Air Products AS – Norway

Presentasjon 24.09.15 1800-1900 for ;
Norsk Teknisk Vitenskapelig Akademi
og
Agder VitenskapsAkademi.

"Hvordan en hulfibermembran har revolusjonert transport av faste og flytende laster til sjøs,

- En mellomstor kristiansandsbedrifts utvikling frem til global lederposisjon"

Rune Damsgaard, Business Director
Hallgeir Angel, Tech. Sales Mgr.
Svein Gunnar Nodeland, Process Manager

Pioneering nitrogen membrane technology worldwide

Air Products AS – Norway

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Pioneering nitrogen membrane technology worldwide

Air Products AS – Norway

4 bolker i foredraget:

1. *Generell firmapresentasjon, historie og markedsområder (Rune Damsgaard)*
2. *Membranteknologi, virkemåte, med mer (Svein Gunnar Nodeland)*
3. *Driverne for utvikling av produkter i APAS og sammenhengen med markeder og segmenter (Hallgeir Angel)*
4. *CO2 fangst (Svein Gunnar Nodeland)*

Pioneering nitrogen membrane technology worldwide

For Marine, Offshore and Petrochemical industries

Air Products Inc.

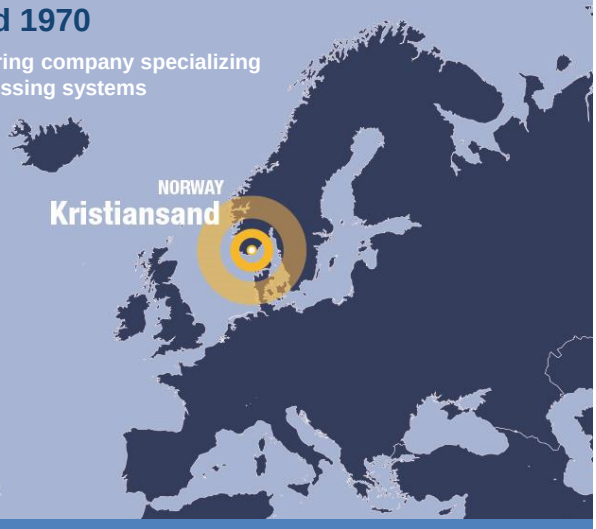
- Multinational Corporation producing Industrial Gases, Chemicals, and Energy / Environmental Systems
- Apx. 9 Billion Dollars in Sales
- World's 4th larges industrial gas company
- Operation in over 40 Countries
  Apx. 20,000 Employees
- Fortune 500 company
- Strives to obtain Best safety record of any Industrial Gas company

Pioneering nitrogen membrane technology worldwide

Air Products AS – Norway

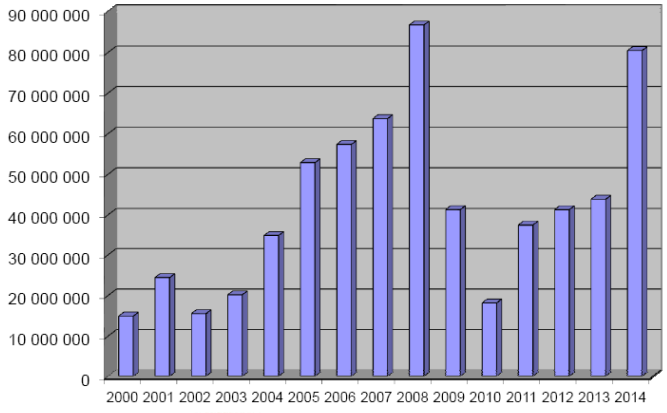
Established 1970

- Engineering and manufacturing company specializing in gas production and processing systems for the Marine, Offshore and Petrochemical industries.
- Part of Air Products' global operations.
- Centre of excellence for marine and other industry spec.-compliant systems.
- In-company manufacturing of membranes (USA)



Pioneering nitrogen membrane technology worldwide

Air Products AS:
Ordreinngang – utvikling USD



AIR PRODUCTS

Eksportprisen 2015

Air Products var en av 3 finalister

EKSPORT PRISEN

2015

Pioneering nitrogen membrane technology worldwide

The beginning of the company

1970: Oddleiv Eidjord founded:

MARITIME PROTECTION

Pioneering nitrogen membrane technology worldwide

The beginning of Inert Gas Systems...

1970 – ***Maritime Protection A/S***

- Inert Gas Systems for crude oil tankers, OBO's and product carriers.

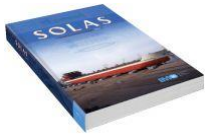
T/T Kong Haakon VII – explosion 1969

Pioneering nitrogen membrane technology worldwide

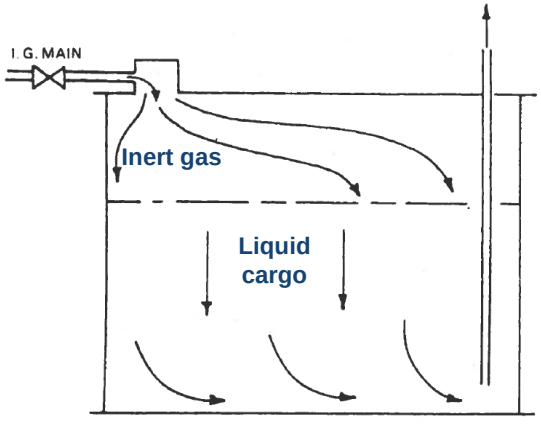
The beginning of Inert Gas Systems...

1974– ***IMO /SOLAS Regulation 62-II***

- Compulsory installation of Full Inert Gas system for any ship exceeding 20.0-00 DWT
- Inert gas capacity: 125% of max. Simultaneous cargo pump discharge capacity.



Inerting of tanks during cargo discharge



But – explosions continue on smaller ships..

Company History of Air Products AS

1970 Establishment of Maritime Protection AS.

1982 Gas Separation by Membranes. Licence with Monsanto Company to use membranes for nitrogen production.

1984 First membrane nitrogen generator installed on a ship "Stolt Integrety"

1985 First offshore nitrogen generator using membranes installed on Conoco UK Murchison Platform

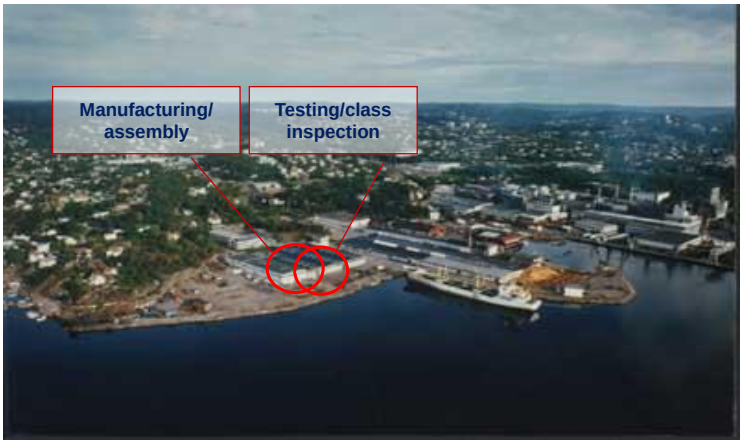
1985 Permea Maritime Protection A/S

1991 Permea Maritime Protection, a Division of Air Products AS
Entire Permea acquired by Air Products and Chemicals.

1999 Air Products A/S (Norway)
Fully integrated into Air Products organization.

2009 Sell out of combustion technology group (Maritime Protection A/S) and continued focus on membrane type systems.

Assembly & test facility site - Lumber



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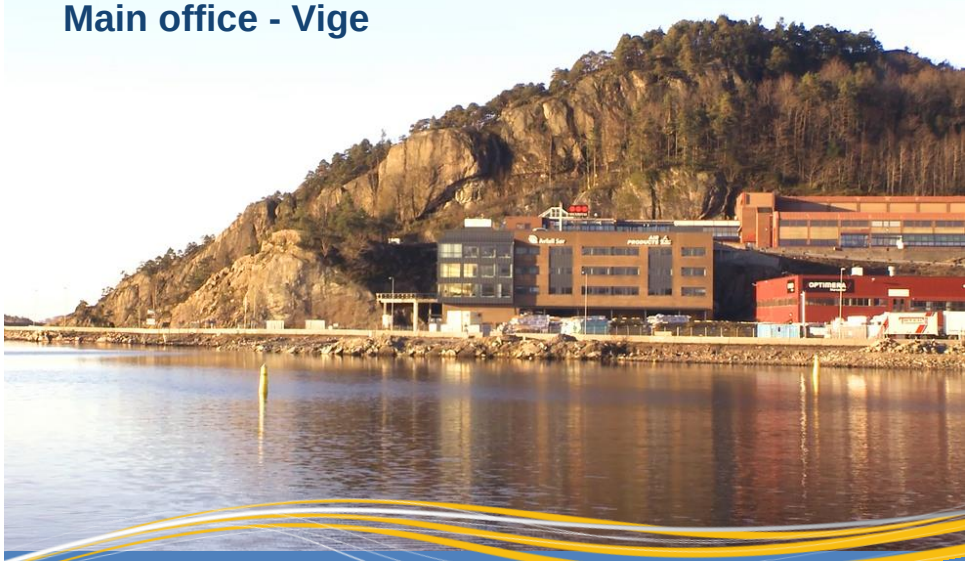
Main office - Vige



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AIR PRODUCTS

References – In brief

woodside · AWILCO · NYK LINE · MARINVEST · Navig8 · MAERSK · TOKIO MARINE · DSME · BROSTRÖM · excelerate energy · eni saipem · HÖEGH LNG · Golar LNG · Stena Bulk · HYUNDAI · SAMSUNG HEAVY INDUSTRIES · NORDIC TANKERS · TEEKAY CORPORATION · MTG Maran Gas Maritime Inc. · ODFJELL · Songa Shipmanagement Ltd. · bp · Statoil · JO TANKERS · PETROBRAS · MOL Mitsui O.S.K. Lines · Bernhard Schulte Ship Owning & Ship Management · SEVAN marine · BG GROUP · WL Westfal-Larsen · NCC · stx · ConocoPhillips · Knutsen OAS Shipping

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AIR PRODUCTS

Air Products Norway's main marine markets

Marine N_2 generators for;

- Chemical tankers
- Product tankers
- LNG carriers
- Offshore supply vessels
- Reefer vessels (Banana Carriers)

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Air Products Norway's main Oil & Gas markets:

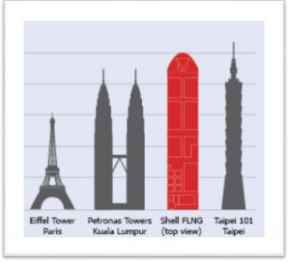
N2 generators for:

- Offshore production platforms
- Onshore production fields
- FPSO
- FSO
- Floating LNG (FLNG) carriers
- Onshore refineries

Pioneering nitrogen membrane technology worldwide

Air Products Norway's main Oil & Gas markets:

Shell "Prelude" LNG-FPSO



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AIR PRODUCTS
Largest N2 generator in the world
– Sempra, Mexico
Pioneering nitrogen membrane technology worldwide

AIR PRODUCTS
Deliveries
210+
Offshore/ Petrochem. Nitrogen Membrane Systems
90+
Industrial Nitrogen Membrane Systems
1170+
Nitrogen Shipboard Systems
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AIR PRODUCTS

Small capacity N_2 generators

2008 90% 2015

GLOBAL MARKET SHARE, LNG CARRIERS

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AIR PRODUCTS

Qatargas LNG carriers- Operated by Shell

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Successful retrofit of a Product tanker - Converted to Methanol trade

Air Products AS – Norway

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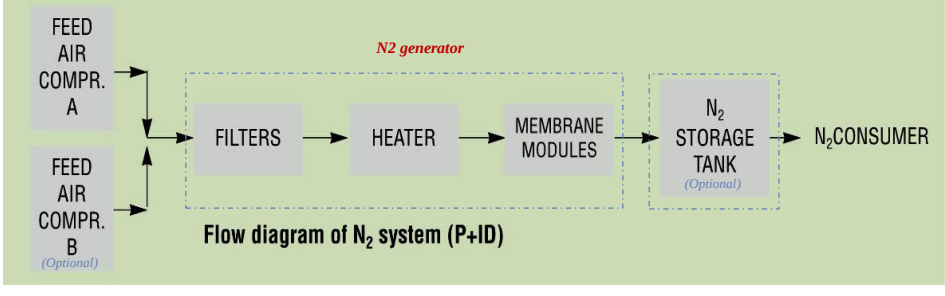
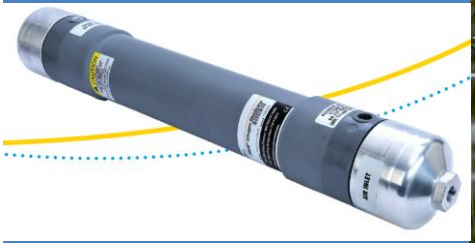
N2 System - flow diagram



Air Products

- In-house technology and manufacturing of membrane modules
- Full process insight (transfer of technology) including diagnostics



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MEMBRANE MATERIAL-POLYMER

- Polysulfone
- Polyetherimid
- Polyvinylamin

AIR PRODUCTS

The membrane separator module

The Air Products PRISM Membranes business unit has management quality systems certified ISO9001 and AS9100 by Lloyd's Registry, meeting the stringent requirements of the global aerospace industry.

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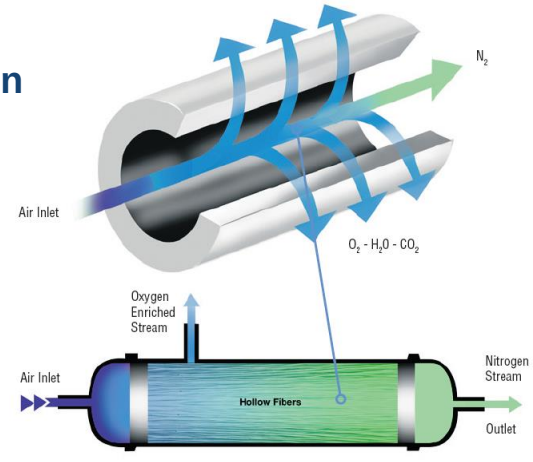
AIR PRODUCTS

Air Separation principle



H_2O	CO_2	O_2	Ar	N_2
"Fast"		Relative Permeation Rates		"Slow"

Prism Marine

Pioneering nitrogen membrane technology worldwide

PERMEATION EQUATION

$$Q_i = {}^{P}i/_{l}\ xAx(P_b - P_s)$$

Q_i **Mass Flux ("capacity")**

${}^{P}i/_{l}$ **Permeation Coefficient (increases with temperature)**

A **Area of Membranes**

P_b **Bore side Partial Pressure modules**

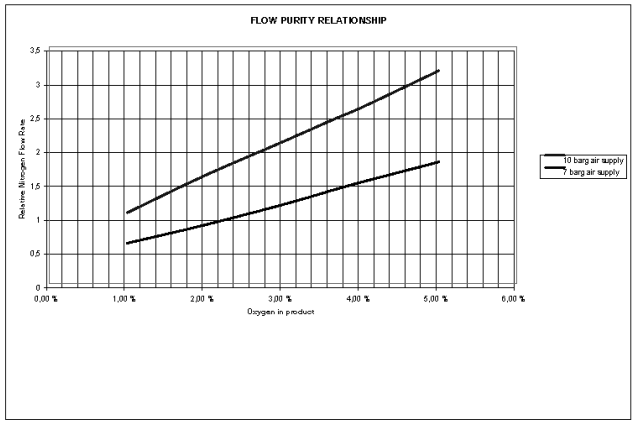
P_s **Shell side Partial Pressure**

Selectivity $\alpha_{ij} = P_i/P_j$

Decrease with increase in temperature

Pioneering Nitrogen Membrane Technology Worldwide

Sheet1 Chart 1



n:\sgn\overheads\Sheet1 Chart 1 Page 1

Pioneering Nitrogen Membrane Technology Worldwide

Air Products AS – Norway

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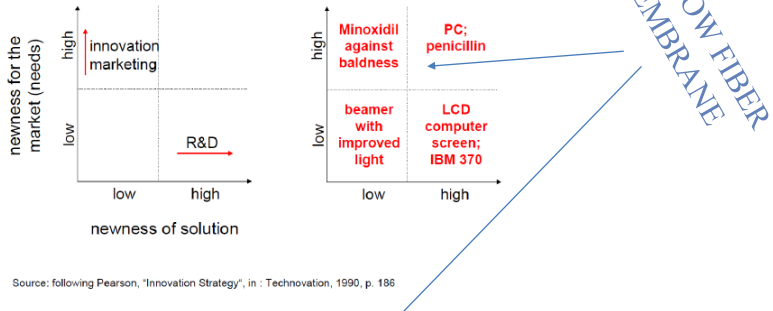
Perspectives on Innovation



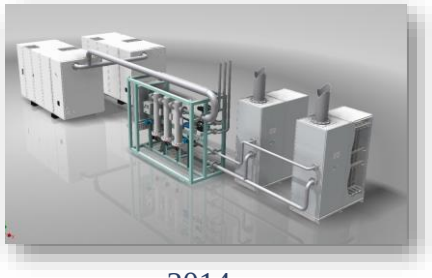
Source: following Pearson, "Innovation Strategy", in : Technovation, 1990, p. 186

- **Radical** innovation; new technology
  - – printers: laser instead of inkjet
  - – cars: fuel cell instead of combustion engine

Continuous product development

1984
The world's first

"PIONEERING NITROGEN MEMBRANE TECHNOLOGY WORLDWIDE"



2014
1450 systems later

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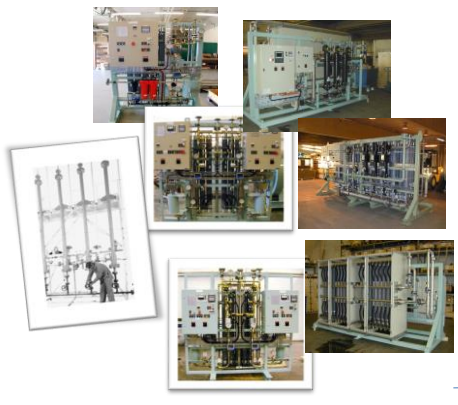
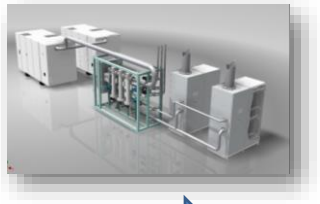
Marine segment
Continuous product development and standardization

Engineer To Order → Make To Order





1980 1990 2000 2005 2015

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AIR PRODUCTS

Marine segment

Continuous product development and standardization

Standardized Product Architecture

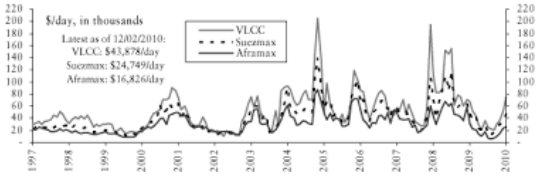
Standardized	X
Modular	X
Scalable	√

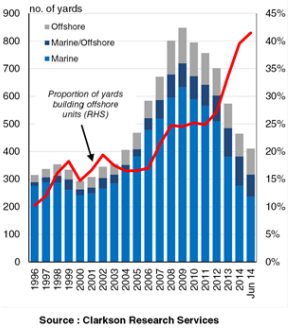
Standardized	√
Modular	√
Scalable	√

AIR PRODUCTS

Marine N2 generators

- What enabeled standardisation in Marine segment?
  - Incentives for standardization?
    - Operational Competitiveness
      - Low Margins → Low cost solutions
        - » Little room for unnessesary specificatio
    - Number of shipyards
      - Low Margins → Low cost solutions
        - » Little room for unnessesary specificatio
      - Standardized hull/architecture

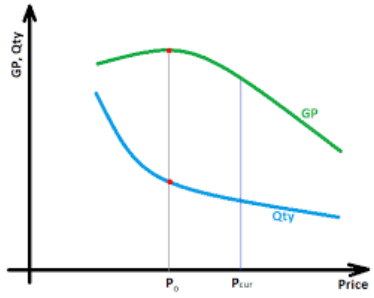




Source : Clarkson Research Services

Marine N2 generators

- The Solution?
  - Standardization



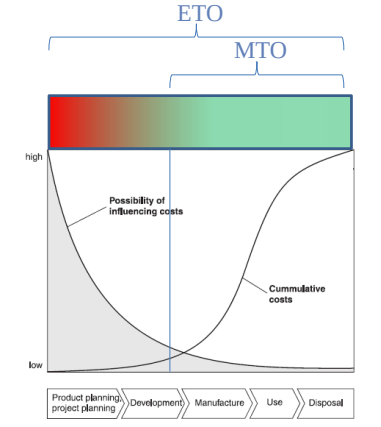


Fig. 2.2-2. Possibilities of influencing and establishing costs over the lifecycle of a product: The "dilemma of product development" (an example of a new design)

* Source; Klaus Ehrlenspiel · Alfons Kiewert · Udo Lindemann
Cost-Efficient Design

Pioneering Nitrogen Membrane Technology Worldwide

Offshore Segment

Continuous product development and standardization

Engineer To Order → Make To Order

??

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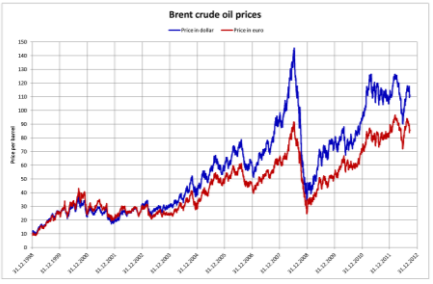
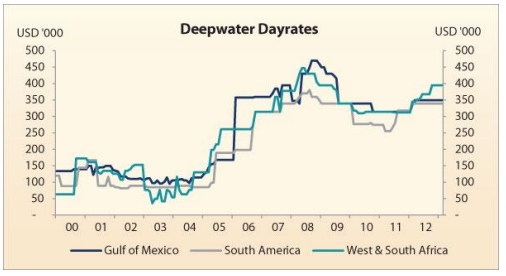
Offshore Segment
N2 Engineered Systems

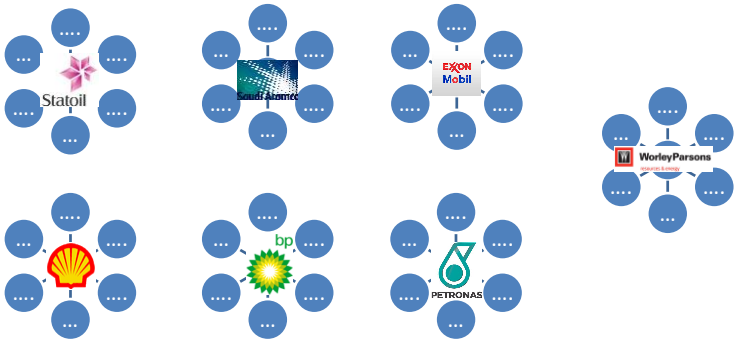
- Situation in Offshore/Onshore?
  - (Missing) Incentives for standardisation?





Offshore Segment
N2 Engineered Systems

- Situation in Offshore/Onshore?
  - (Missing) Incentives for standardisation? → RESULT (?)



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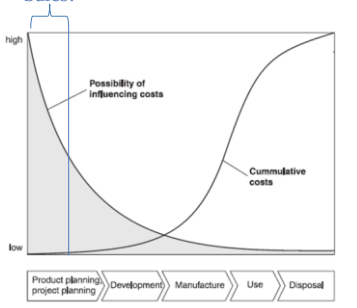
Offshore Segment
N2 Engineered Systems

- (Missing) Incentives for standardisation?
  - Result!

Sales!



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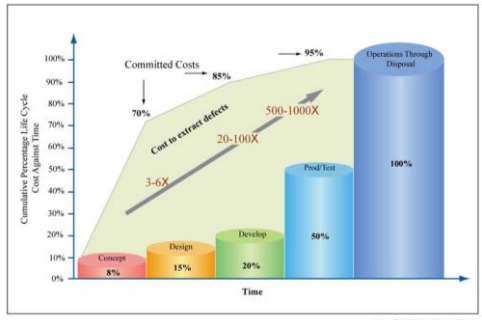
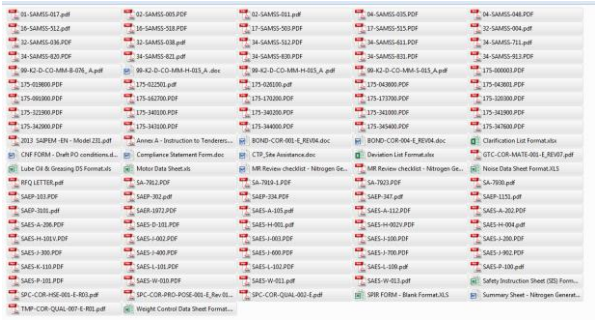
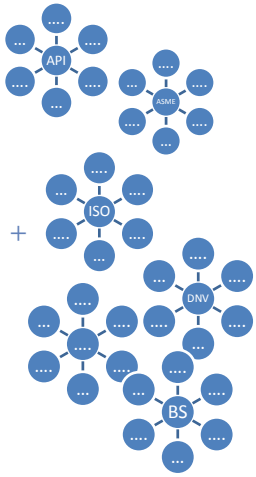
Cost-Efficient Design



Offshore Segment
N2 Engineered Systems

- (Missing) Incentives for standardisation?
  - Result! → Complexity





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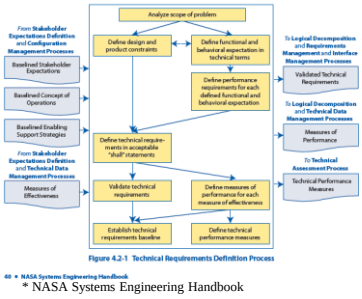
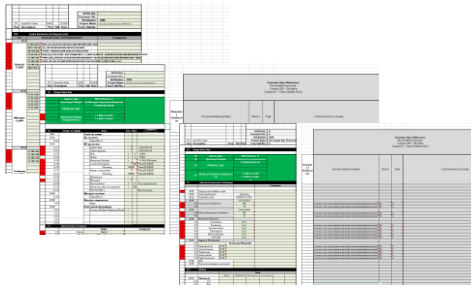
Offshore Segment
N2 Engineered Systems

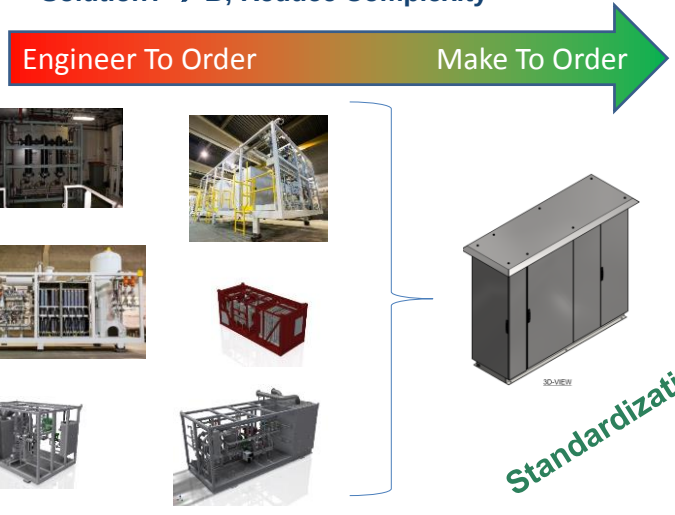
- Solution? → Management Of Complexity
  - **A**; Spend a lot of time and resources in sales/concept phace!
    - *Use a system for managing requirements!*





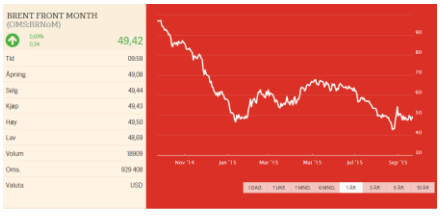
* NASA Systems Engineering Handbook

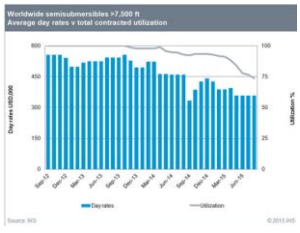
Offshore Segment
Solution? → B; Reduce Complexity



Offshore Segment
N2 Engineered Systems

- Situation in Offshore/Onshore?
  - (Missing) Incentives for standardisation? → OR ??
  - *Situation from 2014*





Pioneering Nitrogen Membrane Technology Worldwide

Offshore Segment
N2 Engineered Systems

- Situation in Offshore/Onshore?
  - (Missing) Incentives for standardisation?
    - Situation NOW 23.09.15

Statoil · bp · WorleyParsons · ExxonMobil · Shell · PETRONAS

MARKET LEADER DICTATES THE STANDARD

Pioneering Nitrogen Membrane Technology Worldwide

Air Products AS – Norway

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4. *CO2 fangst (Svein Gunnar Nodeland)*

Pioneering nitrogen membrane technology worldwide

TEST RIG
Membranes for CO2 Capture at the Cement Industry-MemCCC
(Phase II, NORCEM Brevik)

GASSNOVA

NORCEM
HEIDELBERGCEMENT Group

NTNU

AIR PRODUCTS

Pioneering Nitrogen Membrane Technology Worldwide

CO_2 Emissions from Cement industry

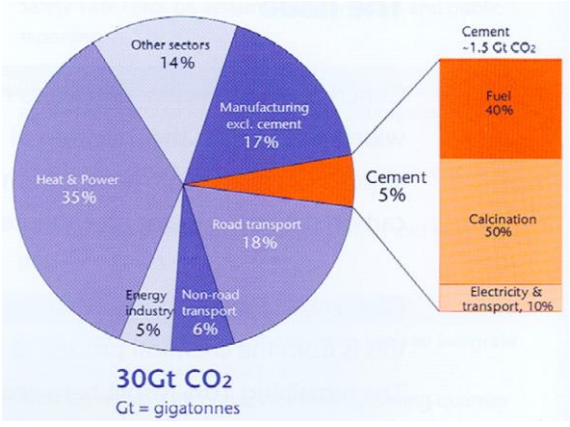
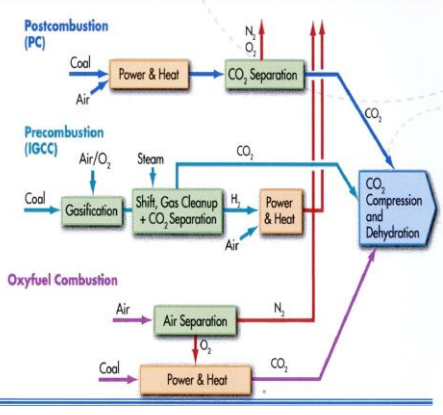


Figure2. Global CO2 production. (Note that in the U.S., cement accounts for 1.5 to 2%). Source: The Cement Sustainability Initiative Progress Report, June 2005.

Pioneering Nitrogen Membrane Technology Worldwide

Membrane technologies for CO2 capture

Potential challenges in postcombustion: fly ash, SOx and NOx



We focus on post combustion

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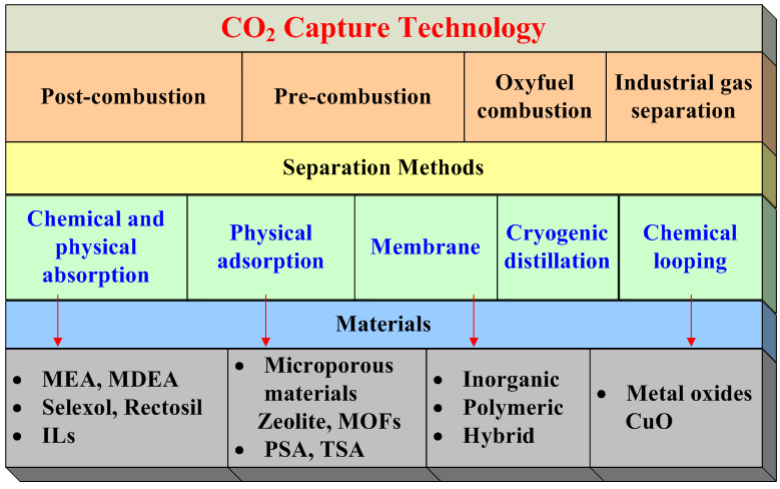
CO2 capture technology

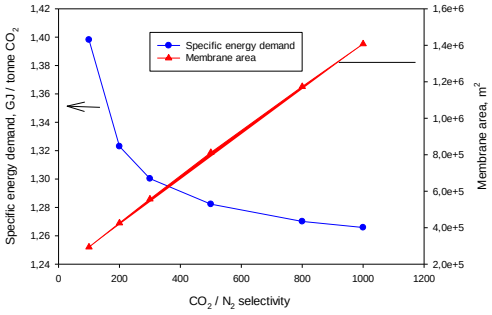


Membrane-based CO2 capture benefits

- high energy efficiency: no phase change is required to achieve separation
- modularity: scalable construction and operation, high flexibility
- green character: neither chemicals nor regeneration steps required
- reliability: no moving parts in the core technology (only in supporting compressors/pumps)
- small footprint: compact installations instead of e.g. large/tall towers

Simulations help identifying best operating conditions

$$J_A = \frac{D_A}{l}(c_{A,0} - c_{A,l}) + \frac{D_{AC}}{l}(c_{AC,0} - c_{AC,l})$$



X.He et.al, CEJ , Jan.2015

General demands, membranes for post combustion CO2 capture:

- High permeance (> 1000 GPU)
- Selectivity > 200 is preferred
- Low feed pressure (<3 bar) and vacuum on permeate side (200-300 mbar)
- Membrane module design should be hollow fibers or spiral-wound
- Process design must be optimized

Spesific demands, FSC

- Humidity level

  > 75%RH

The FSC-PVAm membrane is mimicking Nature (Fixed-Site-Carrier Polyvinylamine)

- Dominating reactions:

$$CO_2 + H_2O -> H_2CO_3$$

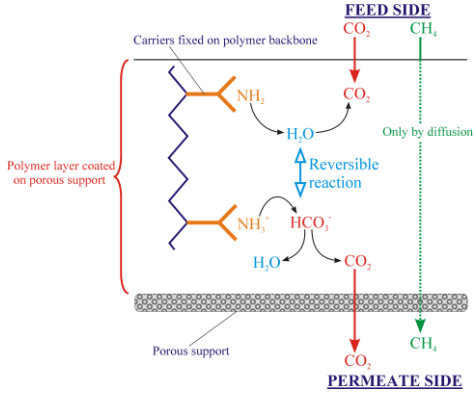
$$H_2CO_3 + NH_2 -> HCO_3^- + NH_3^+$$

$$HCO_3^- + NH_3^+ -> H_2CO_3 + NH_2$$

$$H_2CO_3 -> H_2O + CO_2$$

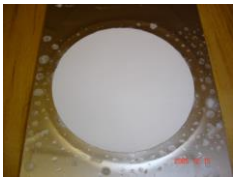
- Flux equation:

$$J_A = \frac{D_A}{l}(c_{A,0} - c_{A,l}) + \frac{D_{A,c}}{l}(c_{AC,0} - c_{AC,l})$$

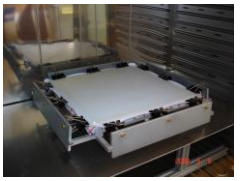


Right hand side:
1st term: Fickian diffusion, 2nd term: facilitated transport

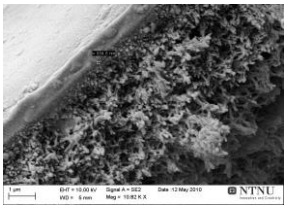
There is a long way from lab to pilot demonstration…….
1) small membrane pieces 2) large sheets, 3) spinning & coating fibers



✓1st step (→2008):
Lab, diameter 5-7 cm



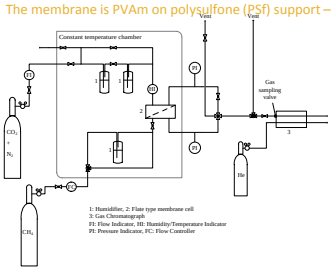
✓2nd step (→2012):
Small bench-pilot,
Flat sheets,0.5 – 2m^2

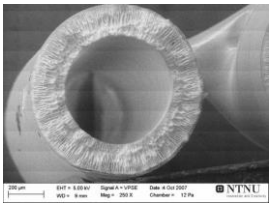


…with durability testing and studies…

3rd step (→ 2015):
Demonstration pilot with hollow fibres 8 - 10m^2

The membrane is PVAm on polysulfone (PSf) support – both as flat sheets and hollow fibers – 3 patents





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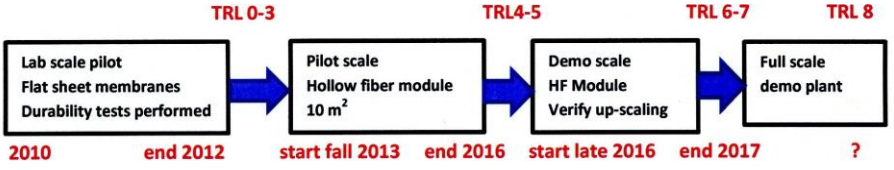
Tasks in the current FSC PVAm Membrane Project



1) Preparation of hollow fibers and coating procedures
2) Characterization of membranes / separation
3) Scaling up hollow fiber modules from lab-scale → 10m2
4) Design and building of experimental rig
5) Testing at different regimes
6) Development of simulation tool
7) Process simulations

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