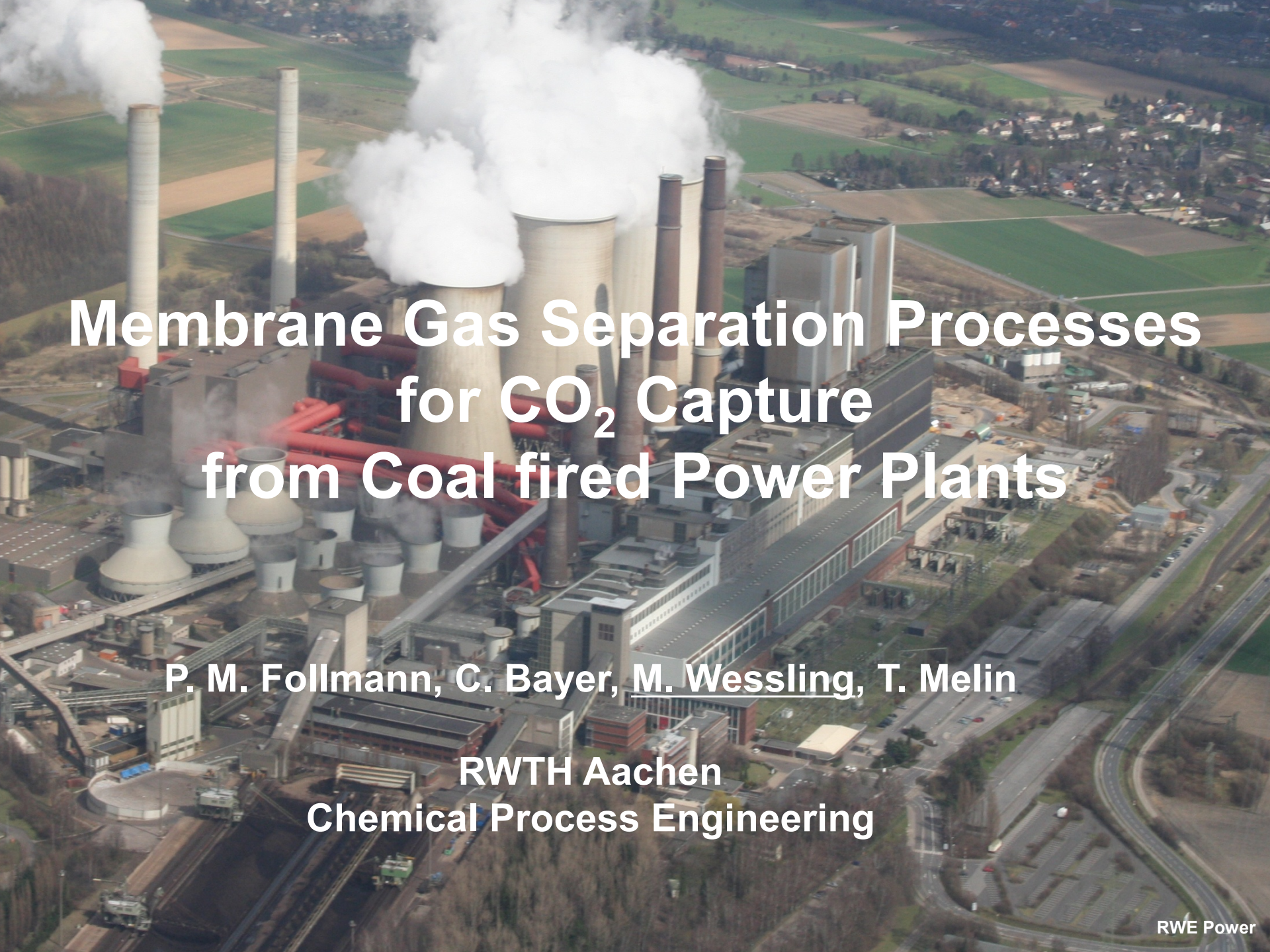

Membrane Gas Separation Processes for CO_2 Capture from Coal fired Power Plants

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RWTH Aachen
Chemical Process Engineering

RWE Power

Some conversations …

- **Polymer membranes?**

  “I have heard they corrode …”

- **How much does it save?**

- **How much can it achieve?**

  “I mean in %?”

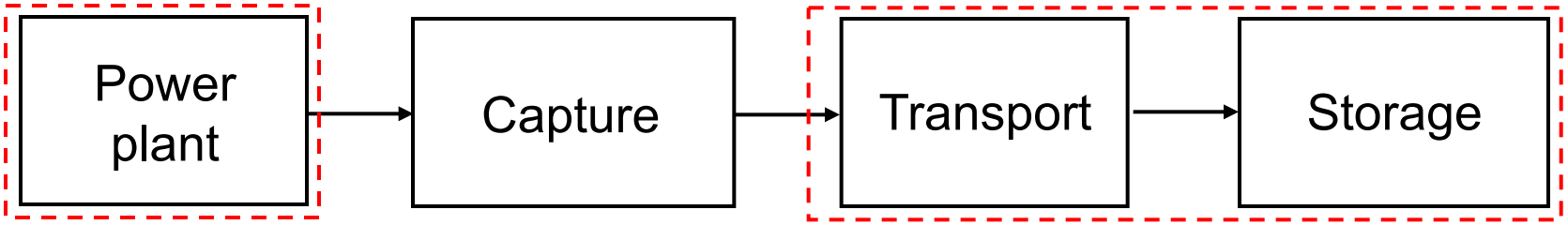
Does it work?

- One year of pilot plant operation in Borselen/NL
  - Water removal
  - Ash hick-up survived
- New pilot plant studies running currently

“How much does it do in %?”

Definition of boundary conditions (I)

- Power plant
  - 560 kg/s flue gas
  - 1 bar, 50°C, saturated in water
  - CO_2 13.6%, N_2 71.2%, O_2 3.2%
  - Contaminants (SO_x, NO_x)



- How much to be captured?
- CO_2 requirements?
  - CO_2 concentration
  - Trace components

Definition of boundary conditions (II)

- Delivery to pipeline at 130 bar and 30°C
- Composition
  - > 95.5 mole-% CO_2
  - max. 4 mole-% of air gases (N_2, Ar, O_2)
- 2 scenarios for O_2 content
  - High purity (only 100 ppm allowed)
  - Up to 4 mole-% O_2
- SO_x and NO_x (max. 0.5 mole-% in worst case)
- Residual water content: not specified
- Optimal capture rate: 90% assumed as optimal

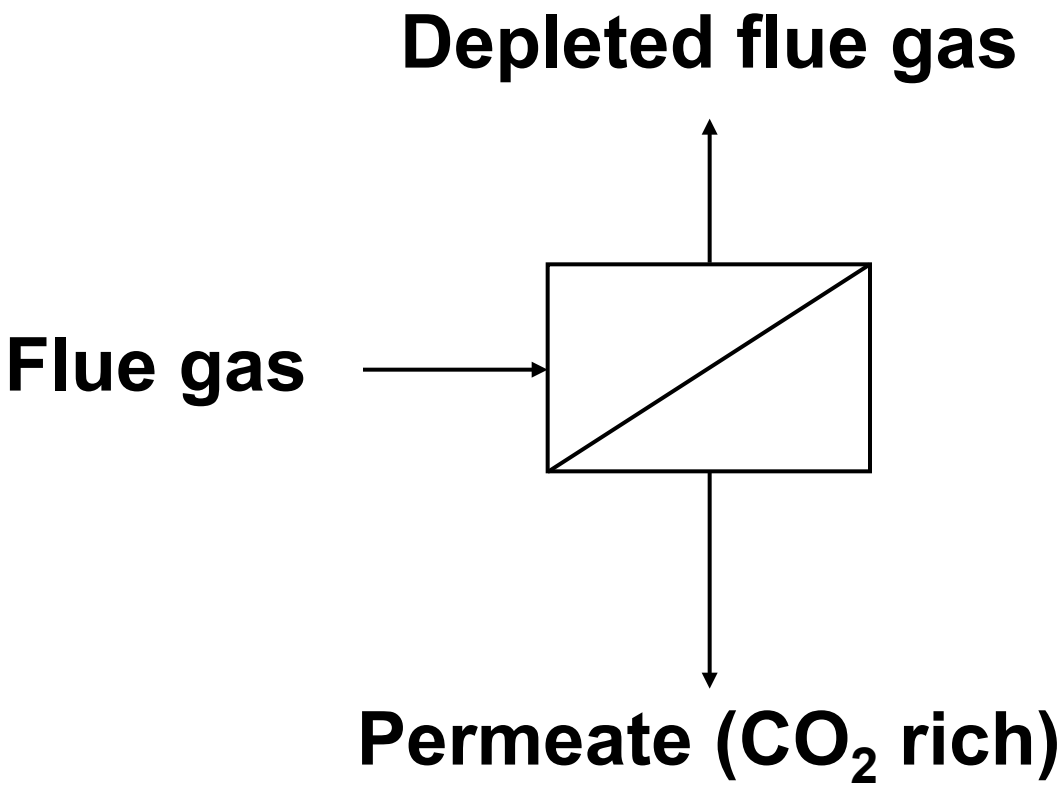
Gas separation membranes

- Polymeric membranes most suitable

	CO_2 Permeance	CO_2/N_2 Selectivity	CO_2/O_2 Selectivity	CO_2/SO_2 Selectivity
PPO	4.1	20	4.5	1
PEO	1.25	45	15	0.2
SPEEK	0.07	85	28	1

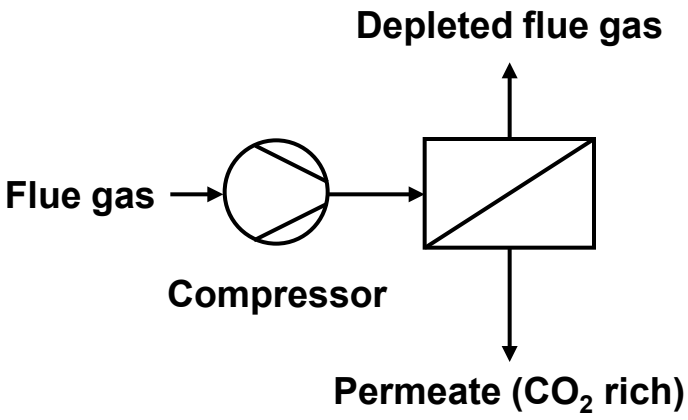
- Permeance H_2O >> permeance CO_2
- Mass transfer across membrane: $n_i = Q_i A_{Mem} (x_i p_F - y_i p_P)$
- Pressure ratio across membrane: $\Phi = p_F / p_P$

CO_2 Removal

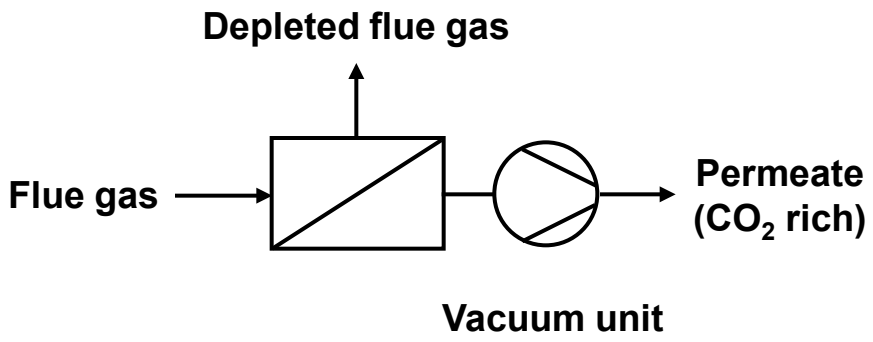


Driving force generation (I)

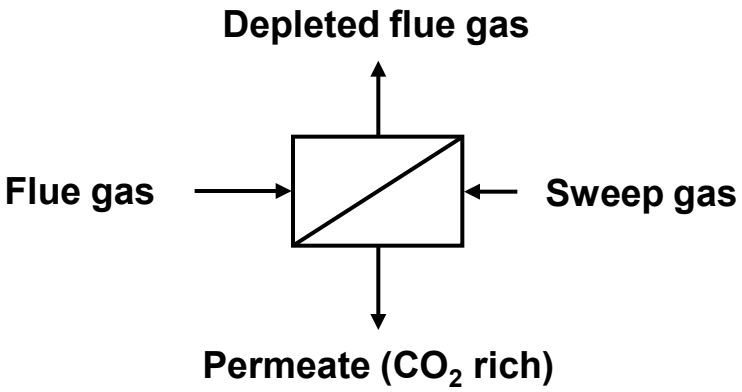
Feed compression



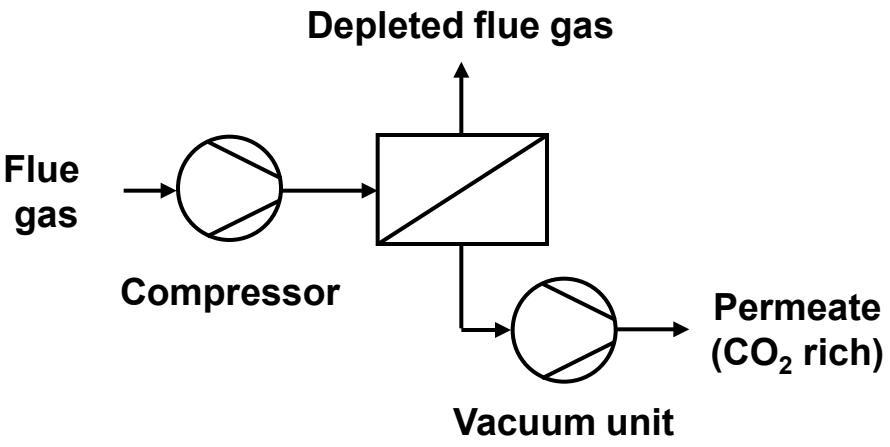
Low pressure at the permeate side



Sweeping at the permeate side



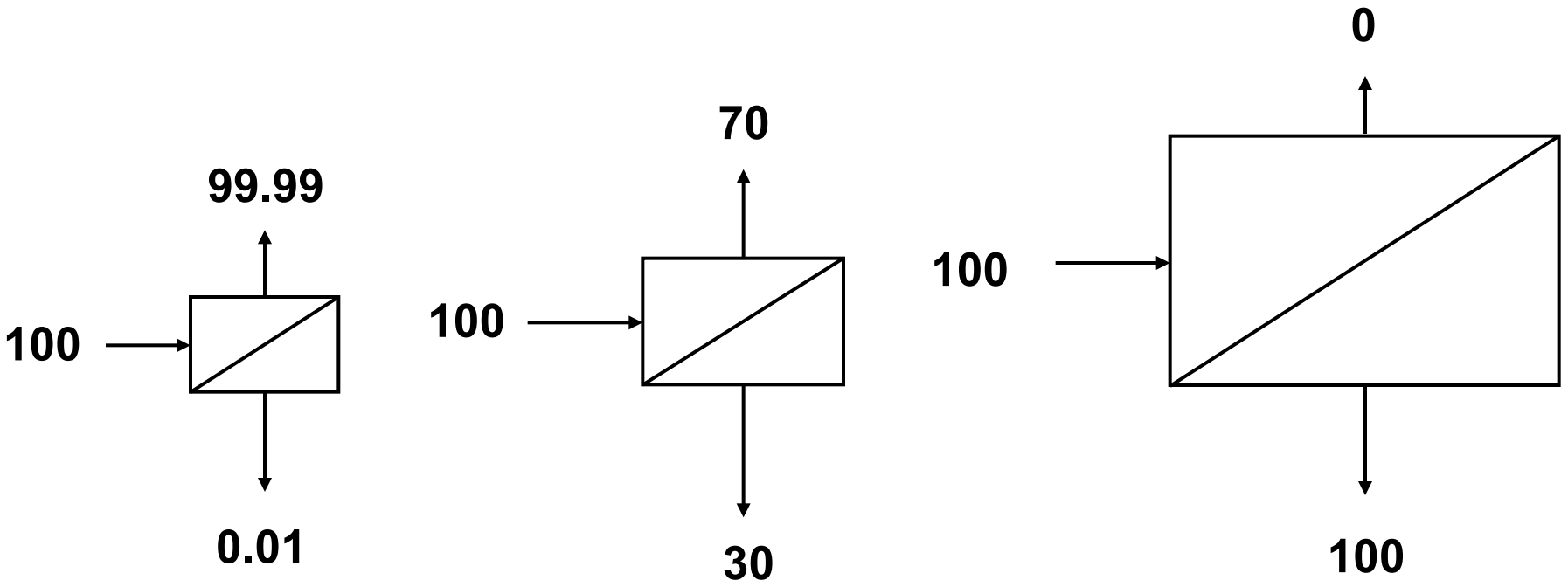
Feed compression and suction



Driving force generation (II)

- Feed compression
  - Area ↘ , energy ↗
  - No pressure limitation
- Suction
  - Area ↗ , energy ↘
  - Pressure limitation: ca. 200 mbar
- Sweeping
  - Only applicable in combination with suction
  - Process steam no adequate sweeping agent
- Feed compression + suction
  - Combines advantages of both technologies
  - Most likely concept for driving force generation

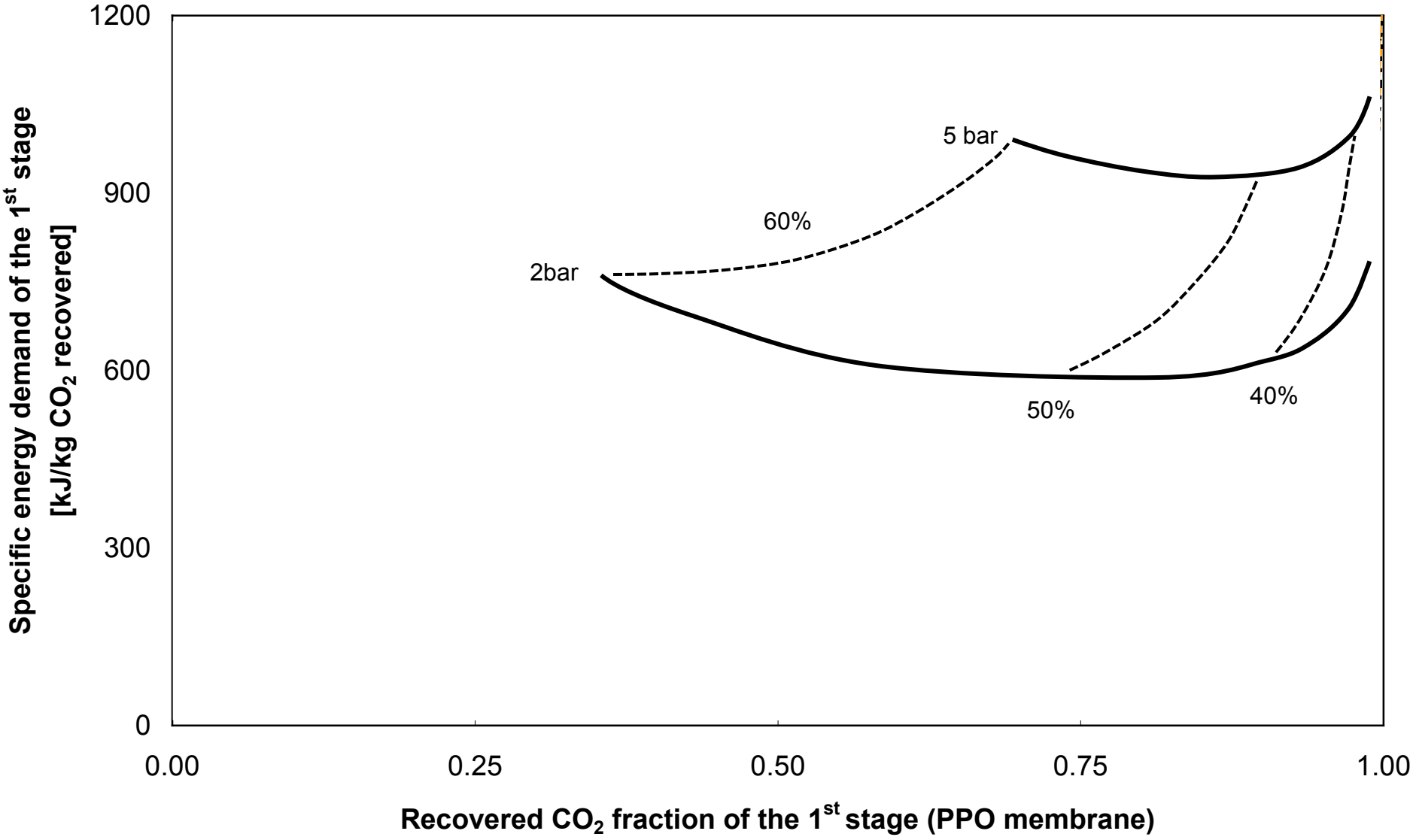
Membrane – A selective splitter



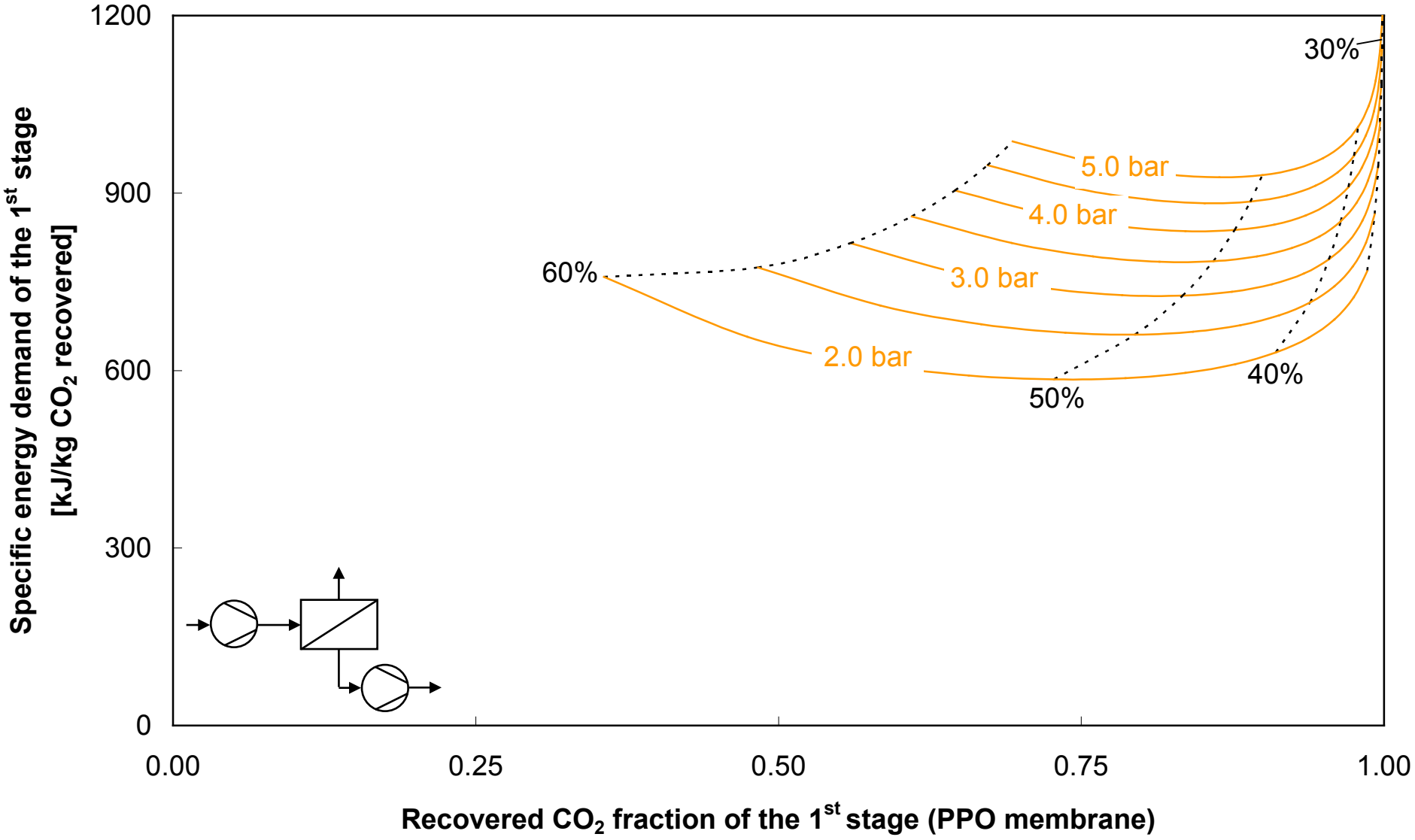
Ideal
Highest Enrichment

Nonsense
No Enrichment

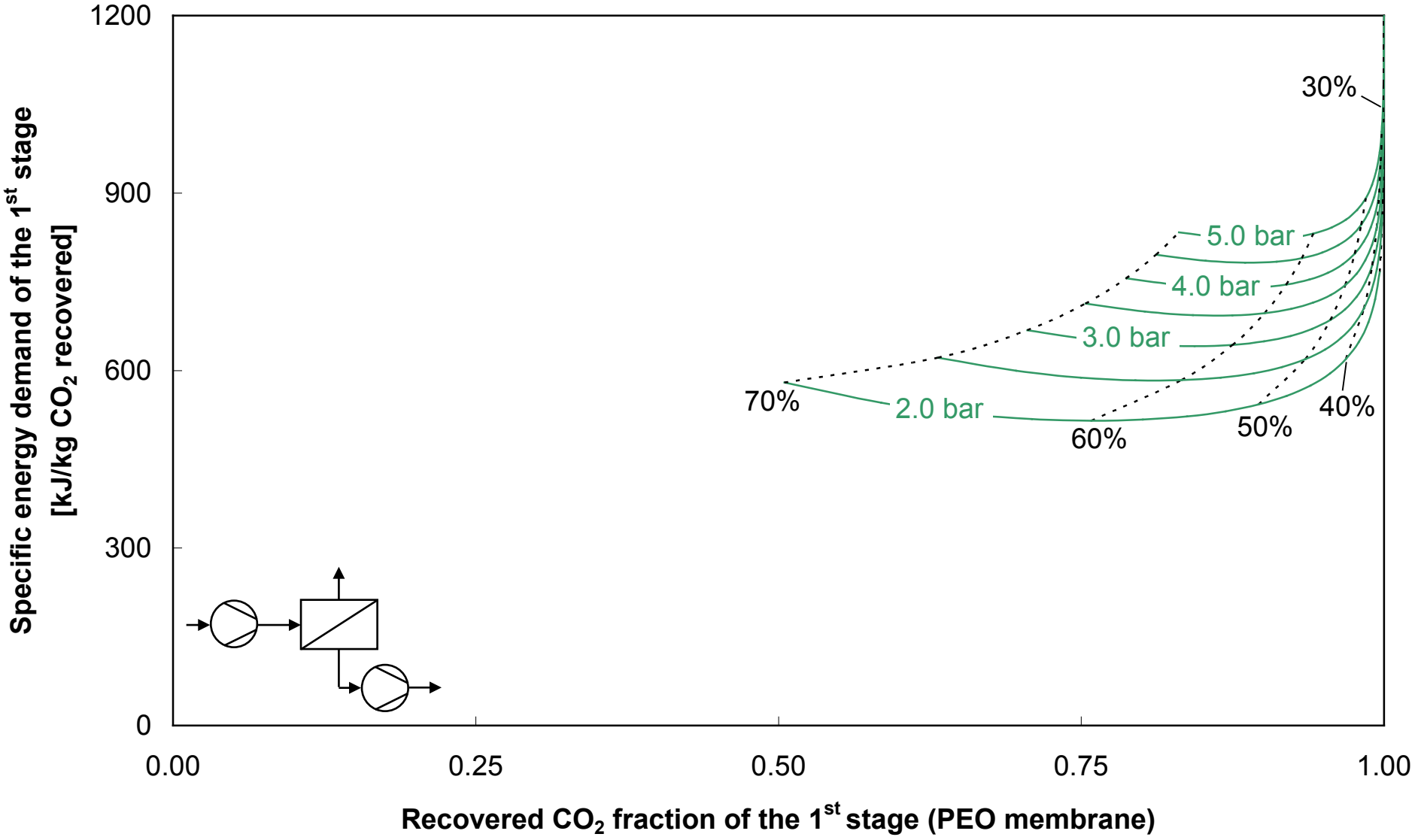
Single-stage membrane system (PPO membrane)



Single-stage membrane system (PPO membrane)



Single-stage membrane system (PEO membrane)



Summary single-stage membrane system

- Trade-offs
  - CO_2 enrichment – CO_2 recovery
  - Energy requirement – membrane area

- Single-stage processes only applicable for enrichment

  Further enrichment / purification by 2nd membrane stage

- O_2 and SO_2 enrich at the low pressure side

  Further treatment to achieve low O_2 and SO_2 content

Economic framework

- Reference power plant

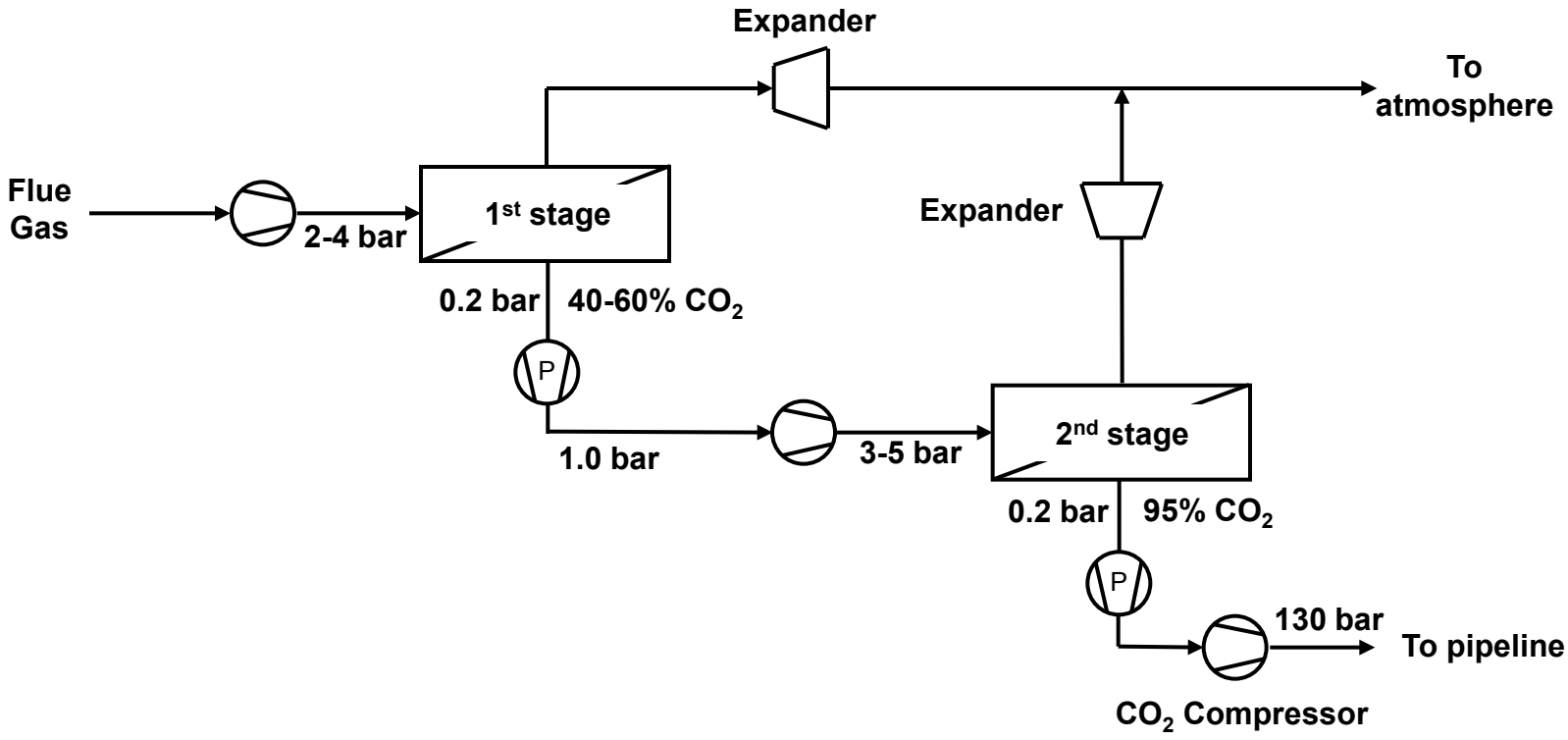
Capital cost	Euro/MWh_{el}	20.50
Fuel cost	Euro/MWh_{el}	15.20
O&M cost	Euro/MWh_{el}	4.60

- Membrane process

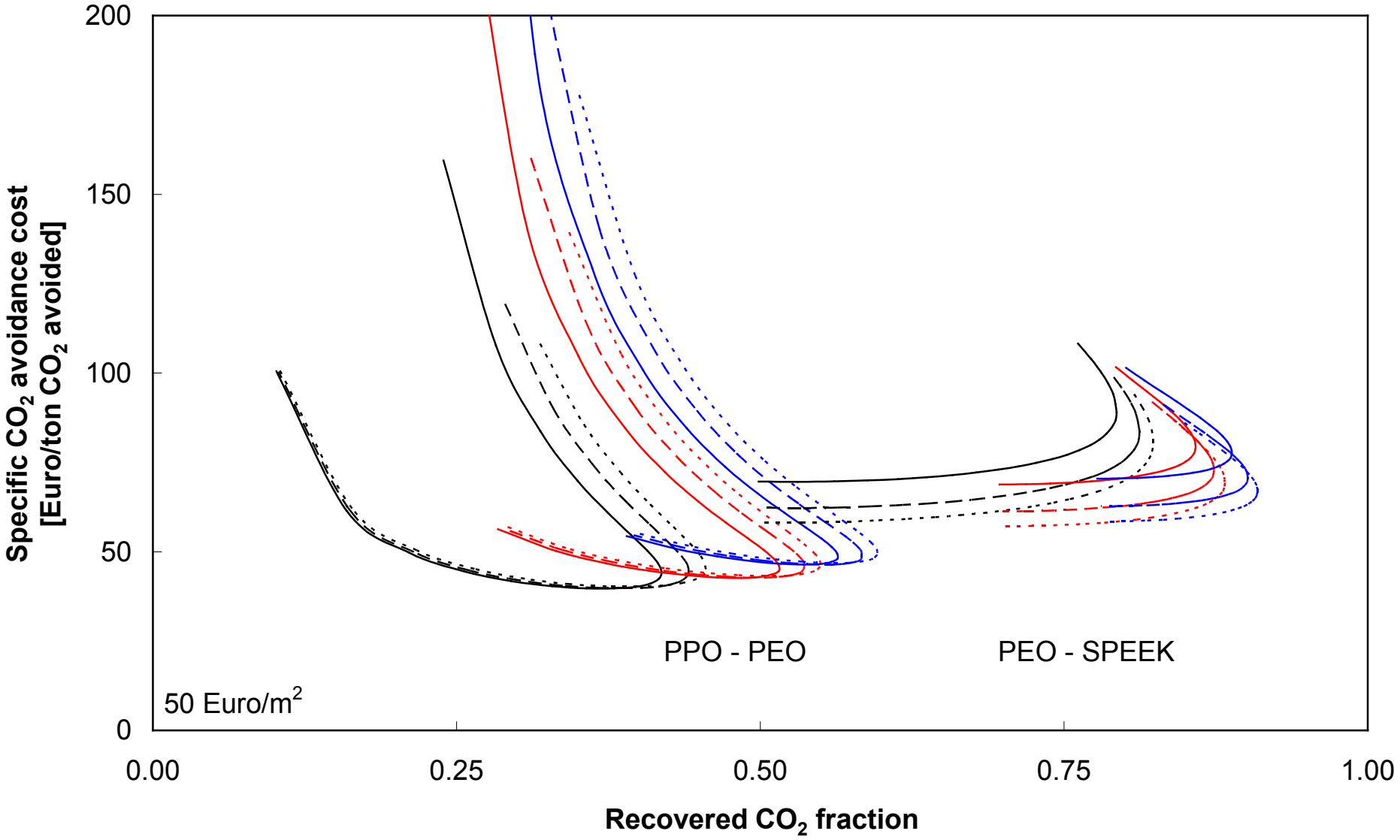
Compression	Euro/kW	500
Vacuum	Euro/kW	1000
Membrane	Euro/m^2	5 - 50

- Specific CO_2 avoidance cost = $$\frac{COE_{Cap} - COE_{Ref}}{CO_{2,Ref} - CO_{2,Cap}}$$

Two-stage membrane processes without recycling



Two-stage membrane processes without recycling



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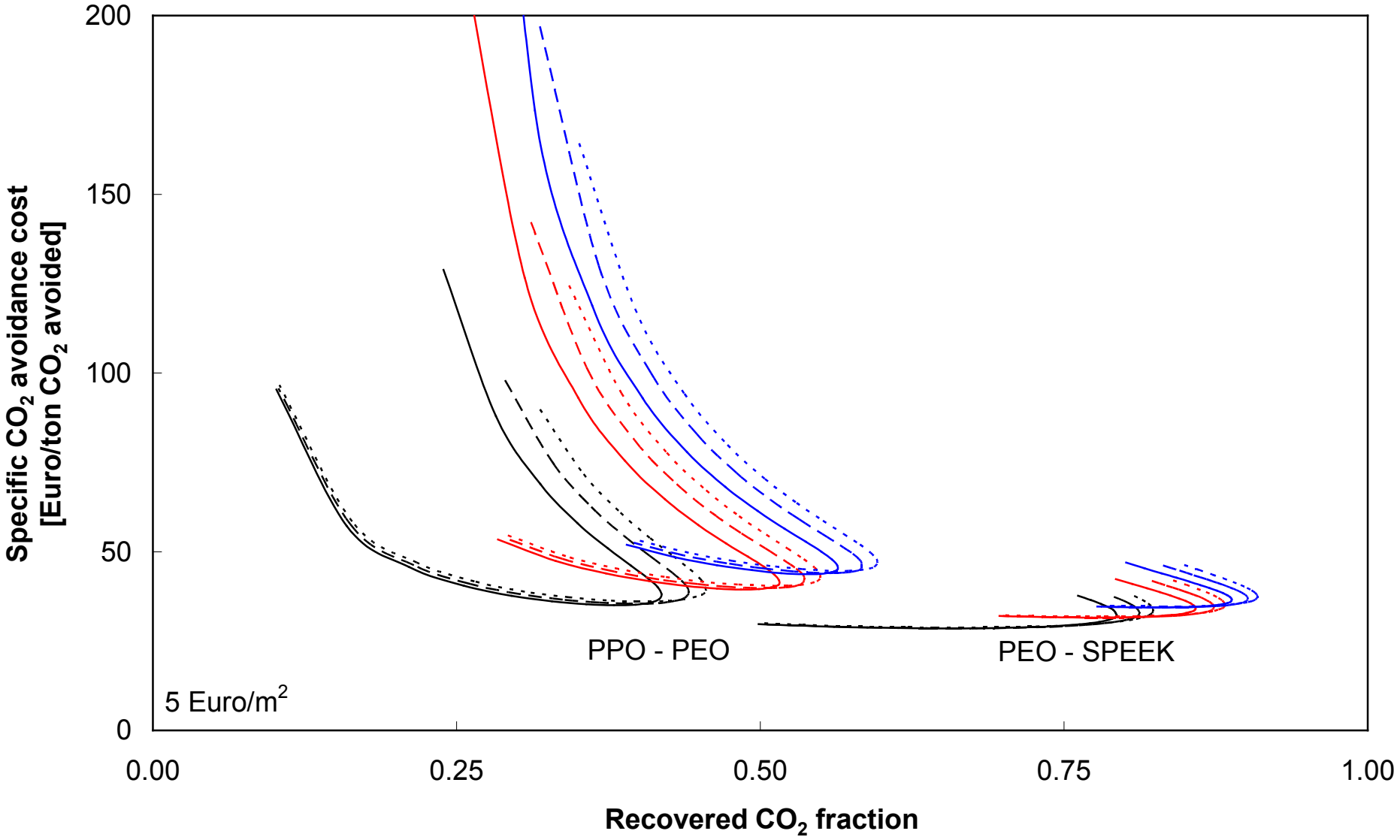
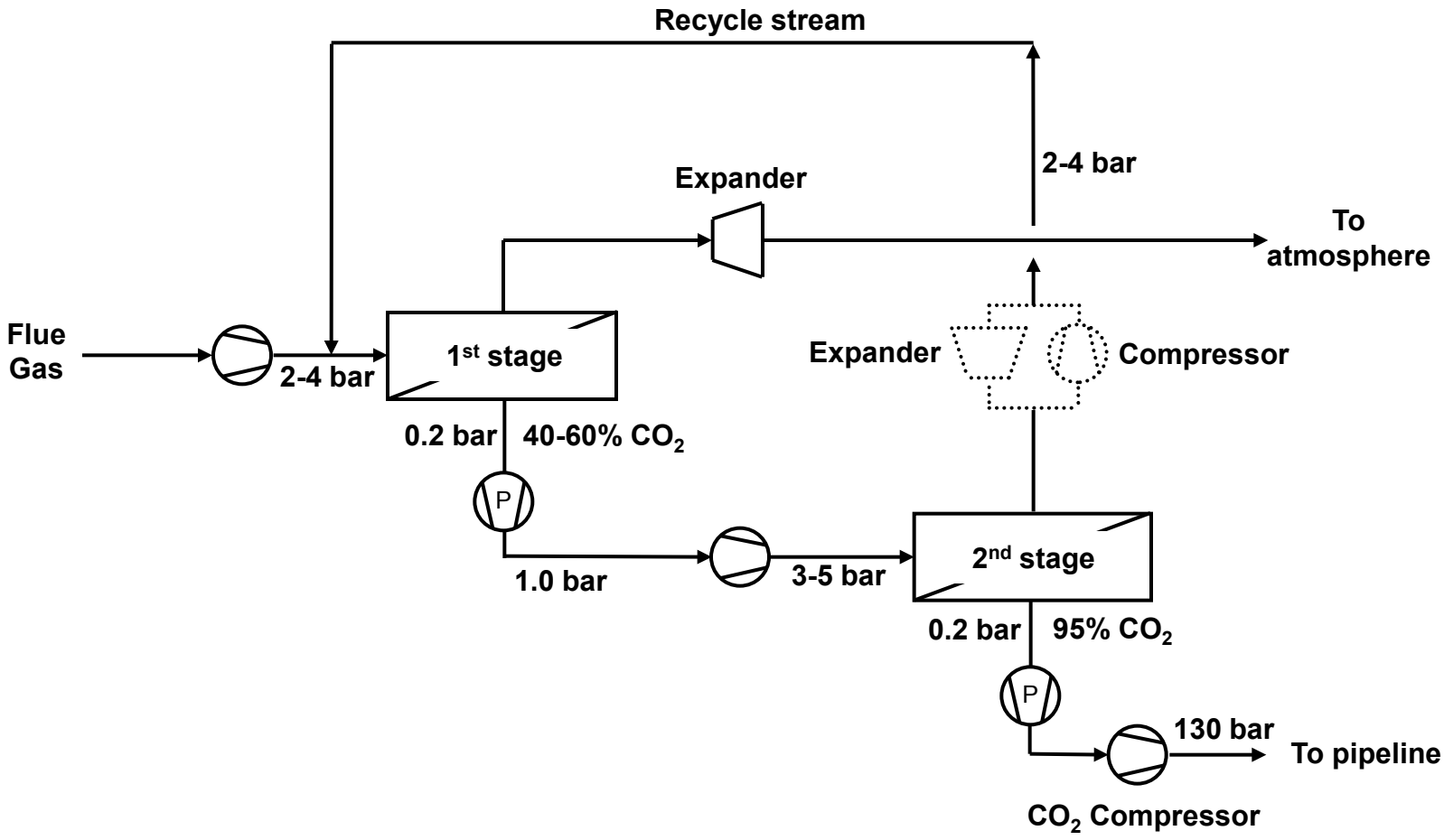


Two-stage membrane processes with recycling



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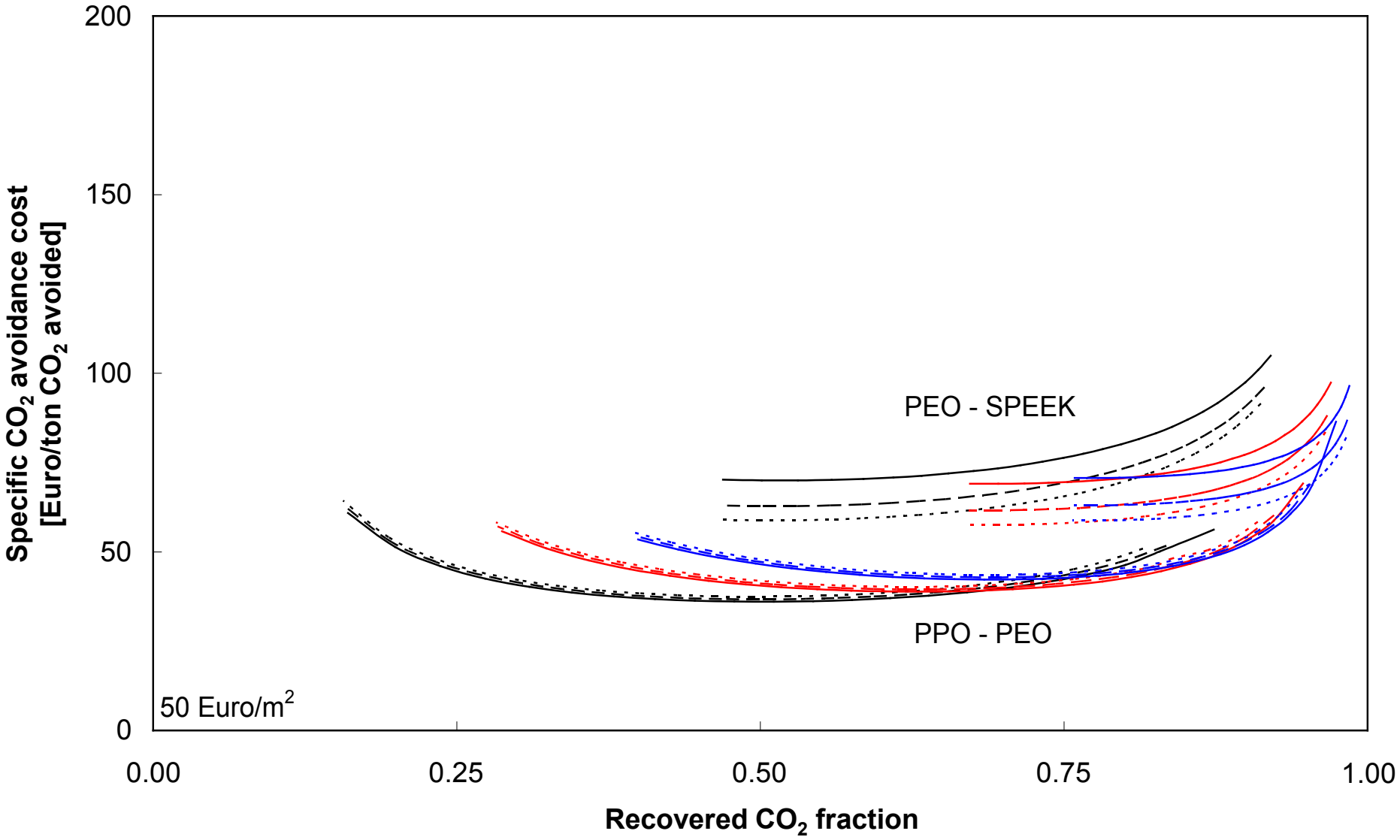

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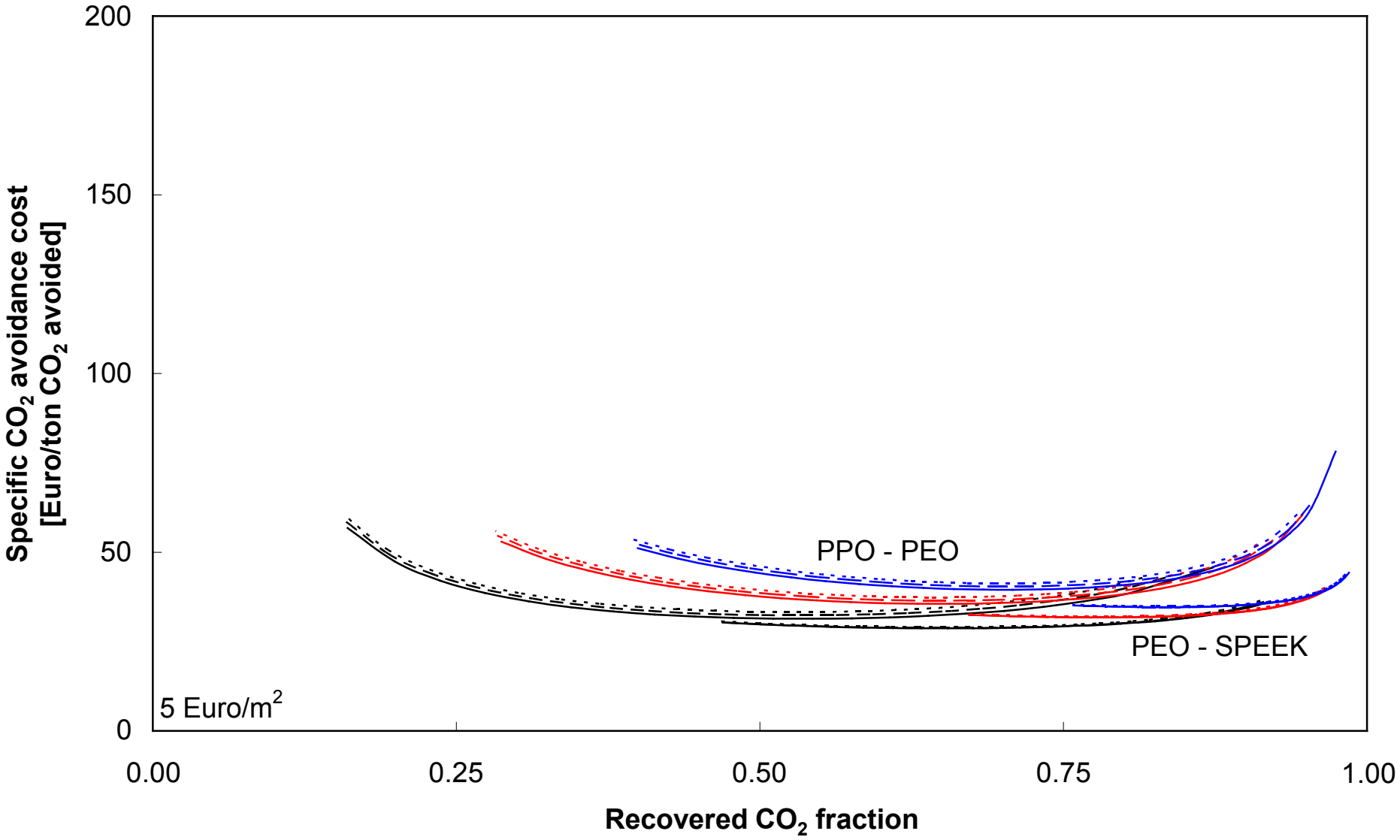


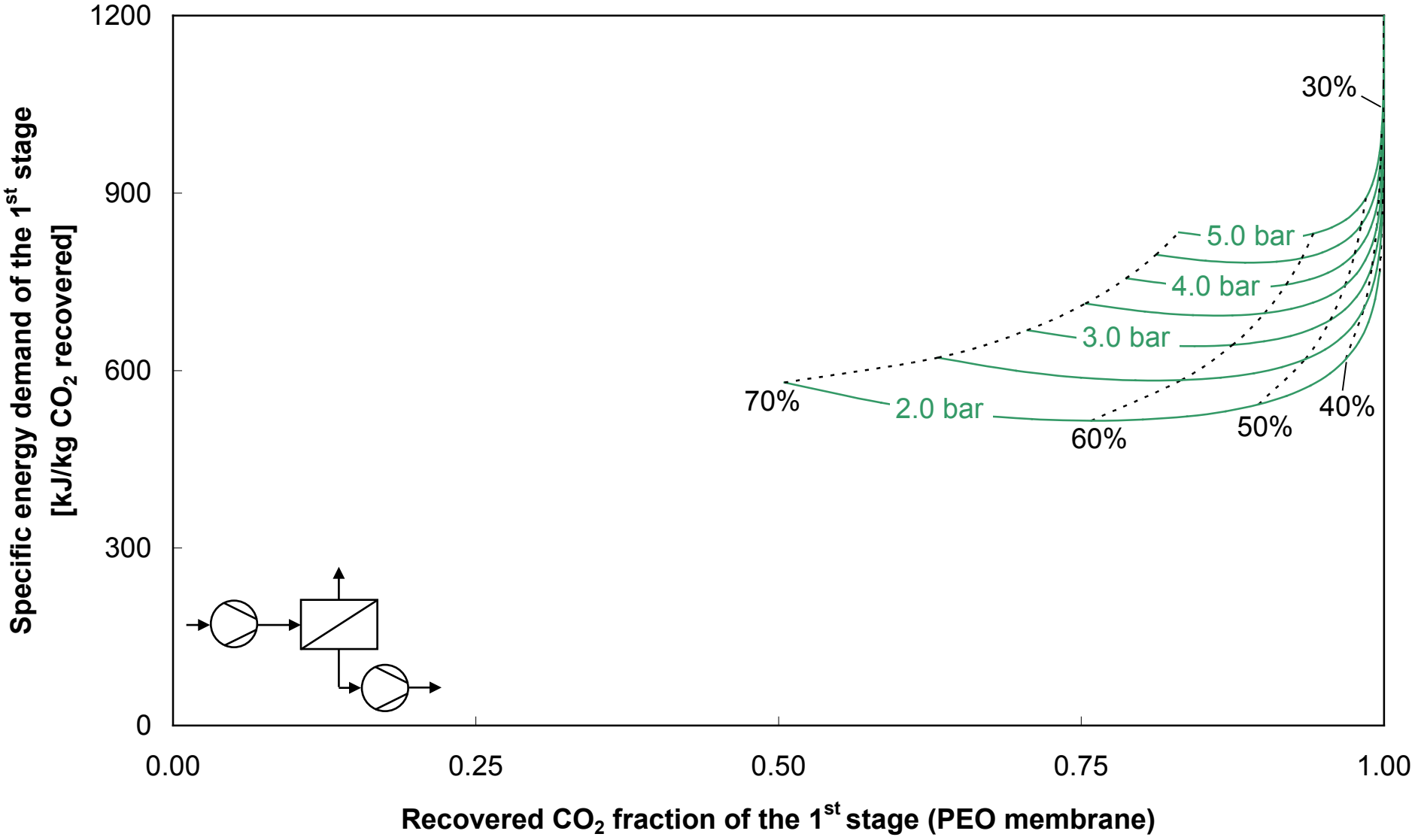
Summary and conclusions

- Chemical durability of polymeric materials proven during one year piloting

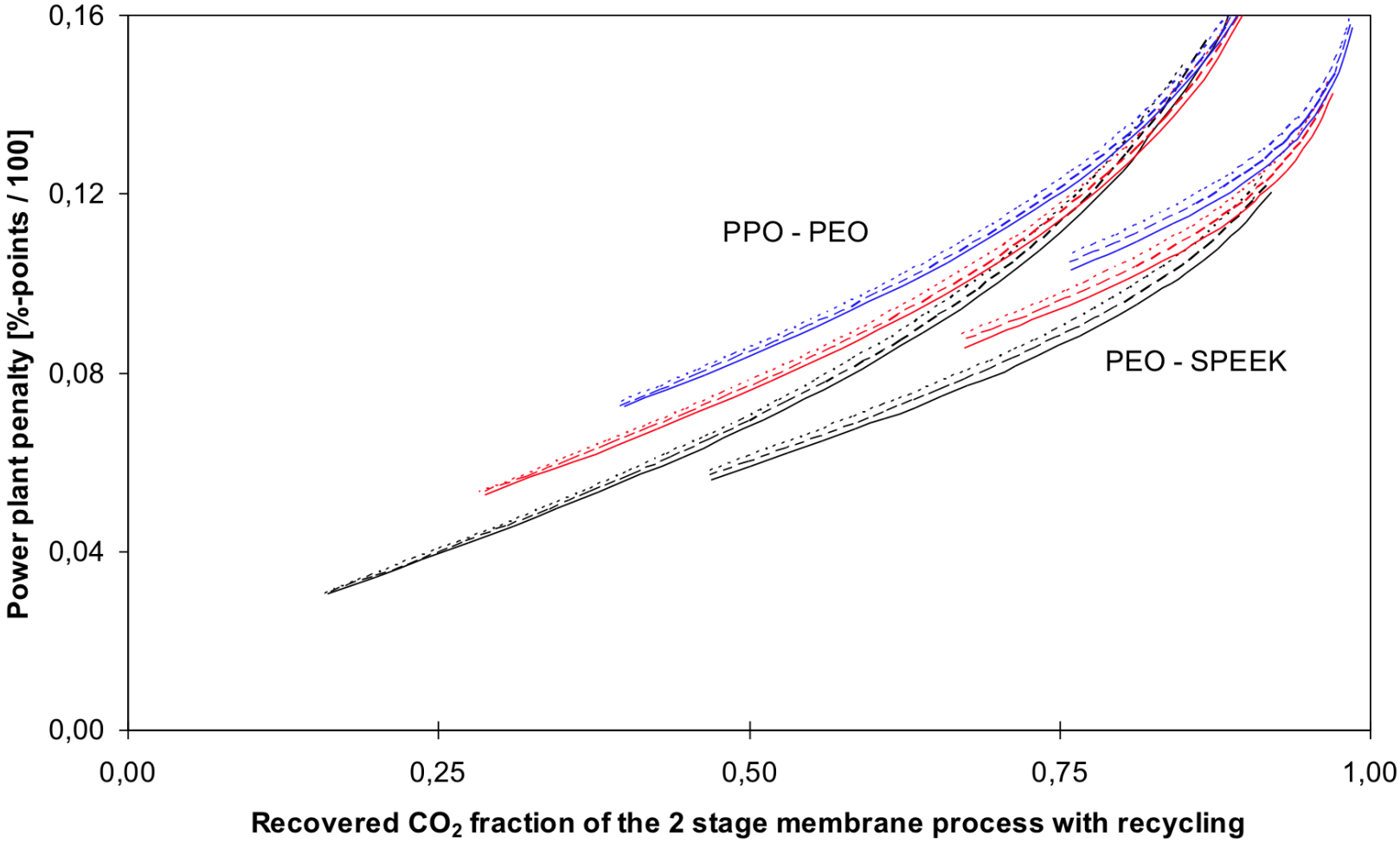
- Two stage membrane processes required
  - \+ 90% CO_2 recovery in conjunction with 95% purity
  - \+ Simple integration in power plant process
  - \+ Competitive economics compared to absorption process
  - \+ Scalable modular membrane area
  - \- CO_2 product does not comply with strict purity requirements
  - \- Specific energy requirement higher than chemical absorption
  - \- Membrane cost have significant impact on process economics

This study is part of the NanoGLOWA project (NMP3-CT-2007-026735), which has been financially supported by the EU Commission within the thematic priority NMP of the Sixth Framework Program.

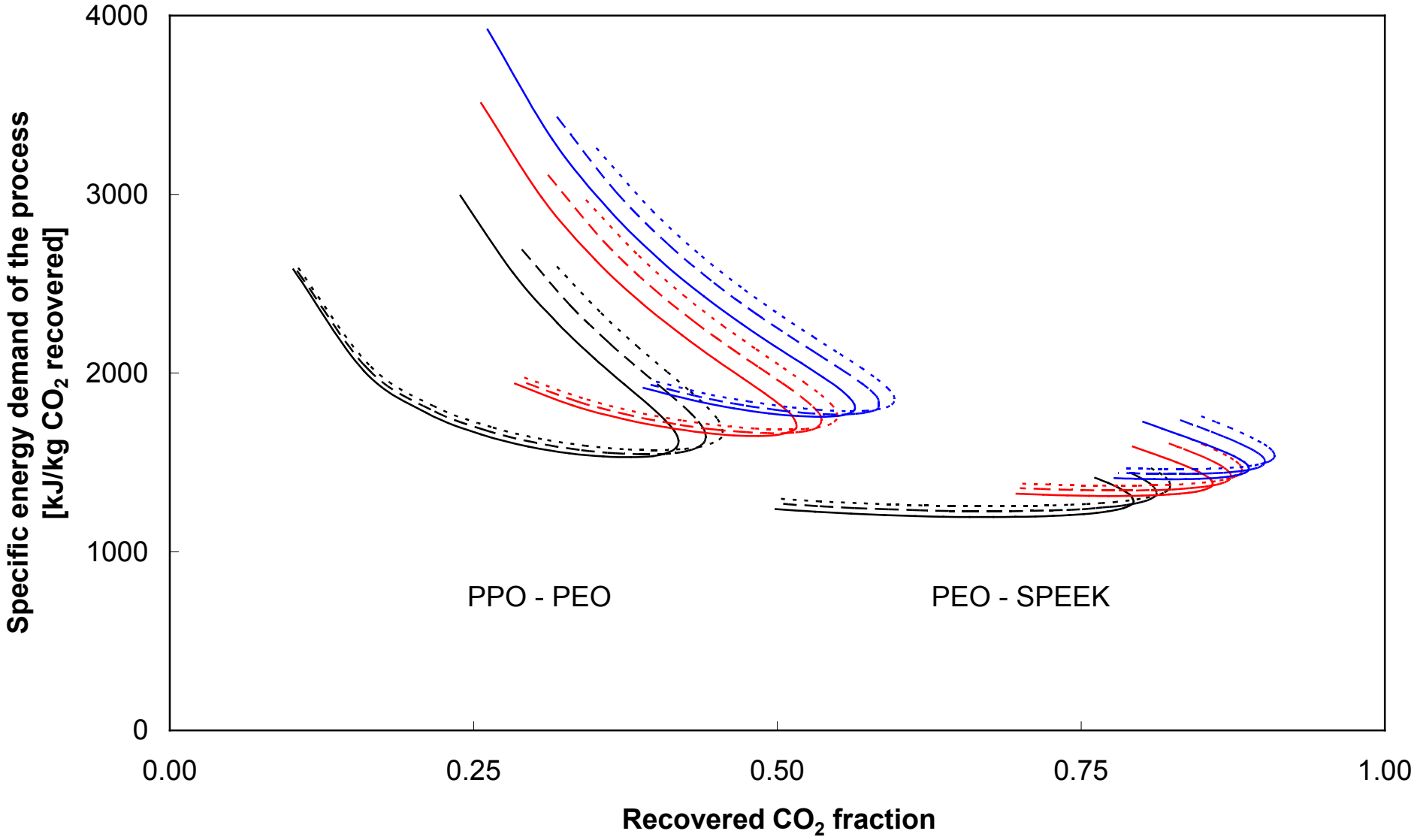
Single-stage membrane system (PEO membrane)



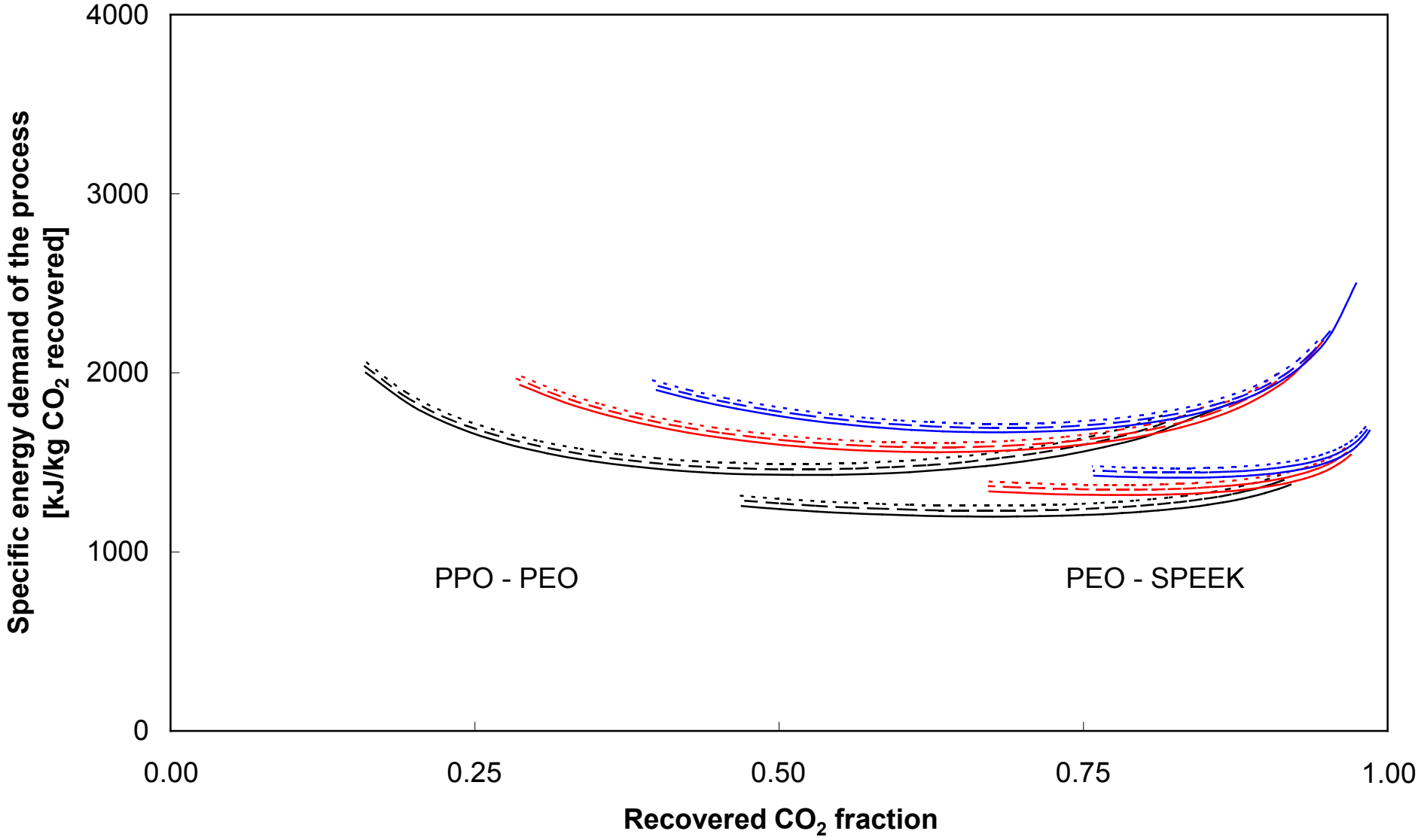
Two-stage membrane processes with recycling



Two-stage membrane processes without recycling



Two-stage membrane processes with recycling



Two-stage membrane processes with recycle

- 90% CO_2 recovery: PPO / PEO system

Feed pres. 1st/2nd stage	Energy [kJ/kg]	Area [10^5 m^2]	O_2 [%]	SO_2 [ppm]
3 bar / 4 bar	1910	7	1.8	510
4 bar / 4bar	1940	5	1.8	510

- 90% CO_2 recovery: PEO / SPEEK system

Feed pres. 1st/2nd stage	Energy [kJ/kg]	Area [10^6 m^2]	O_2 [%]	SO_2 [ppm]
2 bar / 4 bar	1350	8	1.2	520
3 bar / 4bar	1400	5.1	1.2	520