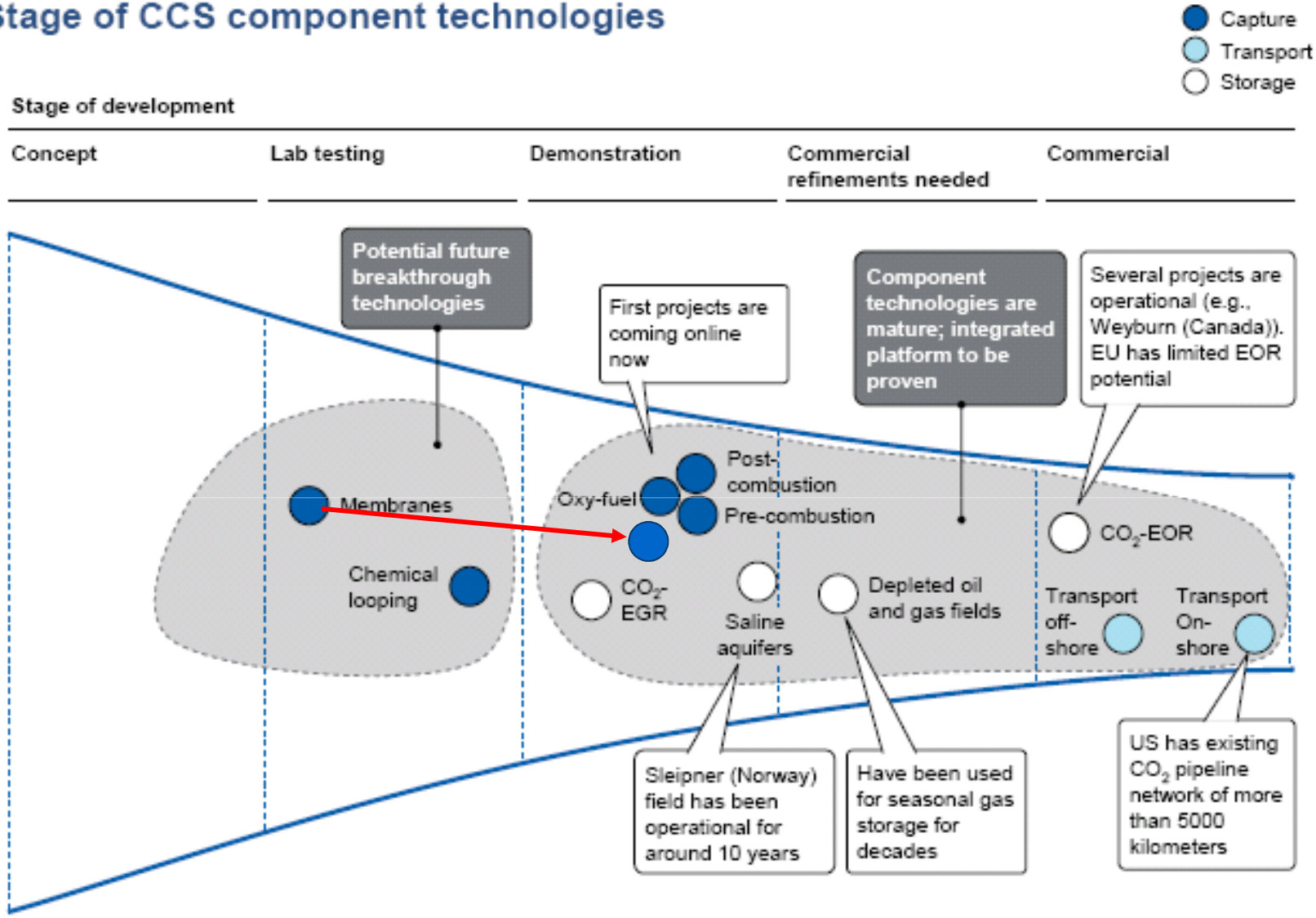
Stage of CCS component technologies



Source: CCS - Assessing the economics; McKinsey 2008

NanoGLOWA post-combustion CO_2 capture membranes

Progress, performance and pilot testing at six industrial test sites

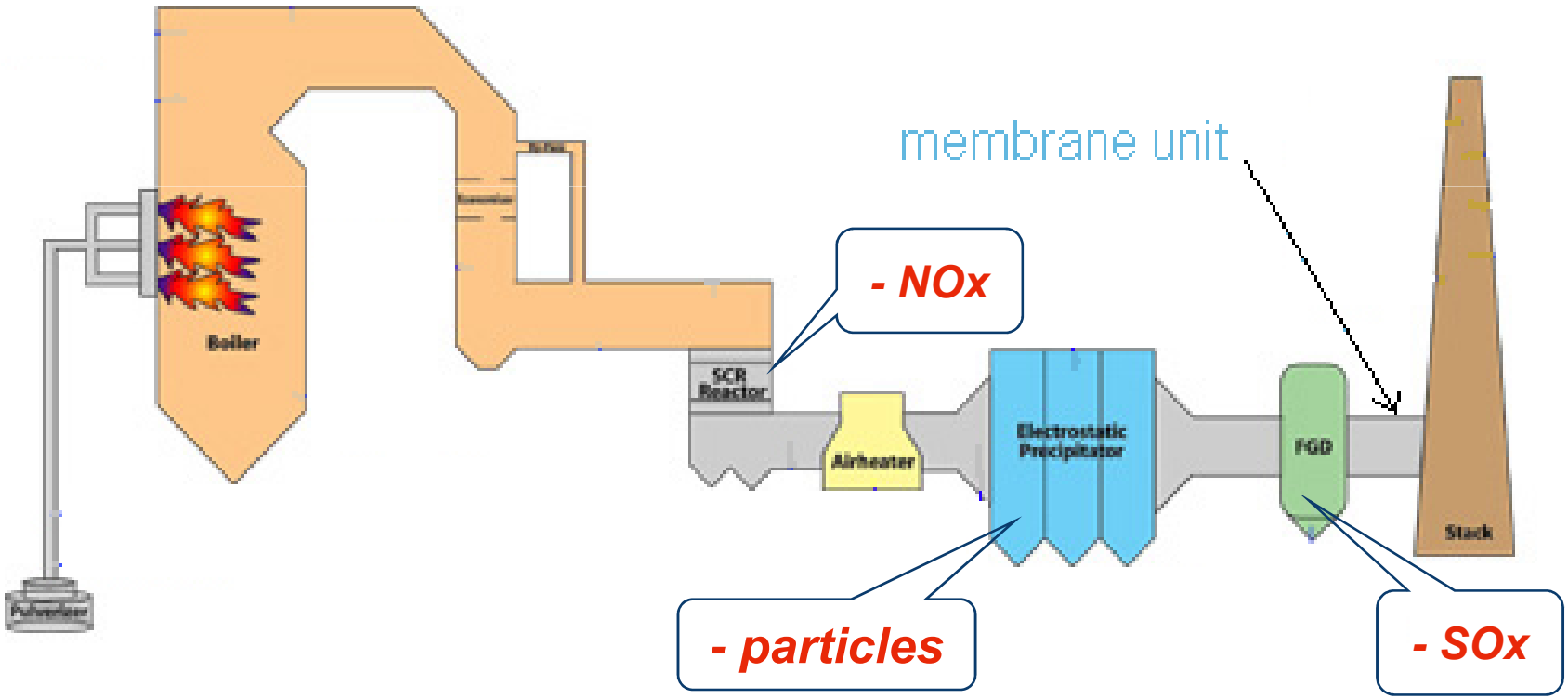
Paul Raats, Ludwin Daal, Martijn Huibers (KEMA, The Netherlands)

TCCS-6, Trondheim, June 15th, 2011

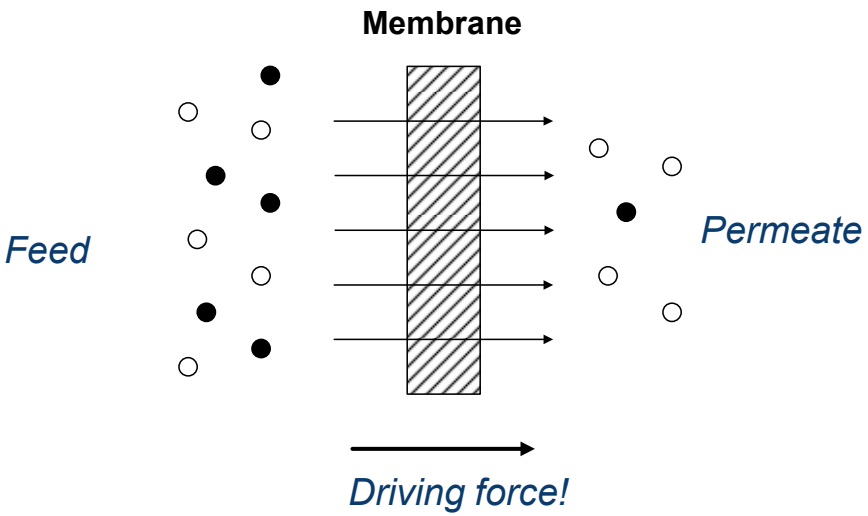
Experience you can trust.

2005: Why not capturing CO_2 with selective membranes?

Flue gas flow at coal-fired power plant

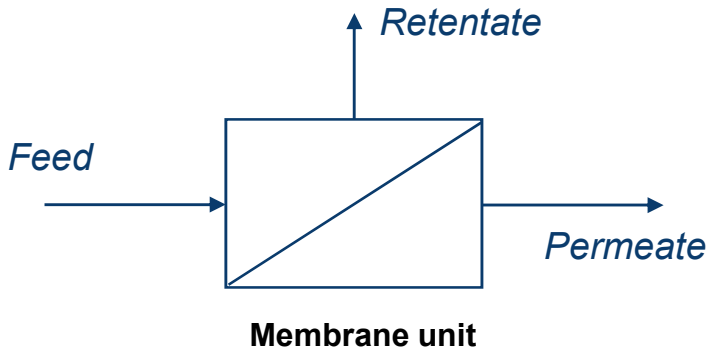


Membranes have an appealing potential …



Appealing potential

- High energy efficiency[1)]
- No separate regeneration step
- No chemicals, no waste streams
- Relative simple power plant integration
- Intensified
- Continuous process



1) No phase change required

…water was already captured from power plants flue gases

Water ‘balance’

400 MW coal-fired PP:

- Emits 150 m^3 / hrs
- Needs 30 m^3 / hrs

NanoGLOWA has been executed

… to develop optimal nano-structured membranes and *installations* for post-combustion capture from coal-fired power plants

	Laboratories	Flue gas simulators	Power plants
Gas supply	CO_2 / N_2 / H_2O	+ O_2 / SO_2 / NO_X	complete flue gases
Feed flow	<< 1 m^3/h	1 - 10 m^3/h	5 - 70 m^3/h
Membrane area	~ 5 cm^2	0.05 - 1 m^2	1 - 10 m^2
Scale factor	n = 1	n = 200	n = 2,000
Tests duration	mins - hours	up to 500 hours	half a year

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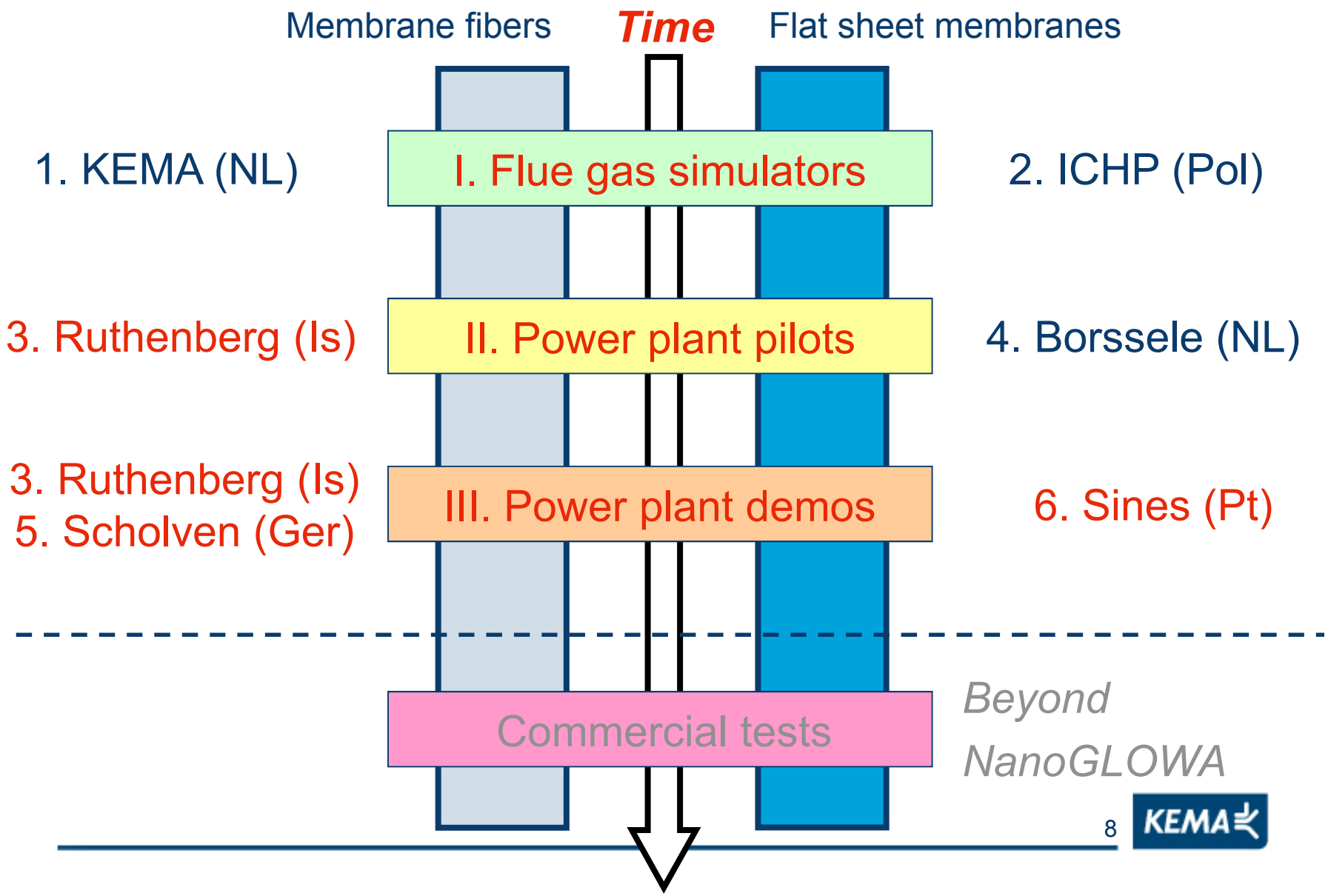
Membranes and economics: tomorrow morning in the A4 session

- Techno-economic analysis of membrane cascades (RWTH)
- Preparation of polysulfone hollow fibers as support for CO_2 selective membranes (NTNU)
- Transport behavior of polymer membranes for flue gas treatment (TU Twente)
- Maps for the evaluation of membrane performance in CO_2 post-combustion capture (ITM-CNR)

Demos at Sines, Ruthenberg & Scholven



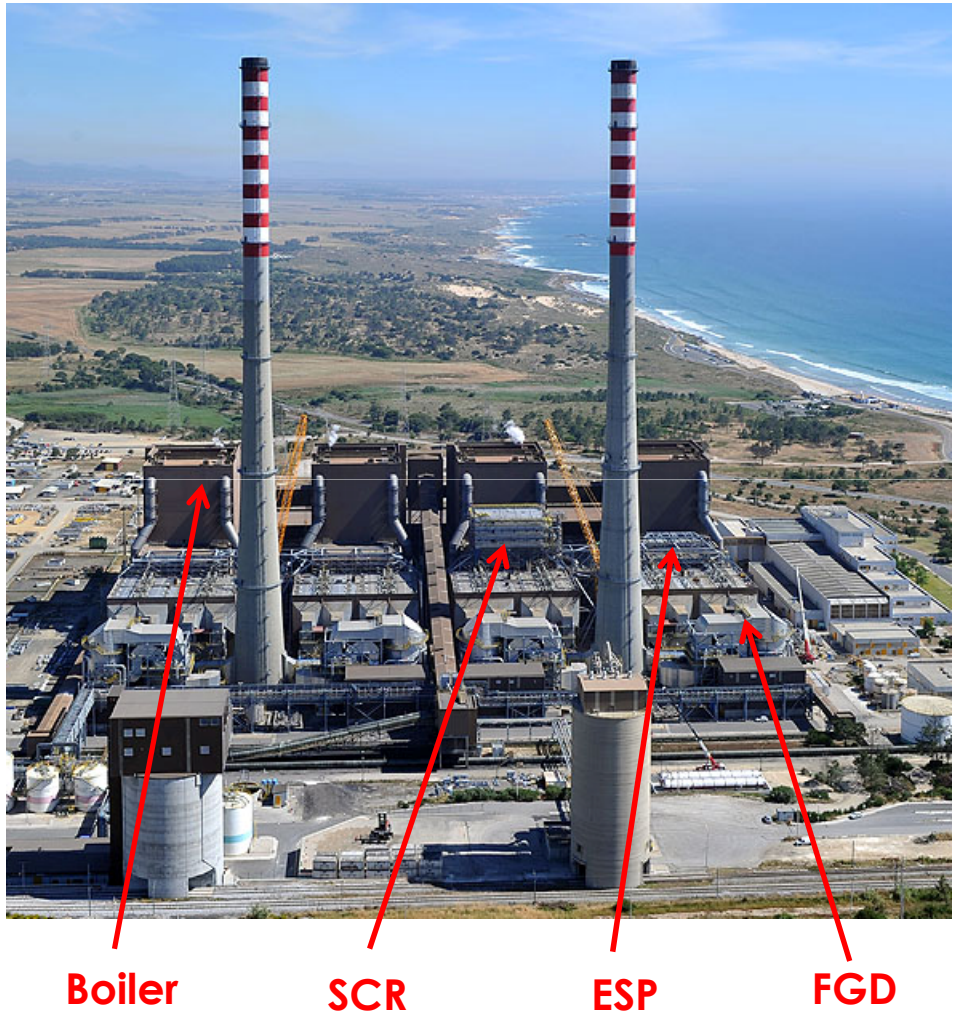
These power plants all burn hard coal

Main components in flue gases of NanoGLOWA's demonstration power plants

Company Power station	**EDP** Sines	**IEC** Ruthenberg	**EOn** Scholven (district heating)
Flue gas flow (Nm^3/h wet)	1,125,000	1,919,000	600.000[2)]
Fuel type	Hard coal	Hard coal	Hard coal
Power output (MWe)	4 x 314	2x575 + 2x550	70
Main flue gas elements (%)			
N_2	70	67.8	..
H_2O	12	16	13 - 15
CO_2	11	12.5	12 - 14
O_2	5	3.7	7 -8
SO_2 (mg/Nm^3)[1)]	200	100	30 - 60

1) At dry conditions 2) temp of 52 – 54 ºC where modules are implemented

Flat sheet membranes at Sines (Pt)



- 20-30 m^3/h flue gas
  - with 500 mg/Nm^3 NO_x
- 1.5 m^2 flat sheet membrane area
- Novel membrane module
- ± 6 months continuous testing
- Special interest: particles, durability, condensation

edp

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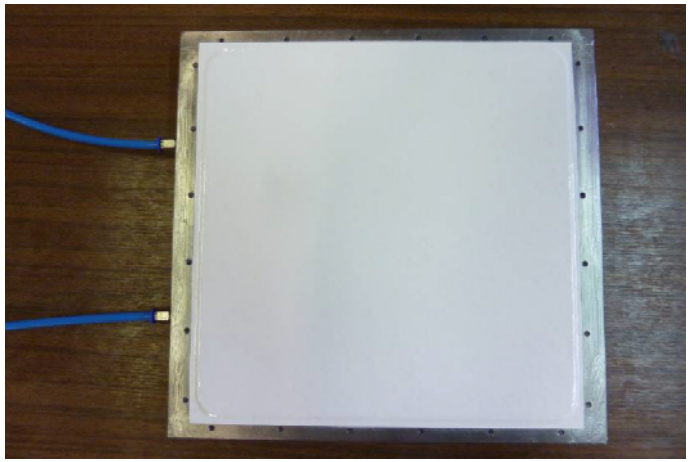
Flue gas duct with controls, membrane module and its installation



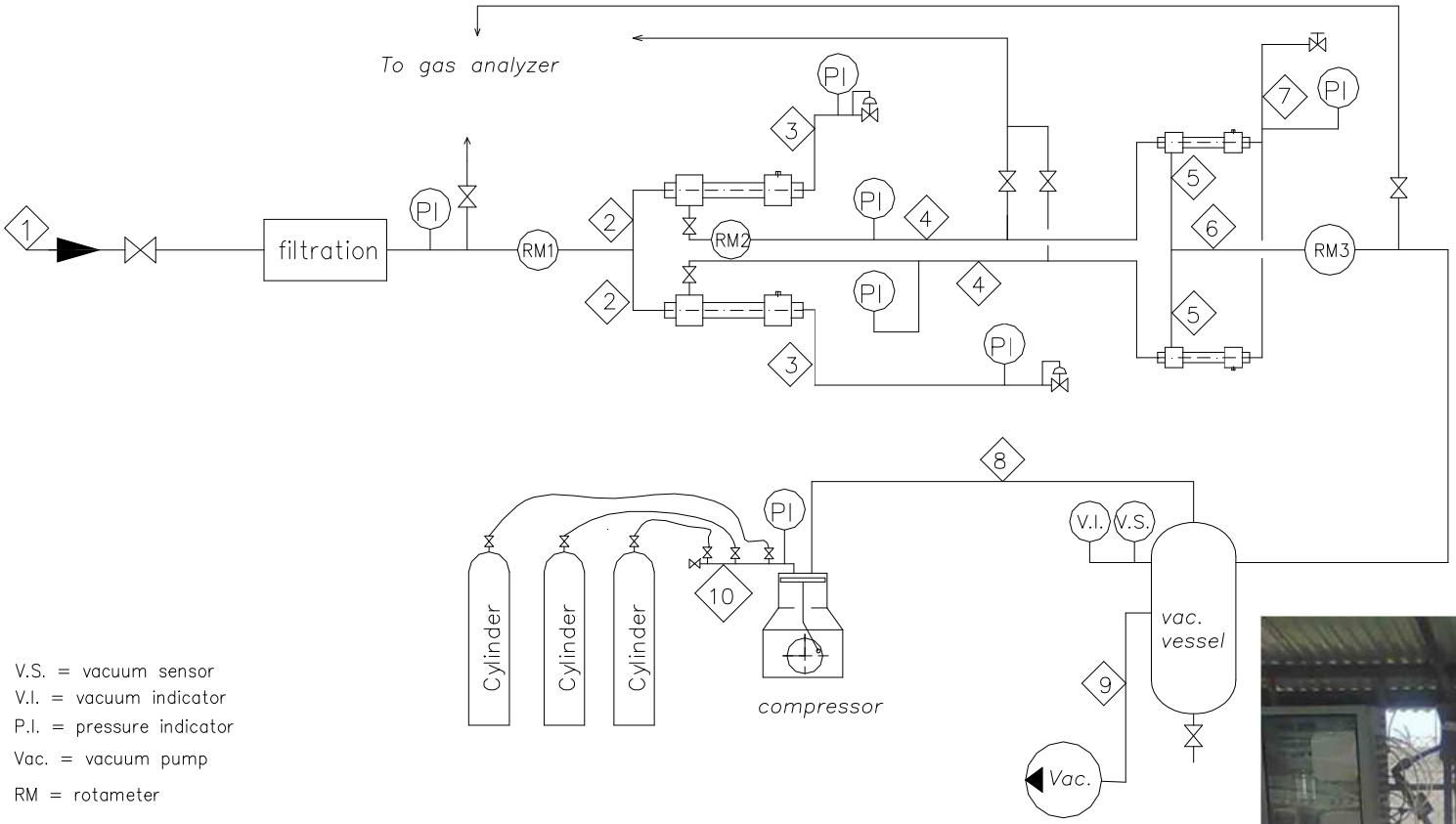
Fibre modules at Ruthenberg (Is) are purifying CO_2 to feed a greenhouse

- CO_2 purity 30-60%
  - dep. on set-up conditions
  - to be optimised
- Permeance
  - >1.0 $m^3/m^2.h.bar$
- Selectivity
  - 25-70 (dep. on T)

israel electric

KEMA

A two-stage membrane system is erected containing 4 modules

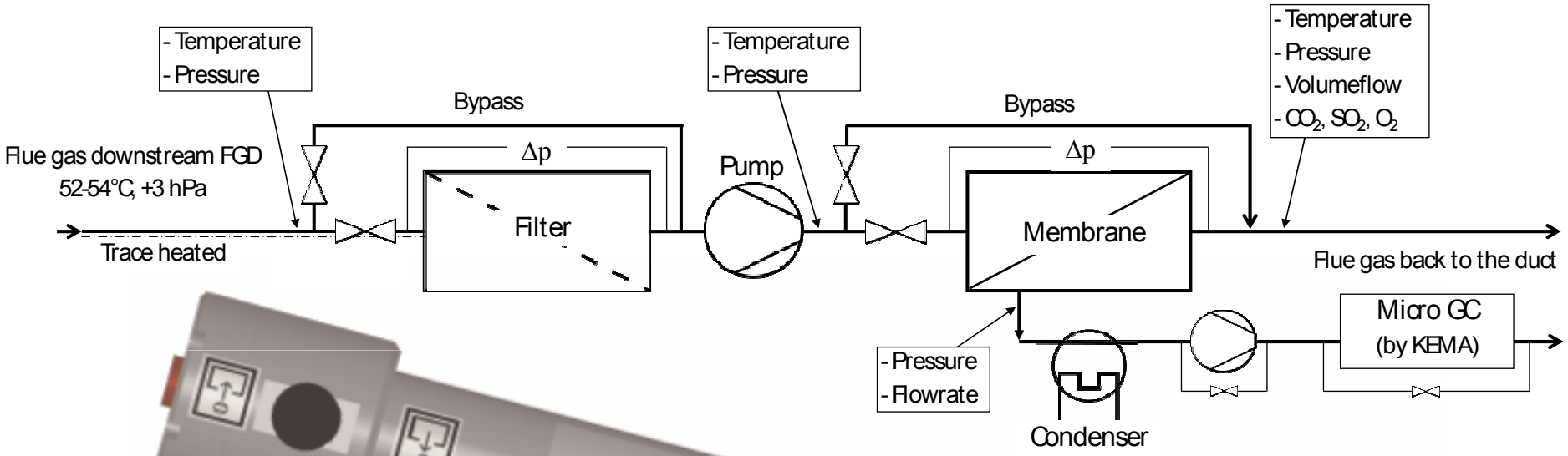


V.S. = vacuum sensor
V.I. = vacuum indicator
P.I. = pressure indicator
Vac. = vacuum pump
RM = rotameter

Thirdly at Scholven (Ger) two more fibre modules are demonstrated

- 2 module types
  - curtain & tube
- 3 weeks test campaign for each module
  - determine optimal process conditions

With the tube module a substantial membrane area is exposed to flue gas



- Fibers: 6,000
- Length: 0.58 m
- Membrane area: 5.8 m^2

Re-looking at the membrane potential

- Post-combustion CO_2-selective membrane advantages:
  - +/- High energy efficiency
  - √ No separate regeneration step
  - √ No chemicals, no waste streams
  - √ Relative simple power plant integration
  - ? Intensified
  - √ Continuous process

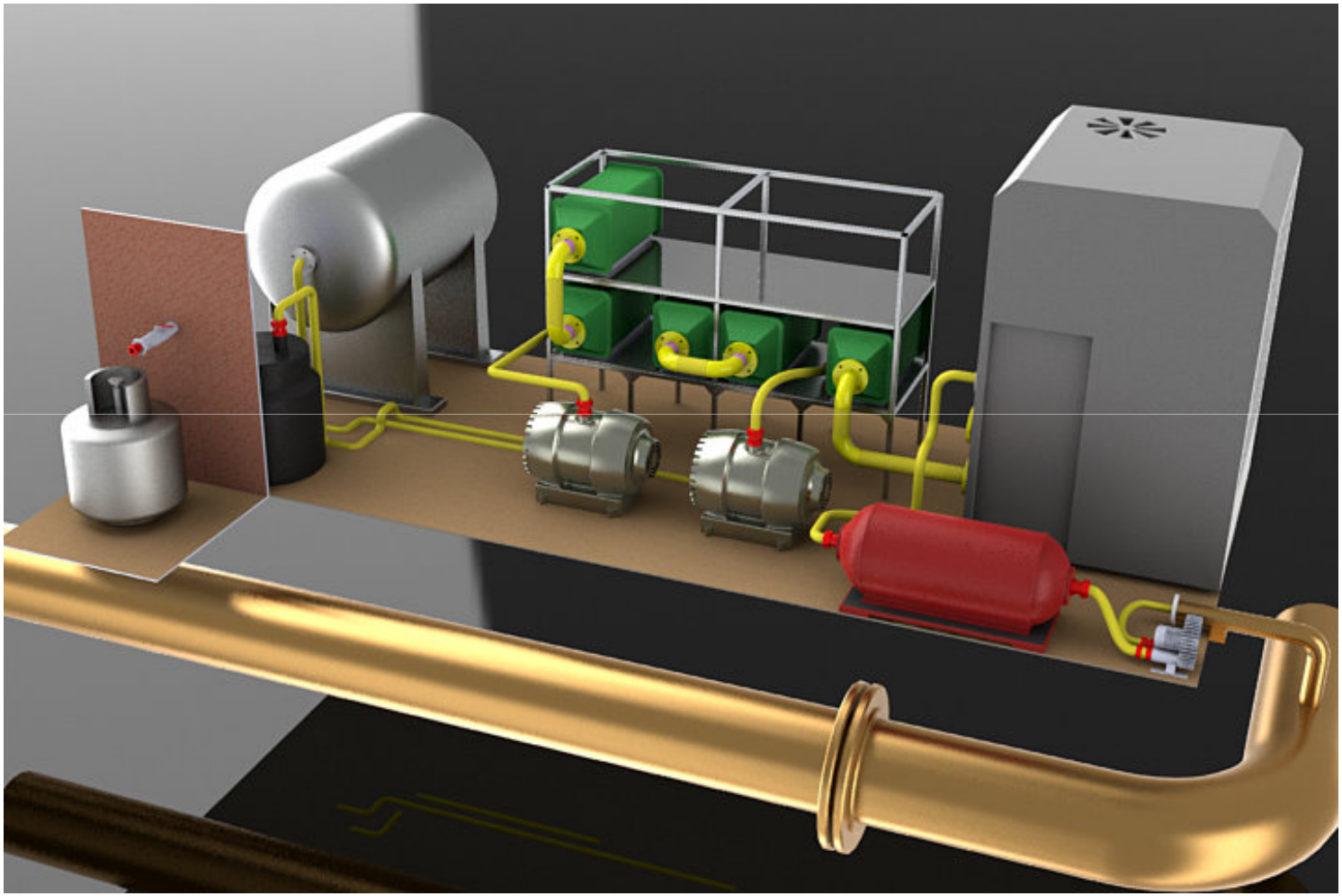
- *Note*: absorber technology might be more mature, however:
  - Membranes are large scale and commercial, e.g.:
    - reverse osmosis (millions of m^2)
  - Absorbers need post FGD SO_2 – polishing
    - NanoGLOWA membranes: so far no pretreatment

What's next ?

- **Completion of duration tests until end of 2011**
  - Durability data: 6 weeks @ Scholven, 6 months @ Sines, a set of 'bottle fills' @ Ruthenberg
  - Performance in time, e.g. purity & recovery
  - Process / system experience: behavior at various settings
- Further explore optimal system layout
  - Tradeoff energy / recovery / purity / area / CAPEX

- Beyond NanoGLOWA:
  - Demonstrate the membrane technology in other flue gases
  - Scale up with another factor 10
  - Combine carbon and water capture

Visualised…



Thanks for your attention

For more information:

- Participate in NanoGLOWA's Workshop at ICOM 2011, July 24th, Amsterdam (www.icom2011.org)
- www.nanoglowa.com
- paul.raats@kema.com

Experience you can trust.