

Process Intensification - Climbing the S-curve

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ECN-L--15-068



Process Intensification

Climbing the S-curve

Y.C. van Delft

PIN-NL Autumn Session 2014

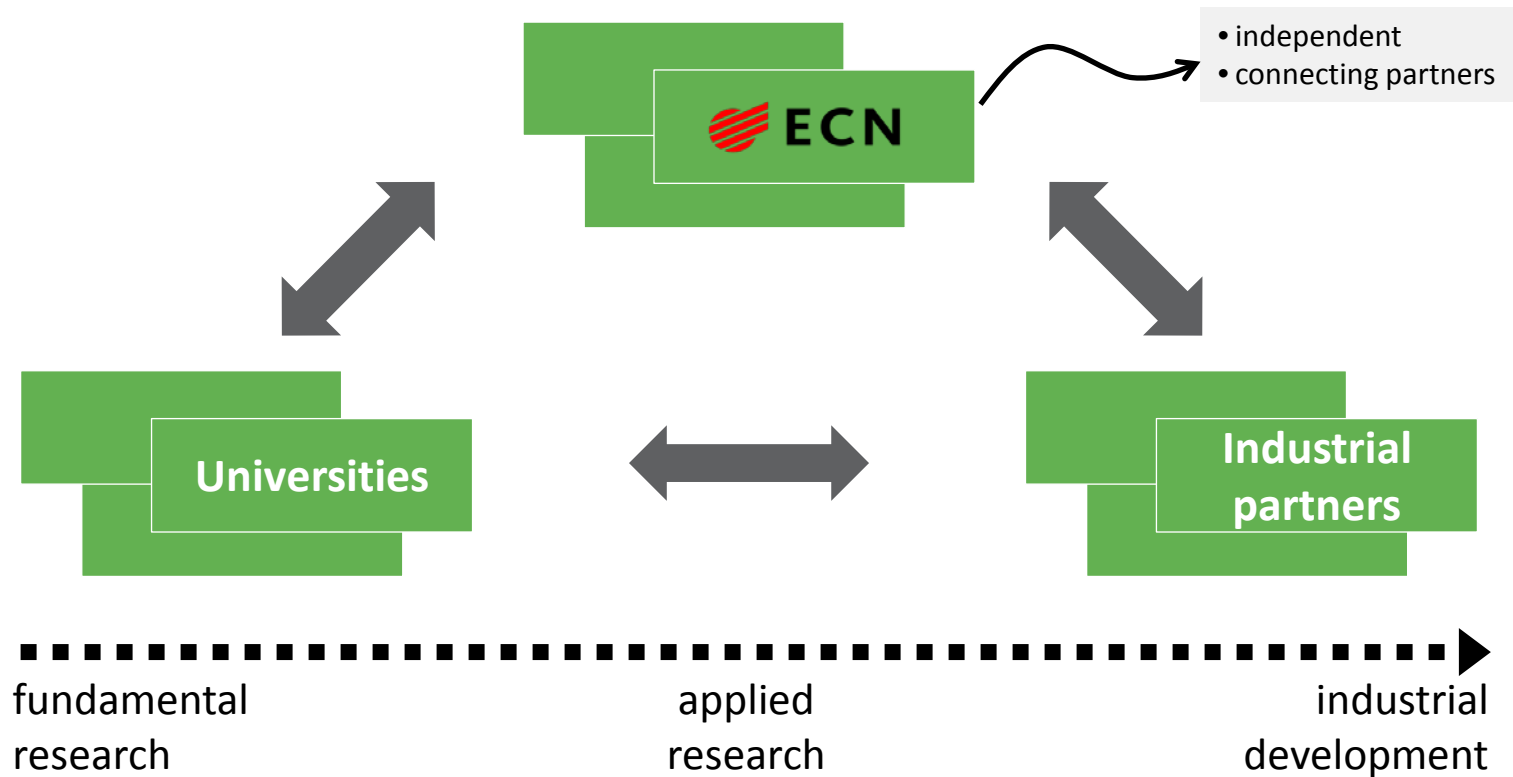
Amersfoort, 19 November 2014

ECN: A rich and evolving history

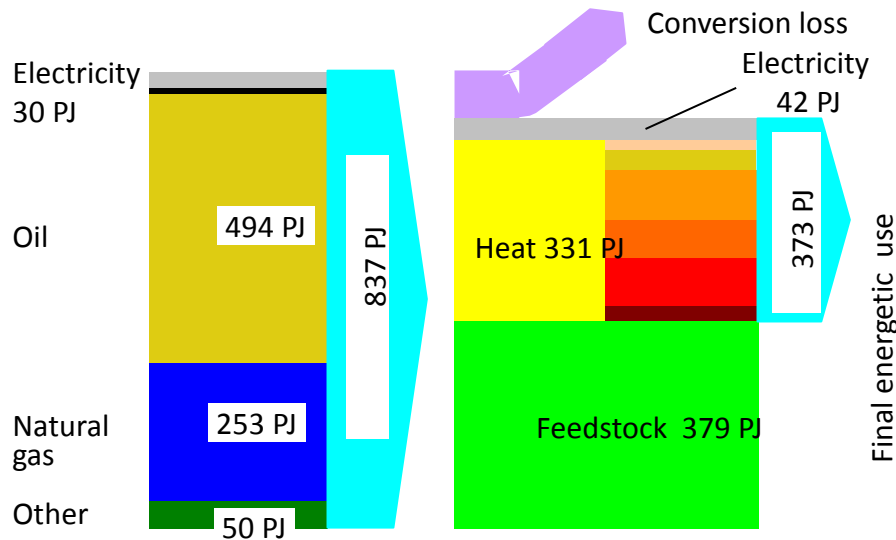


We are in our 58th year of pushing technology boundaries

Position



Driver for ECN



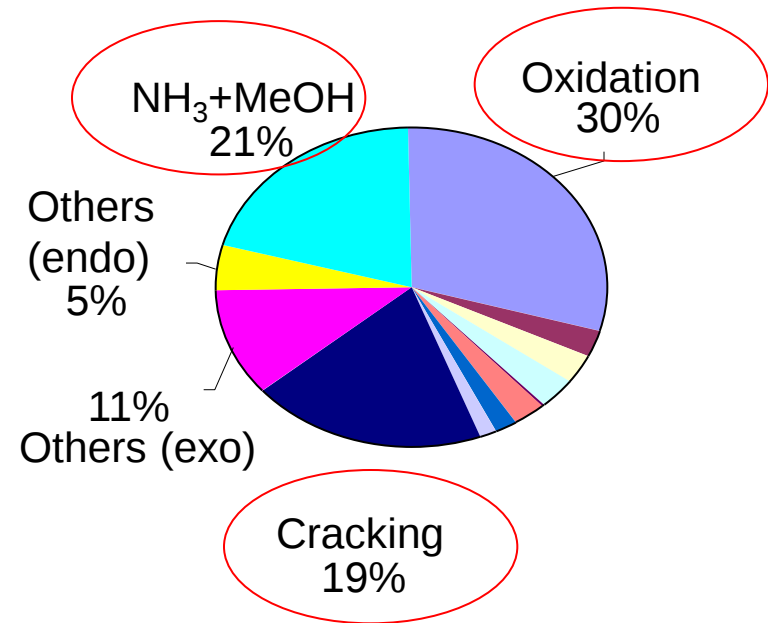
- Primary and final energy consumption of the Dutch chemical & refining industry (data 2000)
- Chemical & refining = 30% of primary energy (including feedstock)

Total NL= 3051

Total NL= 2518

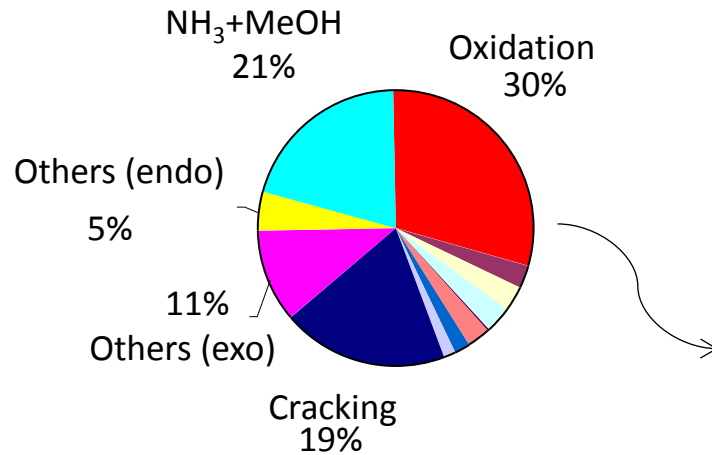
Driver: increasing the efficiency of the chemical and refining industry

Energy loss in the Dutch chemical industry



- Extensive database of Dutch chemical processes
- Covers to 100+ of processes (energy use)
- Searchable on specific aspects
- Valuable tool for analysis of potential of technologies

Process and technology selection



*Energy use in the Dutch
chemical industry (2005)*

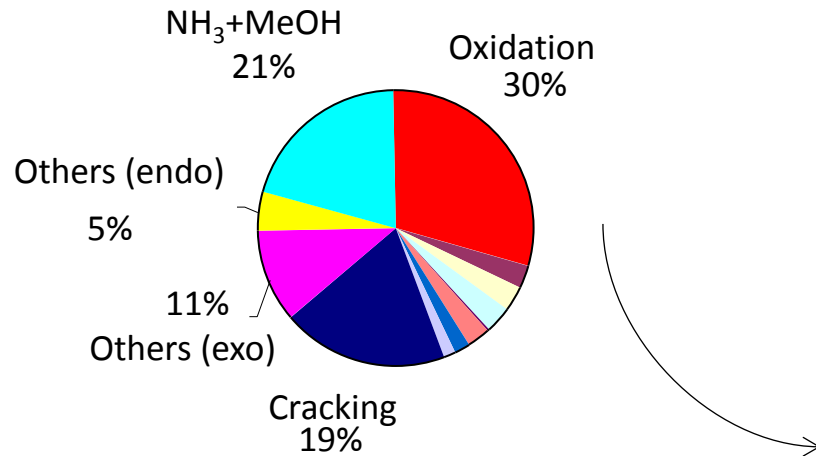


Chemical Process Industry, 2013

**Drastic improvement of efficiency needs
process innovation => Process Intensification!**

G. Agricola, De Re Metallica, 1556

Process and technology selection



*Energy use in the Dutch
chemical industry (2005)*

Pervaporation membranes

Industrial heat pumps

Oxidation in a Taylor flow reactor

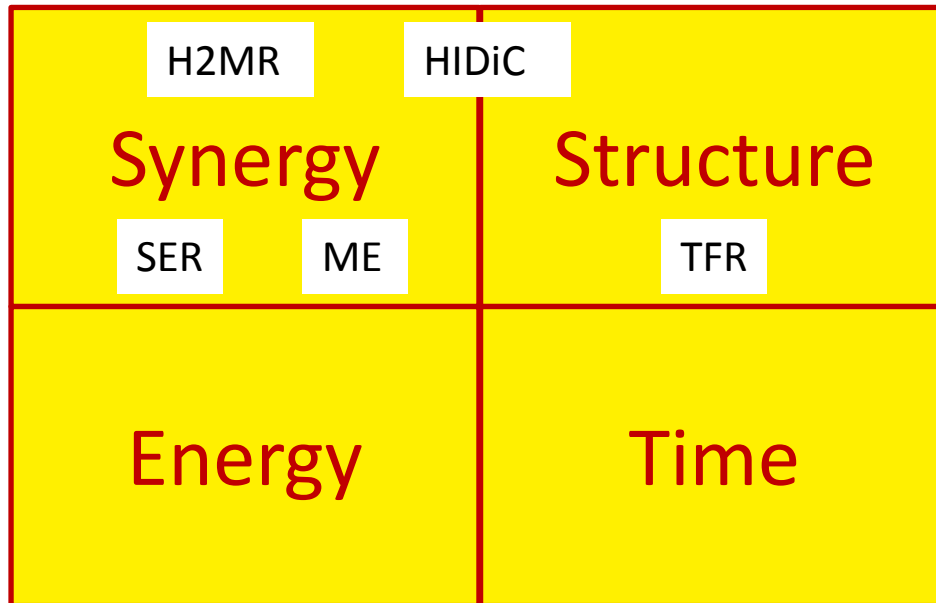
Sorption enhanced reactions

Heat integrated distillation

Membrane reactor for hydrogen production

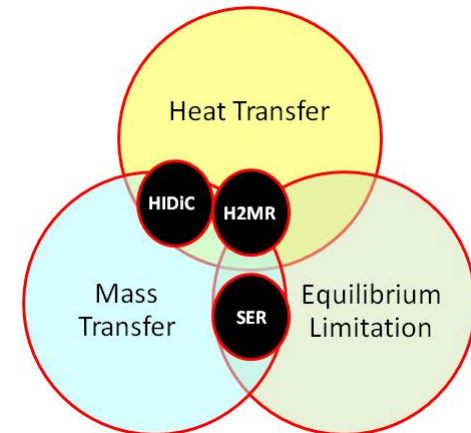
Membrane esterification

PI domains

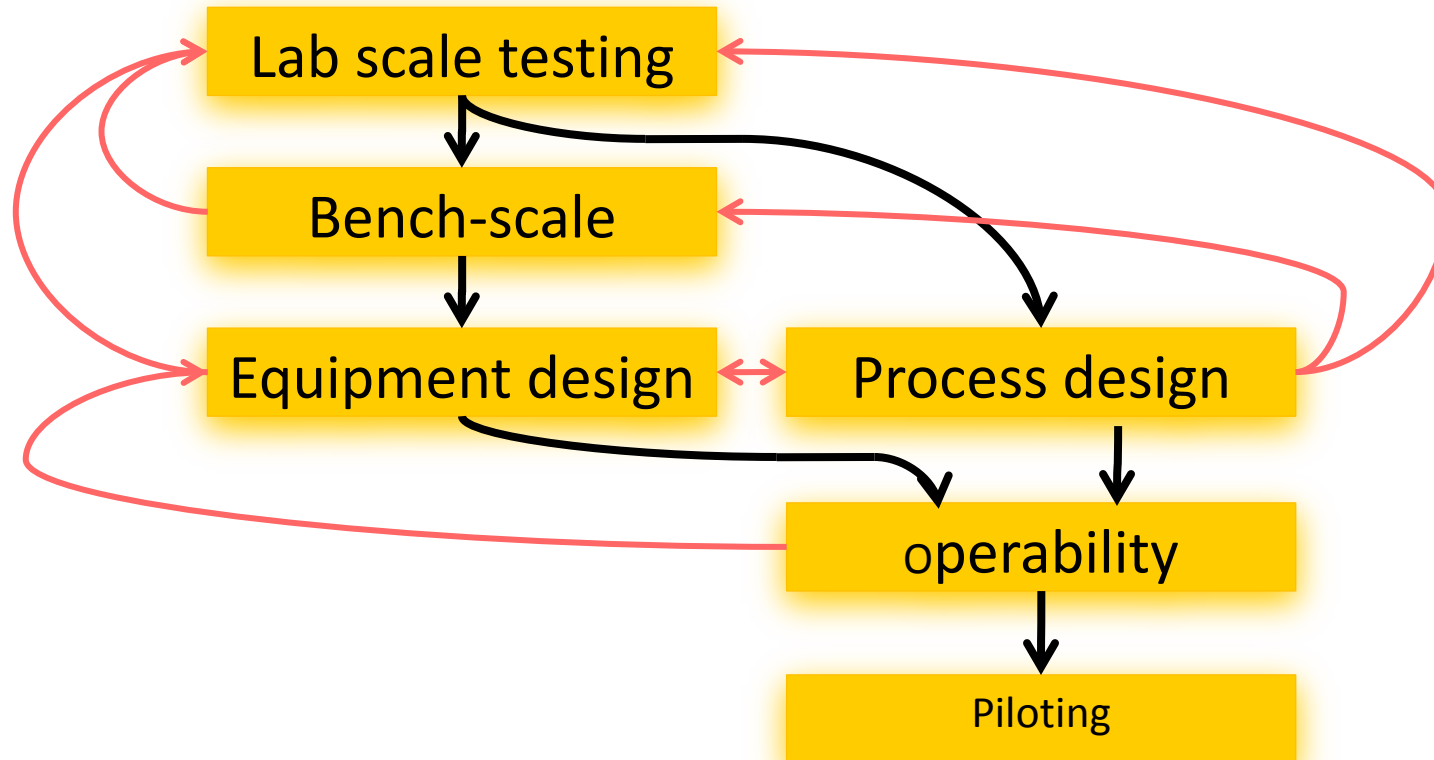


(based on: Andrzej Stankiewicz, TU Delft)

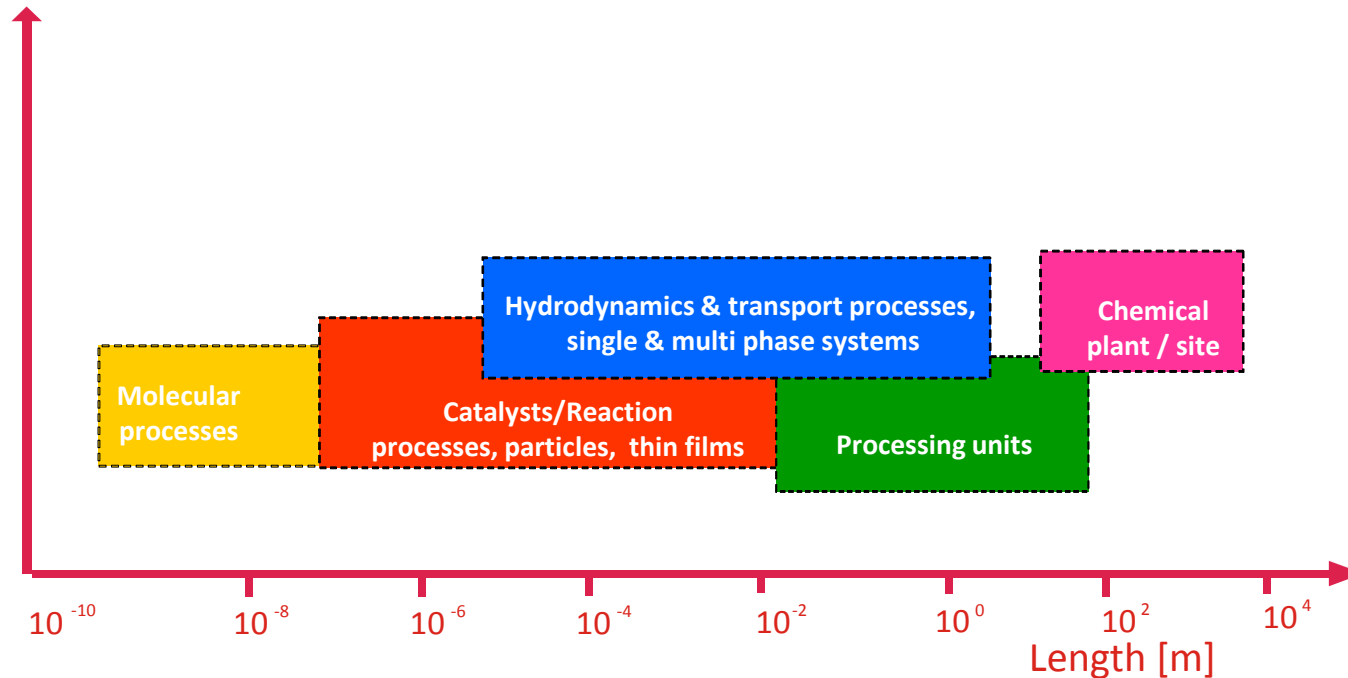
- Focus ECN:
 - PI technologies combining known functions
 - From lab to pilot
 - From particles/thin films to processing units



PI technology: from lab to pilot



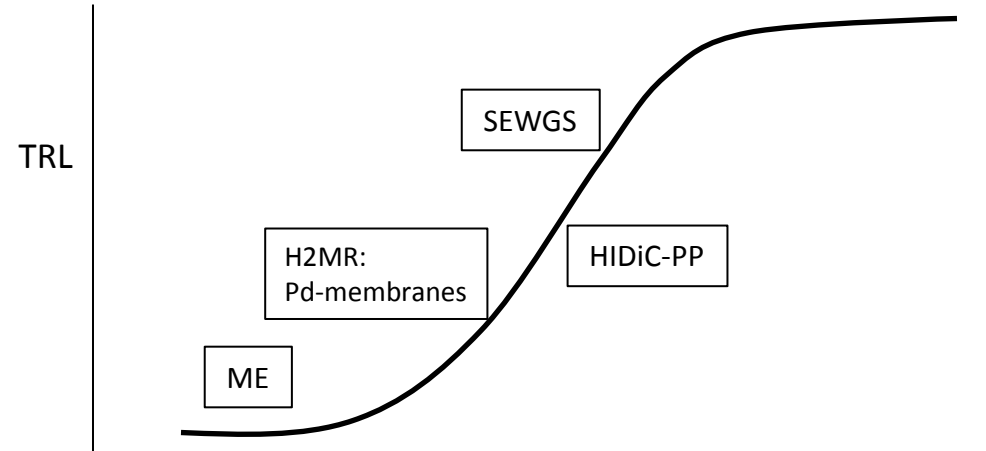
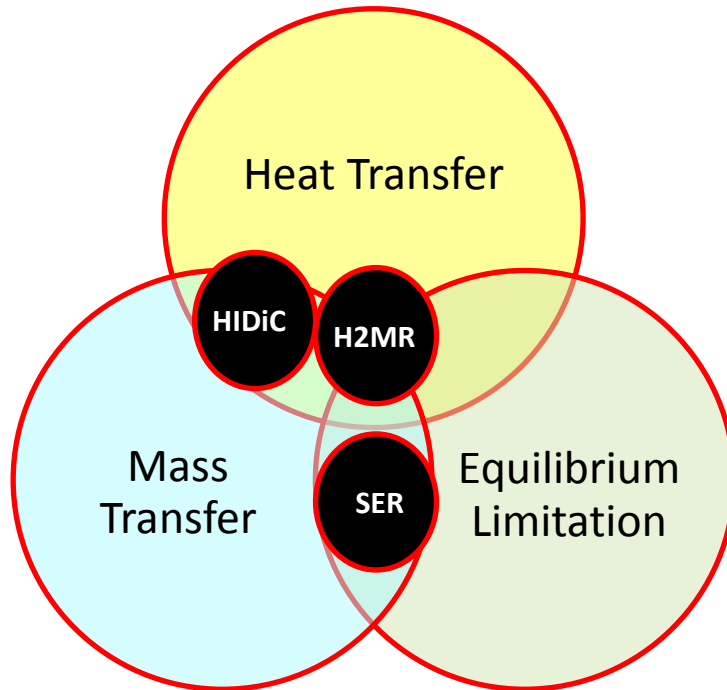
Process Intensification: role of scales



“from the molecule to the plant”

(based on: Andrzej Stankiewicz, TU Delft)

PI at ECN



Process Intensification development lines

- Separation enhanced reactions
 - Membrane reformer (hydrogen separation)
 - SEWGS (CO₂ separation)
 - Membrane esterifications
- Direct selective addition of reactants to a reaction
- Structured reactors for oxidations
- Heat integrated distillation

Membrane
technology

Sorption
technology

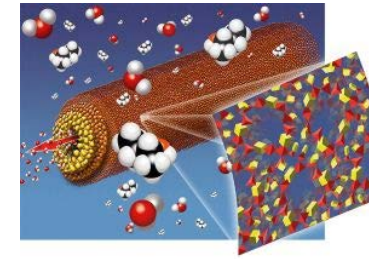
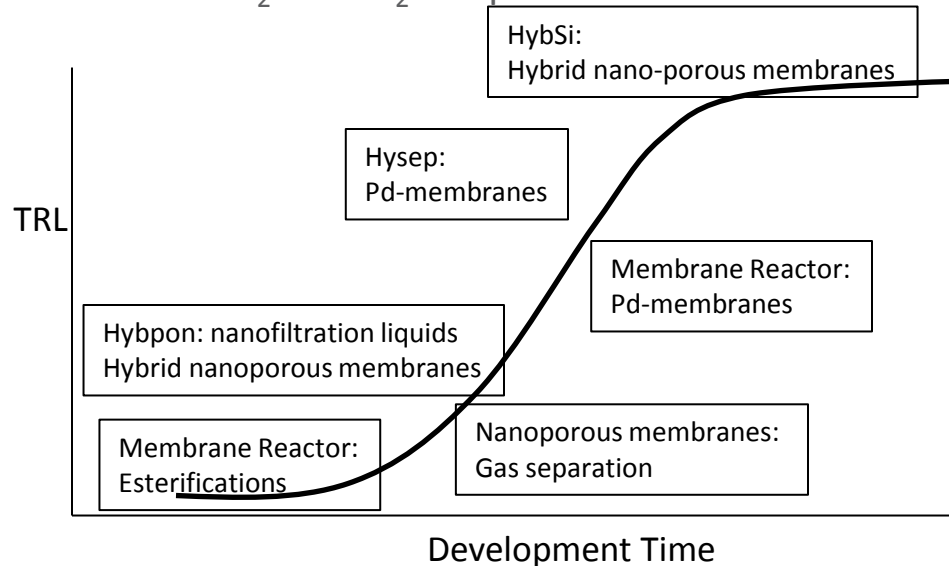
Catalyst
technology

- Process and system studies
 - In cooperation with equipment manufacturers and end-users



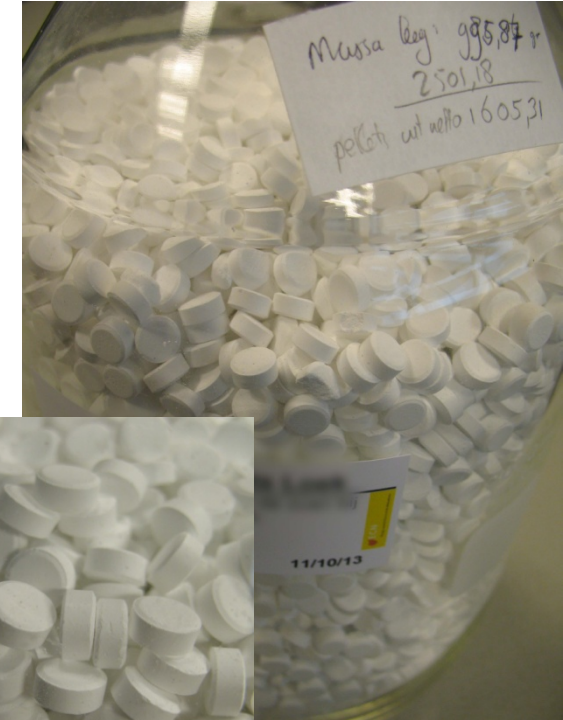
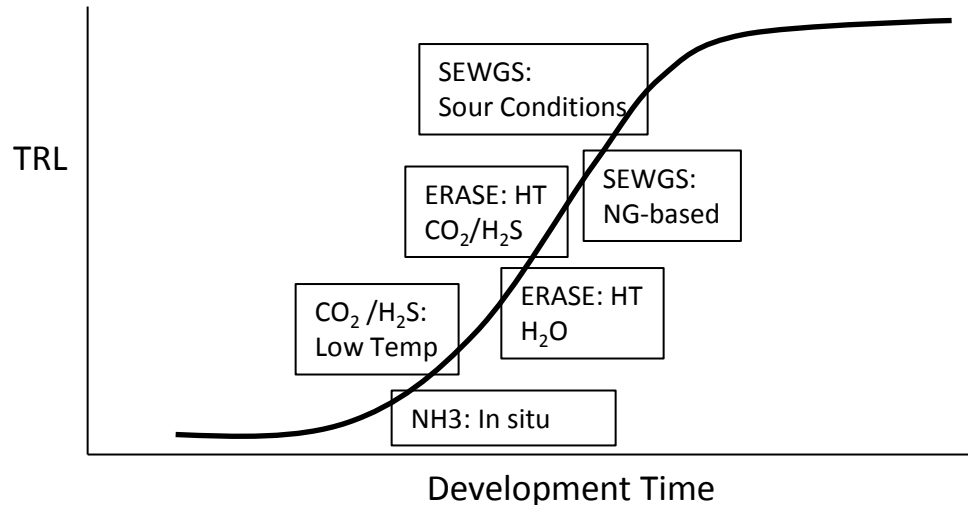
Membrane R&D at ECN

- Different membranes and their development status:
 - Dense metal-based membranes:
 - H₂-separation (HySep)
 - Hybrid nano-porous membranes:
 - Pervaporation (HybSi: Separation of water/methanol from solvents)
 - CO₂- and H₂O-separation



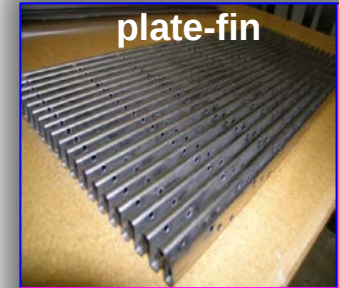
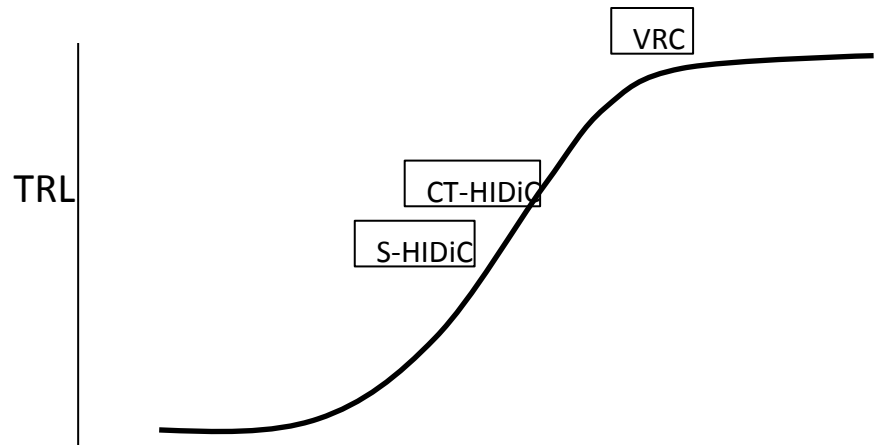
Sorbent R&D at ECN

- Different sorbents and their development status:
 - Hydrotalcites for HT separations and reactions:
 - CO_2 , H_2S and H_2O separations
 - Reforming, Refineries and CCS
 - Low temperature Sorbents:
 - CO_2 , H_2S and H_2O separations
 - Biogas and Natural gas



HIDiC R&D at ECN

- Different concepts and their development status:
 - Application:
 - Separation of close boiling liquids (P/P, EB/Styrene)
 - Concentric tray HIDiC (TUD, JP)
 - Structured HIDiC (ECN):
 - Plate fin
 - Plate packing

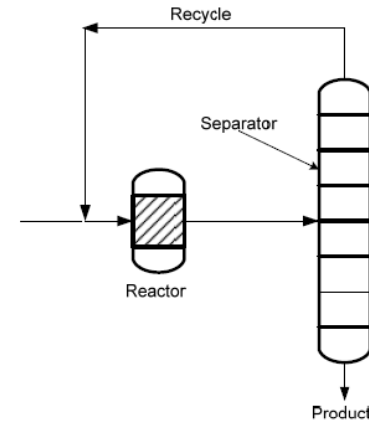


Separation Enhanced Reactions: What problem are we trying to solve?

- Many chemical reactions are thermodynamically limited in conversion

- Consequences:

- Multiple passes
 - i.e. large recycles
- Multiple reactors
 - Heat management
- Need to separate products from reactants
 - Expensive distillation / cold box technology



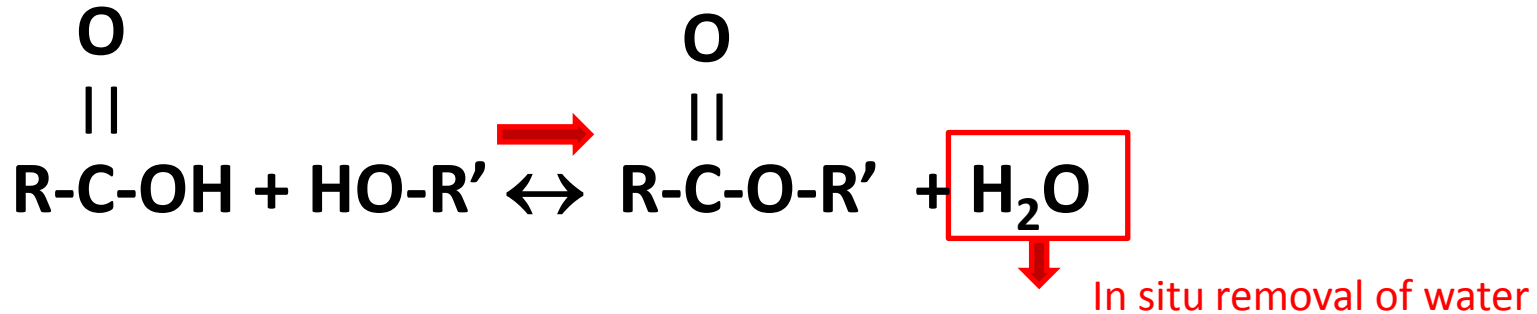
→ Separation-enhanced reaction/catalysis lessens impact of thermodynamic limitation

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

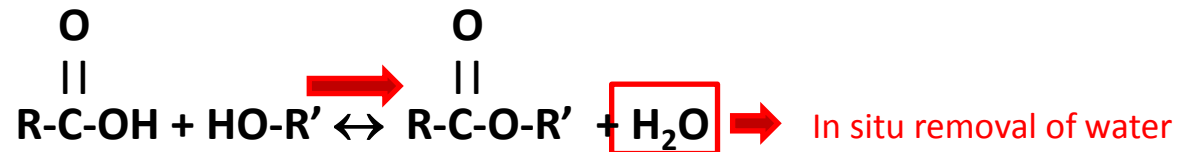
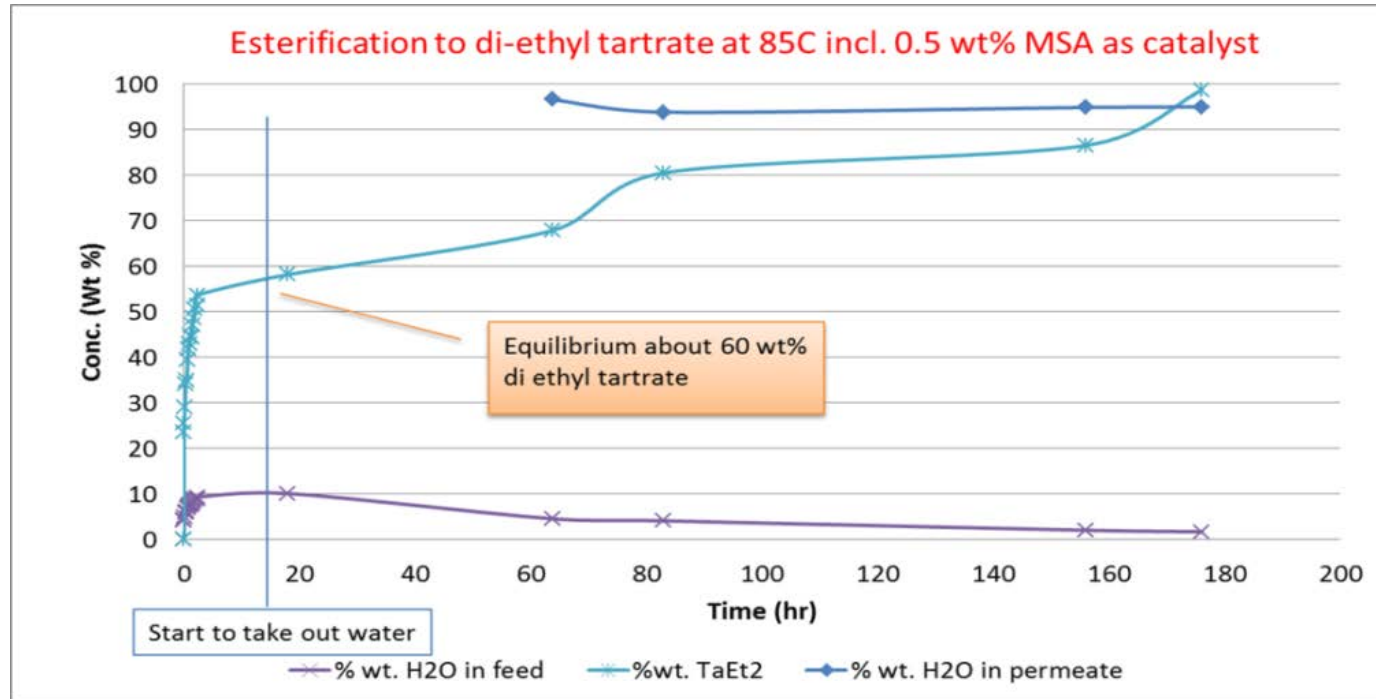
Example:

Membrane Esterification

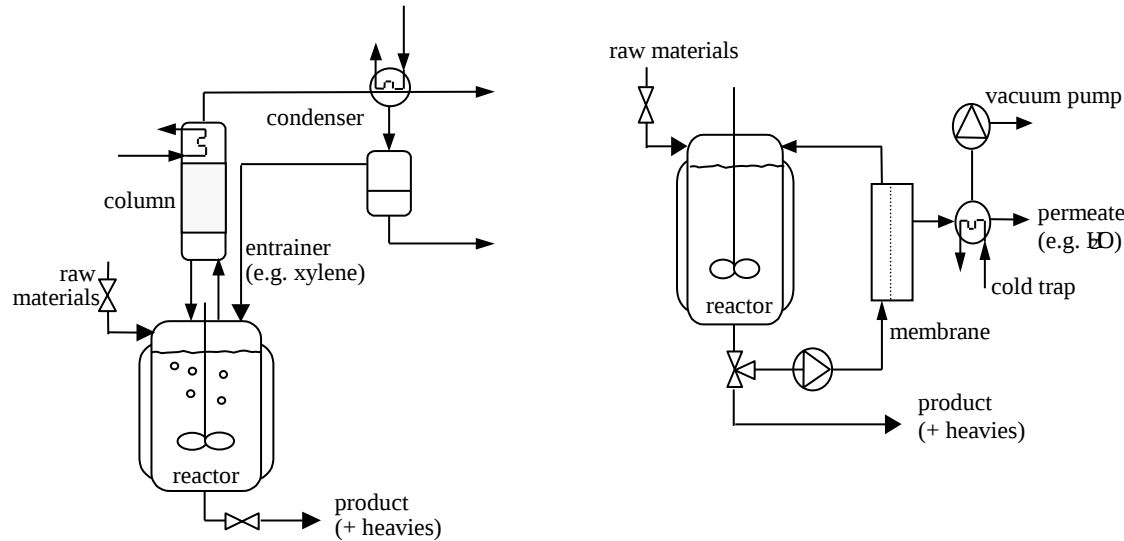
- Membrane esterification
 - If a higher production yield is required or if separation is difficult e.g. 5 azeotropes in acetal production
 - In-situ removal of water during reaction can lead to much higher conversions than normally obtainable at thermodynamic equilibrium



Membrane Esterification



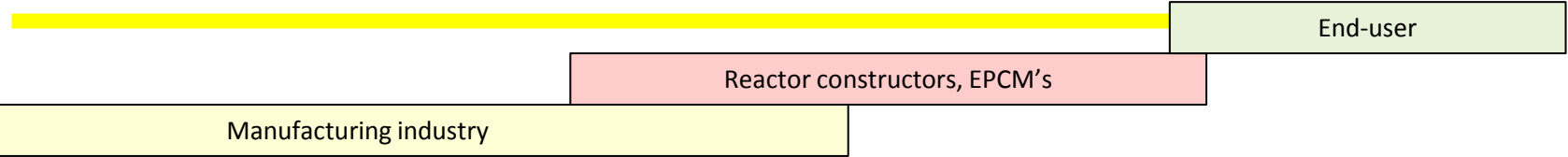
Membrane Esterification



- Higher productivity
- Reduced energy use
- Better product quality
- Less feedstock use

Previous studies on esterification with membranes, have shown 30% productivity increase, 40% lower OPEX and 25% lower CAPEX are possible in industrial processes

Status of H2MR: From powder to demonstration



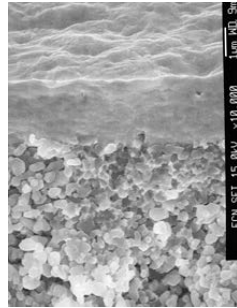
Manufacturing facility from lab to pilot scale

Reactor demonstration from lab to pilot scale

Assistance in technology scale-up



Ceramic processing
Deposition techniques
Shaping processes



Reactor design
System studies
Techno-economic
analysis



Technology Scale-up
After-care
Licensing

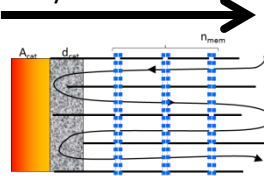


On site pilot to
full scale plant

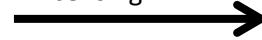
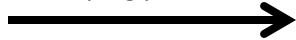
Ceramic powders
Catalyst powders
Metal-organic precursors



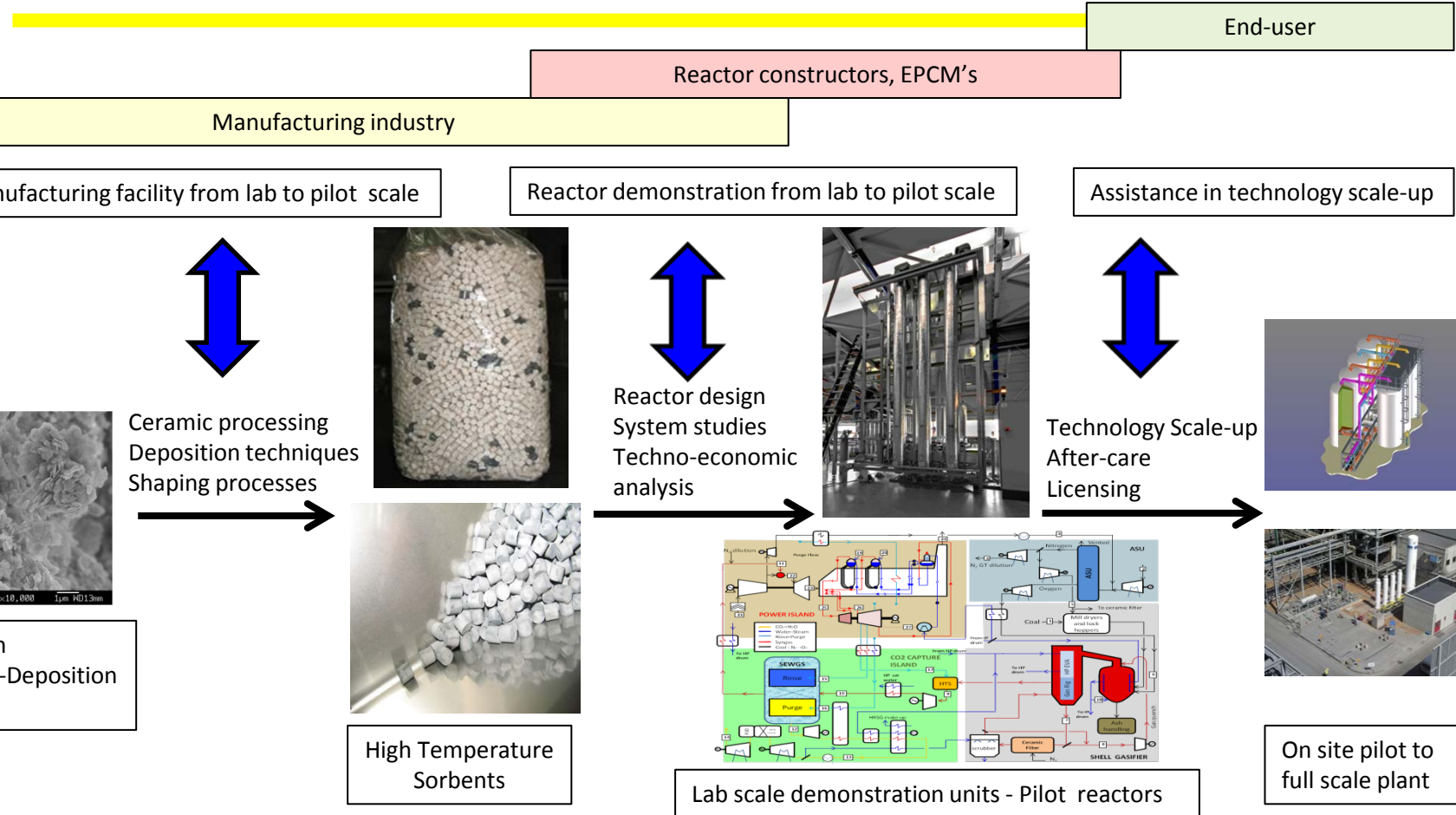
Membranes
Catalyst



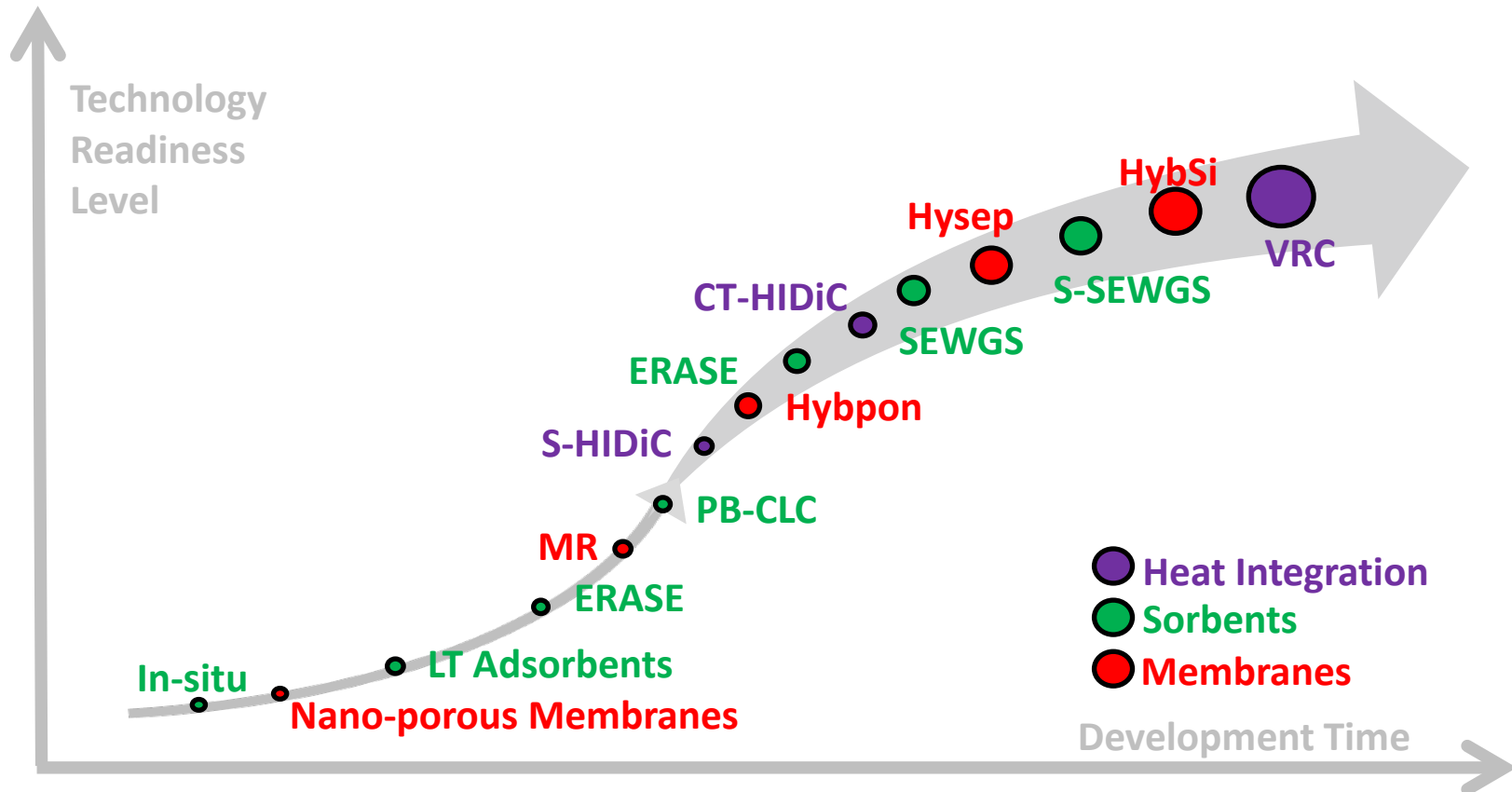
Lab scale demonstration units
Pilot reactors



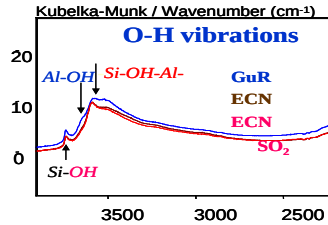
Status of SEWGS: From powder to demonstration



Climbing the S-Curve



From the molecules to plants...



Characterisation
of catalysts,
membranes
and sorbents



Development
of catalysts,
membranes
and sorbents



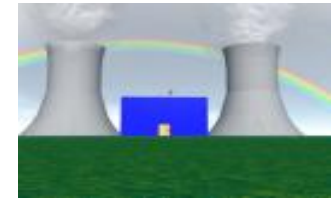
Testing of
of catalysts,
membranes
and sorbents



Reactor
Design

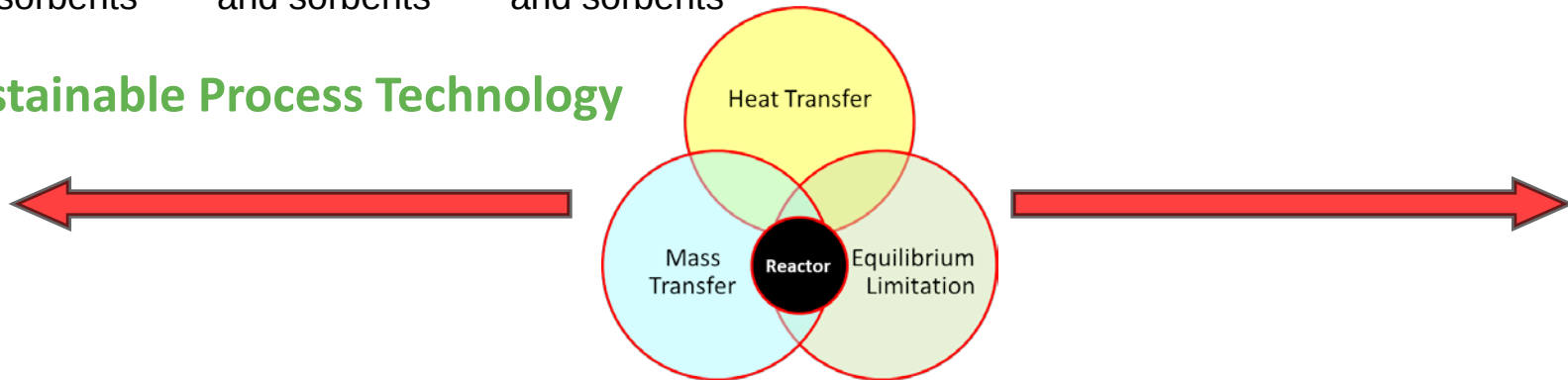


Process
development,
reactor evaluation



Process design,
Systems analysis

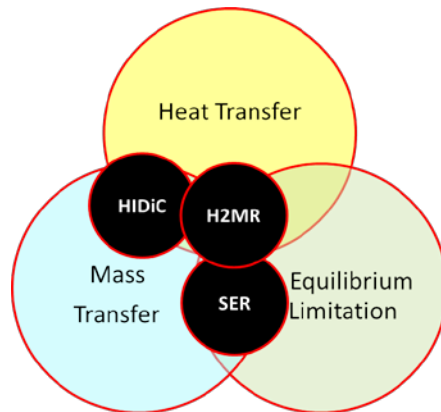
Sustainable Process Technology



ECN's unique view on Process Intensification



- Currently a relatively large group at ECN with knowledge and understanding of separation & conversion with adsorbents, membranes and structured devices
 - Unique equipment available for study of separations & separation-enhanced reactions
 - Running start on developing new processes
 - Benefit from the large number of materials tested in previous projects
 - Solutions/approaches for Close boiling liquids, Ammonia, Methanation, Water Gas Shift, Reverse Water Gas Shift, Methanol, Steam Reforming, Condensation Reactions





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De Rijksdienst voor Ondernemend Nederland gaat nauwer samenwerken met kennisnetwerken NLGUTS, NWGD en PIN-NL. Op 4 november tekenden zij de overeenkomst. Doel is het versnellen van duurzame innovatie in de industrie, om zo sterker bij te dragen aan de Nederlandse energiebesparingsdoelstelling en concurrentiepositie.

De eerste gezamenlijke bijeenkomst van de drie kennisnetwerken is op 14 april 2015 en wordt gehost door ECN (Energieonderzoek Centrum Nederland).

Congratulations and Welcome at ECN on April 14th, 2015

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