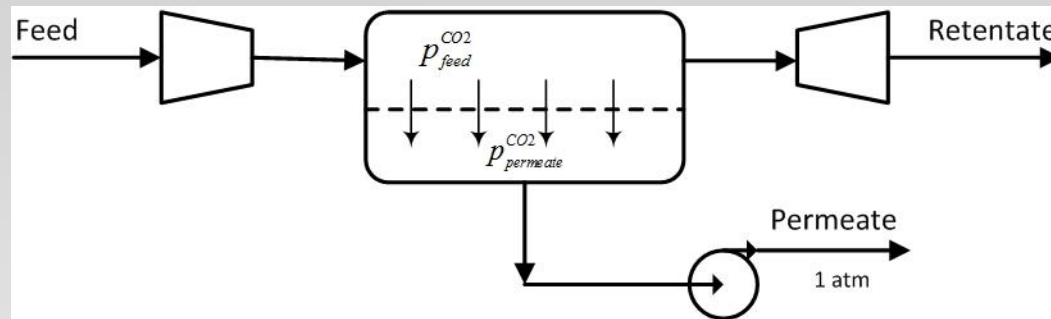




Pre-combustion capture from an IGCC using polymeric membranes

Rahul Anantharaman, SINTEF Energy Research
Brede Hagen, SINTEF Energy Research
Simon Roussanaly, SINTEF Energy Research

Background



- Each membrane stage involves trade-off between product purity and capture rate.
 - Played out as a trade-off between driving force (compression work) and membrane area.
- Significant work in literature on “sensitivity” analysis to design single stage systems.
- For multi-stage process complexity increases further
- Identifying the "best" membrane configuration is not straightforward

Attainable region approach



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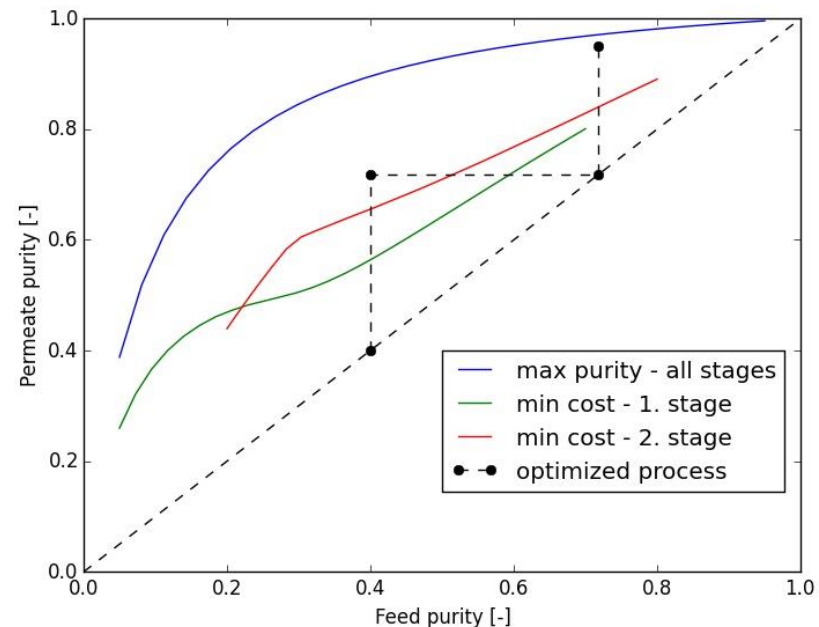
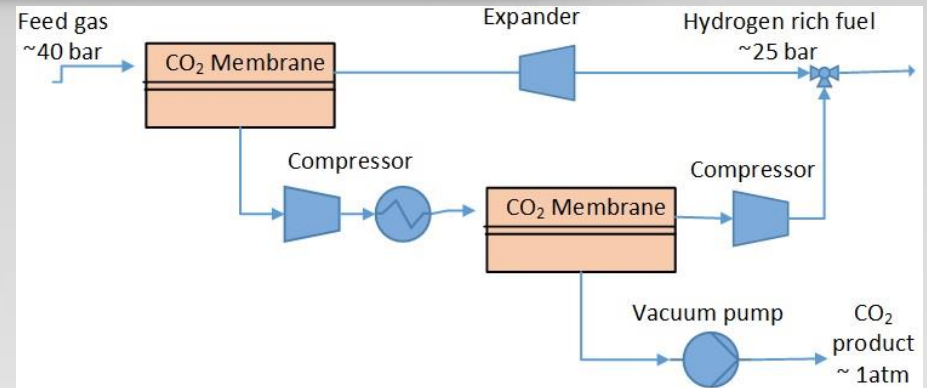
- A novel systematic methodology for design of stage-wise membrane capture has been designed at SINTEF Energy
- It is a simple visual method that allows consistent "optimal" design of membrane processes
- Also provides feedback to membrane developers
- The methodology has been implemented in Python to design membrane processes

Attainable region approach



- **Visualization of an optimized 2-stage membrane process**

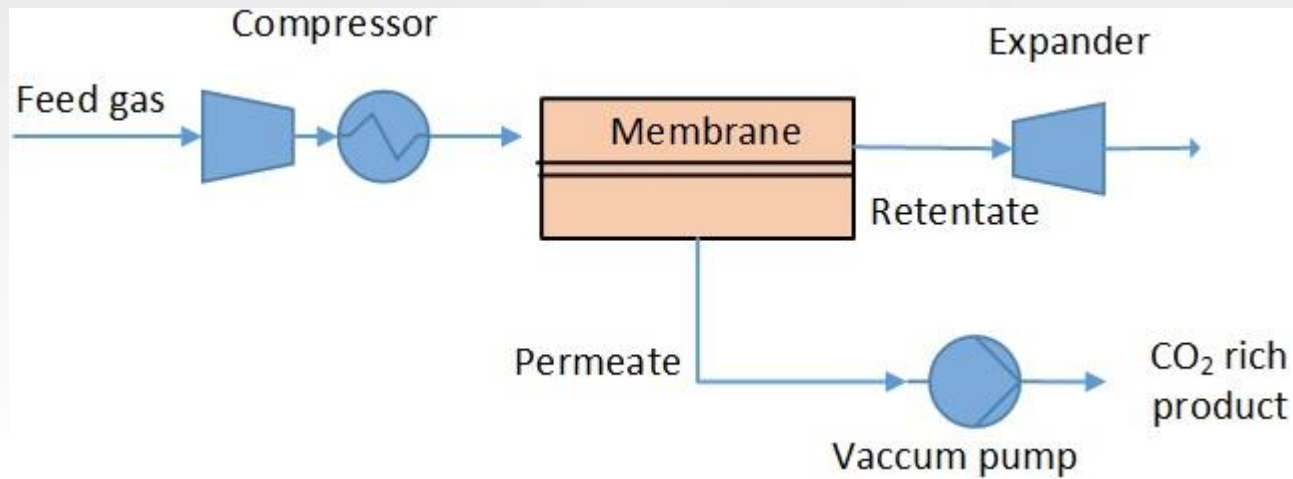
- Permeance = 10 $\text{m}^3 \text{ (STP)}/(\text{m}^2 \text{ h bar})$
- Selectivity = 40
- Overall CCR = 90%
- CO_2 product purity = 95%
- Feed purity = 40%



Membrane process model



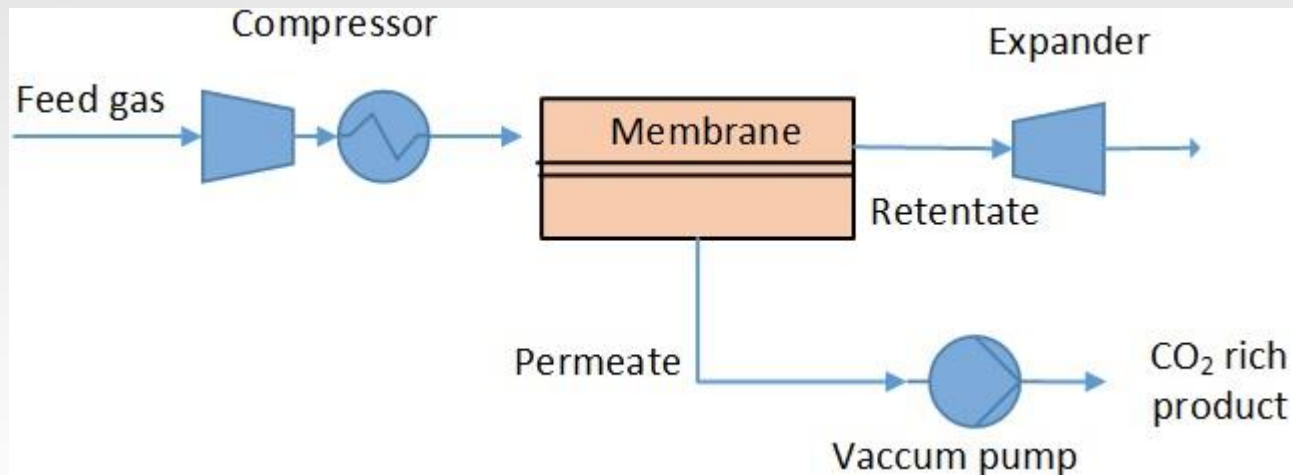
- A simple but flexible membrane process model
 - Multicomponent ideal gas model for the feed gas
 - Constant isentropic efficiency models for rotational equipment
 - Constant heat transfer coefficient model for cooler(s)
 - Membrane model:
 - Two component gas
 - Constant permeance and selectivity
 - Cross flow model – variation in gas composition along the membrane is taken into account
 - Flexible selection of rotational equipment



Membrane cost model



- A detailed life cycle cost model
 - Investment cost of all components
 - Cost of utilities such as
 - Net electricity consumption
 - Cooling water consumption for cooler(s)
 - Membrane module replacement
- Net present value (NPV) of cost and CO₂ capture cost are key performance indicators



Screen shot of the model



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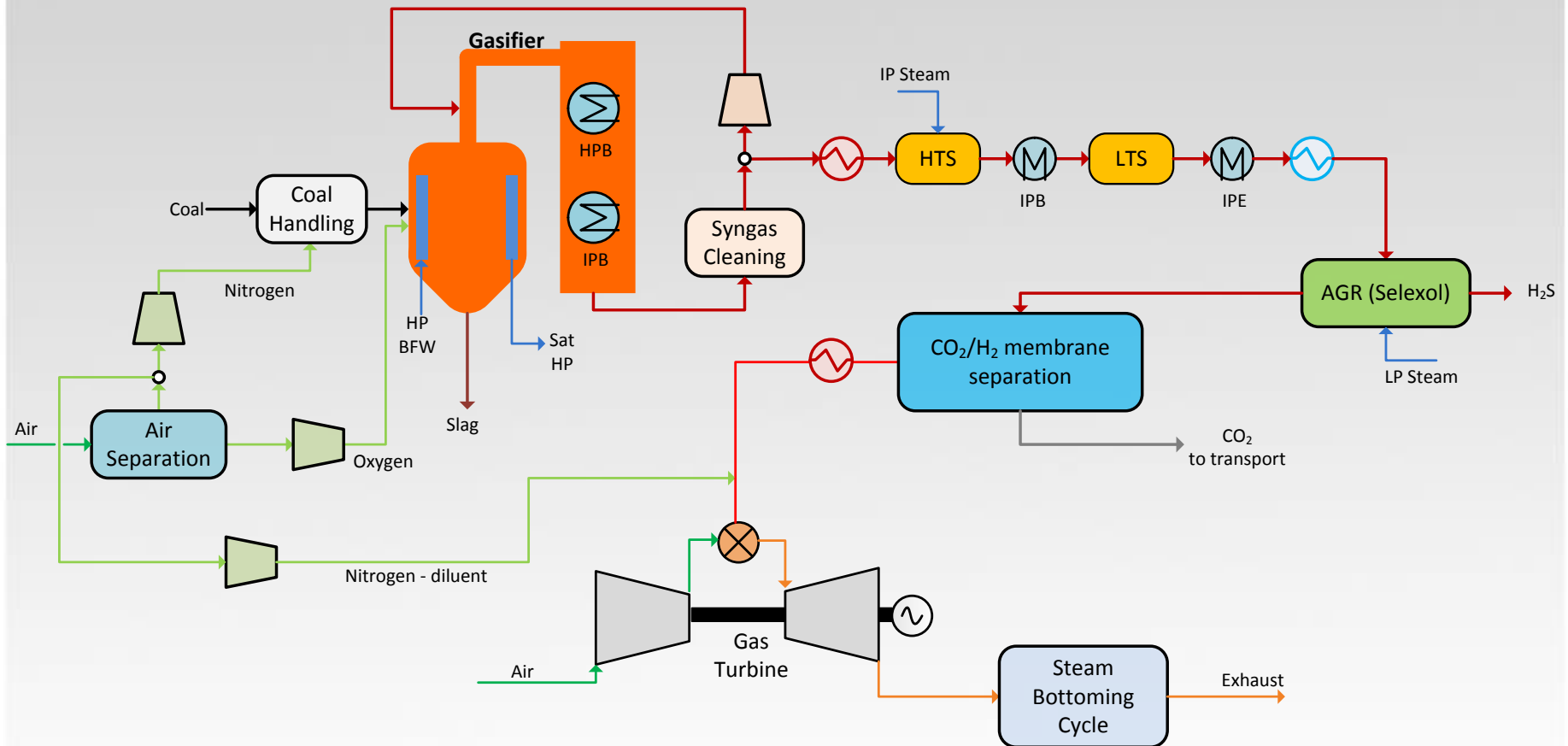
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```
MembraneCarbonCapture
├── src
│   ├── structures
│   │   ├── __init__.py
│   │   ├── attainableRegion.py
│   │   ├── compressor.py
│   │   ├── economy.py
│   │   ├── expander.py
│   │   ├── heatExchanger.py
│   │   ├── idealGas.py
│   │   ├── membrane.py
│   │   └── membraneSystem.py
│   │   └── optimization.py
│   ├── attainableRegionPlotting.py
│   ├── compressorTester.py
│   ├── costModel.py
│   ├── expanderTester.py
│   ├── heatExchangerTester.py
│   ├── ideal_gas_tester.py
│   ├── membraneSystemTester.py
│   ├── membraneSystemAndCostModel.py
│   ├── membraneTester.py
│   └── processOptimization.py
├── Anaconda Python ... aconda\python.e
├── brede
└── RemoteSystemsTempFiles
```

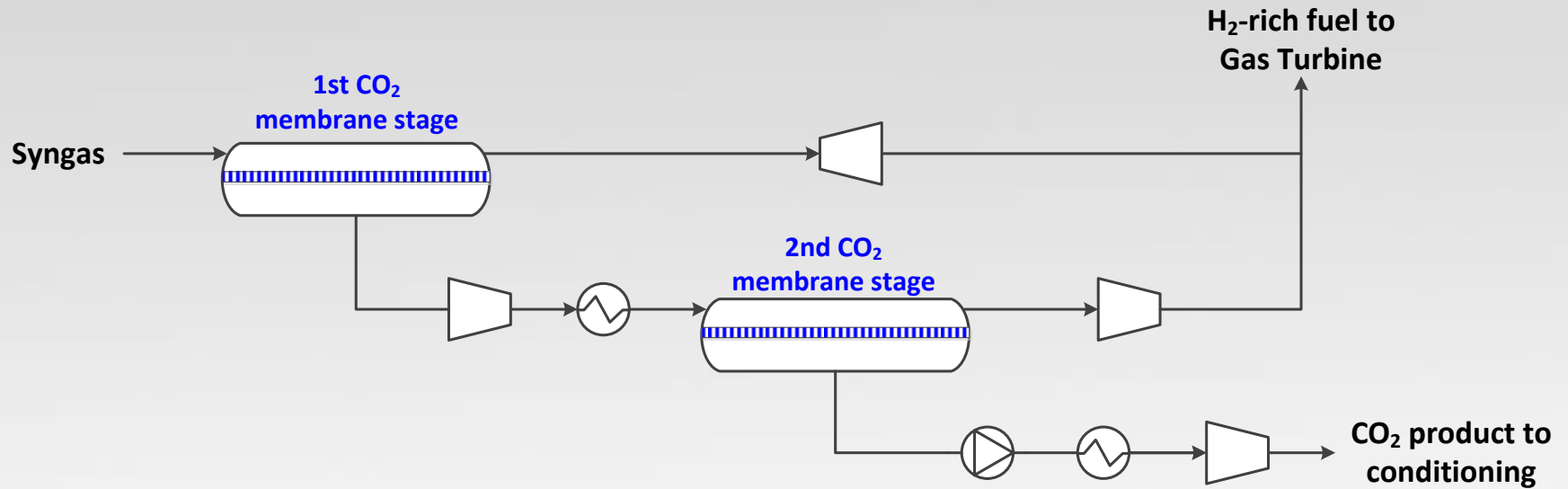
```
189
190
191     for gas in self.streamArr:
192         i += 1
193         p = gas.p/self.kToUnity
194         T = gas.T - self.Ctok
195         mfl = gas.mfl
196         zCO2 = gas.getComponentByName("CO2").z
197         zN2 = gas.getComponentByName("N2").z
198         print str(i).rjust(width),str("%.1f" % p).rjust(wid
199
200 def calculate(self):
201     self.netPower = 0
202     # Compressor
203     self.compressor.calculate()
204     self.compPower = self.compressor.power
205     self.netPower += sum(self.compressor.power)
206
207     # Cooler and intercooler
208     self.coolerArea = 0.0
209     self.coolerMfl = 0.0
210
211     # Intercooler
212     self.coolerArea += self.compressor.interCoolerArea
213     self.coolerMfl += self.compressor.intercoolerWaterMfl
214
215     # Cooling after last compression stage
216     self.cooler.calculate()
217     self.coolerArea += self.cooler.area
218     self.coolerMfl += self.cooler.extMfl
219     #self.cooler.printHx()
220
221     # Membrane
222     self.membrane.solveMembrane(self.inputParamName, self.i
223     self.membraneArea = self.membrane.area
224     self.stageCut = self.membrane.theta
225     self.CCR = self.membrane.CCR
226     self.captureRate = self.membrane.captureRate
227     self.purity = self.membrane.purity
```



Conceptual process diagram



CO₂ membrane



CO₂ membranes selected



Membrane	CO ₂ permeance [m ³ _(STP) /m ² h bar]	Selectivity [CO ₂ /H ₂]
Membrane 1	2.70	10
Membrane 2	0.81	21
Membrane 3	0.37	37

CO₂ membranes – Performance



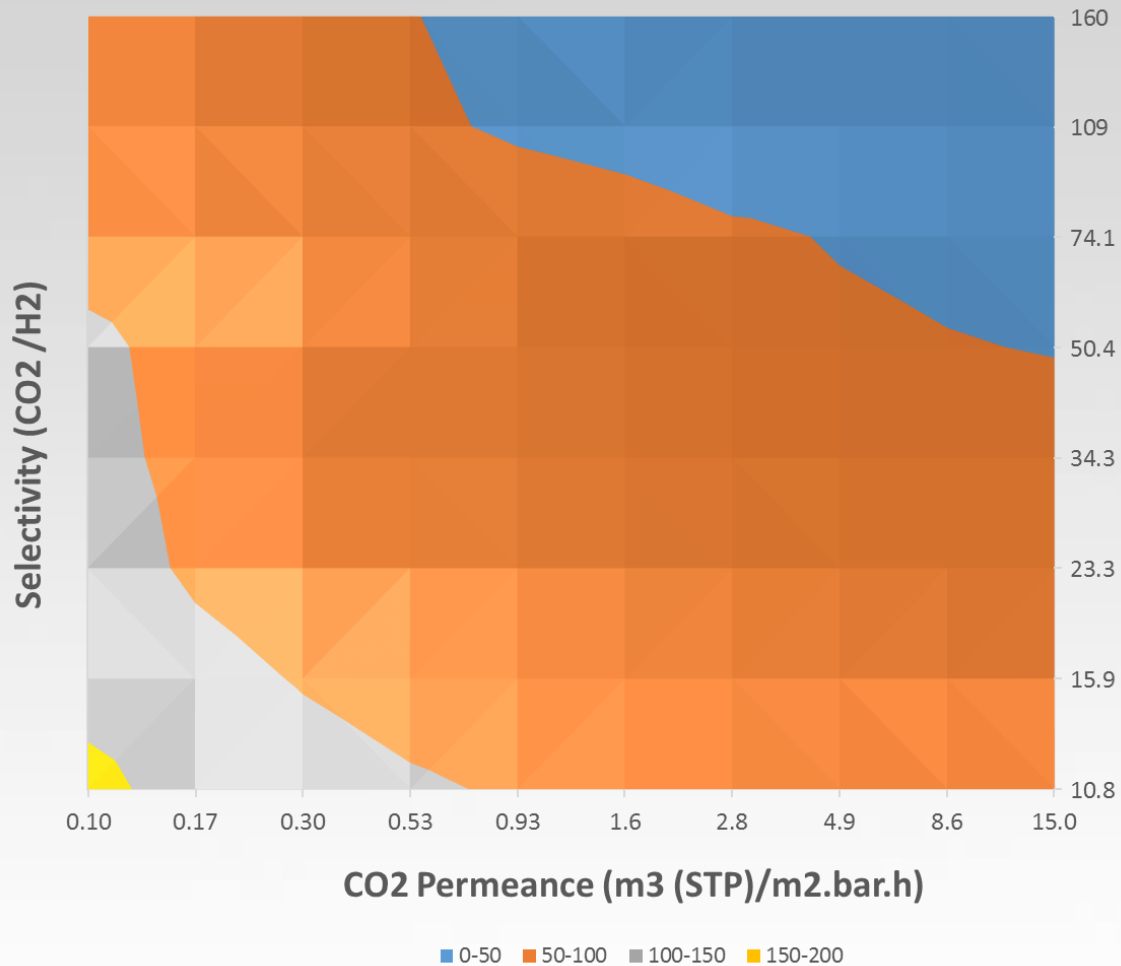
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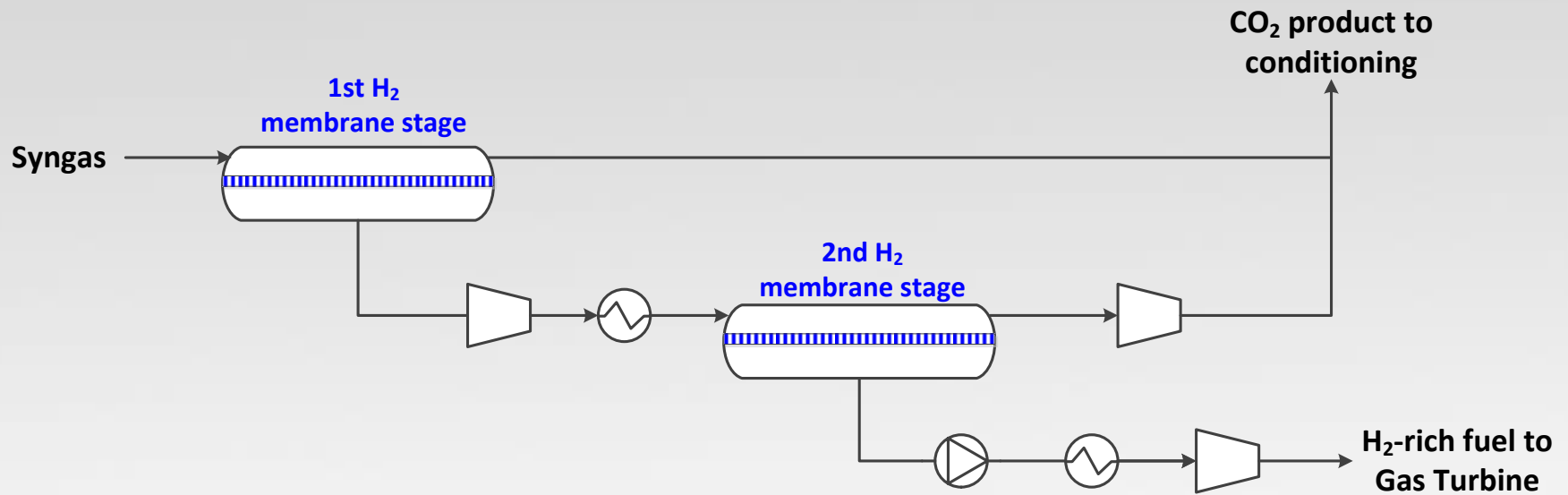
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Performance Parameter	Membrane 1	Membrane 2	Membrane 3
Total membrane area [10^3 m^2]	22.1	47.2	84.6
Power losses [MW]	42.8	20.1	17.8
Net power [MW]	177.2	199.4	205.7
CO ₂ emission [ton/MWh]	0.150	0.133	0.129
Electricity cost [€/MWh]	119.0	103.0	102.7
CO ₂ avoided cost [€/ton]	91.4	63.7	62.9

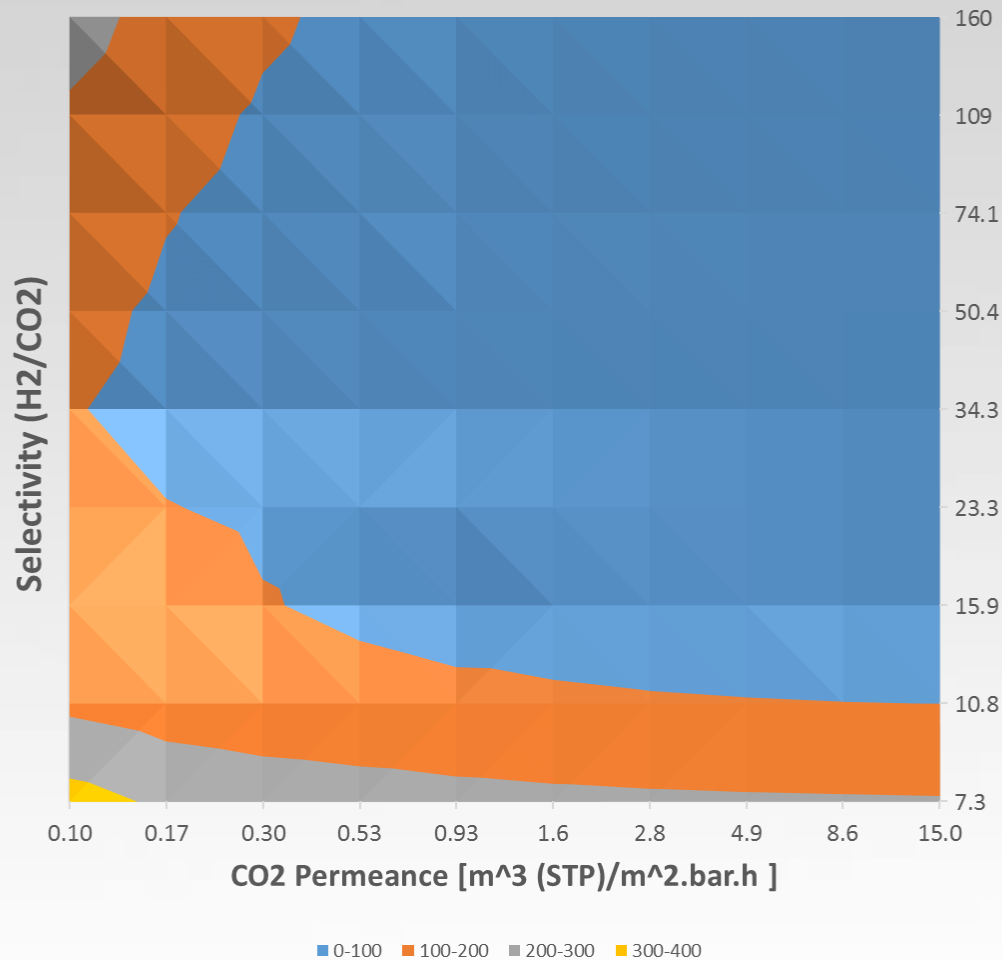
Membrane property map CO₂ membrane



H₂ membrane



Membrane property map H₂ membrane



Summary



- The Attainable Region approach for systematic membrane process design has been extended to pre-combustion capture processes
- Process configurations for typical membranes presented in literature have been designed
- The methodology developed at SINTEF Energy Research allows to identify the membrane properties required for CO₂ capture from a specific application
- The results identify:
 - When advanced configurations will be required
 - The trade-off between membrane properties
- Results can:
 - Guide the development of membrane materials for cost-effective CO₂ capture
 - Help the industry to select membranes that can compete with solvent-based capture systems.