ECN
Your energy. Our passion.

Biomass Conversion Technologies

Jaap Vente
Innovation Manager Gas Processing, Treatment and Conversion
given by Paul Cobden

KIVI, The Hague
April 13, 2015

ECN: A rich and evolving history

~500 employees

~110 patents

1955 Opens as Reactor Centre for the Netherlands

1975 Wind Energy and Coal Programmes

1985 Fuel Cell programme starts

1990 Solar Energy & Environmental research programmes start

1994 Biomass research programme starts

1998 Energy Efficiency in the Industry programme starts

2000 Intelligent Energy Grids Programme starts

2011 New Strategy & Focused activities

ECN technology can be found in

60% world wide solar modules

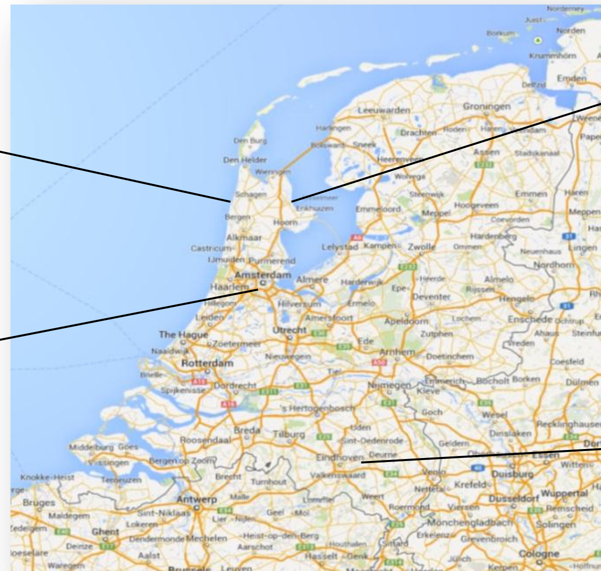
80% of EU off – shore wind farms

We are in our 60th year of pushing the boundaries of technology

Where we are

ECN
Petten
(head office)

ECN
Amsterdam

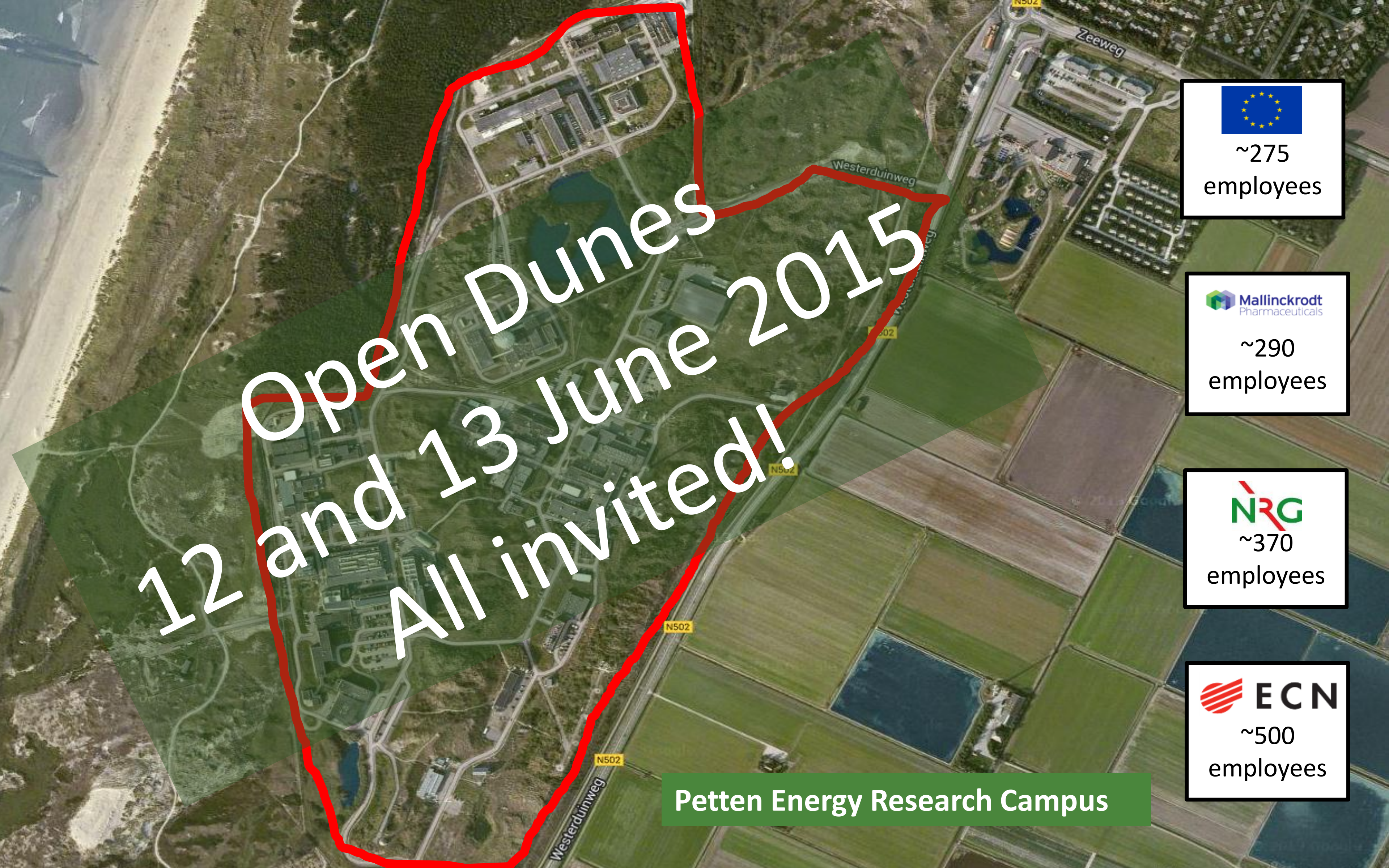


ECN
Wieringerwerf

ECN
Eindhoven

ECN
Brussels

ECN
Beijing



Open Dunes
12 and 13 June 2015
All invited!
~275 employees
Mallinckrodt Pharmaceuticals
~290 employees
NRG
~370 employees
ECN
~500 employees
Petten Energy Research Campus
Zeeweg
Westerduinweg
N502

Contents of today

- Biomass & Energy Efficiency
  - Program, focus areas & approach
- Challenges related to biomass utilization
- Technological options
  - Biomass gasification & refinery
  - Gas phase processes
- Your input to ECN

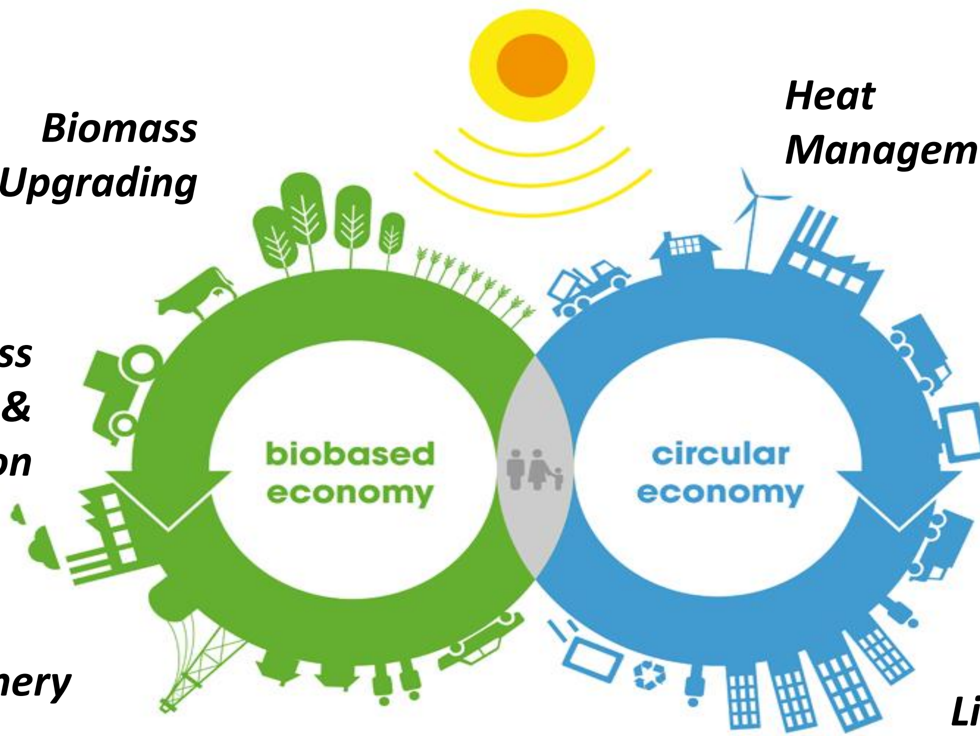
Biomass & Energy Efficiency

Biomass & Energy Efficiency : six focus areas

Biomass Upgrading

Heat Management

Biomass Combustion & Gasification



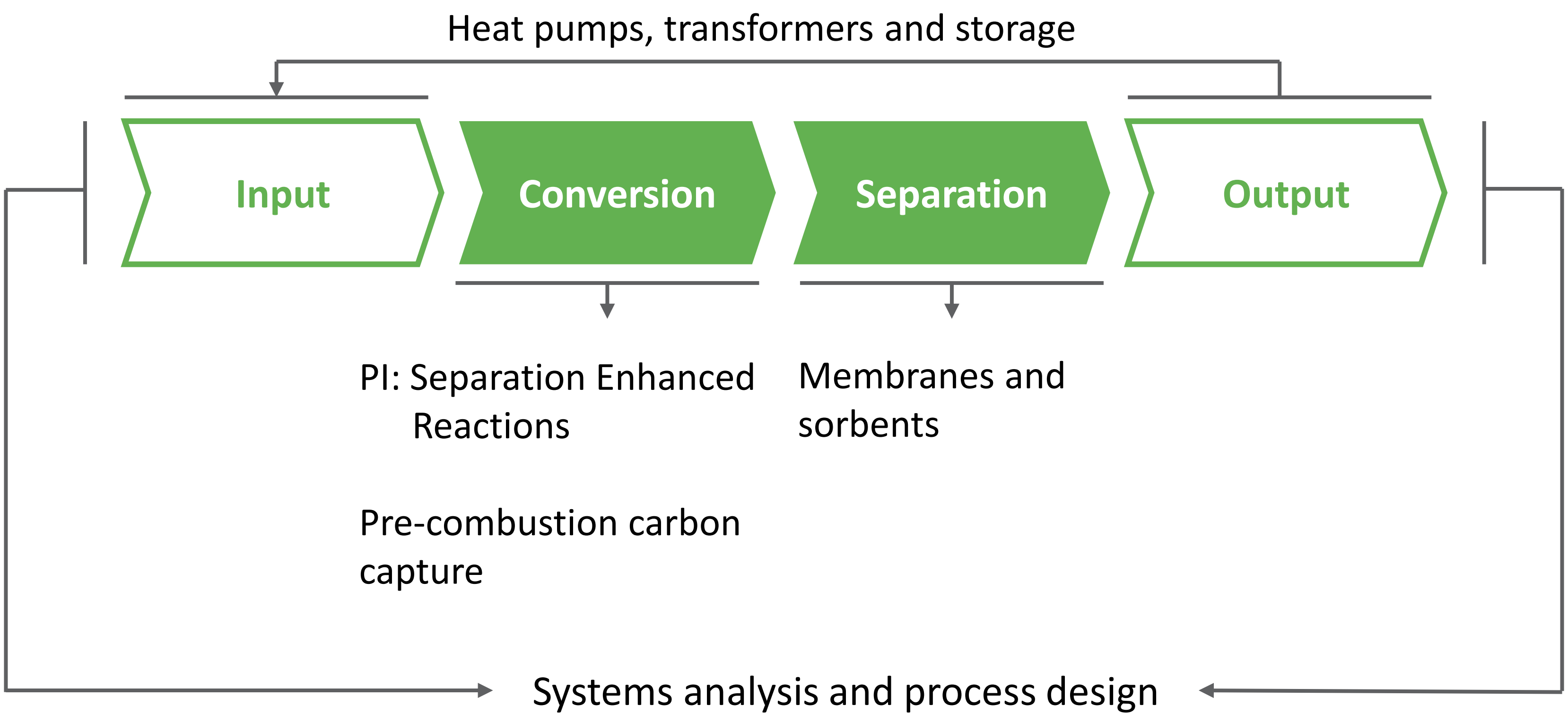
Gas Processing Treatment & Conversion

Biorefinery

Liquid Separation & Conversion

A process approach to improving energy efficiency

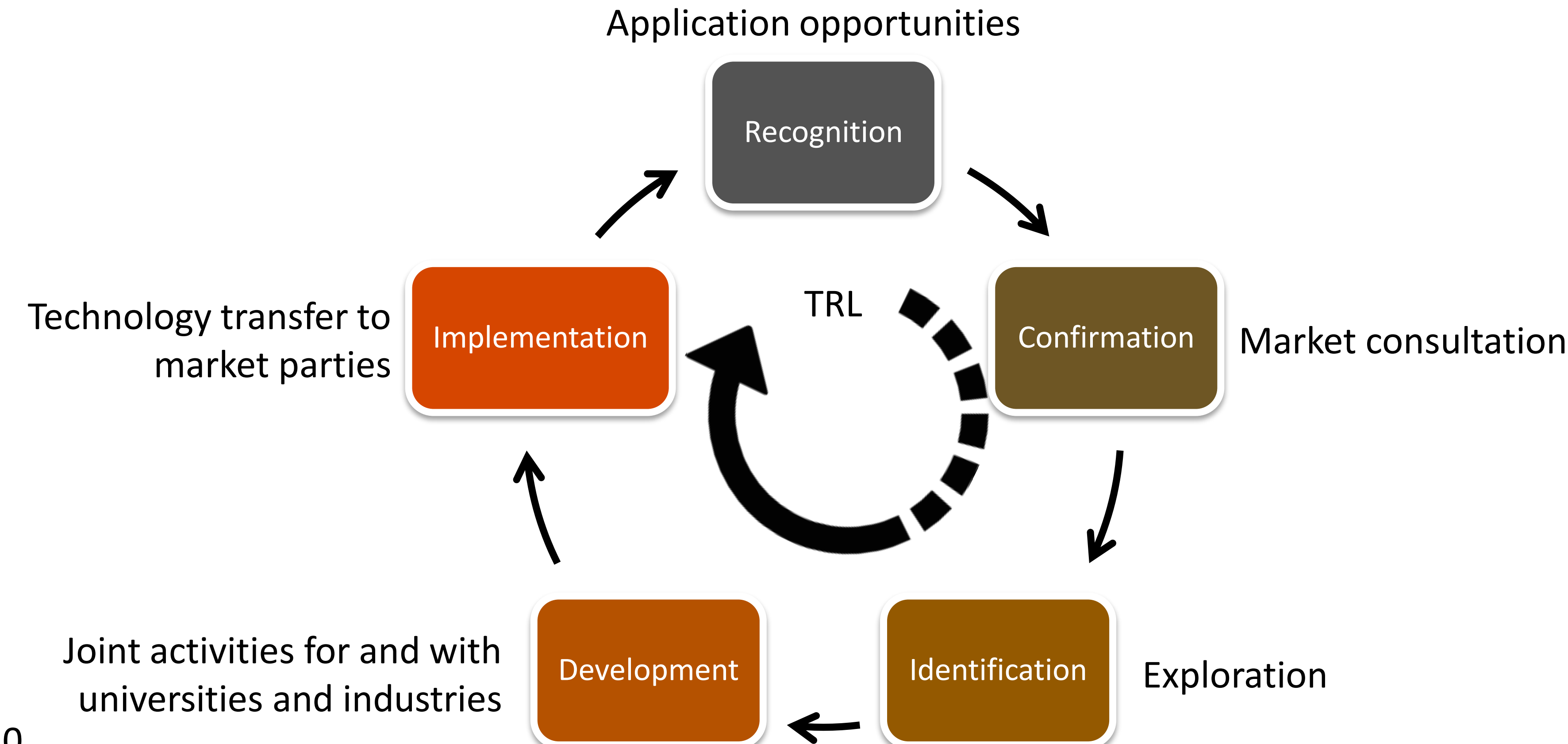
Focus on heat: ~ 80% of energy consumption is heat



Markets
Clients & Partners

- Gas Processing, Syngas Tuning, Refinery, Steel production
- End users, component manufacturers, system integrators
- Public Private Partnerships

Innovation cycle



Biomass as feedstock

Timber storage in Sweden after "Gudrun" storm, 2005, 1 month fuel for SSAB blast furnace

Various sources of biomass

Biomass = all organic material of non-fossil origin meant for energy or chemicals/materials production

waste

wood

(agricultural) residues

energy crops

aquatic biomass

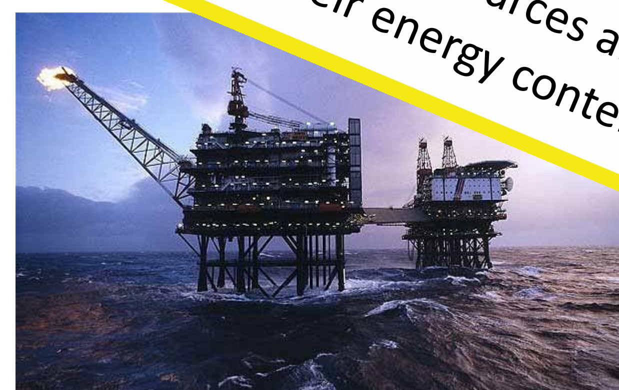
Biomass *vs.* fossil feedstock

- Both very diverse!

- Differences in:
  - Oxygen content
  - Water content
  - Ash – dust – minerals

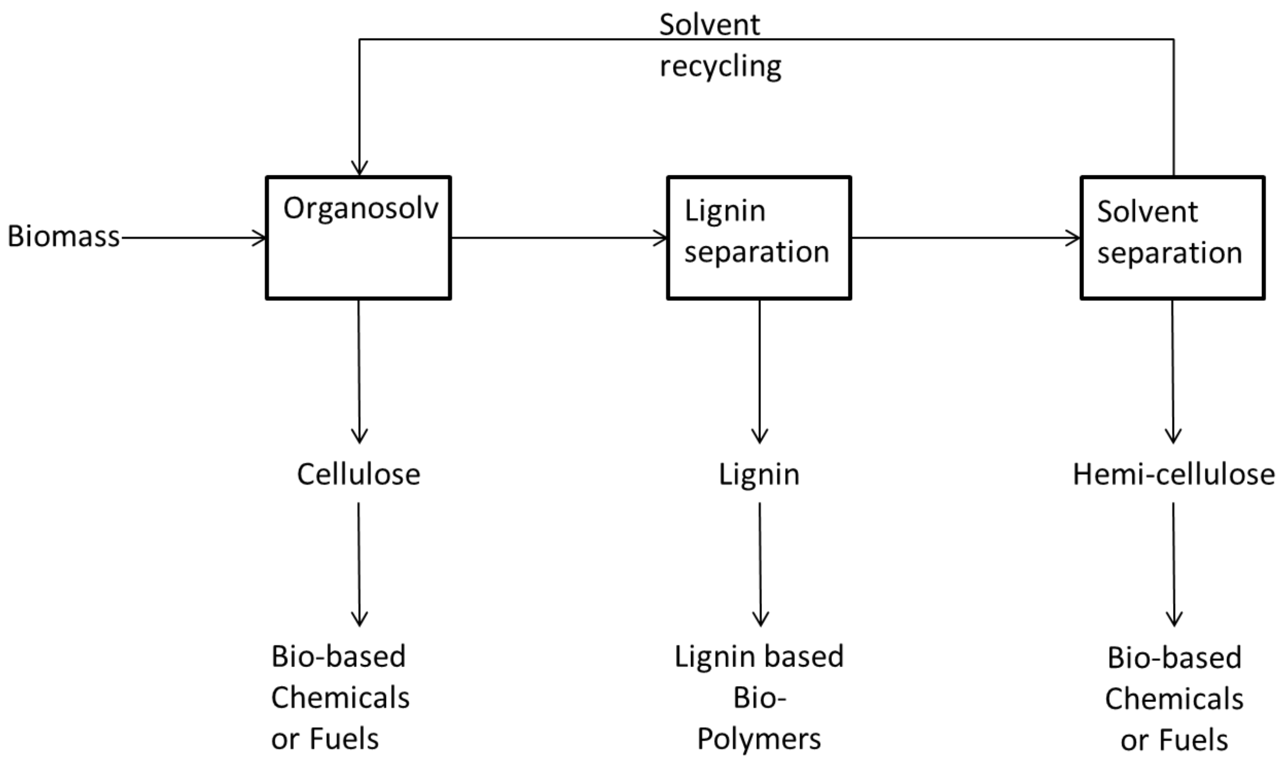
- Two routes to go from biomass to products
  - Biorefinery
  - Gasification

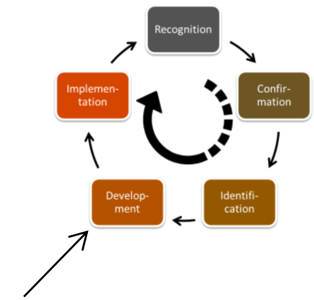
> 90% of fossil natural resources are solely used for their energy content



From fresh seaweed to chemicals via biorefinery

Organosolv based biorefinery





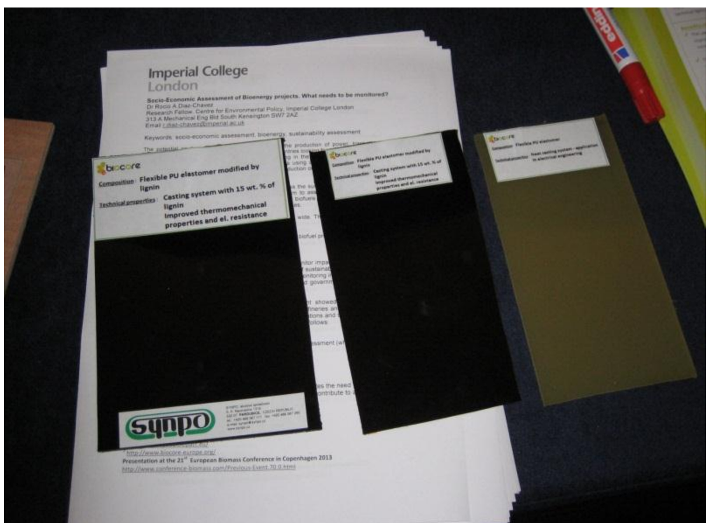
Early markets

Increased functionality

- 15wt% lignin in PU
- Higher resistance: perfect for electrical insulation

Cost reduction

- Phenol-formaldehyde resins
- Same performance
- 100 €/ton cheaper

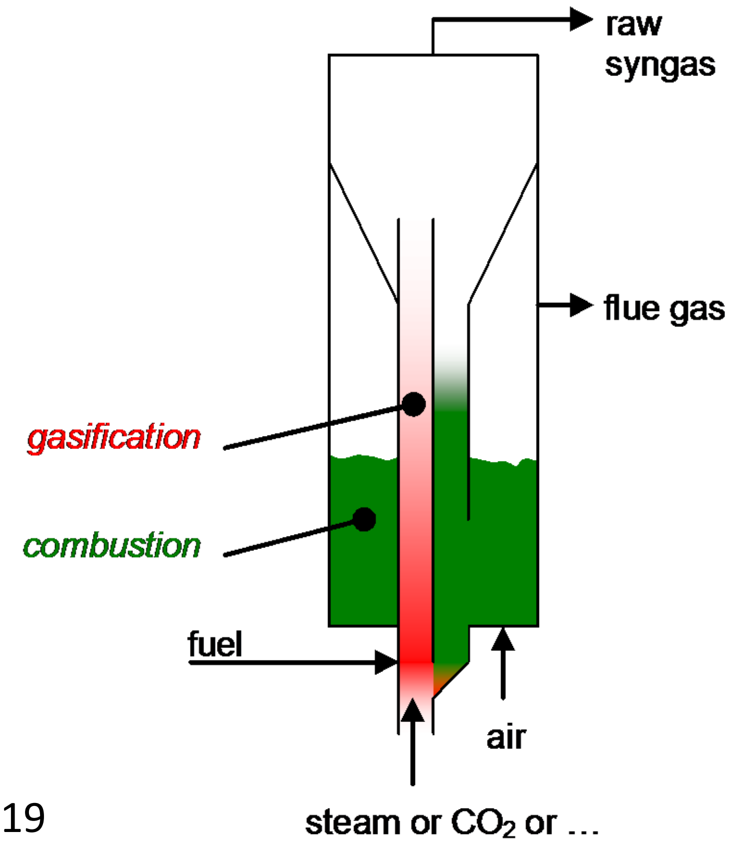


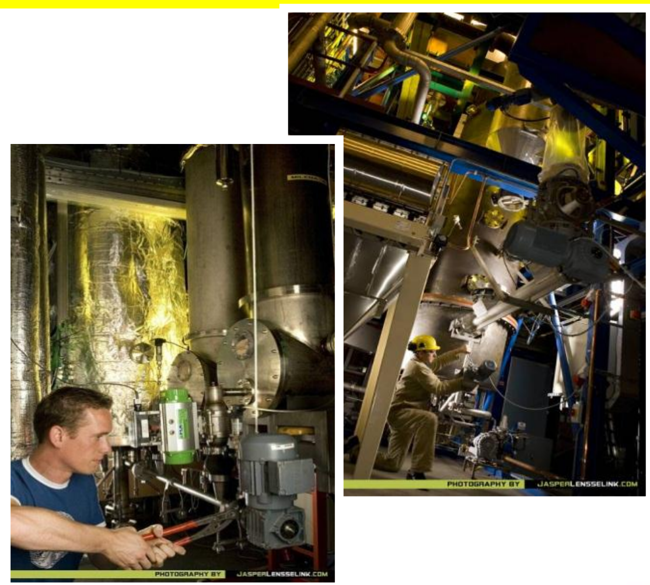
Biomass Gasification

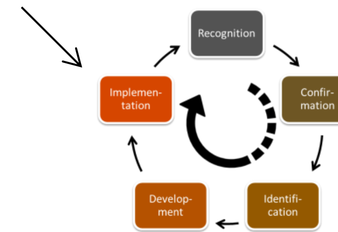
In three steps from biomass to products

Thermal gasification	Gas cleaning	Conversion
Solid become synthesis gas	Removal of tars, particles, sulphur, …	Make and purify valuable component like methane, methanol or AONC
Milena	**Olga**	**Separation Enhanced Reactions**

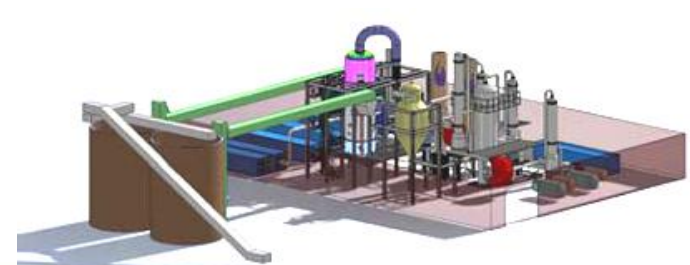
MILENA technology







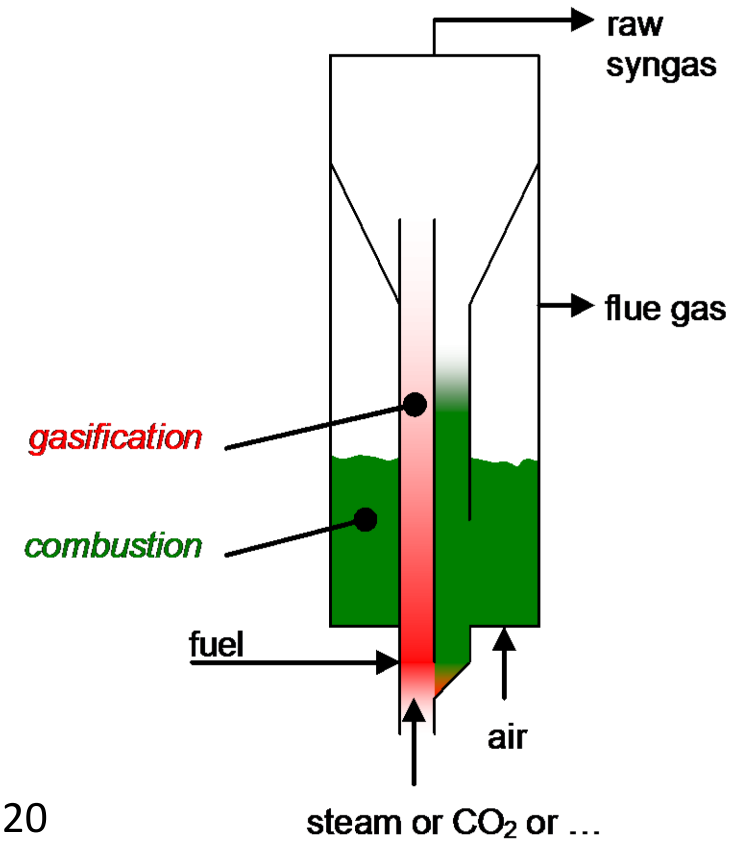
THERMAX
Sustainable solutions
Energy & Environment



DAHLMAN

www.milenatechnology.com

MILENA technology

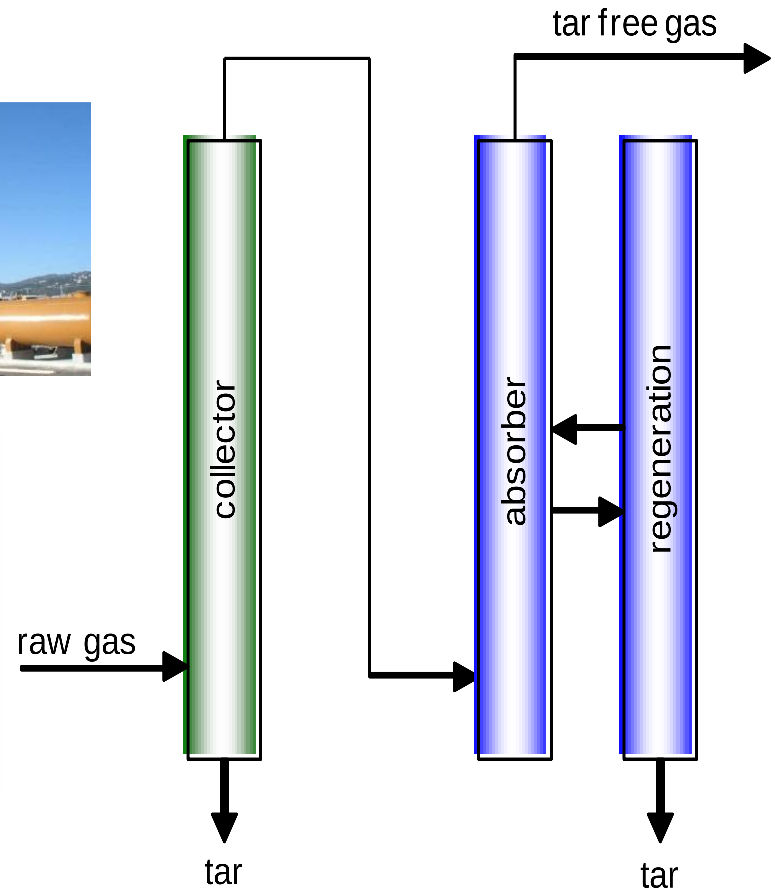


- Two coupled fluidized bed reactors
- Gasification (pyrolysis) in a fast fluidization reactor (~7 m/s) at 700-1000°C
- Combustion in a bubbling fluidization reactor (~1 m/s)
- ~ 40 kg bed material recycle / kg biomass feed, this results in 50-70°C temperature difference between reactors

ECN

OLGA Technology

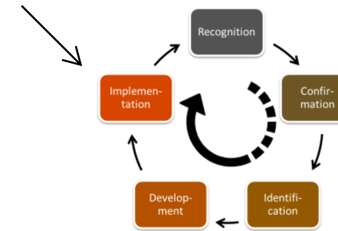
- Tar and particulate removal



DAHLMAN

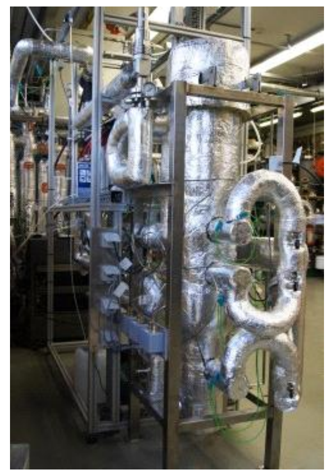
www.olgatechnology.com

Pioneering the complete transformation



MILENA gasifier

OLGA tar removal



HDS reactor

Further gas cleaning

Methanation reactors

70% conversion efficiency from wood to bioSNG

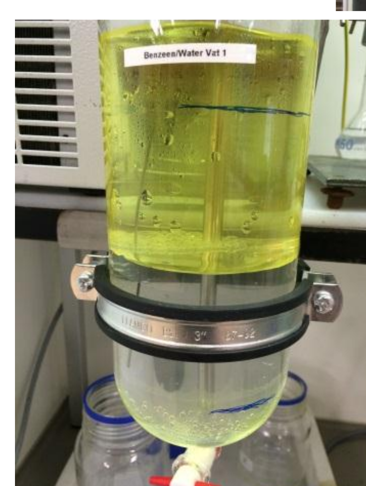
Products with a higher value

Low gasification temperature (800°C)

- BTX production (90/9/1 wt%)
- First step after tar removal, to simplify down stream methanation

High gasification temperature (>1000°C)

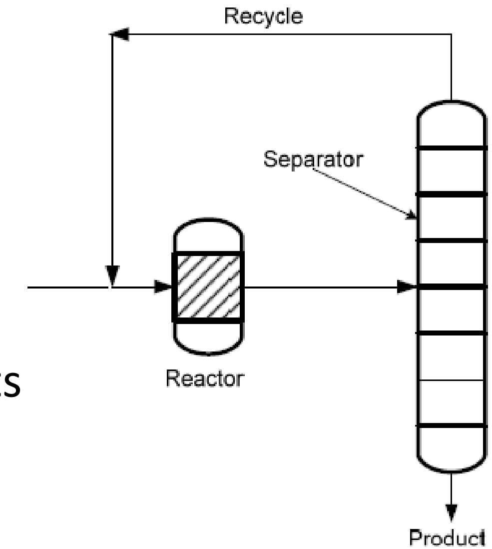
- Complete conversion to syngas
  i.e. $CO/CO_2/\ H_2$
- Perfect feedstock for organic liquids
- But thermodynamic limitations



Thermodynamic limitations

- Conversions hindered chemical equilibria
  - Large recycle streams
  - Complex separator
  - Low conversions
  - Mediocre single pass yields
  - Poor energy efficiency
  - High costs

- Solution: *in-situ* removal of one of the products



Ammonia – Methanation – Water-Gas Shift – Reverse Water-Gas Shift – Methanol – Steam Reforming – Condensation - Dehydrogenation

Separation promoted Water-Gas Shift

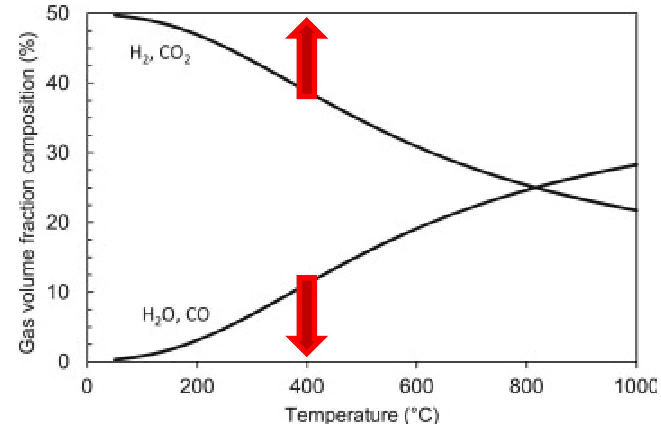
ECN

- Applications in carbon capture and hydrogen production

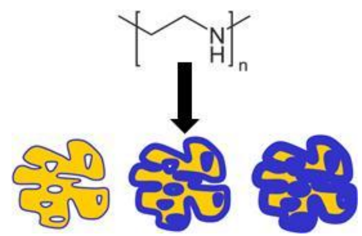
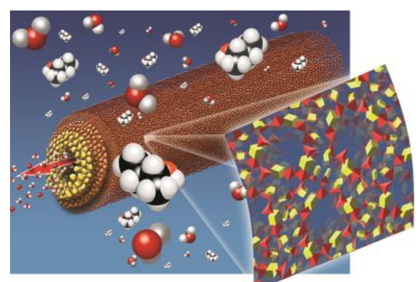
$$CO + H_2O \leftrightarrow CO_2 + H_2 \qquad \Delta H = -41 \text{ kJ/mol}$$

In situ removal of ONE reaction product

- Normal Reaction Conditions
  - Two stage conversion of CO
    - 12% → 3% → 0.5%
    - 350-400°C → 180-250°C
  - 20-30 bar



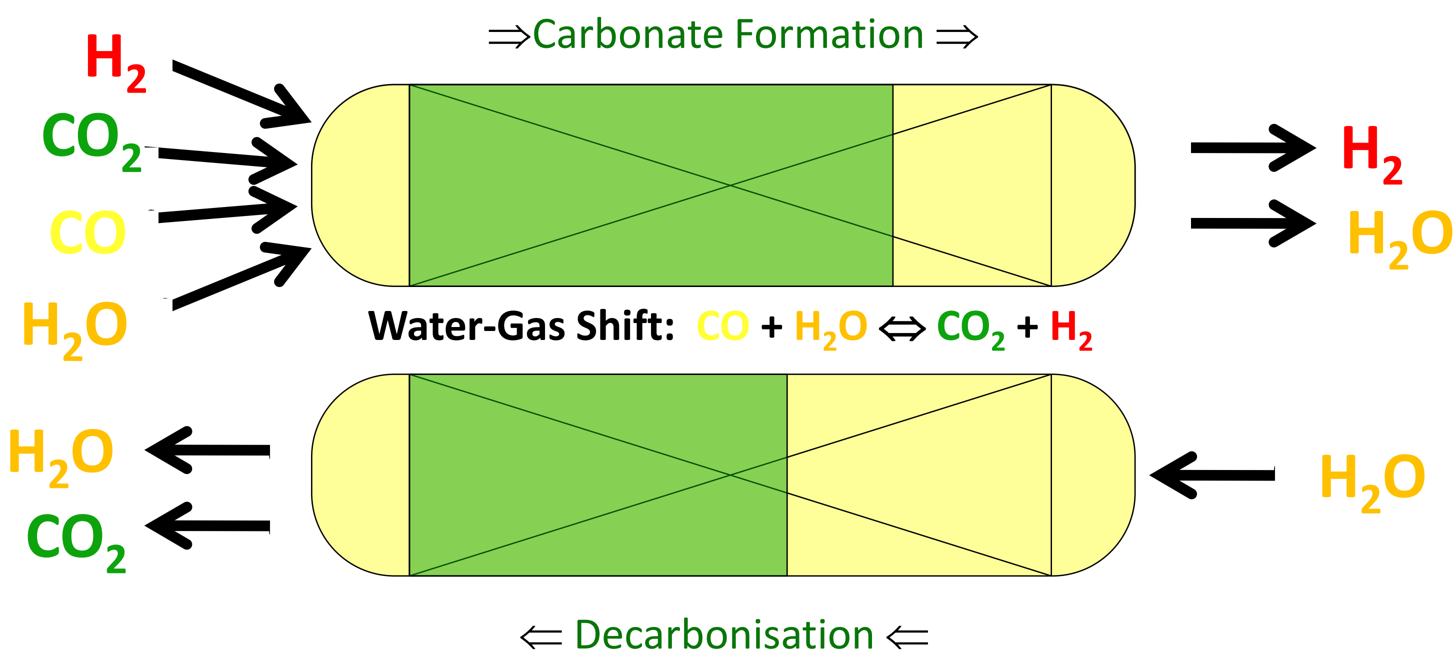
Membranes and sorbents

	$T \leq 150\ ^oC$	$T \geq 300\ ^oC$
Advanced sorbents	 Immobilized amines	 Alkasorb®
Advanced membranes	 HybSi®	 HySep®

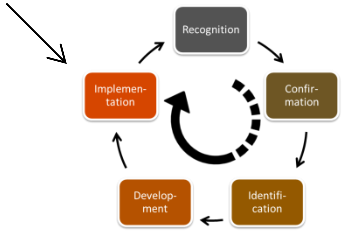
SEWGS: Sorption Enhanced Water Gas Shift

The Intensification Step

- Combines the Water-Gas-Shift reaction with sorbent material to simultaneously produce H_2 at high temperature whilst also capturing CO_2



SEWGS advantages



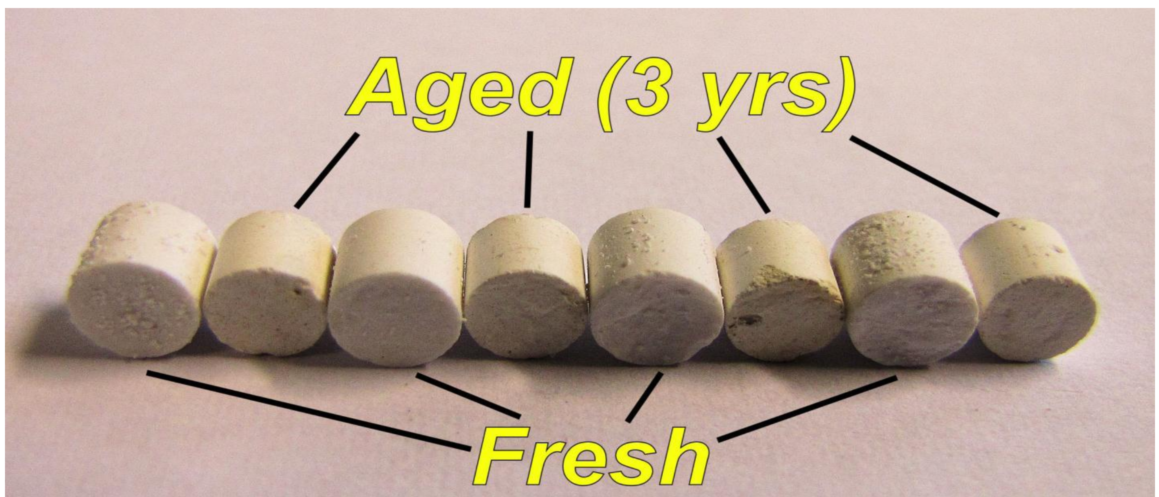
- Cost-effective sorbent
- Synthetic clay industrially produced
- Robust material

- Low energy consumption for CO_2 removal
- Efficient removal of H_2S
- Low steam consumption
- Both high purity CO_2 and high capture rate, low loss of H_2

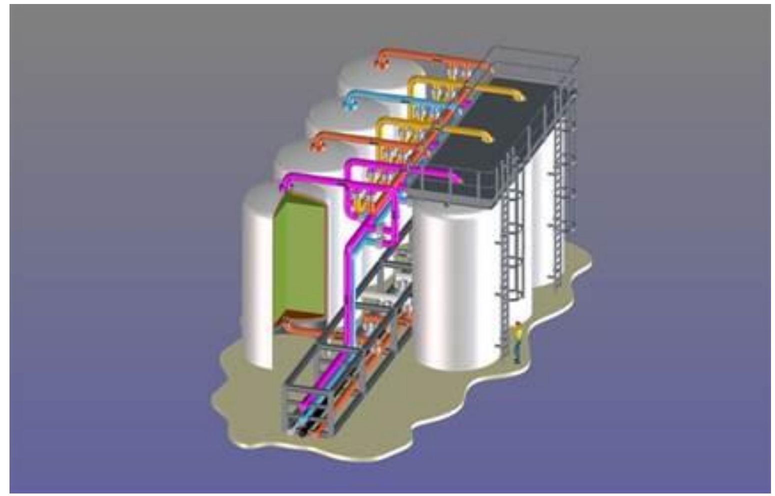
- Typically 30 - 50% more energy efficient than amine scrubbing

Sorbent “stress test”

- Stability of the CO_2 sorbent ALKASORB
  - Combined adsorbing and catalytic activity of material for more than 5000 cycles
  - No deterioration was observed

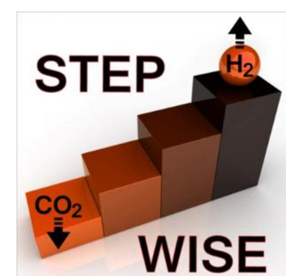


Near future ambition

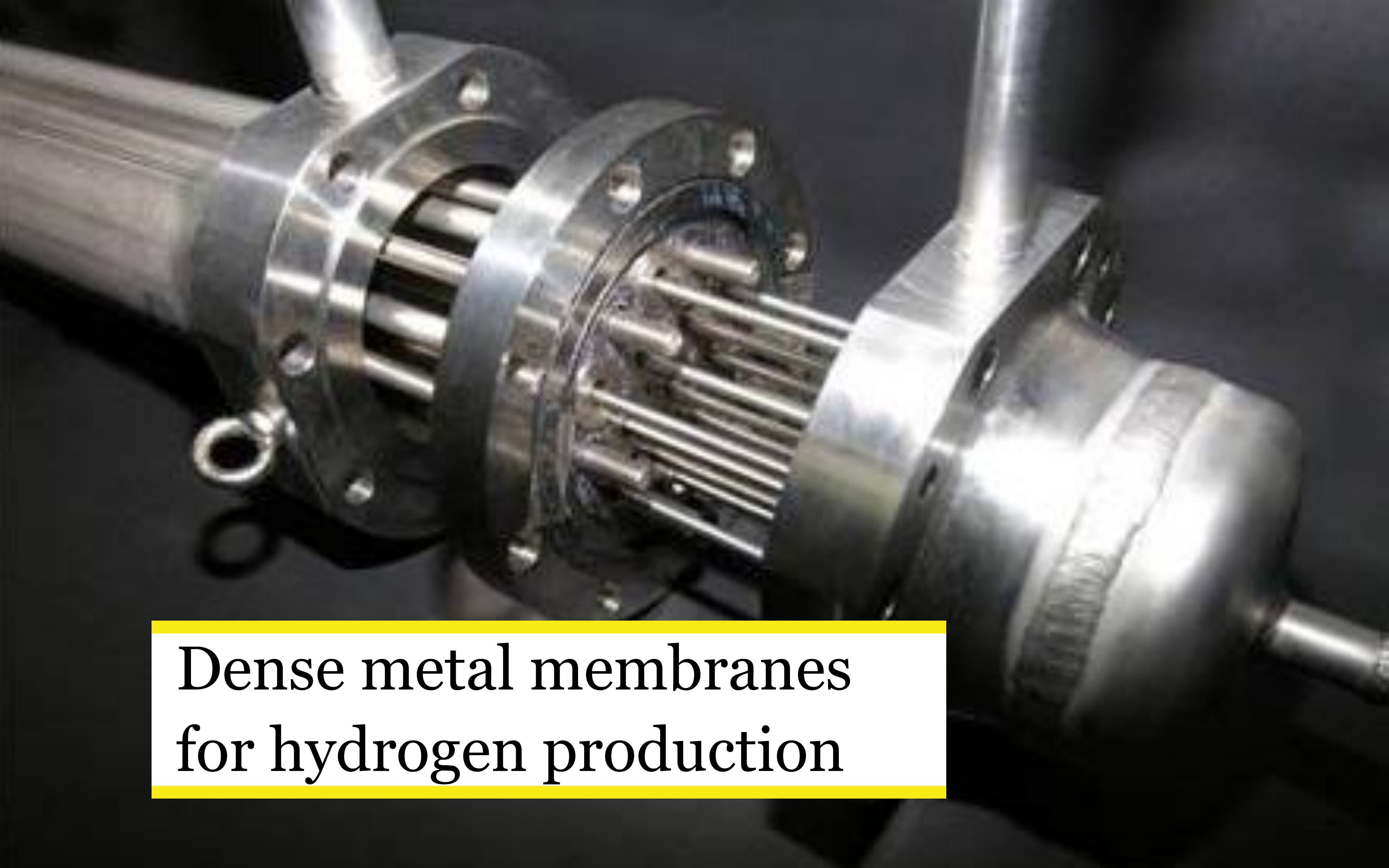


- At ECN laboratory
- 100 kg of sorbents

- In the steel industry
- 100X capacity increase



Dense metal membranes for hydrogen production



Methane steam reforming at pre-pilot scale

ECN

Hydrogen membrane reactor

- Hydrogen production : 2 Nm^3/h
- Methane conversion increase > 30%
- 1000 hour long term testing at 7 bar

- Ambition
  - Continued testing at high pressure to increase methane conversion to >90%

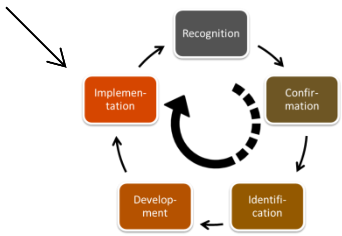
HYSEP®
Hydrogen Separation Modules

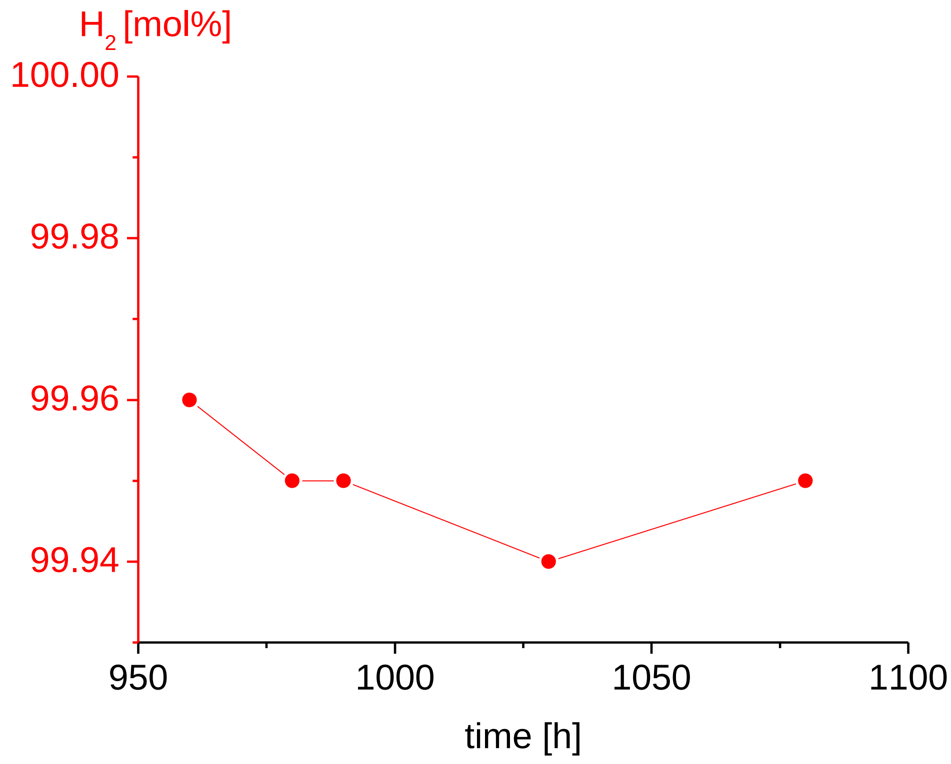
Pre-Pilot membrane testing

- Hysep module 1308
- Membrane area = 0.4 m^2
- 13 membranes, 26 seals, L = 70 cm

Designed parameter	Value
H_2 production [$Nm^3 \cdot h^{-1}$]	4-6
H_2 max. recovery [%]	30
H_2 purity [%]	>95
T [°C]	450
P_{feed} [bar]	21

From 32% to 99.95% H2 purity





Feed

CO_2 ~ 6 mol%

CO ~ 2 mol%

H_2O ~ 50 mol%

H_2 ~ 32 mol%

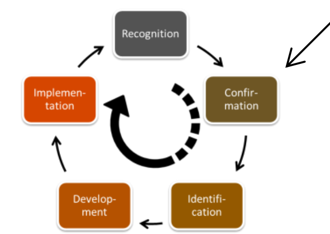
CH_4 ~ 10 mol%

Recovery of valuable components

ECN

Valuable components

- Valorizing gases in the steel industry
  - CO, H_2
- Monomer recovery
  - Various
- Propane in the Rotterdam area
  - In action!
- Hydrogen recovery from PSA reject
  - For hydrogen lean locations



- Many many others
  Your input is appreciated!

- Upcoming workshop in collaboration with ISPT

www.milenatechnology.com
www.olgatechnology.com
----
www.hysep.com
www.hybsi.com
----
caesar.ecn.nl/the-sewgs-process

Jaap Vente, vente@ecn.nl, +31 88 515 8615