Membrane-Based CO_2 Capture with Selective Exhaust Gas Recycle

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Outline

- Background on MTR CO_2 capture development
- Selective exhaust gas recycle for natural gas CO_2 capture
  - All membrane capture approach
  - Hybrid approach

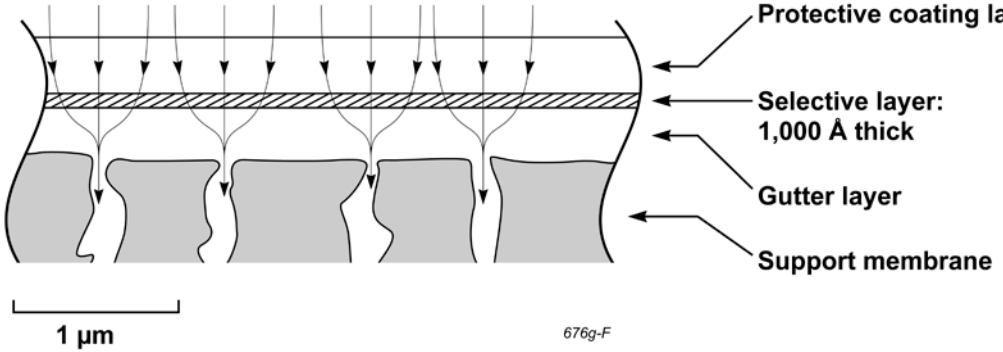
MTR Introduction

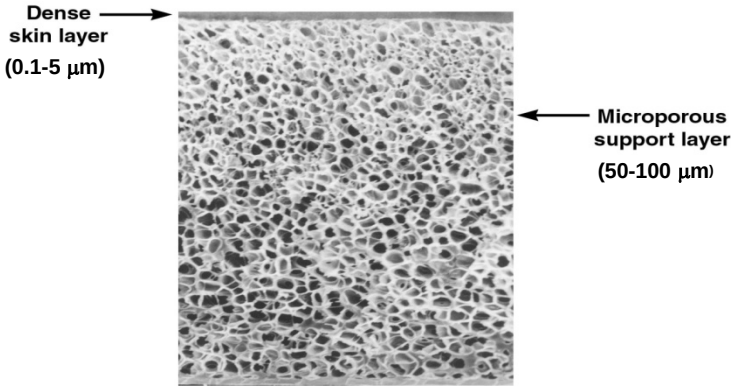
- Privately-held, 100 employees mostly located in Newark, California
- Started in 1982 funded by US SBIR grants
- Focused on commercializing membrane gas separation technology
- Commercial products in petrochemical, natural gas and refinery industries
- Provides complete turn-key solutions with about 200 membrane systems installed worldwide
- 90% of revenue from commercial sales
- 20 person R&D group has worked with DOE on CO_2 capture membranes for the past 7 years

Customers: BP, Chevron, Dominion Exploration, Ercros, ExxonMobil, Formosa Plastics, Innovene, Sabic, Sasol, Sinopec, Solvay, Statoil and others.

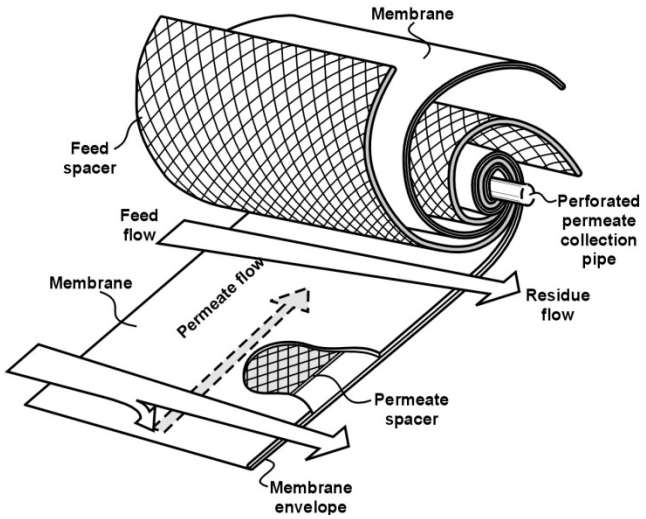
Background: Membrane Technology

- Membranes have composite structures to maximize flux





- Membranes are packaged in modules for industrial use

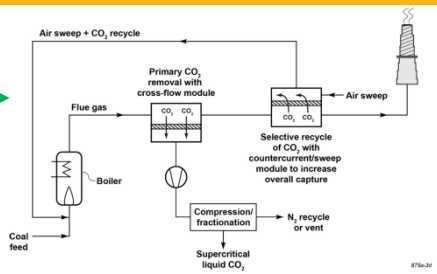


Advantages of a Membrane Capture Process

- No hazardous chemical handling, emissions, or disposal issues
- Not affected by oxygen, SO_x or NO_x; co-capture possible
- Water use lower than other technologies (recovers H_2O from flue gas)
- No steam use → no modifications to existing boiler/turbines
- Near instantaneous response; high turndown possible
- Very efficient at partial capture (40-60%)

MTR CO_2 Capture Development Timeline

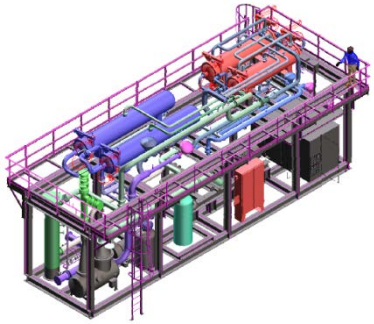
Feasibility study (DE-NT43085)
- Sweep concept proposed
- Polaris membrane conceived



APS Red Hawk NGCC Demo
- First Polaris flue gas test
- 250 lb/d CO_2 used for algae farm

APS Cholla Demo (DE-NT5312)
- First Polaris coal flue gas test
- 1 TPD CO_2 captured (50 kW_e)

NCCC 1 MW_e Demo (DE-FE5795)
- 8,500 hours of 1 TPD system operation
- 1 MW_e (20 TPD) system to run 6 months



Low Pressure Mega Module (DE-NT7553)
- Design and build a 500 m^2 optimized module

Hybrid Capture (DE-FE13118)
- Membrane-solvent hybrids with UT, Austin

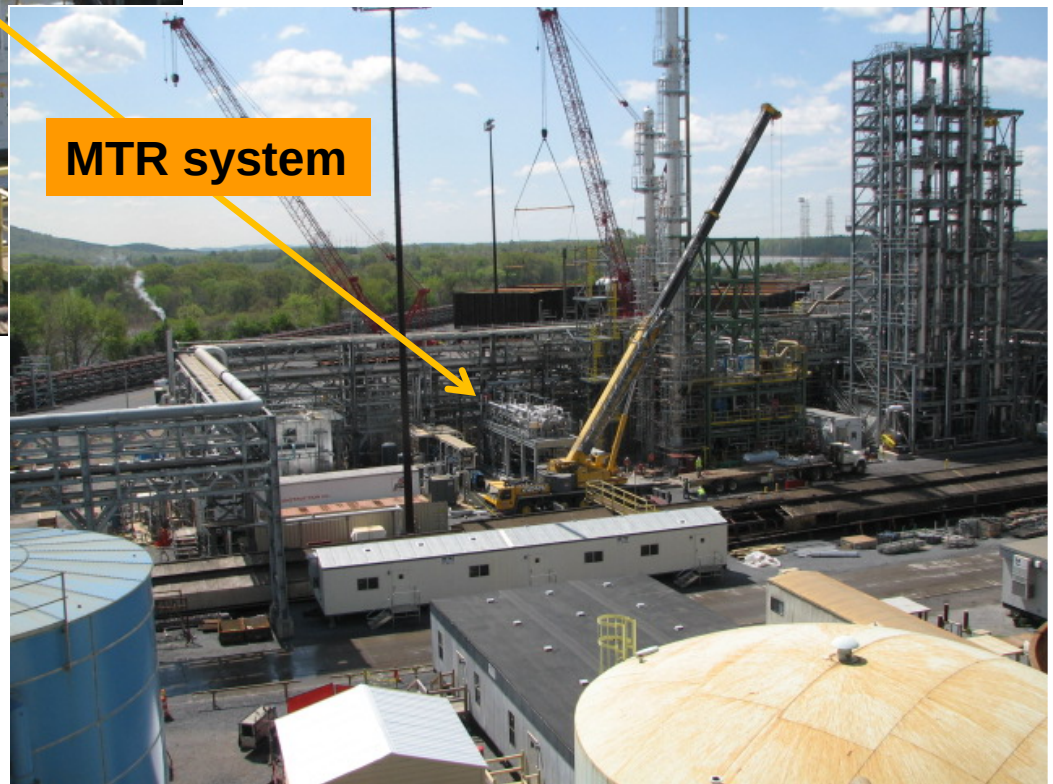
B&W Demo **Future 10 MW_e Large Pilot**

TRL3 TRL4 TRL5 TRL6 TRL7 TRL8

2006 2008 2010 2012 2014 2016 2018 2020

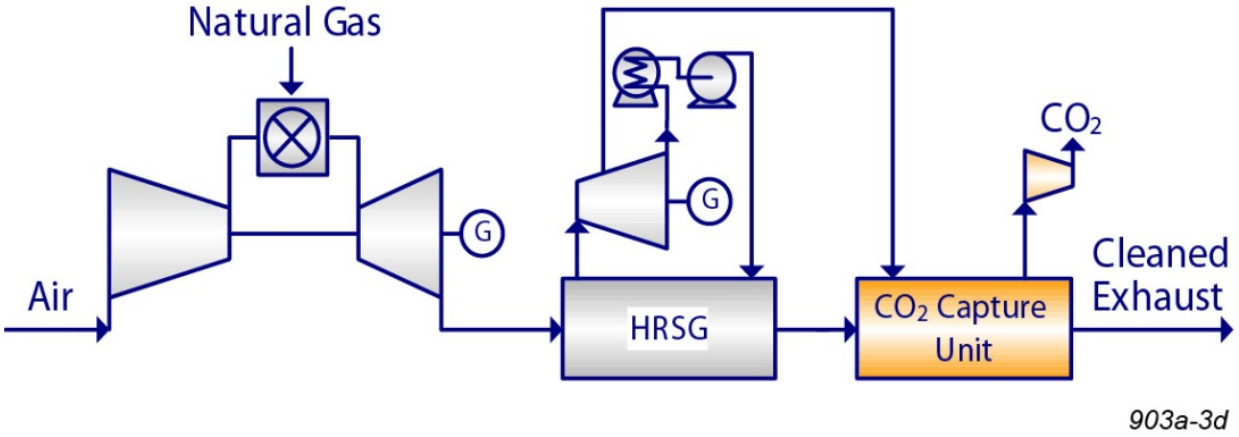
Current Status of Membrane Capture Technology

- In a current DOE program, a 1 MW small pilot membrane skid is in operation at the National Carbon Capture Center (NCCC)



- This relatively compact system treats a 20 TPD (CO_2) slipstream of coal flue gas from Plant Gaston

Challenges of CO_2 Capture From Natural Gas Power Plants



- Natural gas combined cycle (NGCC) plants use a large excess of air (>150%)
- As a result, NGCC flue gas contains only 3-5% CO_2 compared to 10-13% for coal, resulting in higher CO_2 capture costs ($/tonne) for gas
- Typically, membranes are not the optimal separation technology for dilute, low-pressure streams; however, creative process designs may allow membranes to play a role in these separations

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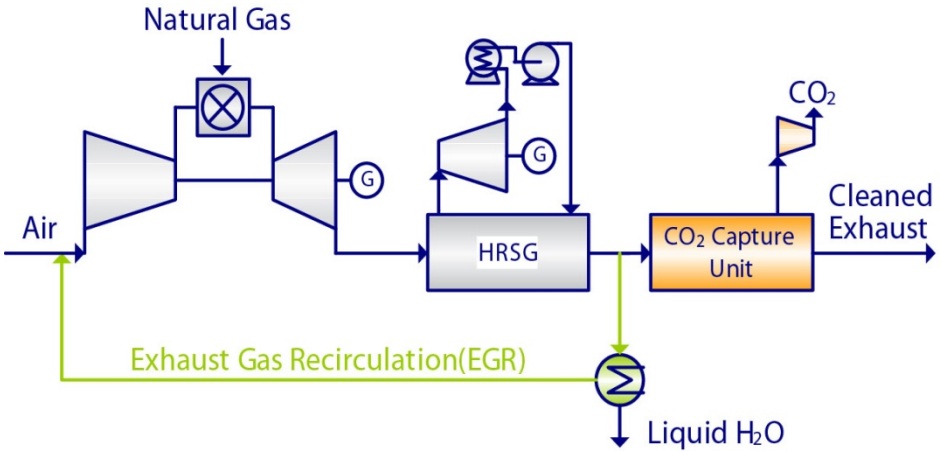
Selective Exhaust Gas Recycle

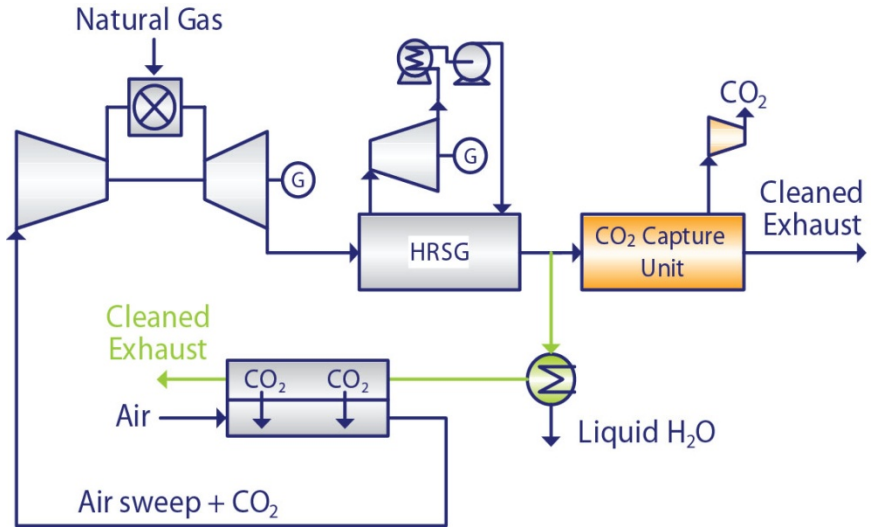
Exhaust gas recycle (EGR)



- CO_2 concentration increases in the flue gas
- O_2 concentration decreases in the combustion air

A. T. Evulet *et al., Energy Procedia 1,* 3809-3816 (2009).

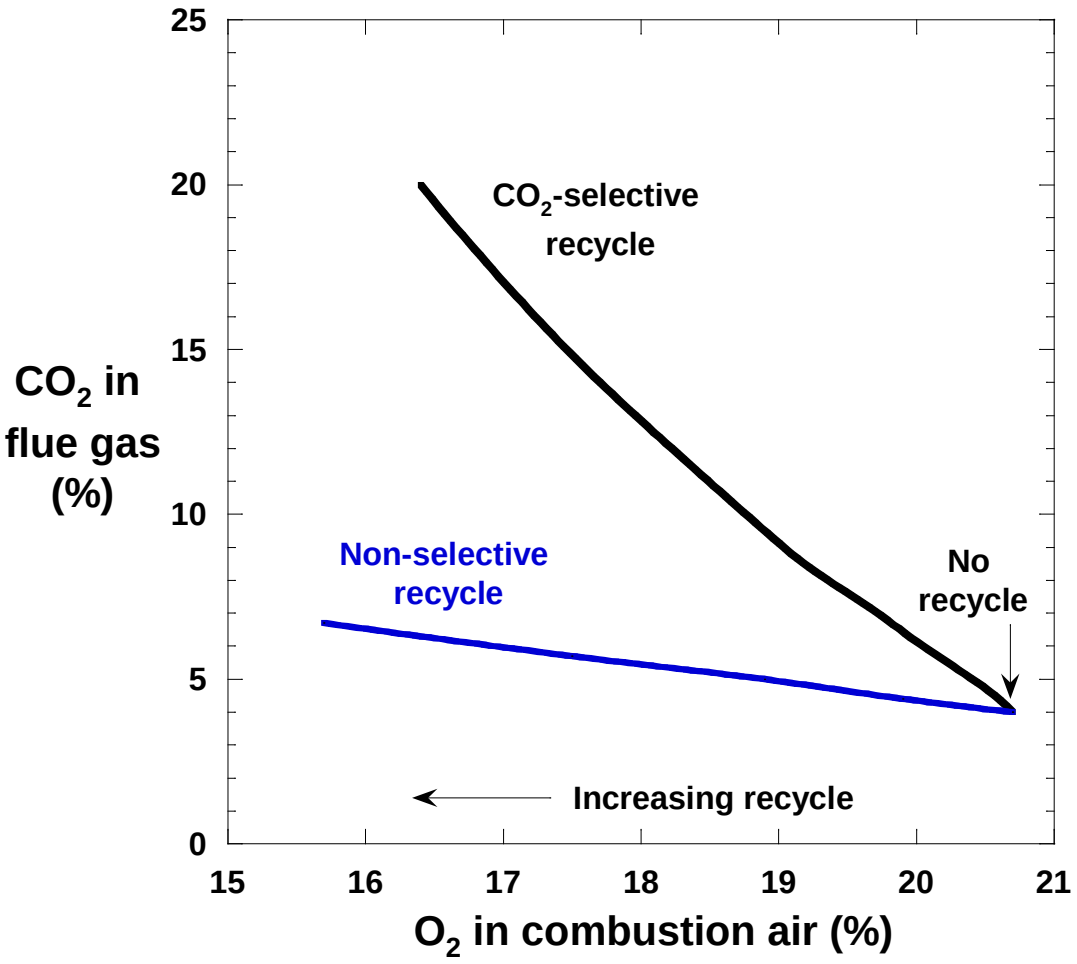
Selective exhaust gas recycle with a membrane



- Selectively recycle CO_2 by using sweep modules
- Avoid dilution of O_2 in combustion air with N_2 in the flue gas

Merkel *et al., Ind. Eng. Chem. Res.*, 52, 1150-1159 (2013).

Benefit of Selective Exhaust Gas Recycle

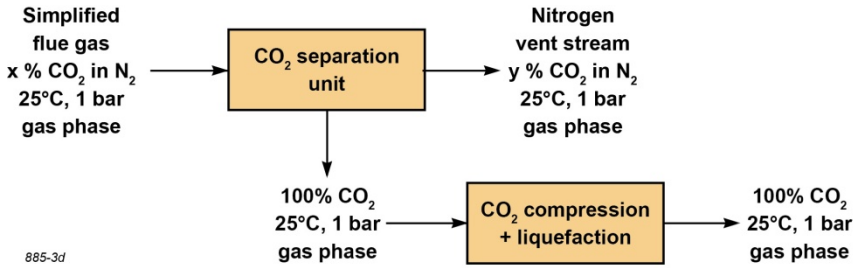


Effect of Recycle

	O_2%	CO_2%
No recycle	21%	4%
Non-Selective Recycle	16%	7%
CO_2-Selective Recycle	16%	23%

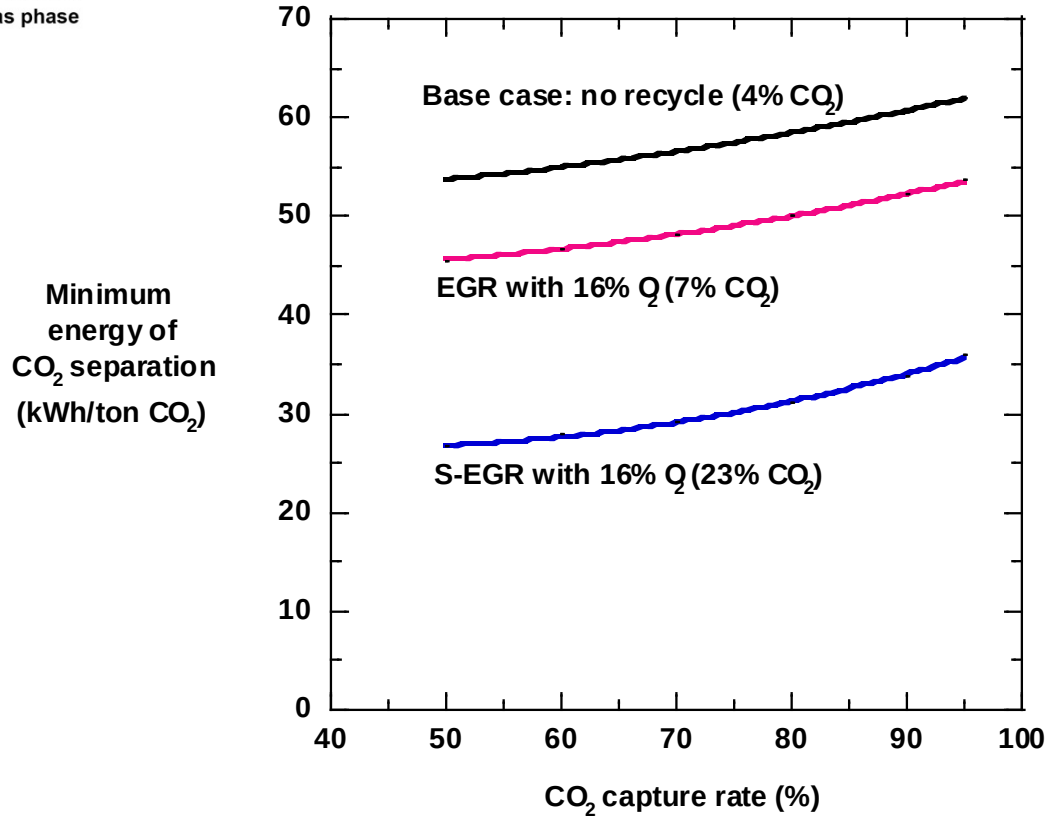
At the same O_2 content, selective EGR gives much higher flue gas CO_2 concentration than standard EGR

Impact of Selective EGR on Minimum Energy of Separation

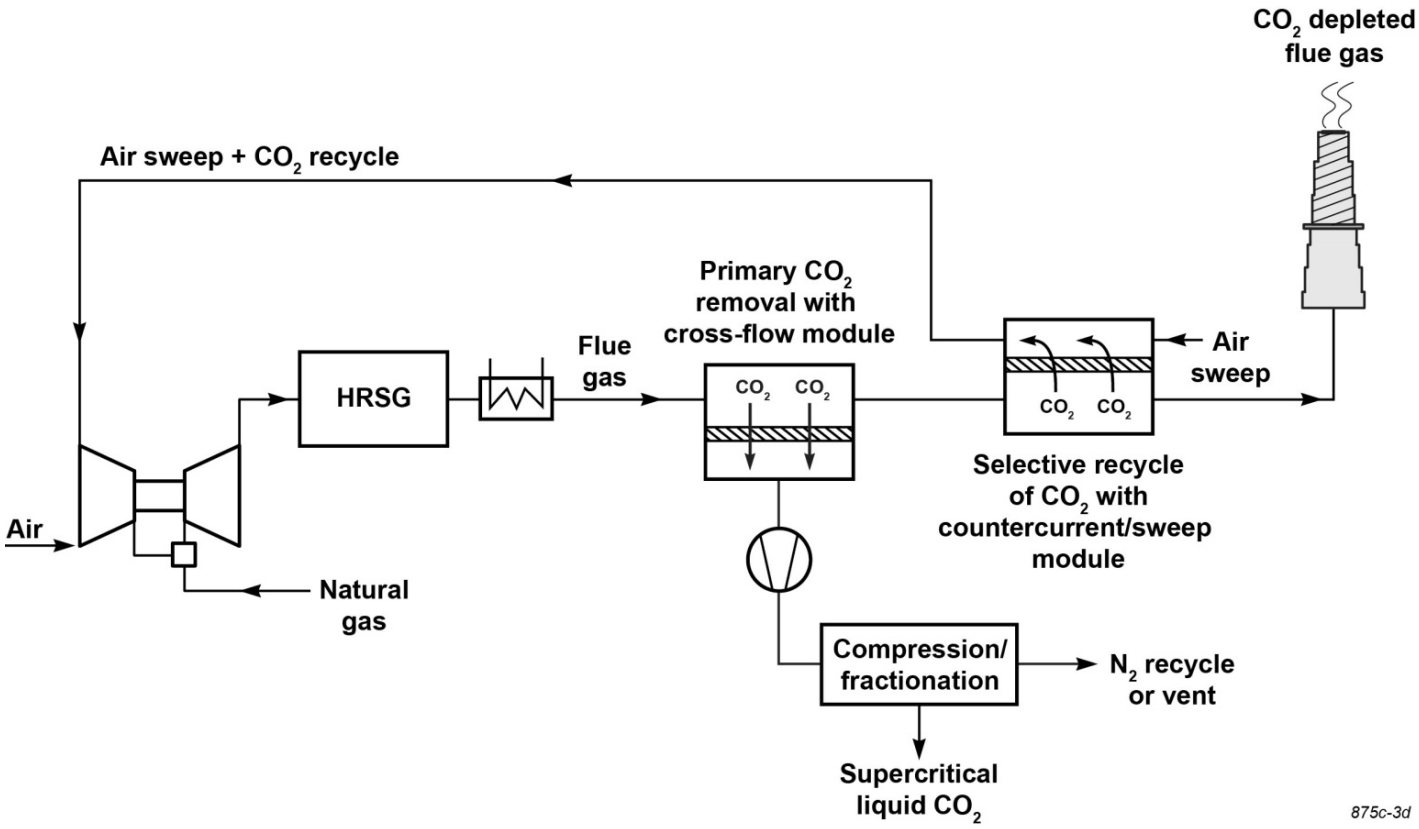


- Minimum energy of separation can be calculated from the change in Gibbs free energy

- Compared to no recycle, S-EGR reduces the minimum energy of separation by >40% over a wide range of capture rates

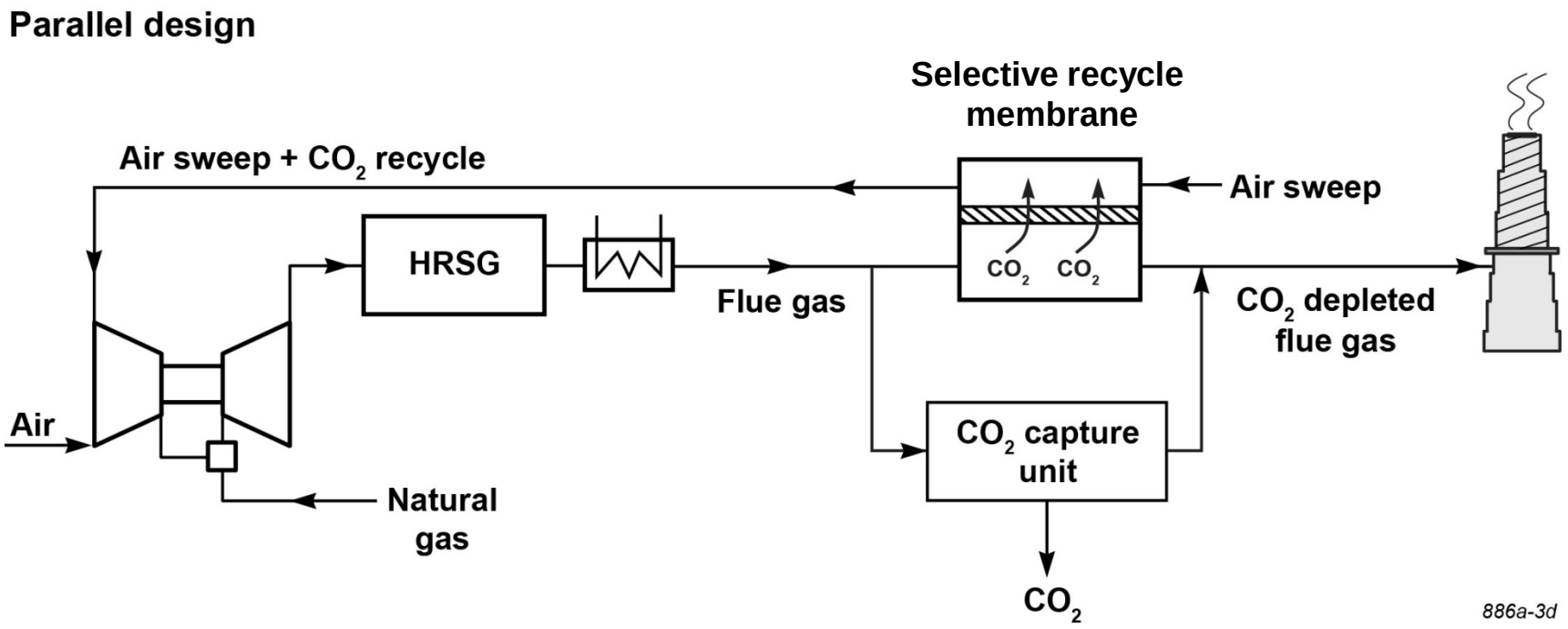


Membrane-Only Capture Approach



- Initial techno-economic analysis shows lower COE than DOE baseline for amine absorption (7.9 cents/kWh versus 8.8 cents/kWh); cost of capture is ~$50/tonne
- Assumes combustion turbine can operate with 15-20% CO_2, 16% O_2

Hybrid Approach with Selective EGR



Benefits of the selective recycle membrane:

- Increases the CO_2 in the flue gas from 4% to 15-20%,
- Reduces the quantity of flue gas going into the CO_2 capture unit by a factor of 3;
- Hybrid design with absorption avoids the use of compression/vacuum equipment.

Status of Membranes for Natural Gas CO_2 Capture

- Preliminary discussions with a major turbine manufacturer indicate selective EGR is feasible; however, concept not tested yet
- MTR Polaris membranes developed with DOE support for coal CO_2 capture can be used for gas plants
- Design study of a hybrid membrane-absorption process applied to natural gas plants will be conducted this summer

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Summary

- Membranes offer some advantages for CO_2 capture (simplicity, environmentally friendly, water recovery)
- Membrane technology is at the small pilot stage for capture from coal plants
- The membrane selective EGR concept can be used to reduce the energy of CO_2 capture from natural gas
- Either all membrane or hybrid capture designs can benefit from selective EGR
- A key next step will be to test selective EGR with a combustion turbine

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