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TECHNOLOGY & RESEARCH

CO₂ Capture from Power Plant Flue Gas with the MTR PolarCap™ Process: Update on Field Demonstration Tests

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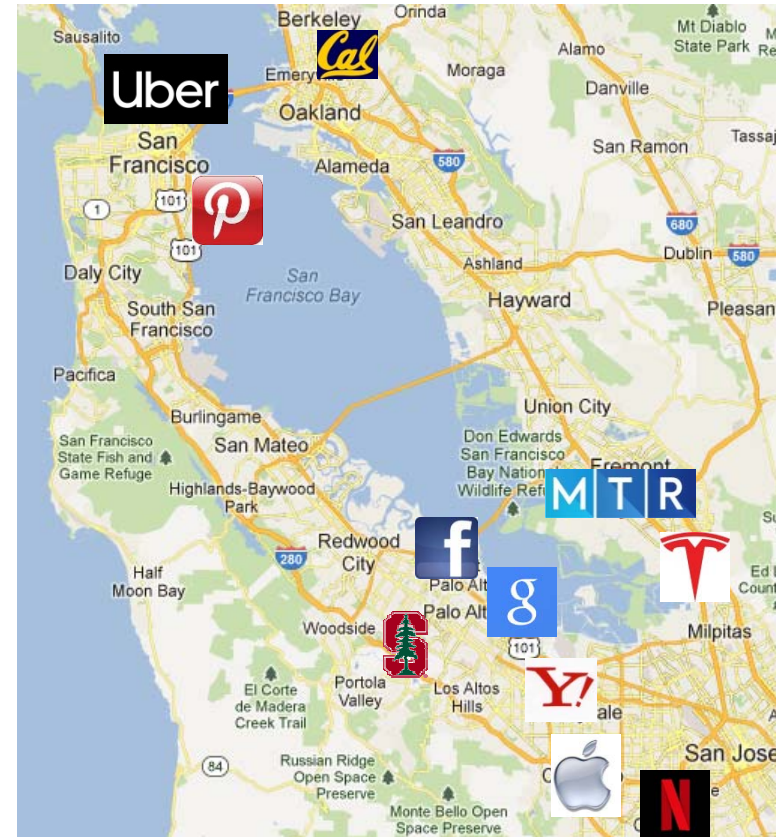
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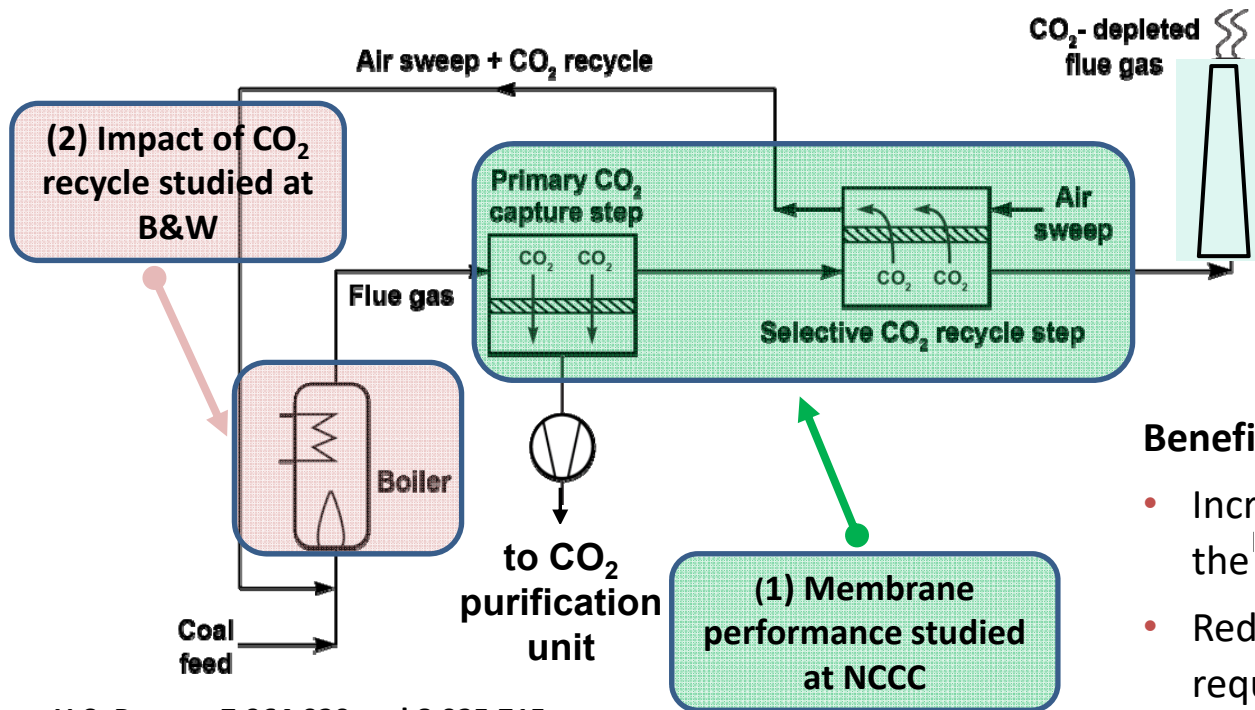
MTR Introduction



- Privately-held company based in Newark, CA
- Started in 1982 funded by U.S. SBIR grants
- Commercial products in petrochemical, natural gas and refinery industries
- Provides complete turn-key solutions with over 300 membrane systems installed worldwide
- 15 person R&D group with expertise in membrane materials/formation and process design



Background: MTR CO₂ Capture Process

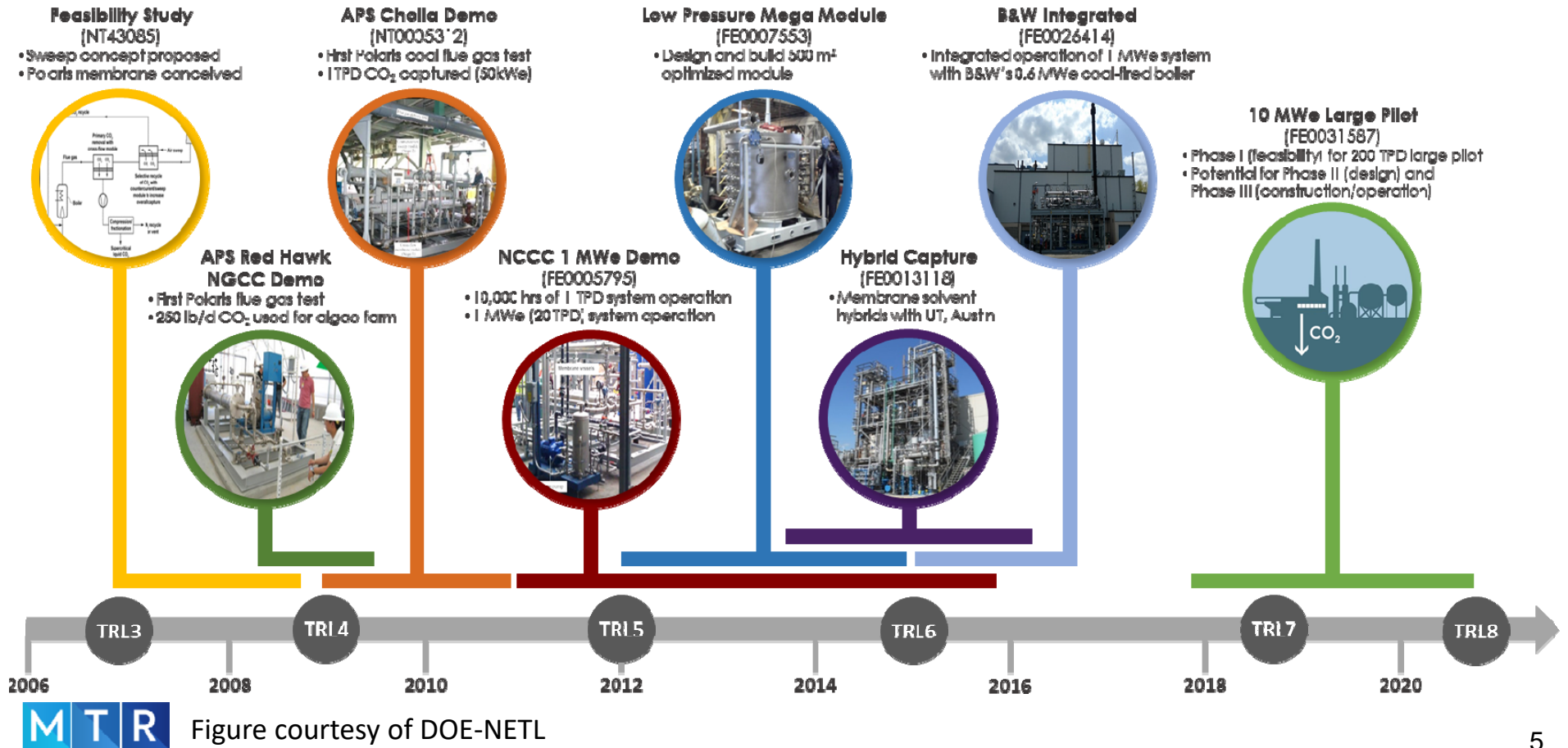


U.S. Patents 7,964,020 and 8,025,715

Benefits of selective recycle:

- Increases CO₂ concentration going to the capture step, and
- Reduces the fractional CO₂ removal required by the capture step

MTR CO₂ Capture Development Timeline

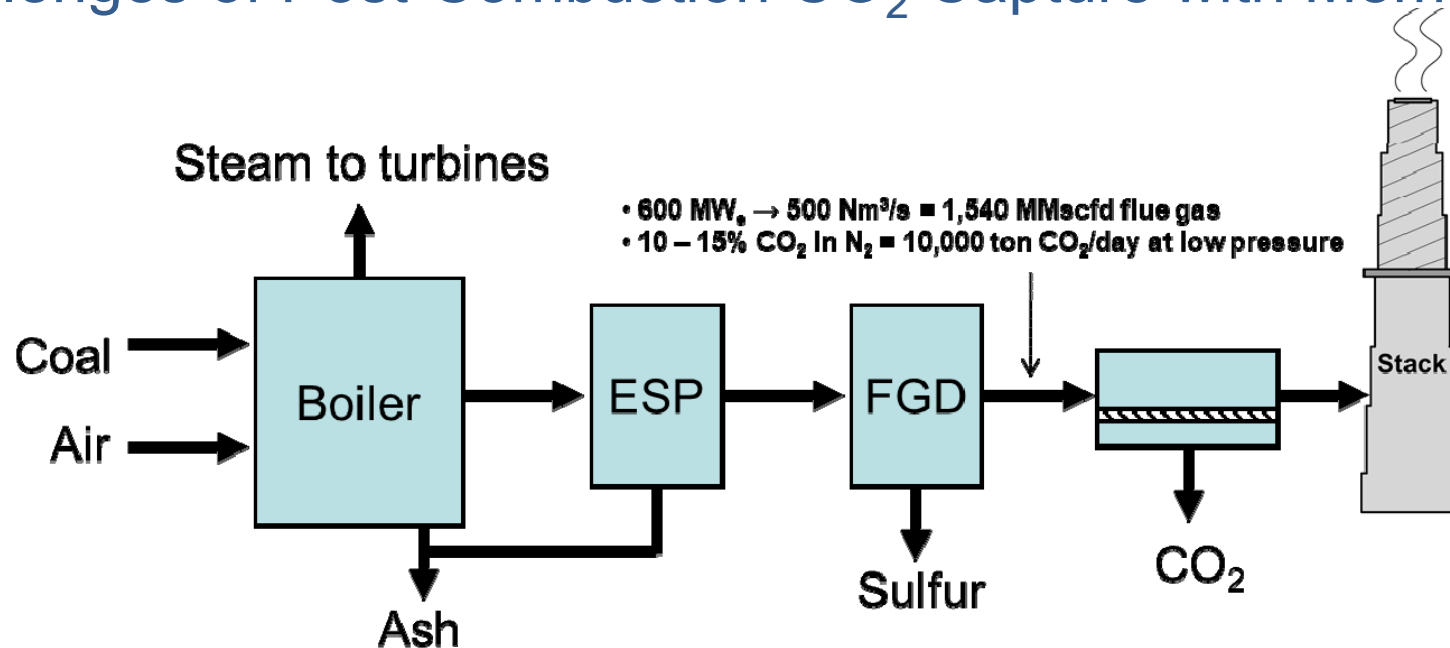


– CO₂ Capture with Membranes has Advantages –

- Simple, passive operation with no hazardous chemical handling, emissions, or disposal issues
- Very compact compared to alternatives
- Water use lower than other technologies
- No steam use → no modifications to existing boiler/turbines
- Near instantaneous response; high turndown possible
- Very efficient at partial capture (40-60%)

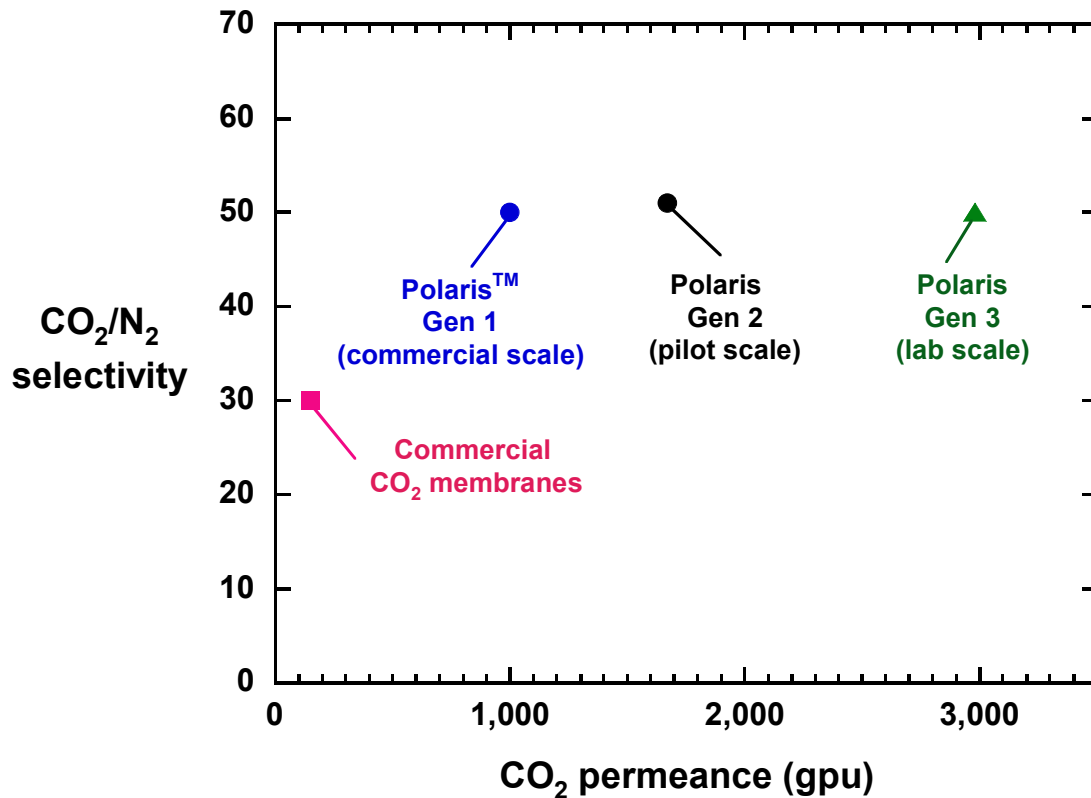


- Challenges of Post-Combustion CO₂ Capture with Membranes -



- Very low partial pressure driving force favors high permeance membranes
- Pressure drops must be minimized to reduce energy losses
- Field tests needed to assess the impact of impurities (ash, SO₂, NO_x) on membranes and membrane-module lifetime

Polaris™ Membrane: State of the Art for CO₂ Capture



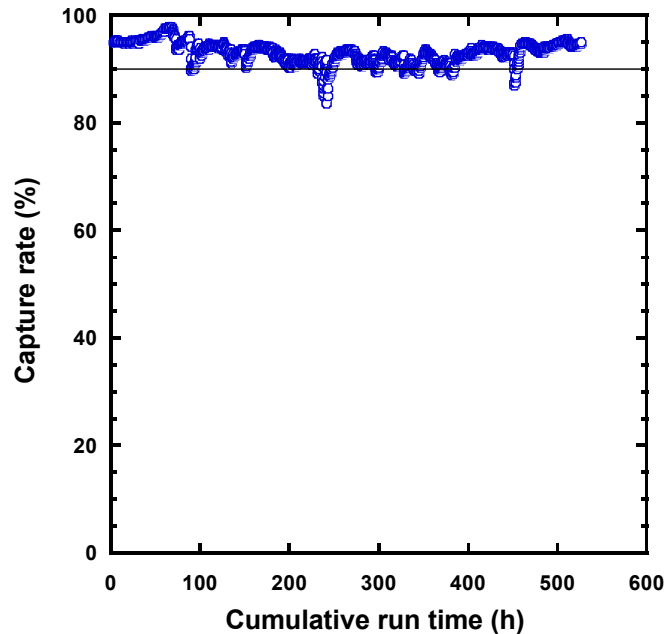
- Polaris Gen 1 has been evaluated in extensive testing at NCCC (>11,000 hours)
- Polaris Gen 2 was bench-scale tested at NCCC and will be used in the TCM field test
- Today, Polaris Gen 1 is used commercially in the natural gas industry for shale gas treatment
- Lab-scale research membranes show potential for future optimization



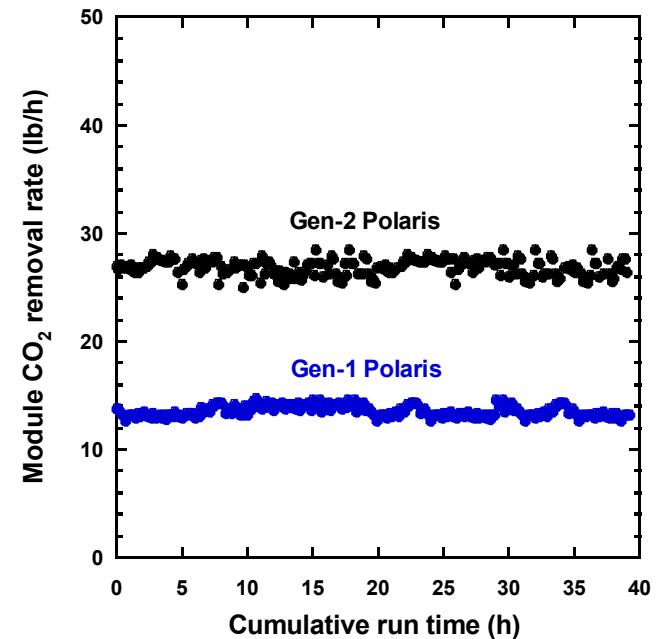
1 gpu = 10⁻⁶ cm³(STP)/(cm² s cmHg) = 3.35 x 10⁻¹⁰ mol/(m² s Pa)

0.05 MW_e (1 TPD) Testing at NCCC

Capture Rate vs. Time



New Membrane Validation



- Field laboratory that allowed lifetime evaluation (>11,000 hours cumulative), and validation testing of new membranes and modules

- System was in operation from Spring 2012 through Summer 2015



1 MW_e (20 TPD) System at NCCC



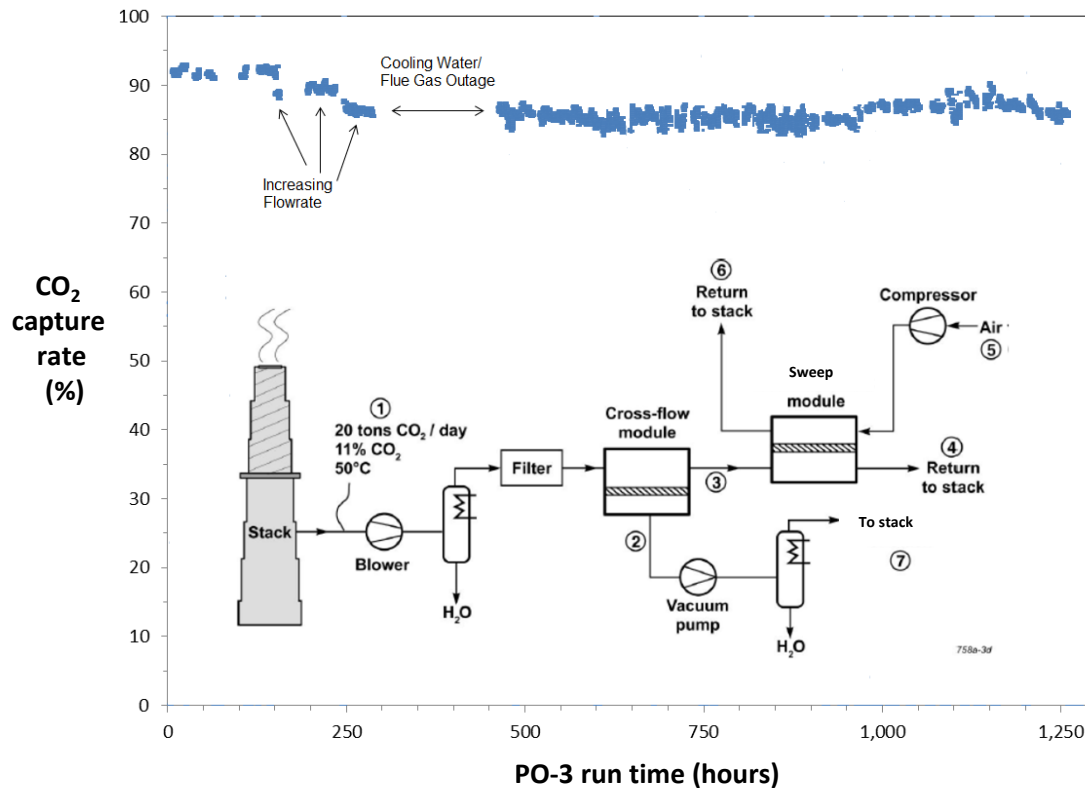
- MTR small pilot system completed successful 6 months of operation at NCCC

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- Testing included evaluation of new low pressure drop modules



— 1 MW_e System Shows Stable Performance —



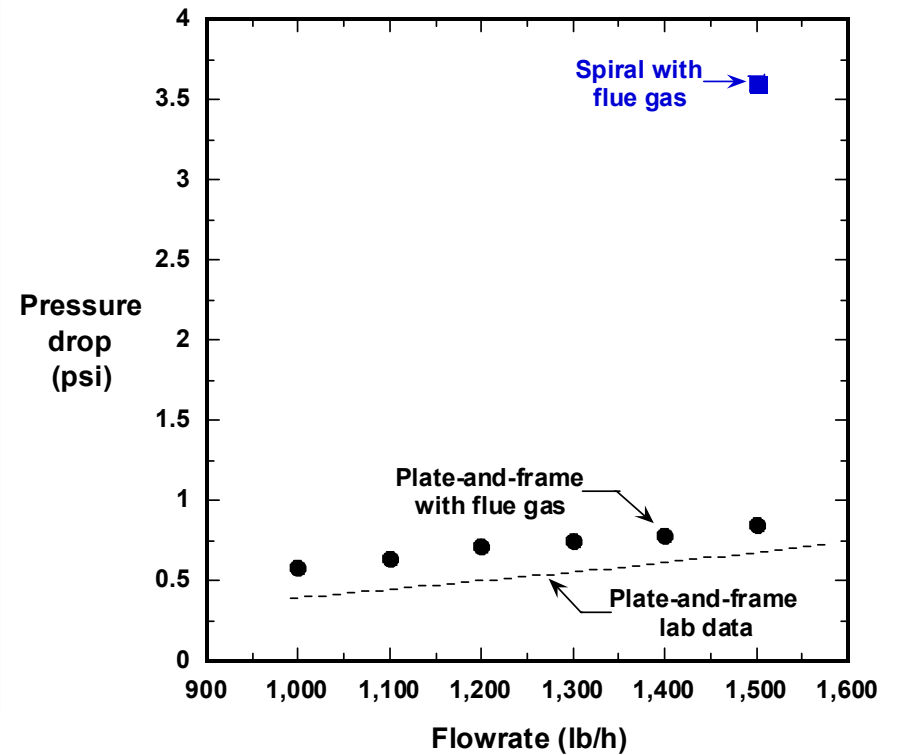
- System operated in slipstream mode (no recycle to boiler) with varying ambient conditions (sub-freezing in January to >95°F in June)
- Stable performance, reaching up to 90% capture
- System goes from cold start to steady state in ~15 minutes
- Small pilot system also tested in integrated boiler-membrane field test at B&W site; currently being renovated for hybrid membrane/sorbent operation at TCM site in Norway

— New Module Design Offers Lower Pressure Drop —

Module Size



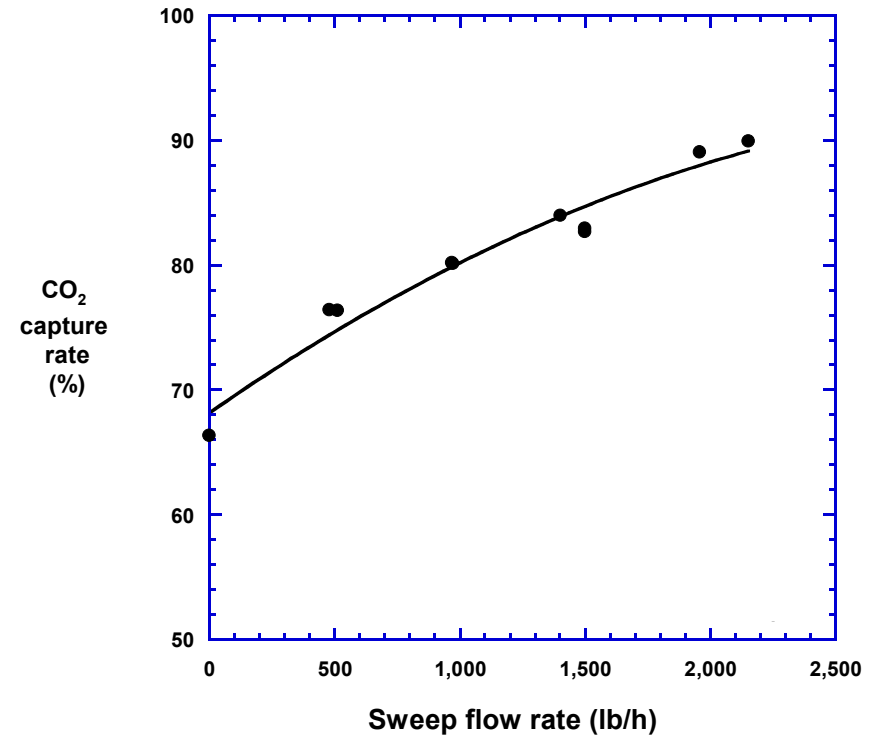
Module Pressure-Drop



- Reduced pressure-drop with new module saves $\sim 10 \text{ MW}_e$ of blower energy at full-scale
- New module performance validated at both NCCC and B&W field tests

— B&W Test Evaluated Impact of Sweep Recycle —

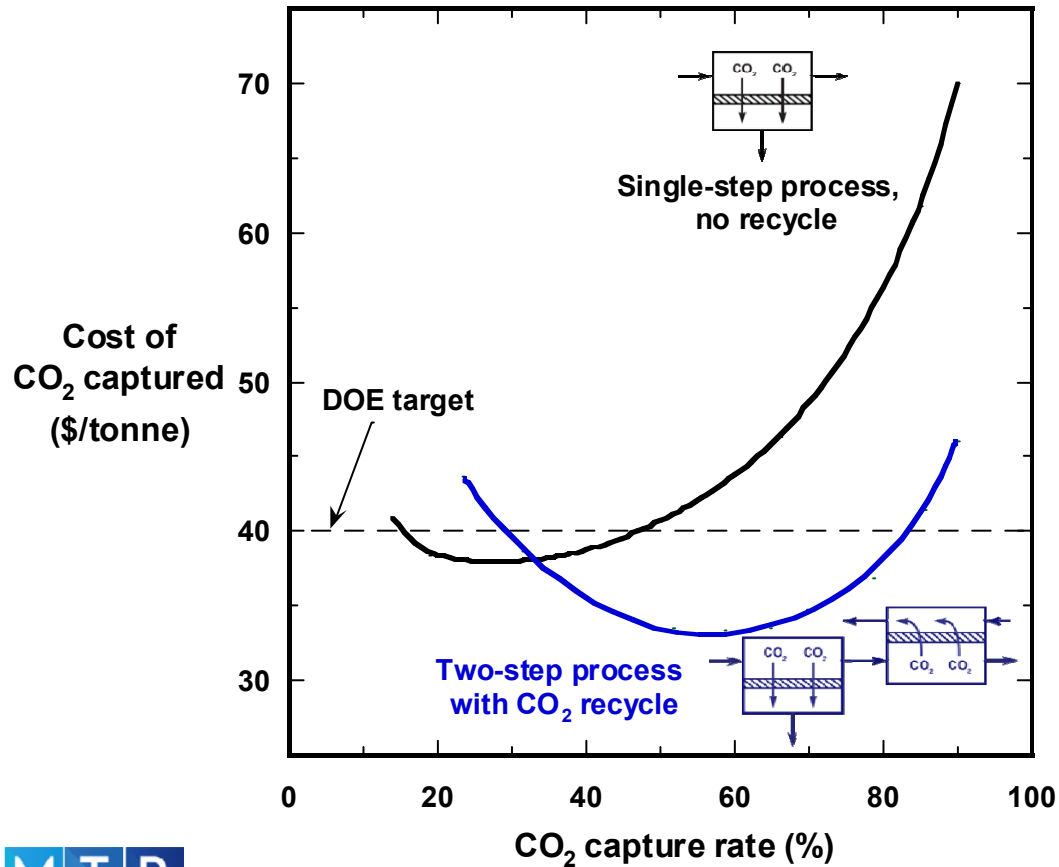
MTR 20 TPD system (foreground) installed at
B&W's coal boiler facility (background)



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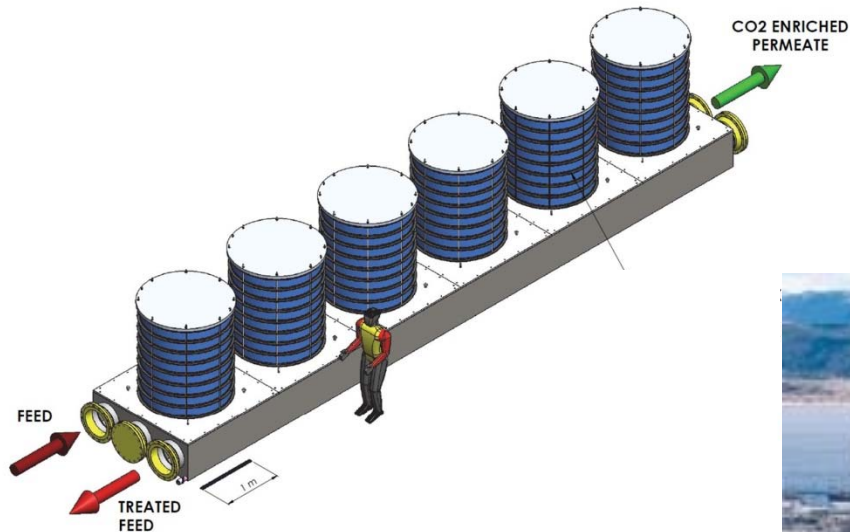
- By changing the amount of air used as sweep, capture rate was varied

Membranes are Particularly Effective at Partial Capture



- Membranes show a minimum in capture cost. There is a sweet spot for the technology between 40 – 70% capture
- To reduce coal plant emissions to that of natural gas (~50% capture), a simple system without recycle may be preferable
- Cost difference shows the benefit of CO₂ recycle, particularly at high capture rates (~\$25/tonne at 90% capture)

— Current MTR/DOE CO₂ Project – TCM Field Test —



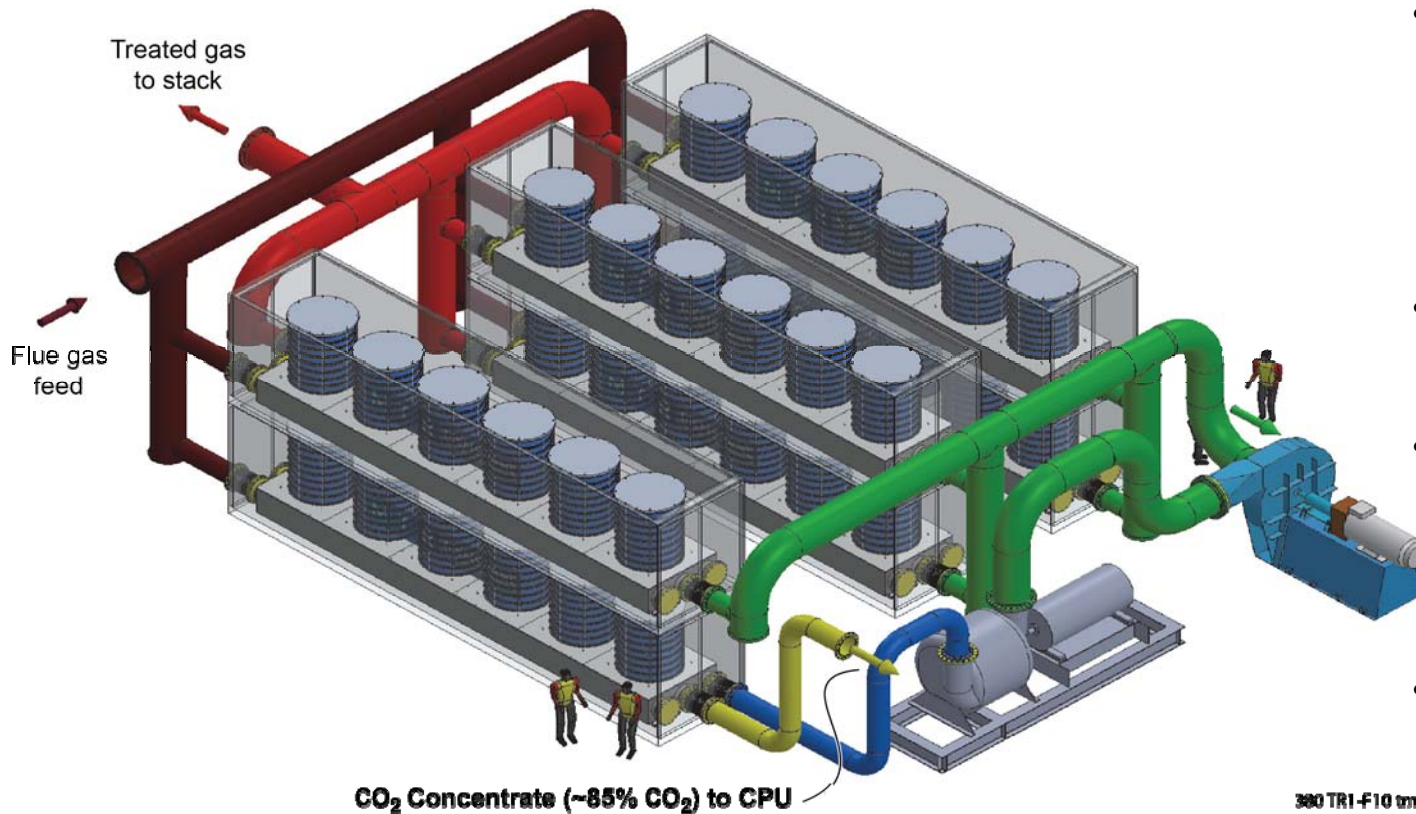
**New MTR Skid Design with
Gen 2 Polaris Membrane
in Low-Cost Modules and
Container to be Evaluated**



**Technology Centre Mongstad in Norway
to host 6 Month Field Test in 2020**

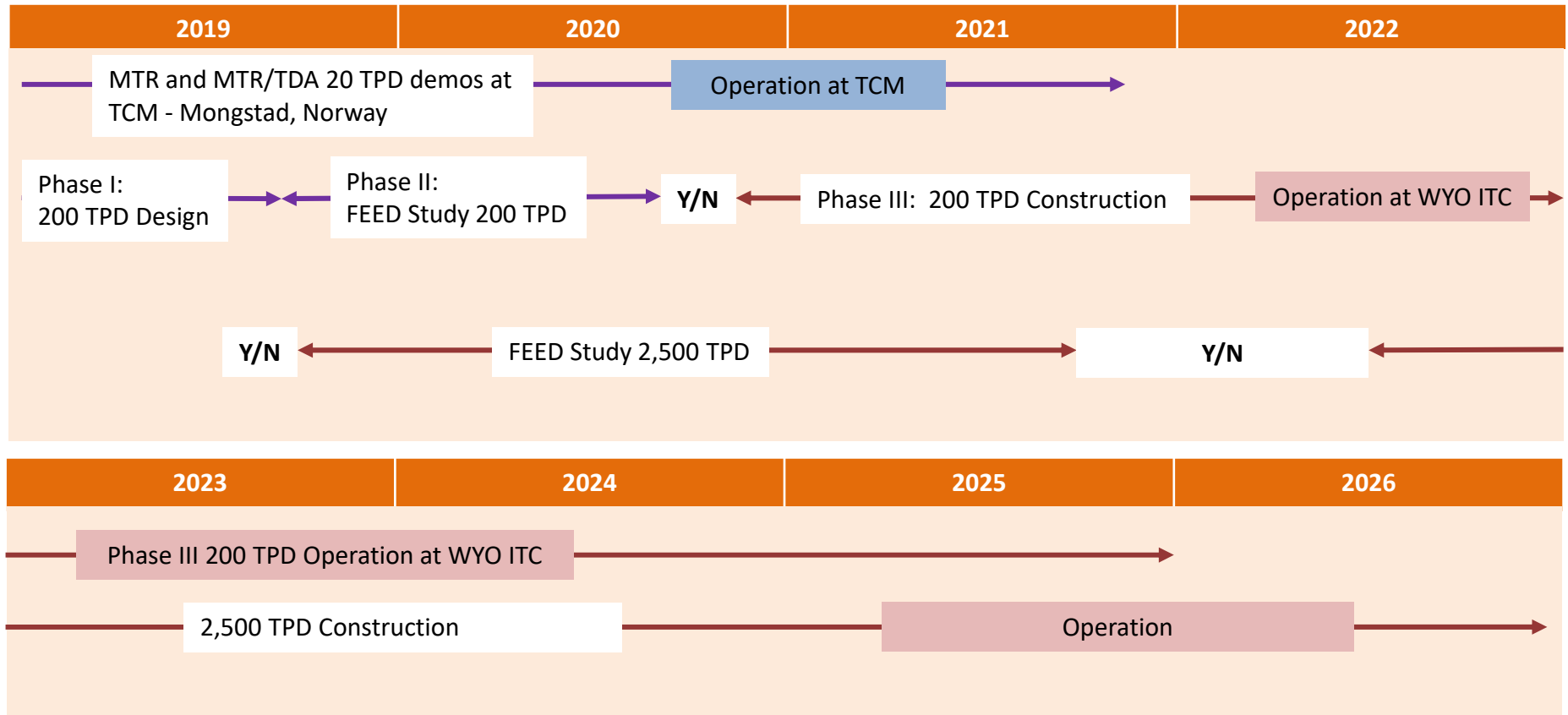


— Currently Designing a 200 TPD Large Pilot —



- Proposed system would capture 200 TPD CO₂ from a coal-fired power plant at the Wyoming ITC
- High purity (>99%) CO₂ produced for EOR
- Phase II recently awarded; FEED and permitting activities underway
- Planned installation 2021-22 (Phase III)

MTR CO₂ Capture Demo Time Line



Summary

- CO₂ capture membrane performance continues to improve and has been validated on a 0.05 MW_e slipstream system with over 11,000 hours of runtime at NCCC
- A 1 MW_e small pilot unit was used in successful slipstream testing at NCCC and integrated membrane-boiler operation at B&W
- Prototype low pressure drop sweep modules were validated at both NCCC and B&W field tests
- Membranes are effective at partial CO₂ capture; high capture rates are possible and competitive with novel process design
- Current projects include 20 TPD field tests at TCM in Norway and design of a 200 TPD system at the WYO ITC

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