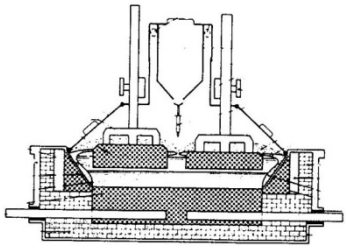


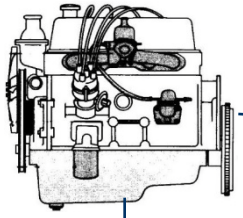
Heat and Power from Thermochemical Conversion of Biomass

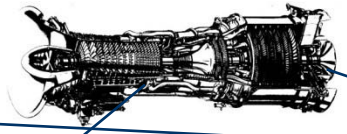
Pyrolysis | **Gasification** | **Combustion**

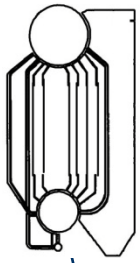
Charcoal | **Bio-oil** | **Combustible gas** | **Heat**

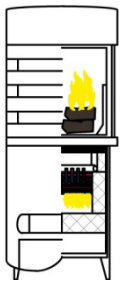
Barbeque | **Metalurgical industry** | **Diesel Engine** | **Gas-turbine** | **Boiler** | **Woodstove**



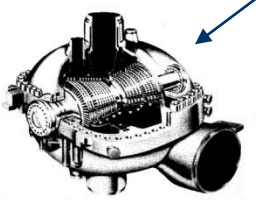








Generator



Steam-turbine

District heating

Electricity

Liquid Biofuels from Thermochemical Conversion of Biomass

Pyrolysis

Gasification

Combustion

Charcoal

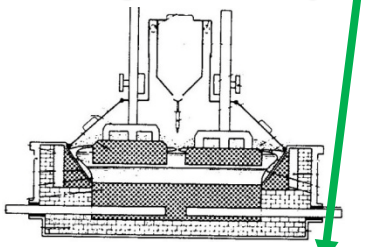
Bio-oil

Syn-gas

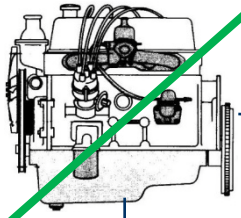
Heat

Barbeque

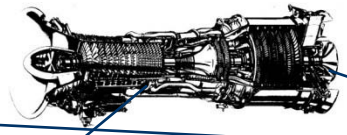
Metalurgical industry



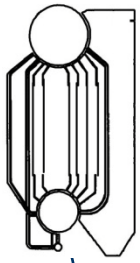
Diesel Engine



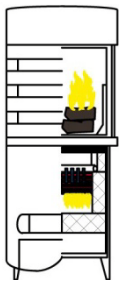
Gas turbine



Boiler

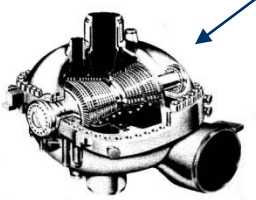


Woodstove



Reforming + FT

Generator



Steam-turbine

District heating

Fuel

Electricity

Both agricultural and wood based materials are involved in biofuels production

Bioethanol

Sugar cane

Brazil, India, China, Colombia

Sugar beet

Europe, China

Corn

US, China

Wheat

Europe, India, China, US

Biodiesel

Rapeseed

Europe, Canada, China, Russia

Palm

Indonesia, Malaysia, Nigeria

Jatropha

Africa, South Eastern Asia, India

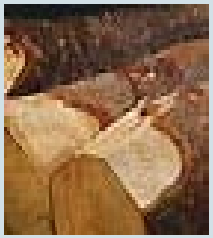
Biomass to liquids (Second generation)

Switchgrass

Miscanthus

Bagasse

Straw



Wood

Three different technologies will coexists for production of biofuels

Bioethanol

Hydrolysis → Fermentation → Distillation → Bioethanol

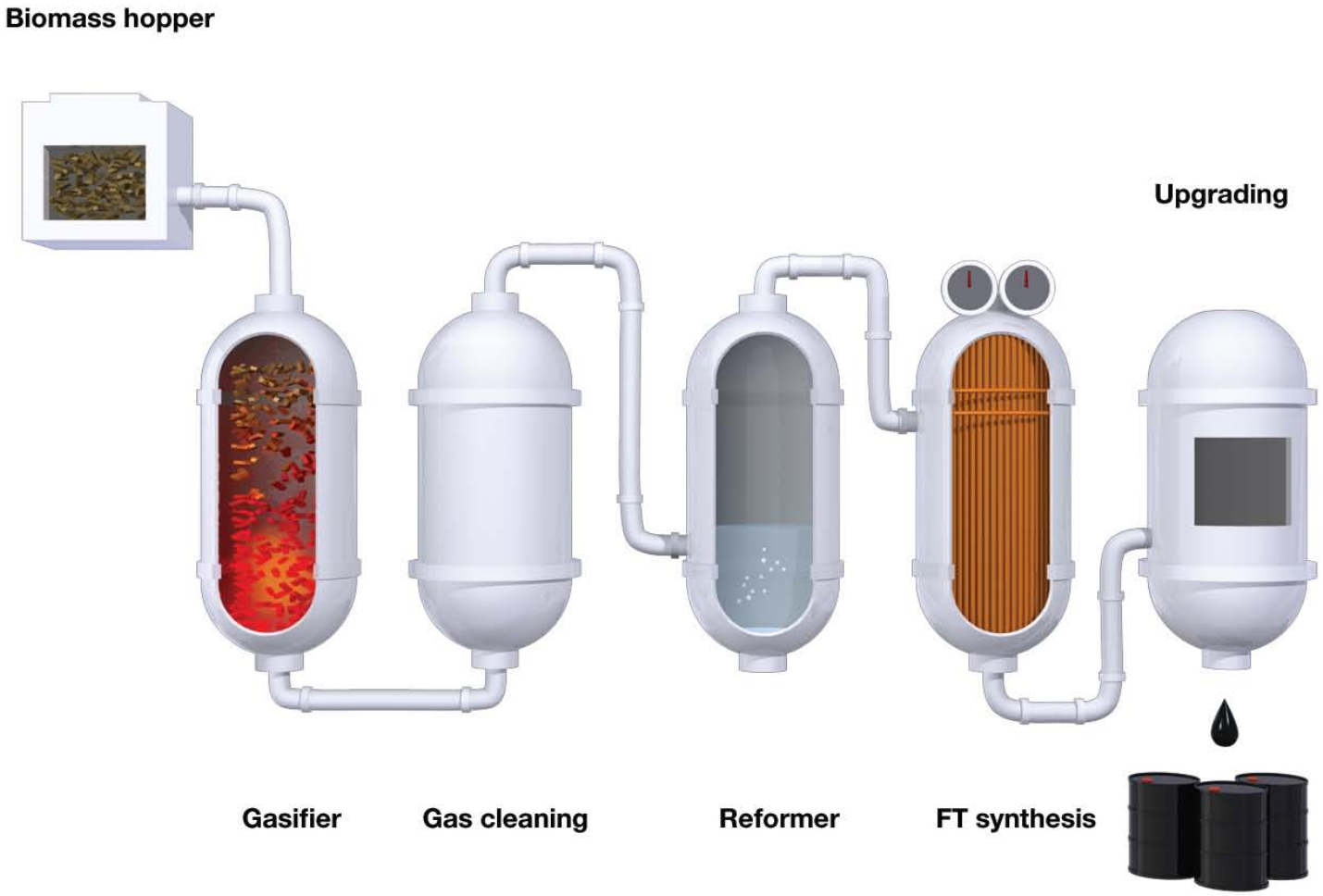
Biodiesel

Esterification → Separation → Biodiesel

Biomass to liquid (BTL)

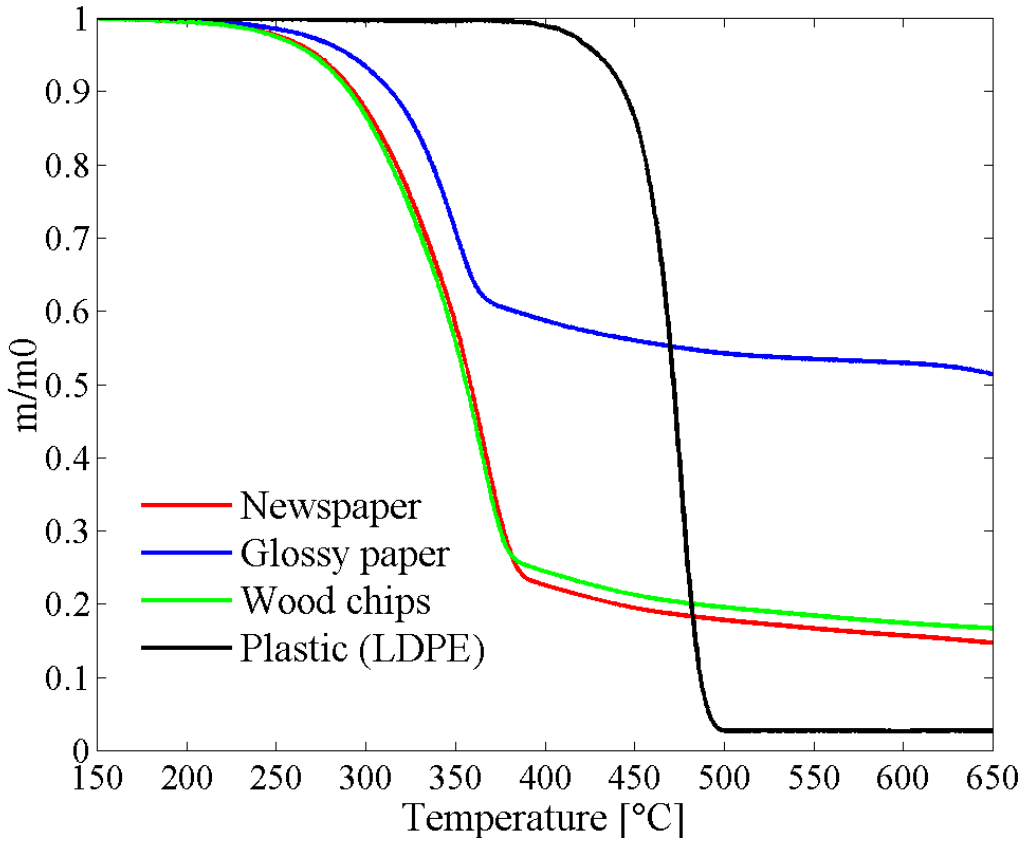
Gasification → Catalysed synthesis → Distillation → Biodiesel

Gasification + Reforming + FT



Experiments - Micro TGA

Pyrolysis of waste component



Experiments – Macro TGA

Dimensions:

Diameter: 100 mm

Height: 1000 mm

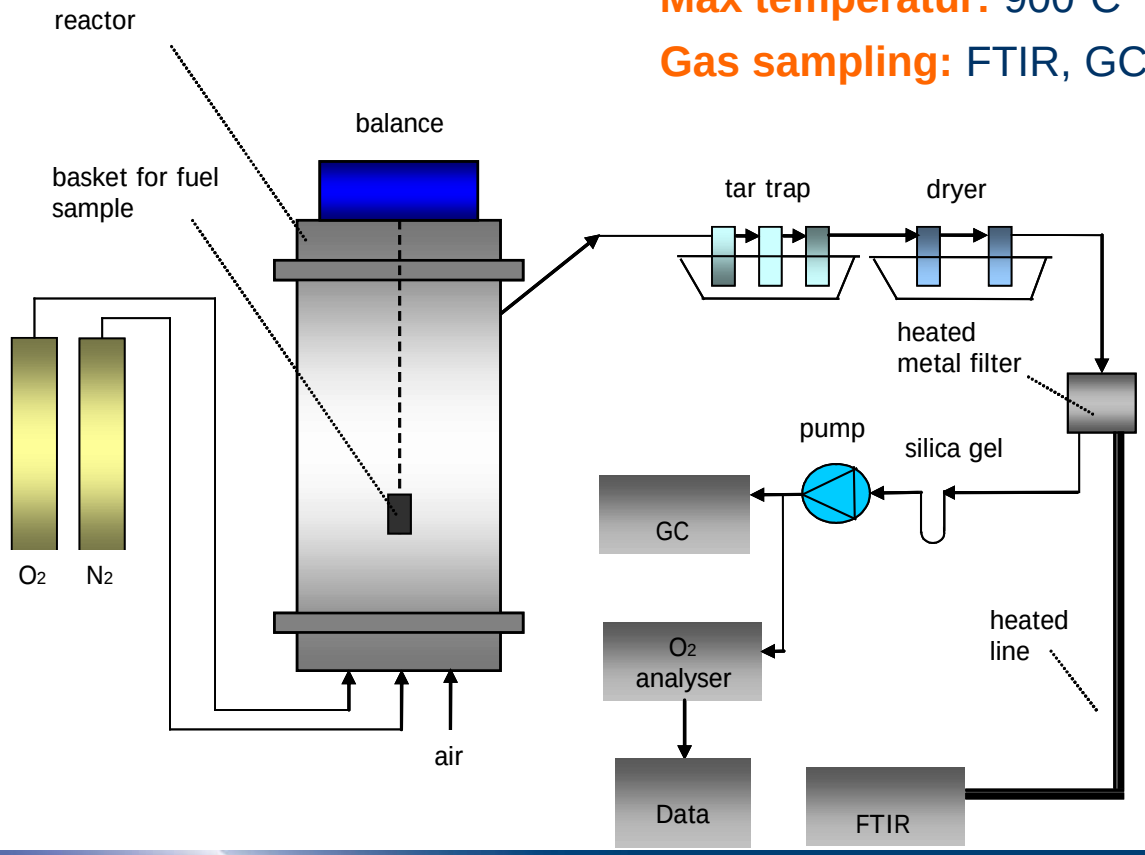
Configuration:

macro TGA, fixed bed

fluidized bed

Max temperatur: 900°C

Gas sampling: FTIR, GC

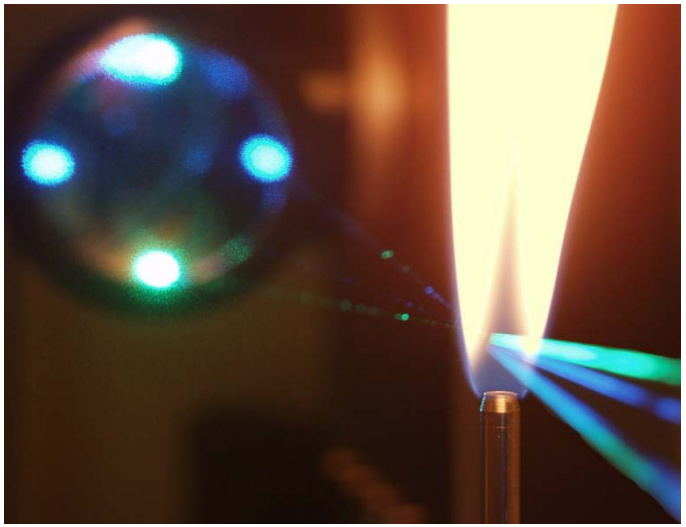


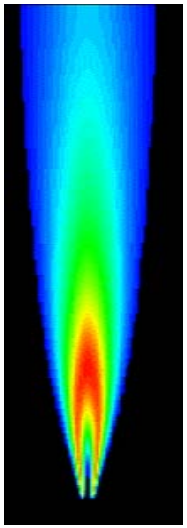
Multifuel reactor

- Fuel testing
  - Fuel mixtures
  - Additives
  - Impact on:
    - Flue gas quality
    - Particle formation
    - Corrosion and fouling
- Input and comparison with modelling work
  - CFD
  - Equilibrium calculations

CFD-modeling

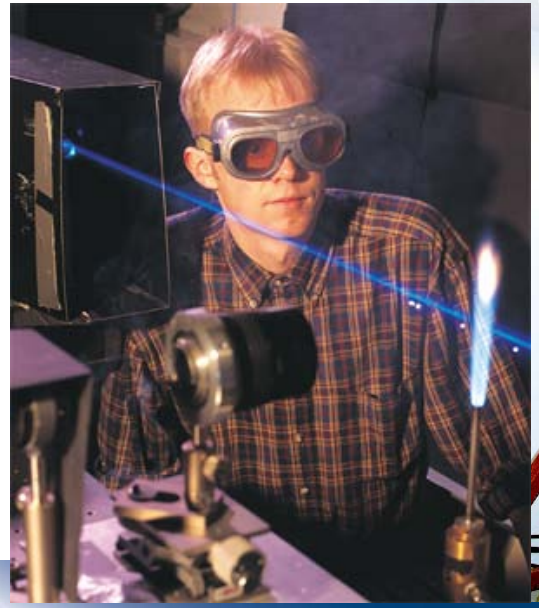
- Computational Fluid Dynamics
- Computation of (reactive) flows
  - Flow field (velocity)
  - Temperature field
  - Species concentrations (e.g. emissions as NO, CO)
  - Radiative fluxes
  - Wall heat transfer
  - ...
- Multidimensional (2D/3D)



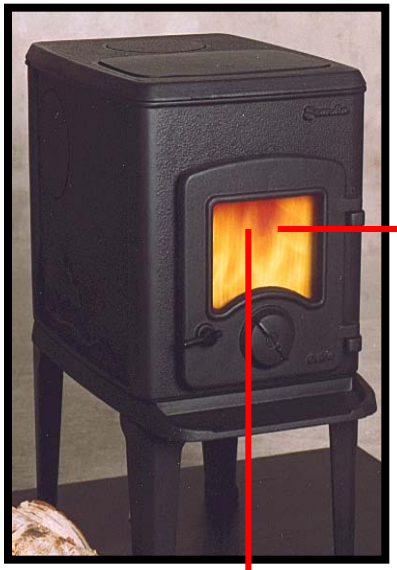


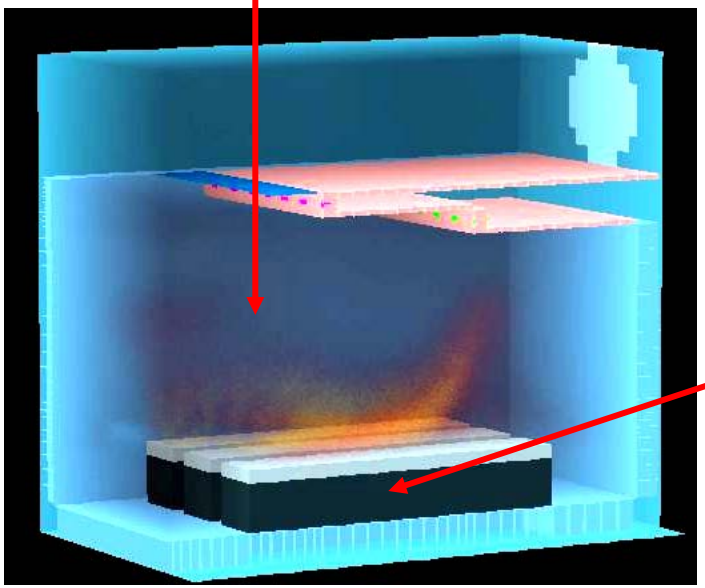
Why use CFD?

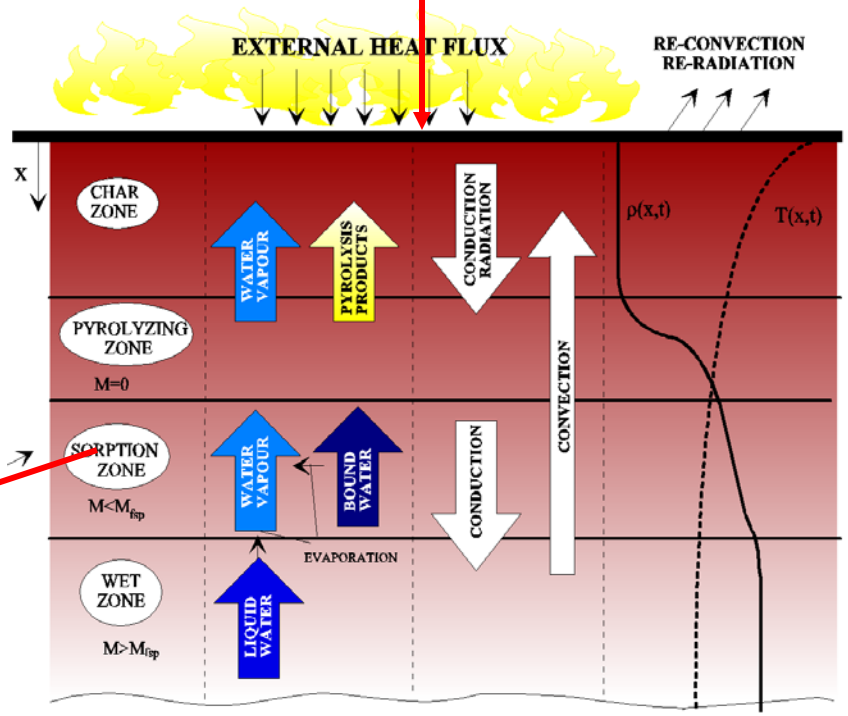
- Real problems
  - industrial furnaces
  - boilers
  - wood stoves
- Interaction of physical phenomenons
  - Fluid flow
  - Heat transfer
  - Chemical reactions
  - Phase interchange
- Cheaper than experiments



Modelling






EXTERNAL HEAT FLUX
RE-CONVECTION
RE-RADIATION
x
CHAR ZONE
PYROLYZING ZONE
M=0
SORPTION ZONE
M<M_fsp
WET ZONE
M>M_fsp
WATER VAPOUR
PYROLYSIS PRODUCTS
CONDUCTION RADIATION
CONVECTION
CONDUCTION
BOUND WATER
EVAPORATION
LIQUID WATER
ρ(x,t)
T(x,t)

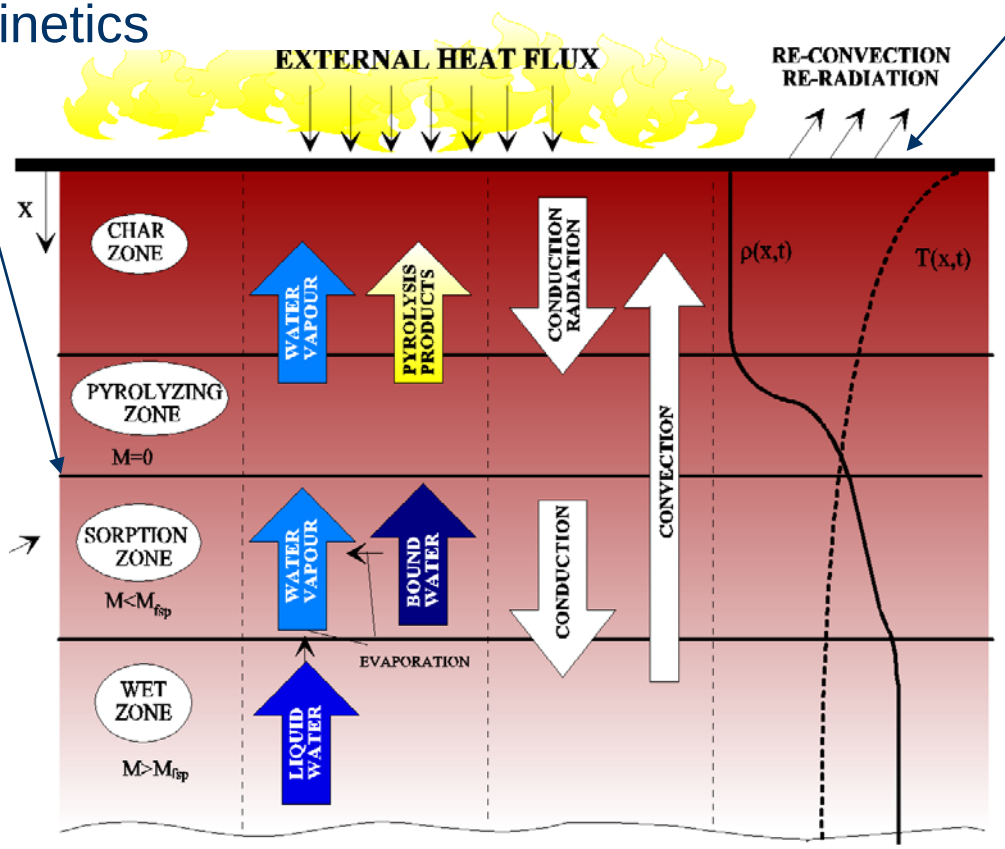
Biomass modeling

Grønli & Sørum

- Single particle modelling
- Pyrolysis kinetics

Barrio, Risnes & Khalil

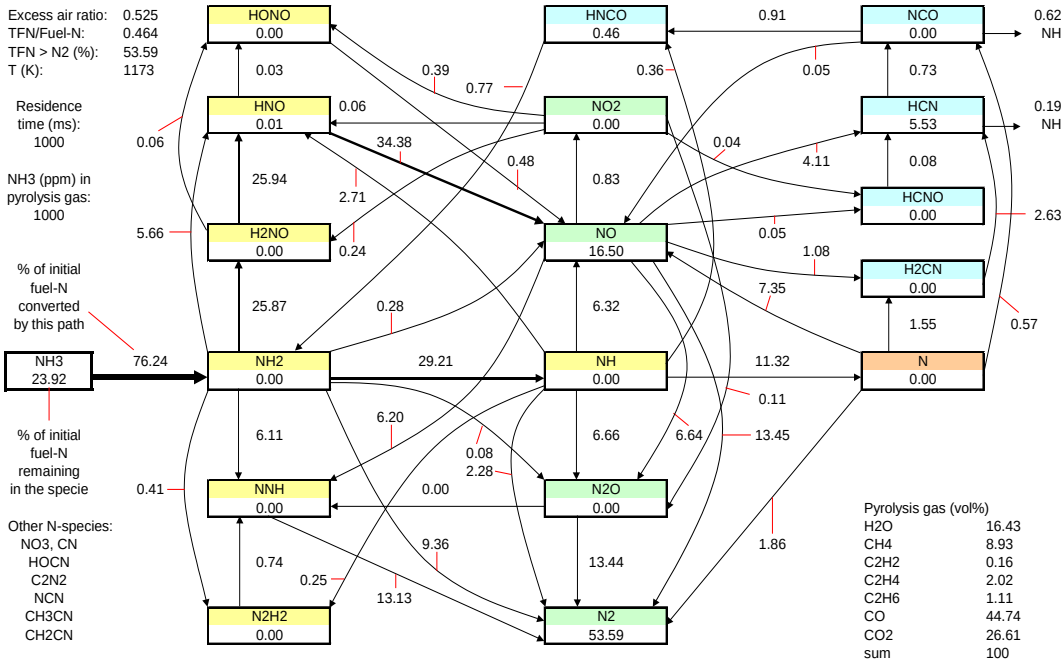
- Char reactivity



NOx & SOx formation and reduction

Skreiberg & Becidan

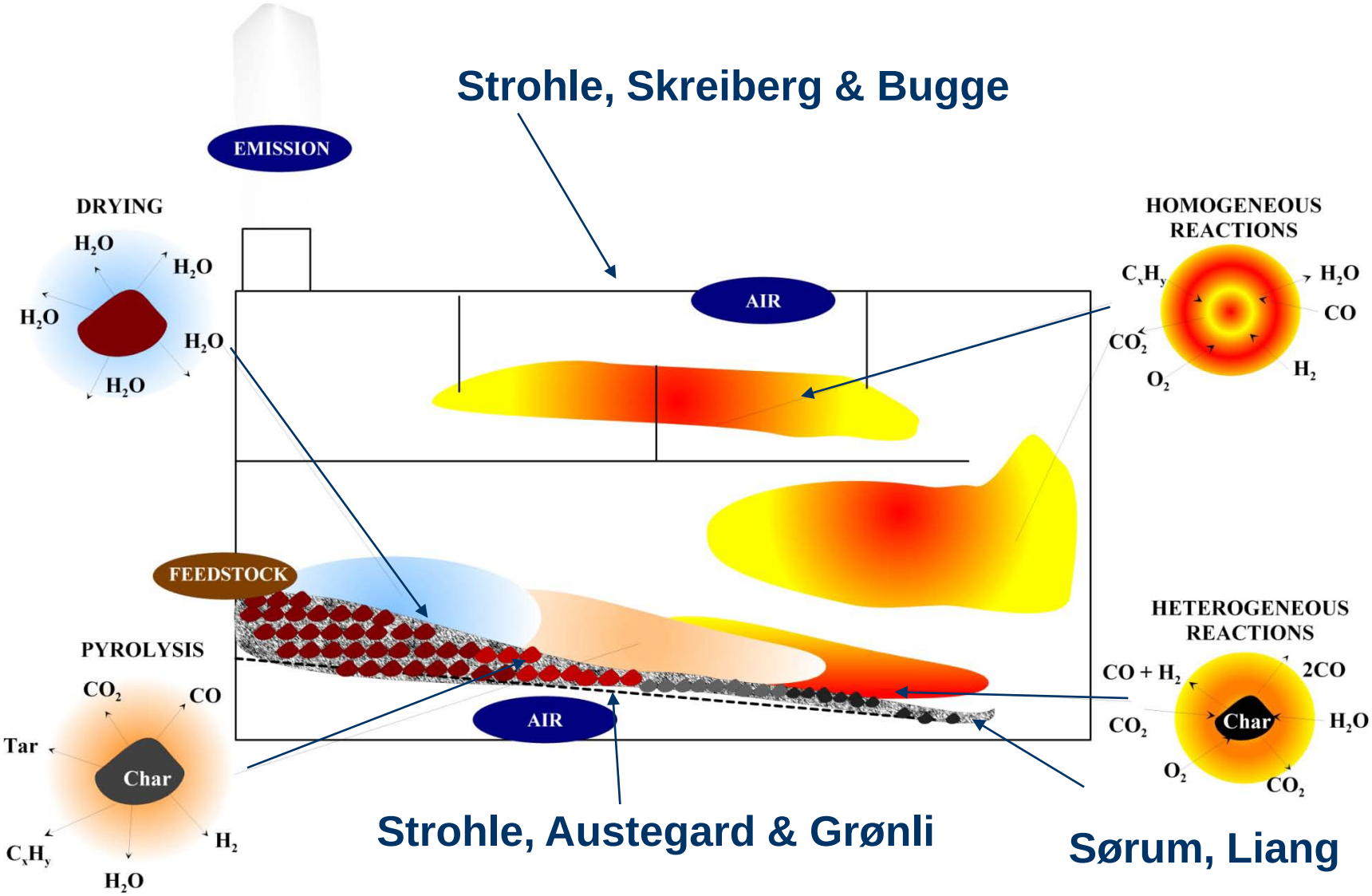
- NH3 & HCN release
- NOx- chemistry

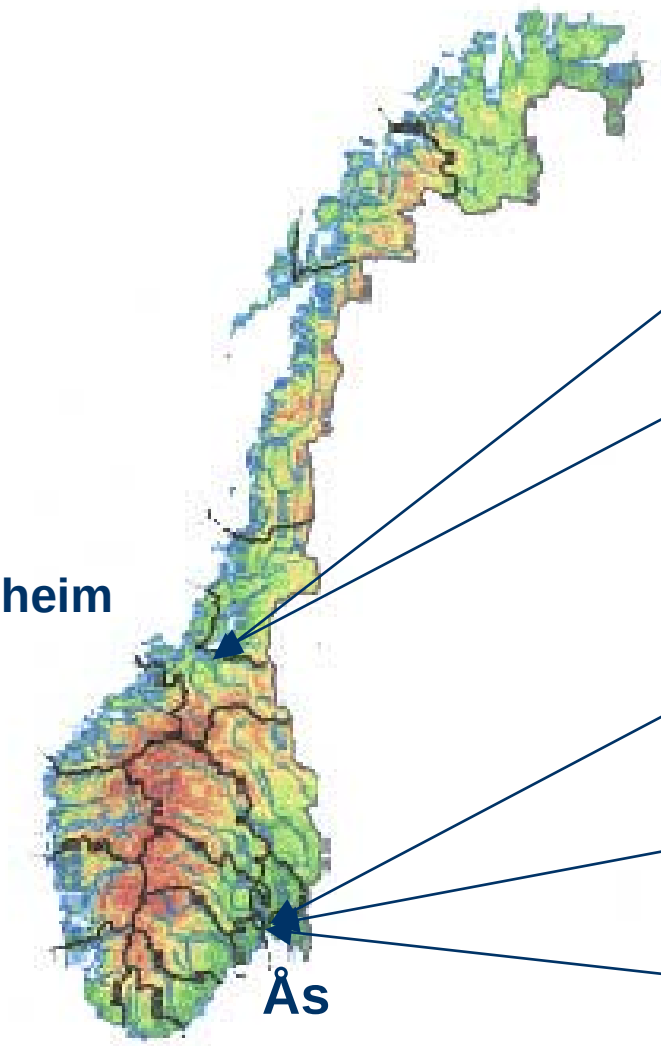


Khalil

- SOx – release

Grate Furnace (biomass & waste)





SINTEF

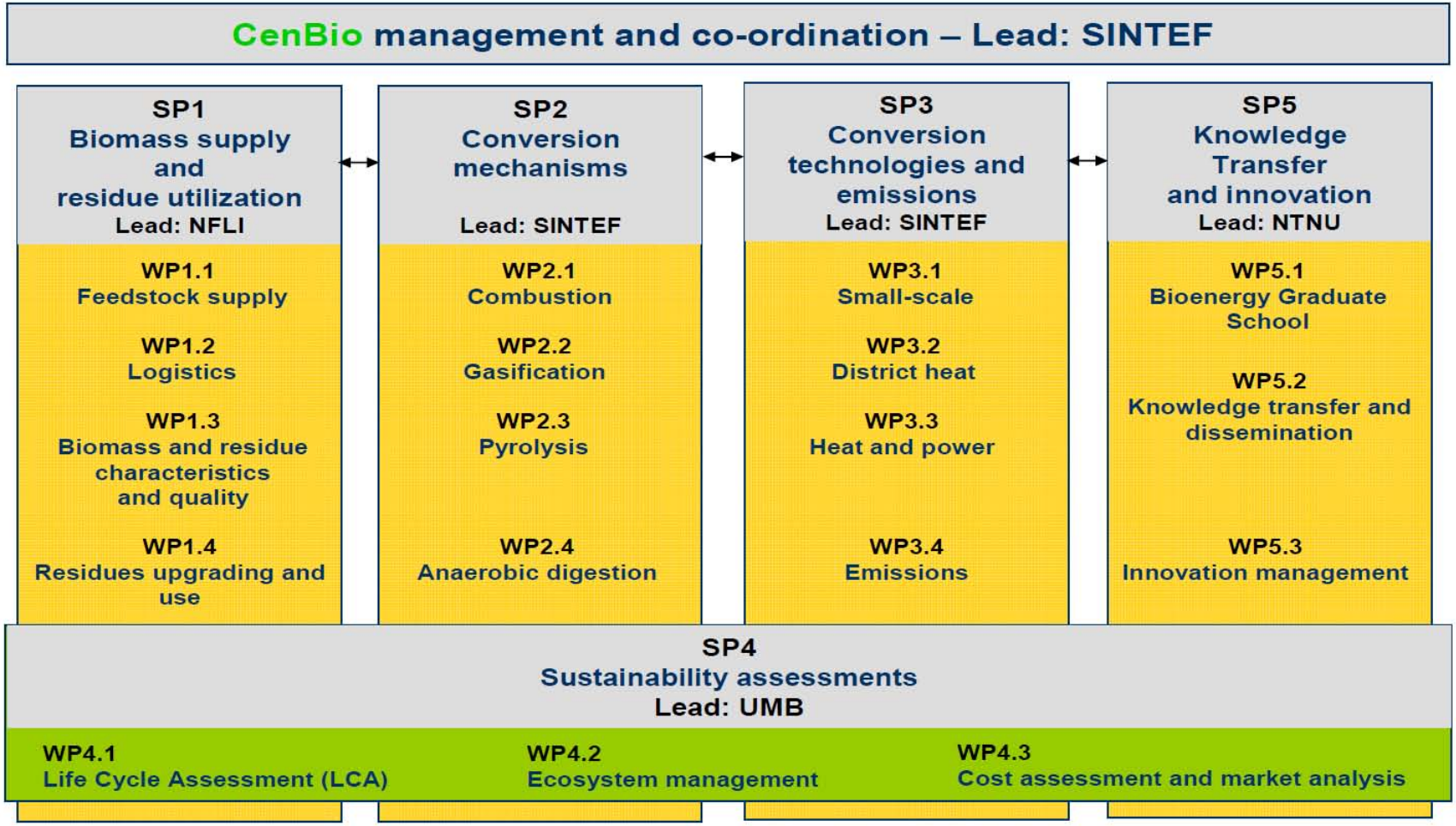
NTNU

NORWEGIAN UNIVERSITY OF LIFE SCIENCES

skog+ landskap
NORWEGIAN FOREST AND LANDSCAPE INSTITUTE

Bioforsk

CenBio Work Breakdown Structure



Organisation	Category	Expertise
UMB (Host institution)	Education / R&D	Sustainability analyses
NTNU	Education / R&D	Life Cycle Analyses. Bioenergy Graduate school
Sintef (Centre Lead)	R&D Institute	Conversion Process & Technology (Thermal)
Bioforsk	R&D Institute	Conversion process (Biogas).
NFLI	R&D Institute	Raw materials. Logistics. Residue upgrade
Vattenfall R&D	R&D Department	Corrosion. Fuel knowledge. CHP systems.
Arena Bioenergi Innlandet	Bioenergy cluster	Education, demonstration and dissemination
Norges skogeierforbund	Forestry association	Raw materials. Logistics.
Agder Energi	End user energy company	District heating. Heating plants.
Eidsiva Energi	End user energy company	District heating. Heating plants.
Hafslund	End user energy company	Upgraded bioenergy fuels. Heating plants.
Trondheim Energi/Statkraft	End user energy company	District heating. Waste-to-energy. Biopower
Norske Skog	Biomass end user	Raw materials. Logistics. Heat and power.
Xynergo	Biomass end user	Biofuels
Norsk Protein	Waste raw materials	Waste fractions
NTE Holding	Biogas. Energy company	Biogas
Norges Bondelag	Waste raw materials	Waste fractions. Raw materials.
EGE	Energy from Waste end user	Waste to energy. Biogas. Heat and power.
Avfal Energie Bedrijft (NL)	Energy from Waste end user	Waste to energy (Largest plant in Europe.)
Avfall Norge	Waste association	Waste to energy. Biogas. Residue upgrade.
Energos	Conversion technology company	Waste gasification / combustion technology
Cambi	Conversion technology company	Biogas conversion technology
Jøtul	Conversion technology company	Small scale wood combustion
BioNordic	Conversion technology company	Small scale pellet combustion
Granit Kleber	Conversion technology company	Small scale wood combustion
Vattenfall Nordic Heat (SE)	End user energy company	Large scale heat and power

Objectives

The overall objective of CenBio is to enable sustainable and cost-efficient bioenergy for stationary use in Norway.

• Objective 1 (SP1): To determine how the present volumes of biomass harvested for energy purposes may be doubled by 2020, and what implications this has for energy fraction qualities

• Objective 2 (SP2): To discover the feedstock requirements and technology implications for efficient use of new bioenergy fractions and mixtures.

• Objective 3 (SP3): To demonstrate that all the biomass conversion energy efficiencies listed in the CenBio Vision 2020 are practically and economically feasible, as well as environmentally benign.

• Objective 4 (SP4): To provide sound and solid analyses to bioenergy investors, regulating authorities and other stakeholders of the overall environmental and economic impacts of existing and proposed bioenergy value chains.

• Objective 5 (SP5): To educate and train the current and next generation of bioenergy specialists in Norway.

4. International cooperation

The research groups involved in the Centre have, individually, firmly established networks and widespread cooperation within the Bioenergy activities of the ***EU research framework programs***, the ***IEA*** implementing agreements on Bioenergy, as well as within the ***Nordic Energy Research*** programmes. This cooperation will be extended and intensified through CenBio.

CenBio will also establish more formal ***cooperation agreements*** with the following internationally renowned bioenergy research institutions, where exchange of personnel may be expected on a frequent and regular basis:

- Stanford University, Thermosciences group (LoI included)
- US Forest Service, Forest Products Laboratory, Madison, Wisconsin, USA (LoI included)
- University of Minnesota, Initiative for Renewable Energy and the Environment, Saint Paul, Minnesota, USA (LoI included)
- METLA - The Finnish Forest Research Institute, Vantaa, Finland (LoI included)
- The Forestry Research Institute of Sweden, Uppsala, Sweden, (LoI included)
- Chalmers University of Technology, Dept. of Energy and Environment, Gøteborg, Sweden (LoI included)
- Åbo Akademi University, Process Chemistry Centre, Åbo, Finland (LoI included)
- The Technical University of Denmark, Dept. of Chemical and Biochemical Engineering, Lyngby, Denmark.(LoI included)
- The University of Copenhagen, Danish Centre for Forest, Landscape and Planning, Copenhagen, Denmark (LoI included)
- Vienna University of Technology, Institute of Chemical Engineering, Vienna, Austria (LoI included)
- University TU Bergakademie Freiberg, Institute of Energy Process Engineering and Chemical Engineering, Freiberg, Germany (LoI included)