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A Membrane Approach to CO2 Capture

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Membrane Technology and Research, Inc.

Engineering Conferences International CO2 Summit III

Calabria

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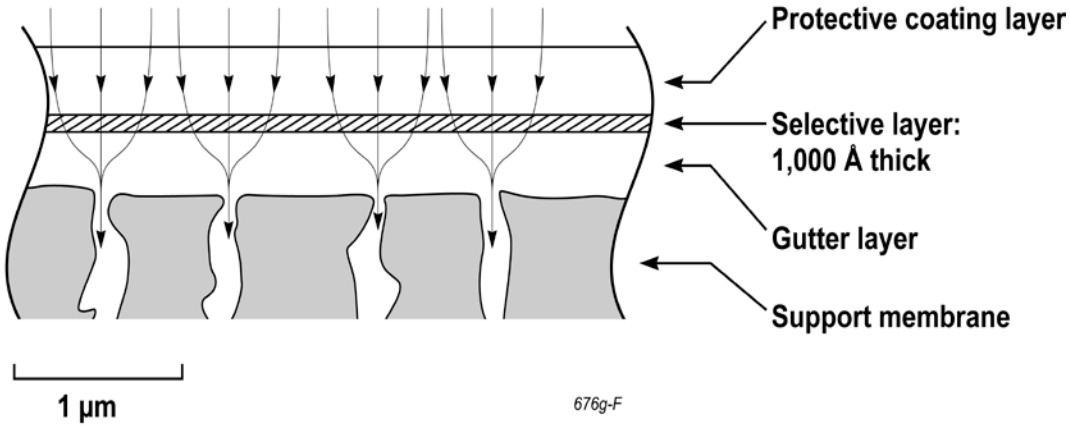
I work for a company that develops and makes membrane gas separation equipment

AKAL-C8 – AB82 – Final Skids
Installation on Platform
(Max Flow inlet – 100 MMSCFD at 900 psig)

Outline

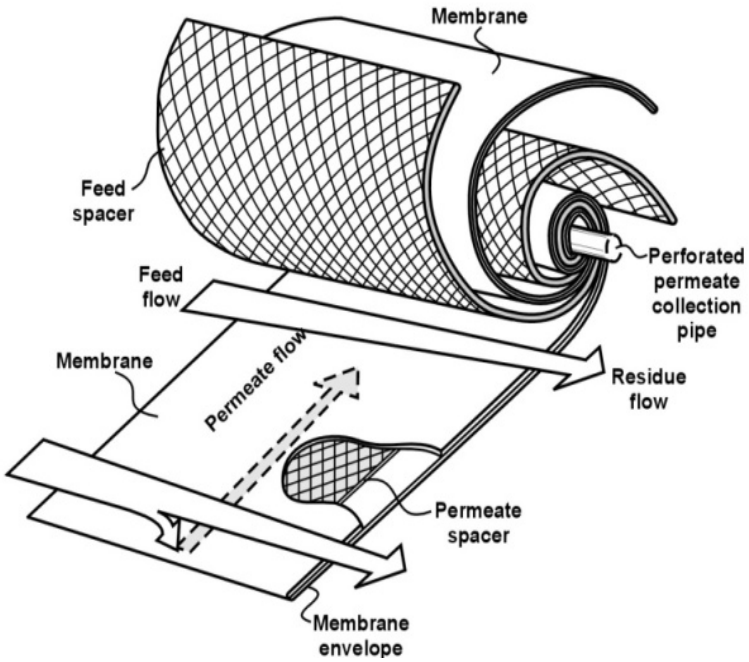
- Introduction and background
- Overview of recent test programs
  - NCCC
  - B&W
- Future plans
  - DOE large pilot

Membranes and Modules



Thin composite membrane

Spiral wound module



CO2 Capture Systems Need ~5,000M2 of Membrane/ton-h of capacity

An Example of a Large Area Membrane Plant

The Ashkelon desalination plant contains 1.5 million m^2 of RO membrane
(more membrane than required for 90% capture from a 500 MW coal power plant)

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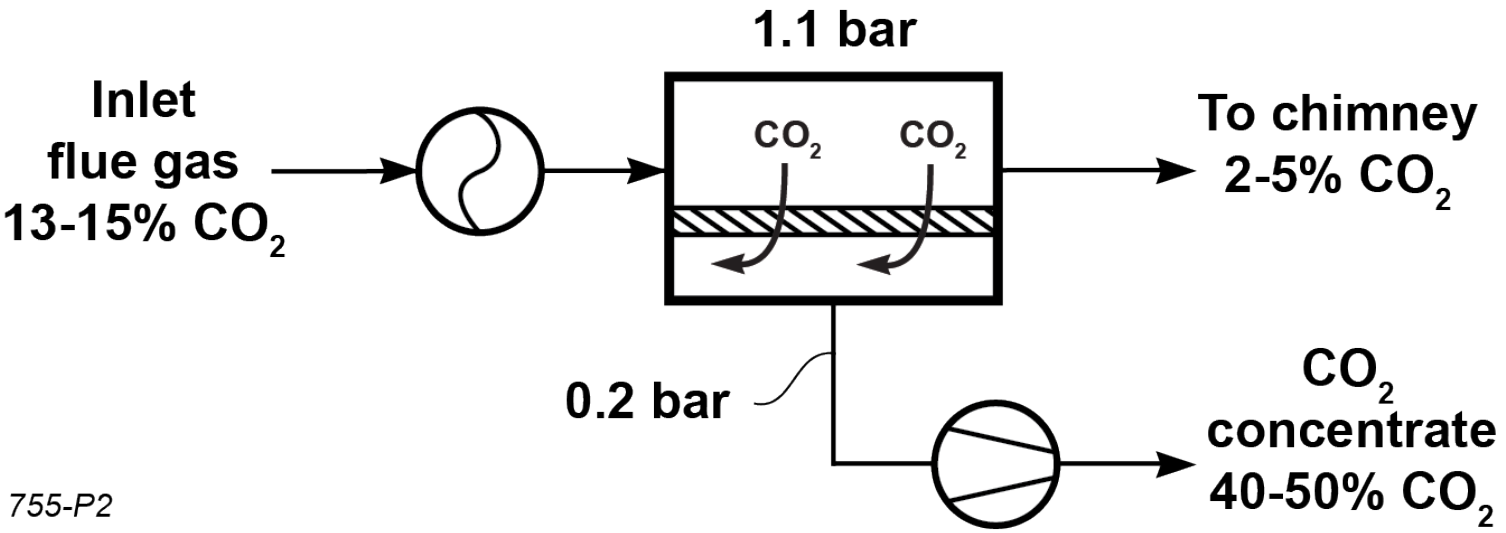
Membrane Separation Basics



- Power consumption is key
- Permeate vacuum – not feed compression.
- A total separation needs a multi stage process.
- Process needs very high permeance membranes (>1,500 gpu).
- CO_2/N_2 mixed gas selectivity (25) is enough.

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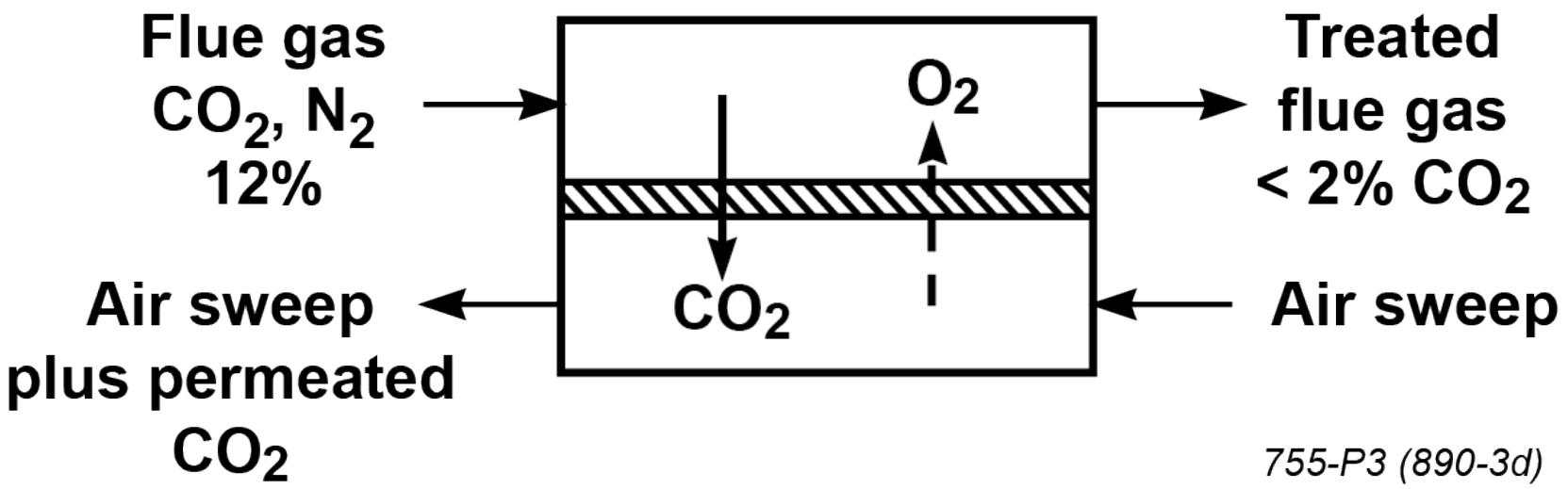
The MTR Membrane Contactor



A separation is performed at no energy cost.

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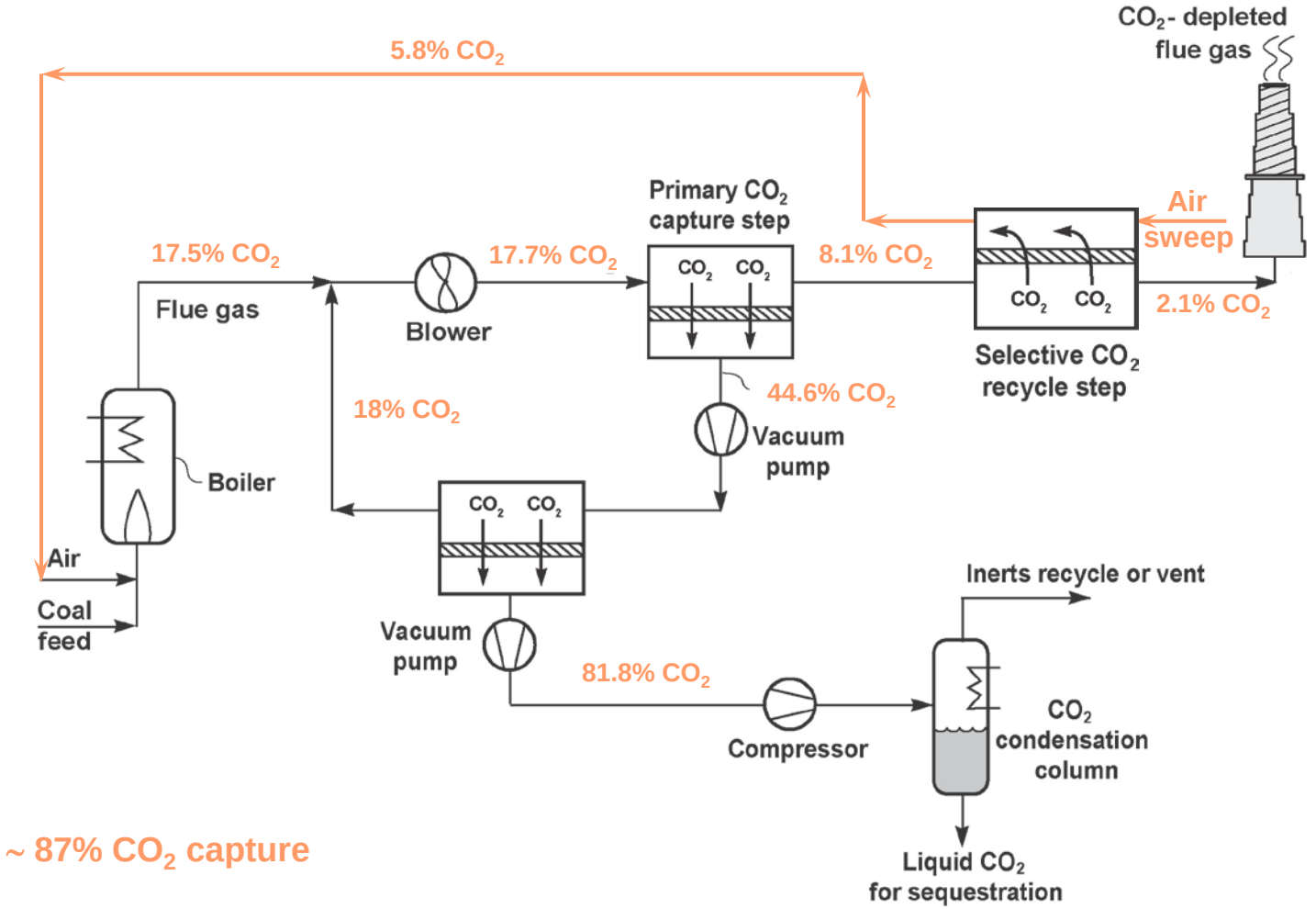
The Impact of a Membrane Contactor on the MTR CO_2 Capture Process



At 87% capture uses 25% of the power plant electricity

At 60% capture uses 15% of the power plant electricity

The Advantages of Membranes

Low Capex , Low Opex

Small footprint

Modular (containerized) construction

Uses electricity , no steam

No emissions , no hazardous waste

Simple flow sheet , easy to operate

Cold start to steady state in 15 minutes

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Installation of 20 TPD Small Pilot at NCCC

1st floor of system arriving by truck

Crane lowering 2nd floor of system into place

Photos courtesy of Tony Wu

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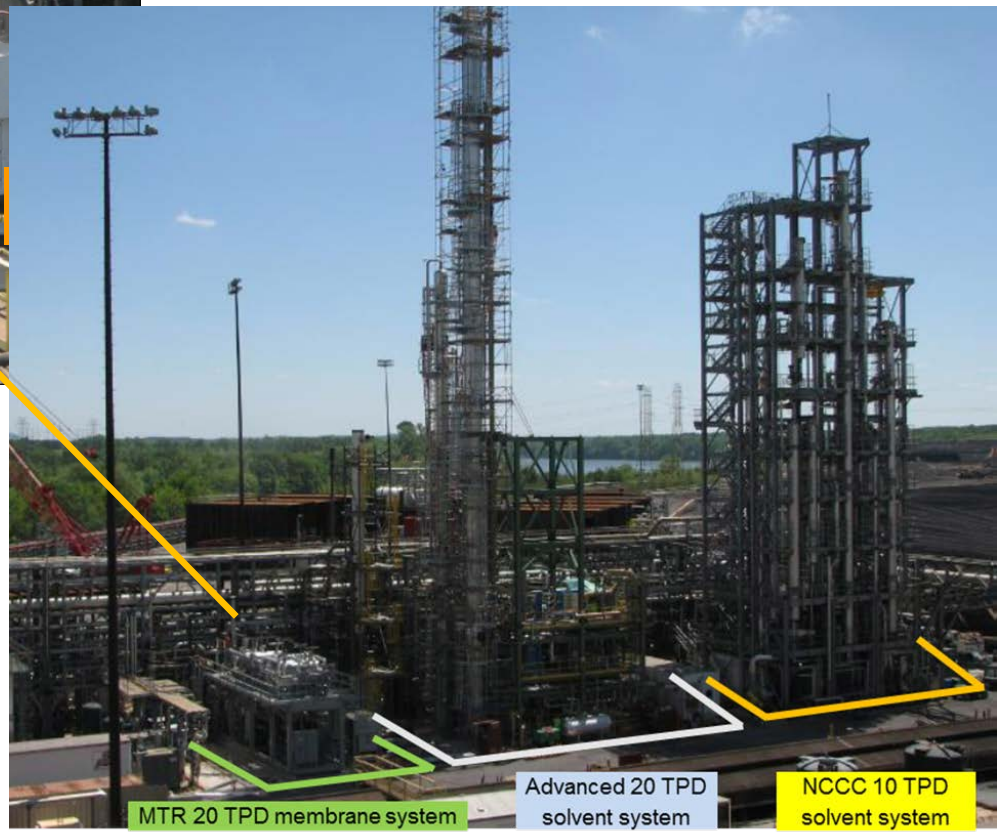
20 TPD System at NCCC

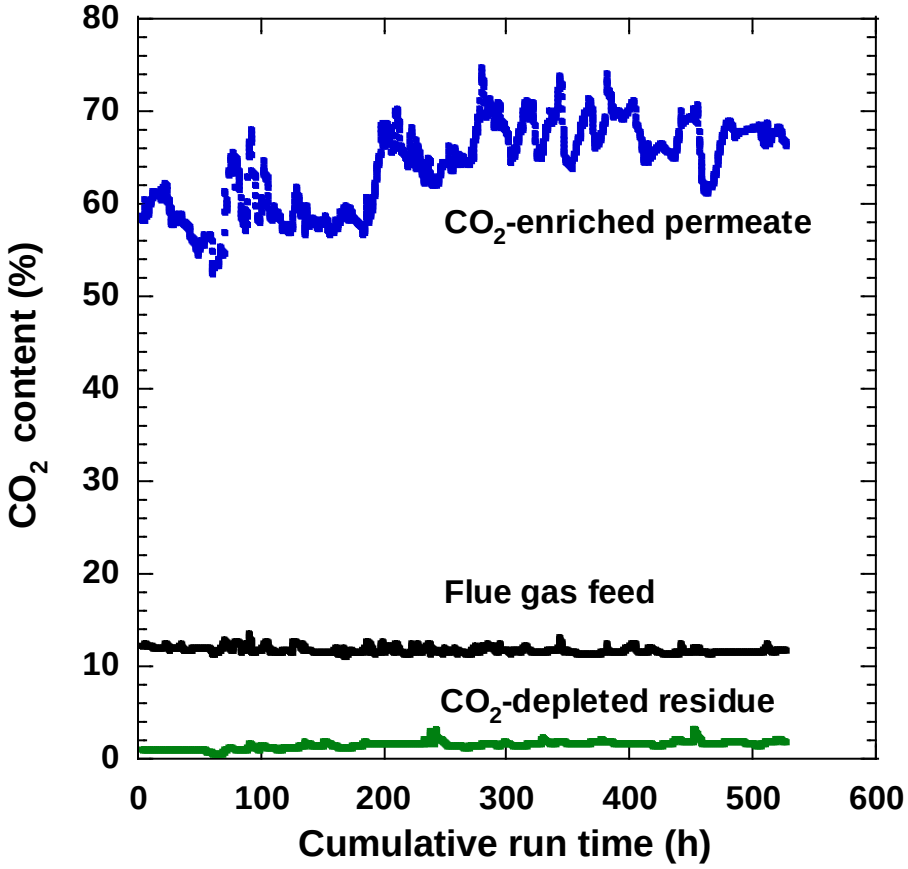
- U.S. DOE considers MTR technology a leading Gen2 CO_2 capture approach
- Membranes are simple and compact compared to competing technologies, such as amines (see columns in photo)



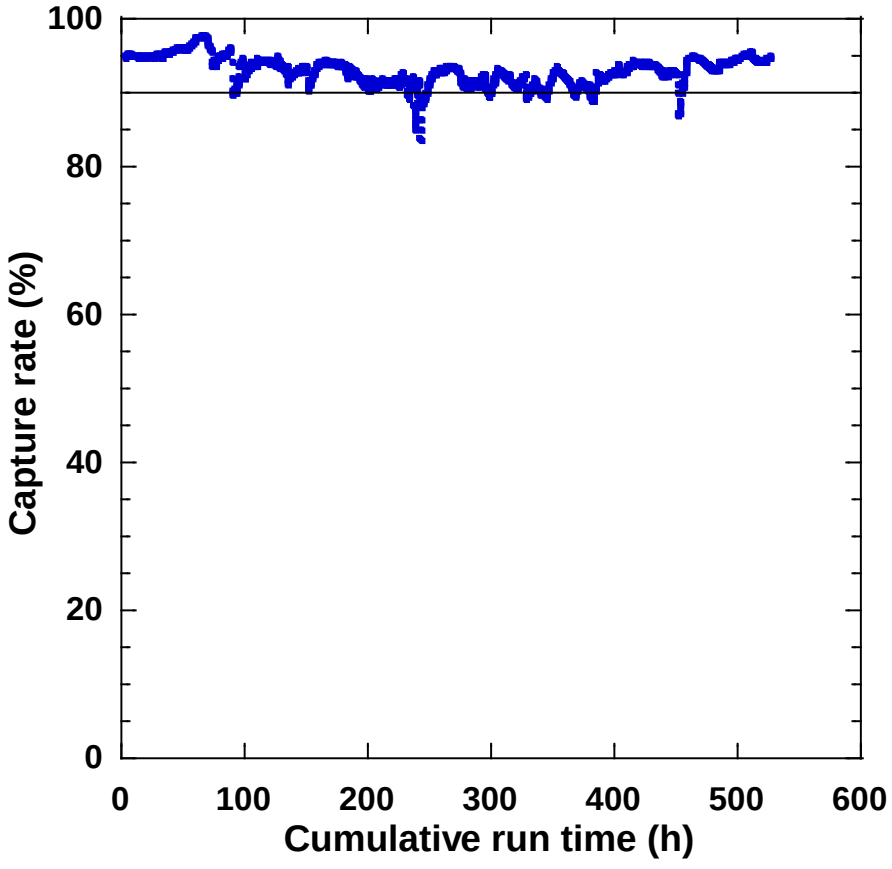
- MTR pilot system completed successful 6 months of operation at NCCC in June 2015
- Currently, system is installed at B&W for an integrated boiler test

Sample Results From NCCC

CO_2 Concentration



Capture Rate



Most concentration fluctuations are due to changes in ambient temperature.

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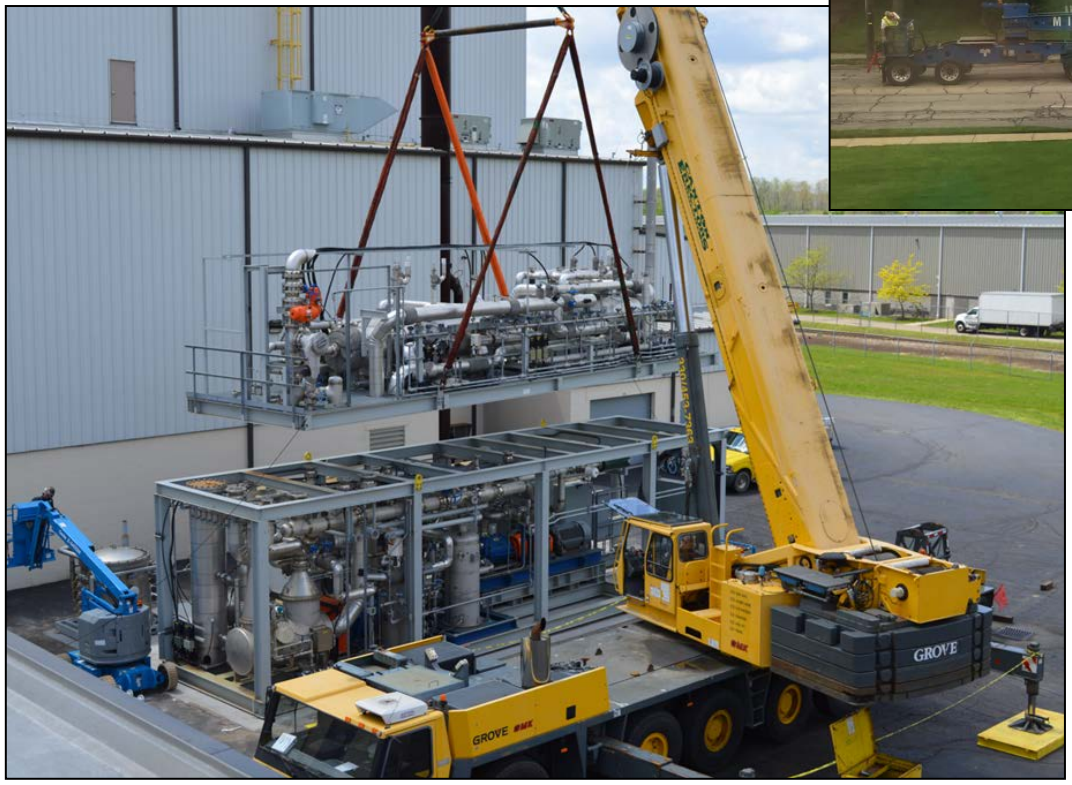
MTR Skid During Transport and Installation at B&W – May 2016

Skid arriving at B&W →



← Installation of 2nd floor

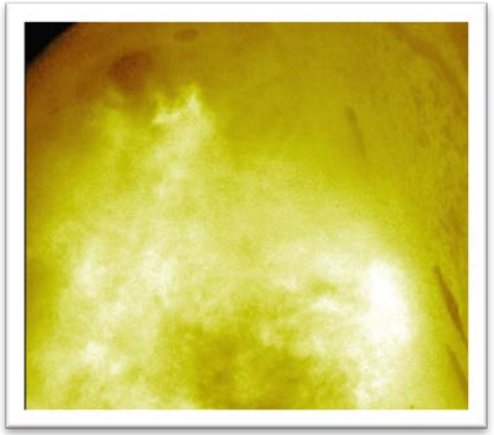
MTR Skid at B&W Research Facility
June 2016

Skid with B&W 0.6 MW_e SBS-II boiler facility in background

B&W Pilot Testing Highlights

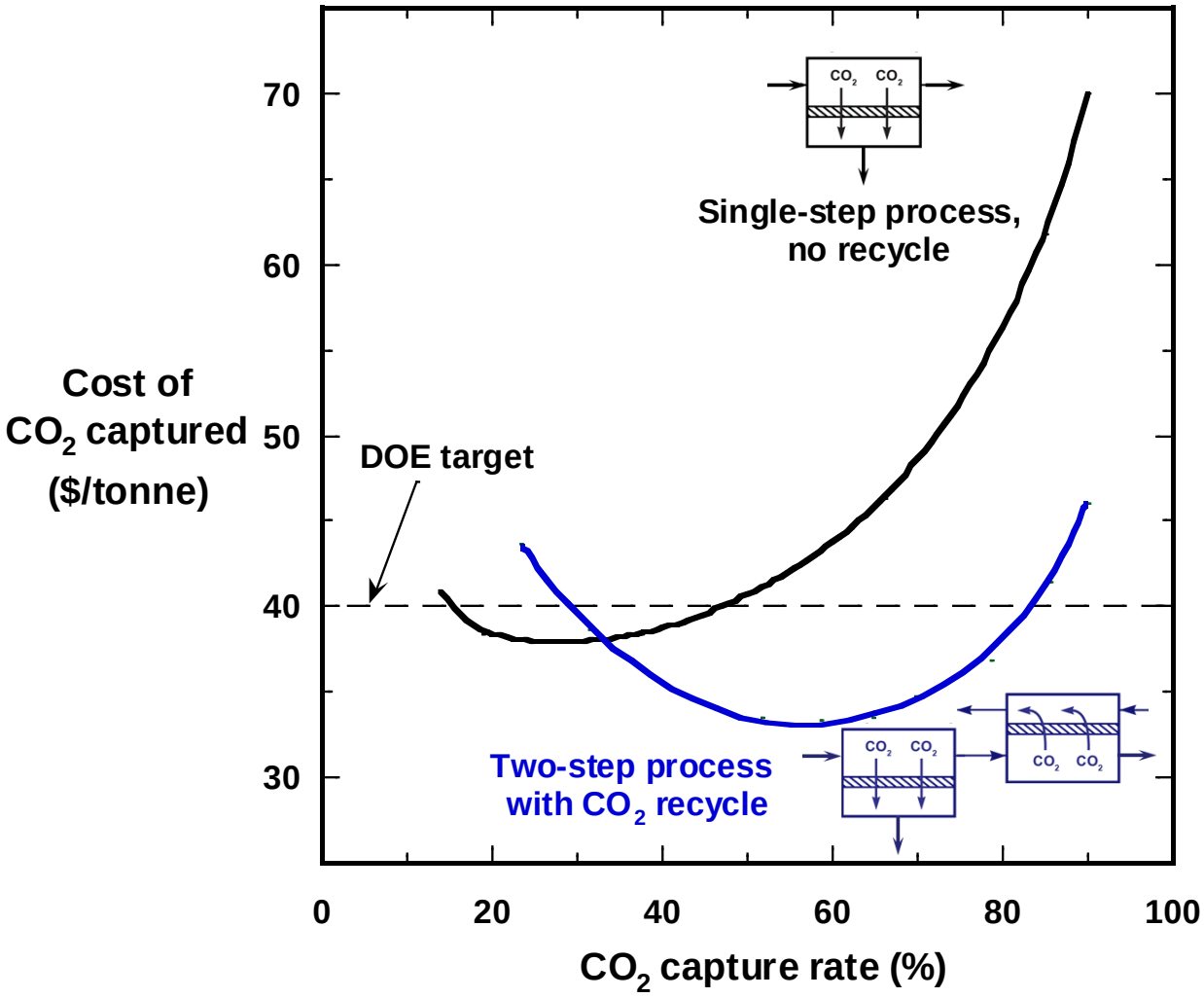
- Stable and attached flames with air (21% O_2) and CO_2-enriched air (16-18% O_2)
- CO_2-enriched flame was less luminous than air-fired case
- Lower furnace heat absorption but higher convection pass/air heater heat transfer for CO_2-enriched operation relative to air
- For bituminous coal, 30% lower NO_x emissions with CO_2-enriched air
- No burner modifications necessary
- Net reduction in plant efficiency of ~0.75% at 18% O_2

Flame image from combustion of PRB coal with air (21% O_2)



Flame image from combustion of PRB coal with CO_2–enriched (18% O_2)

Systems Analysis Shows Membranes are Particularly Effective at Partial Capture



- Membranes show a minimum in capture cost
- To meet proposed U.S. EPA emission limits for coal (~30% capture), a simple system without recycle may be preferable

Where Does the Money Go

Estimate cost: ~$35-$45/ton CO_2 (99.5% 150 bar) at 40 to 80% CO_2 capture rate

- Membrane skid Capex (~1/3)
- Power (~1/3)
- Compression/vacuum equipment Capex (~1/3)

– Increase permeance 1,500 to 3,000 gpu
– Lower cost vacuum and compression equipment
– Reduce vacuum pressure 0.2 bar – 0.1 bar

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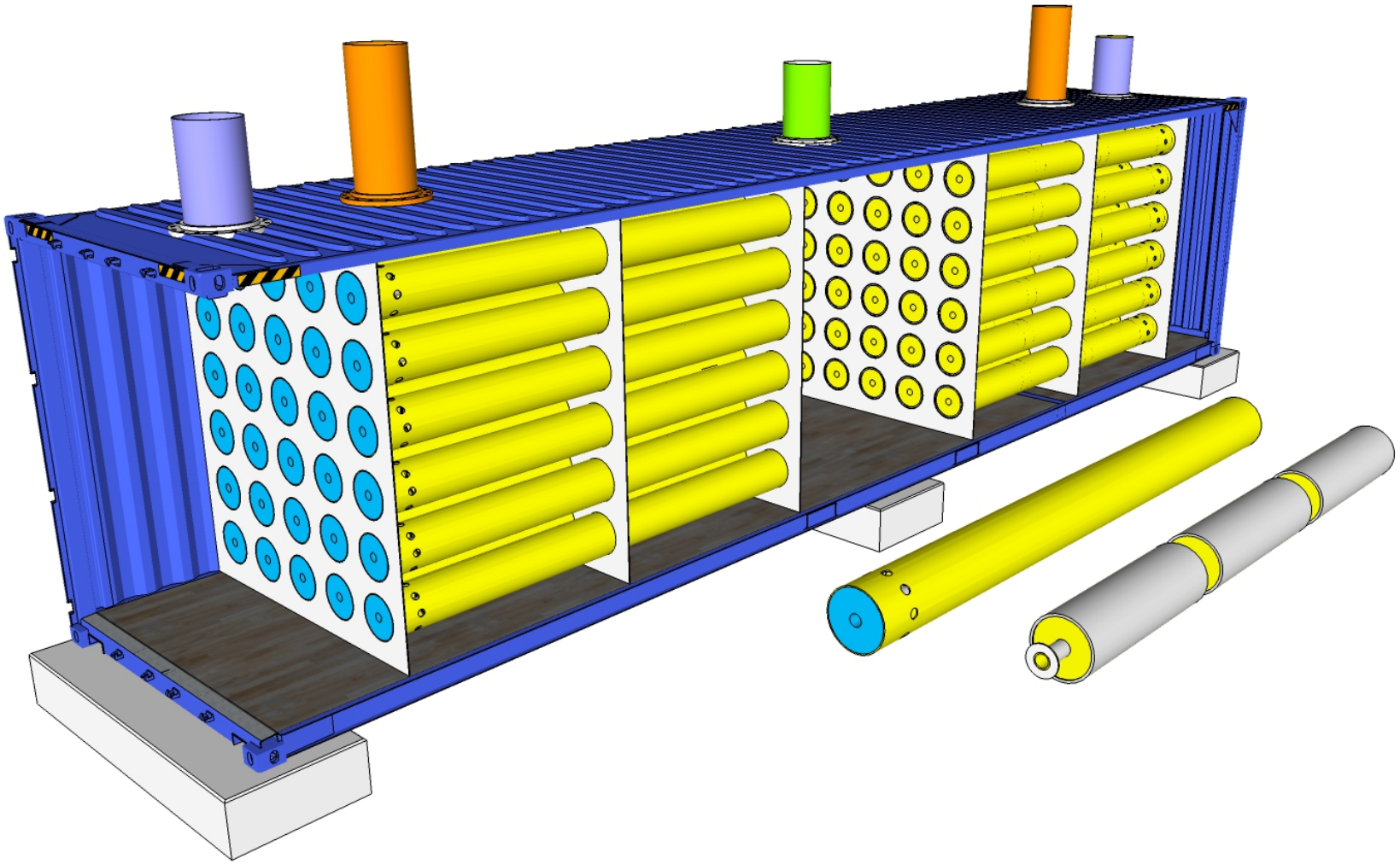
The NCCC 1 MWe system used nested module tubes in a single large vessel.

Bundled spiral sweep modules

Bundled Polaris spirals

Low-Pressure Containerized Capture Modules for the 10 MW_e System



Selective Exhaust Gas Recycle Modules Used on the 1 MW_e System

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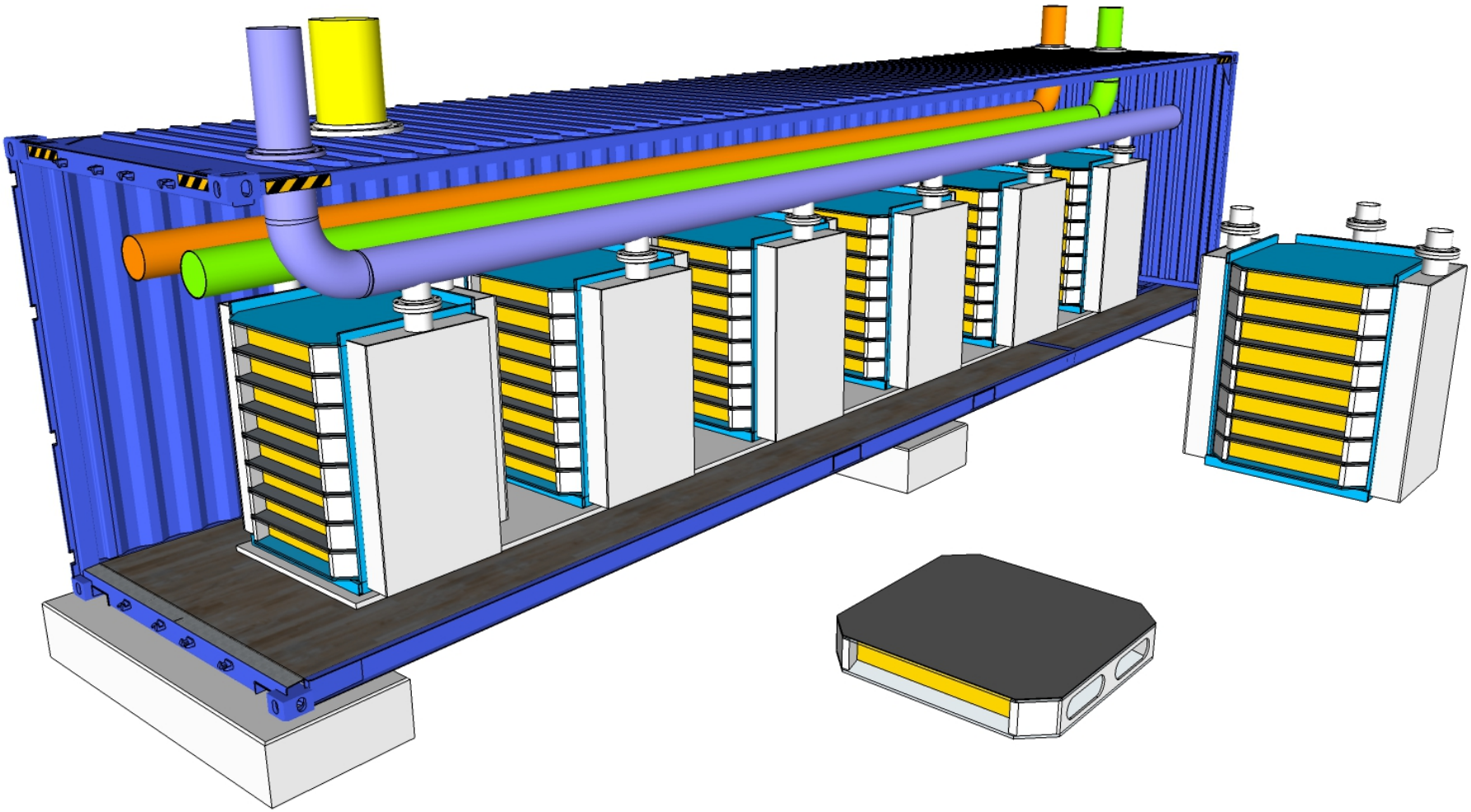
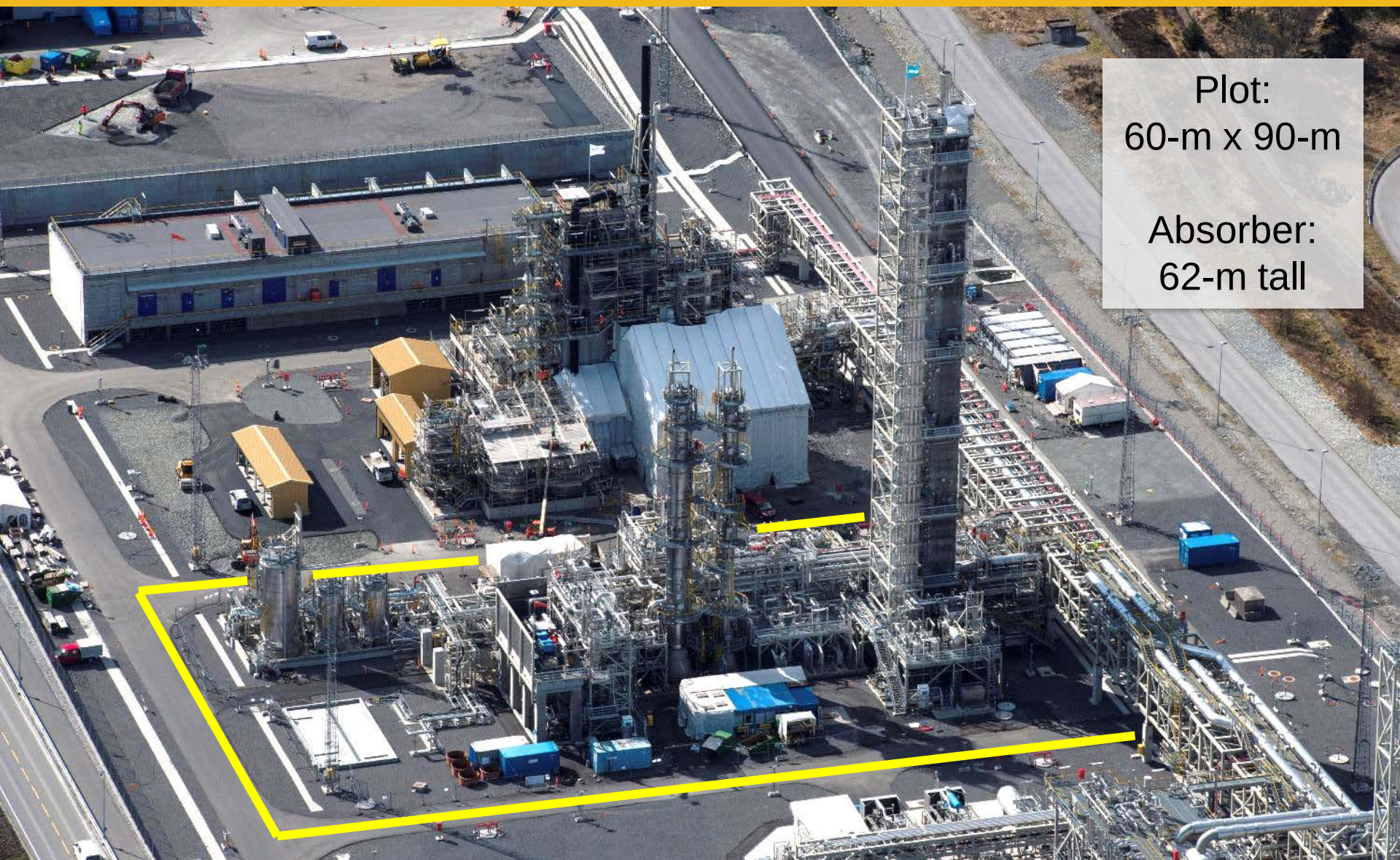
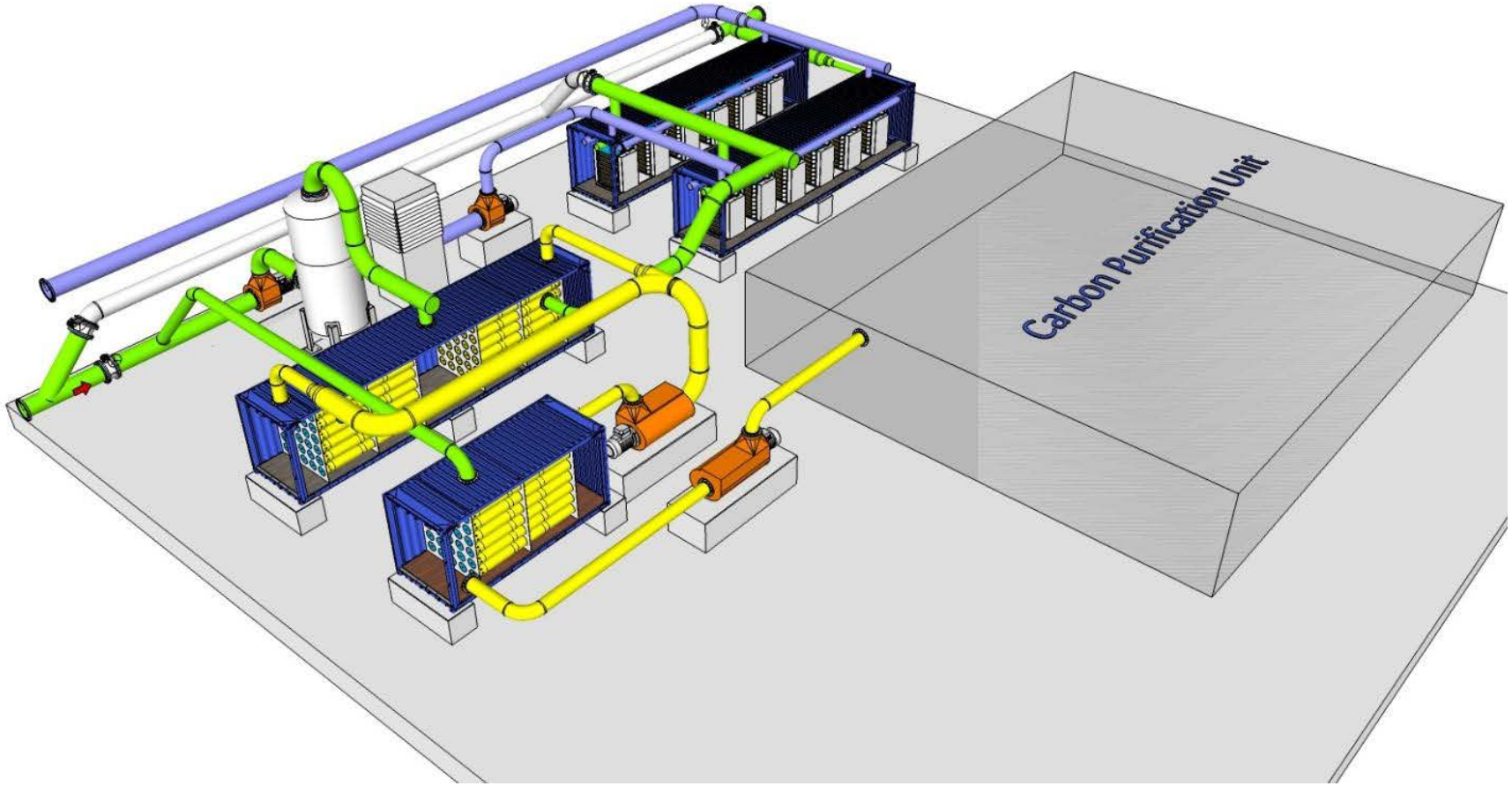
Low-Pressure Containerized Recycle Modules for the 10 MW_e System



12-MW_e Amine Capture Process at Technology Center Mongstad (Norway)



The Future ? -- Bird's Eye View of MTR's Proposed 10 MW_e MTR Pilot



Expected Footprint 30 meters x 30 meters

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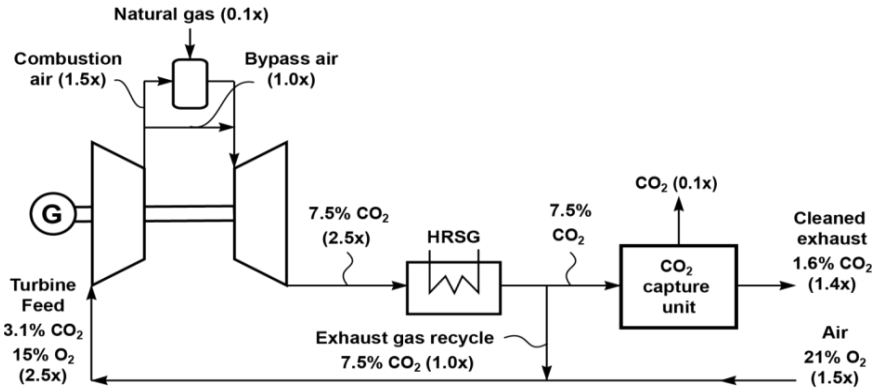
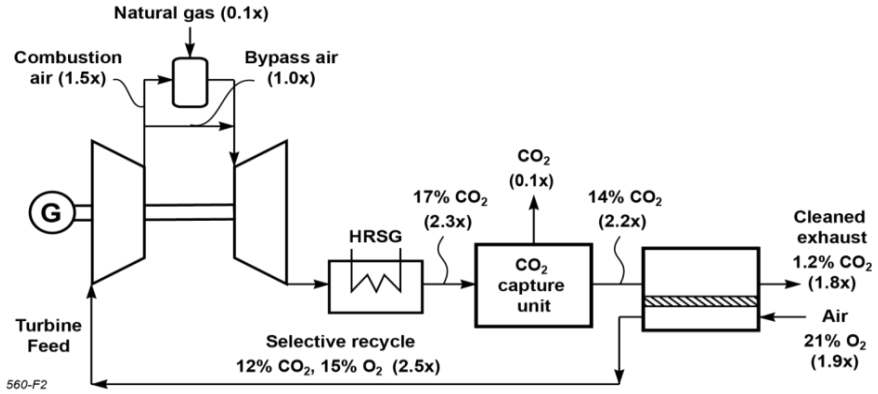
Exhaust Gas Recycle in Gas Turbines

2(a) Conventional Exhaust Gas Recycle (EGR) - 80% Capture



2(b) Selective Exhaust Gas Recycle (S-EGR) - 80% Capture



Selective exhaust gas recycle can increase the CO_2 concentration in flue gas a lot

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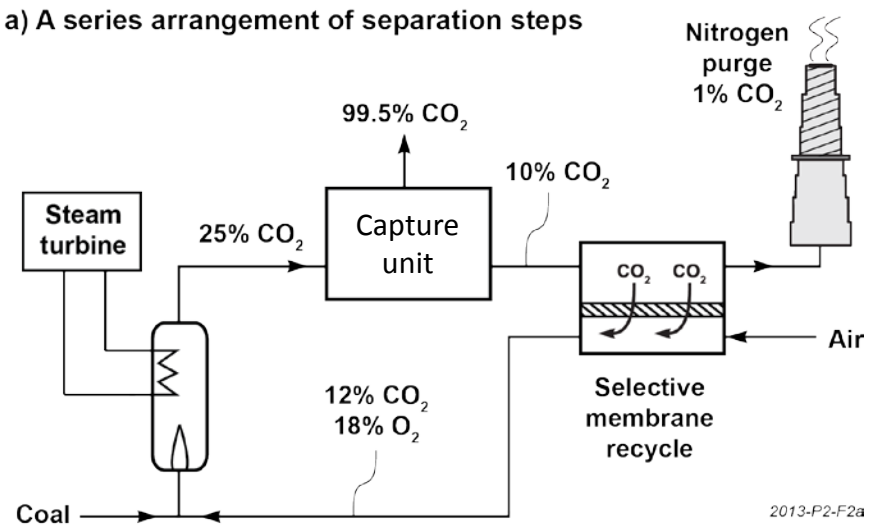
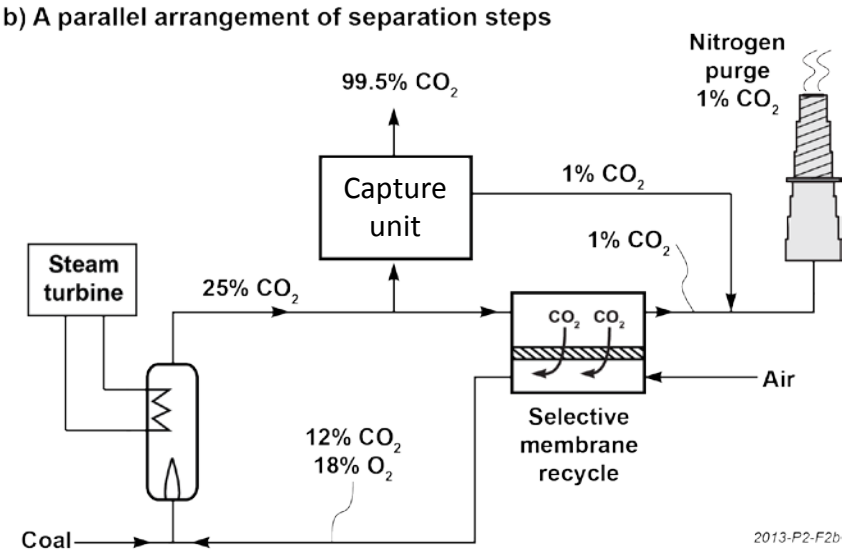
Hybrid Capture Systems





A membrane contactor can change the separation needed.

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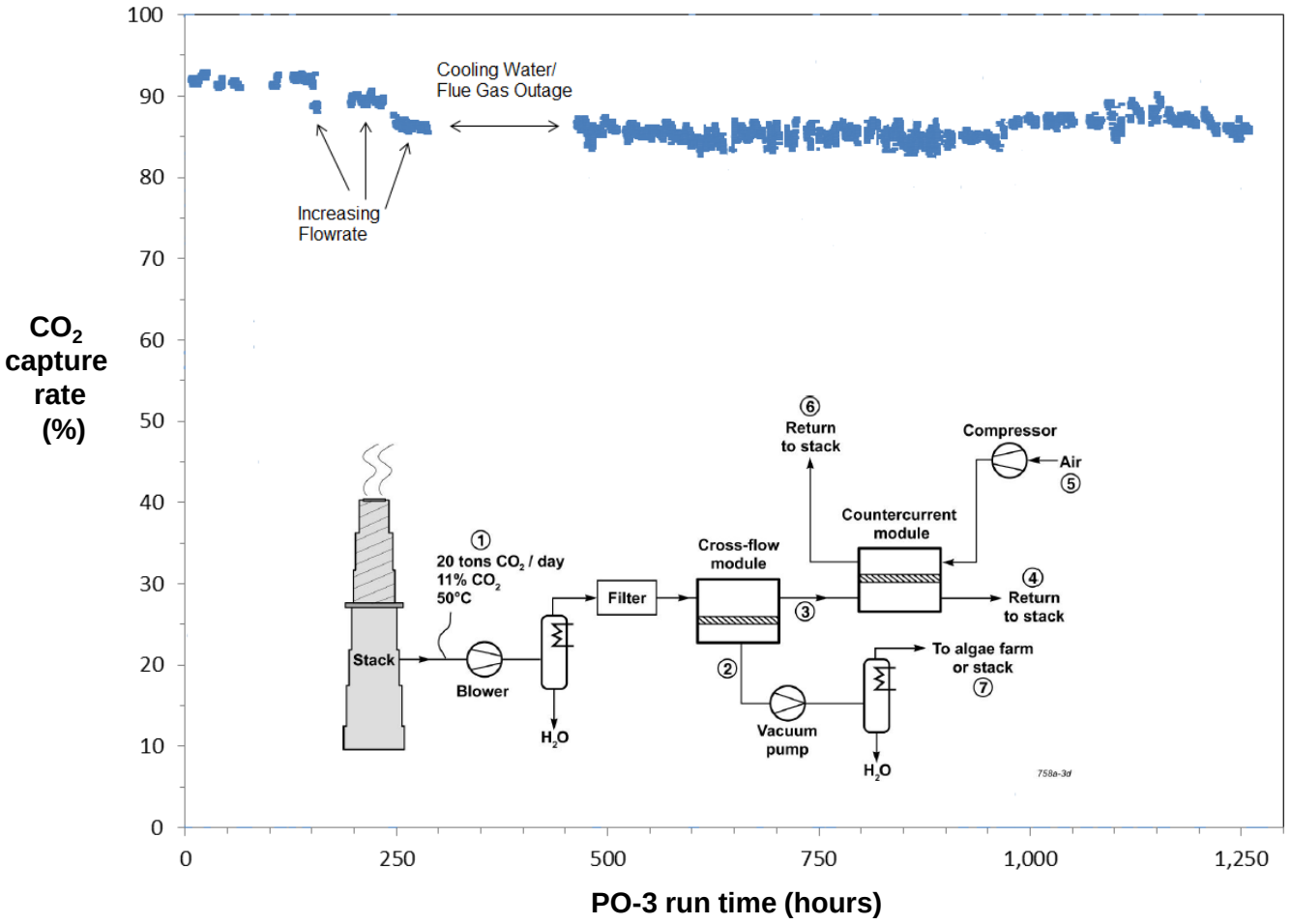
Thank You For Your Attention

20 TPD System Shows Stable Performance



- System operated in slipstream mode (no recycle to boiler)
- Stable performance, reaching up to 90% capture
- System goes from cold start to steady state in ~15 minutes

Figure data from NCCC campaign PO3 (May to July 2015)

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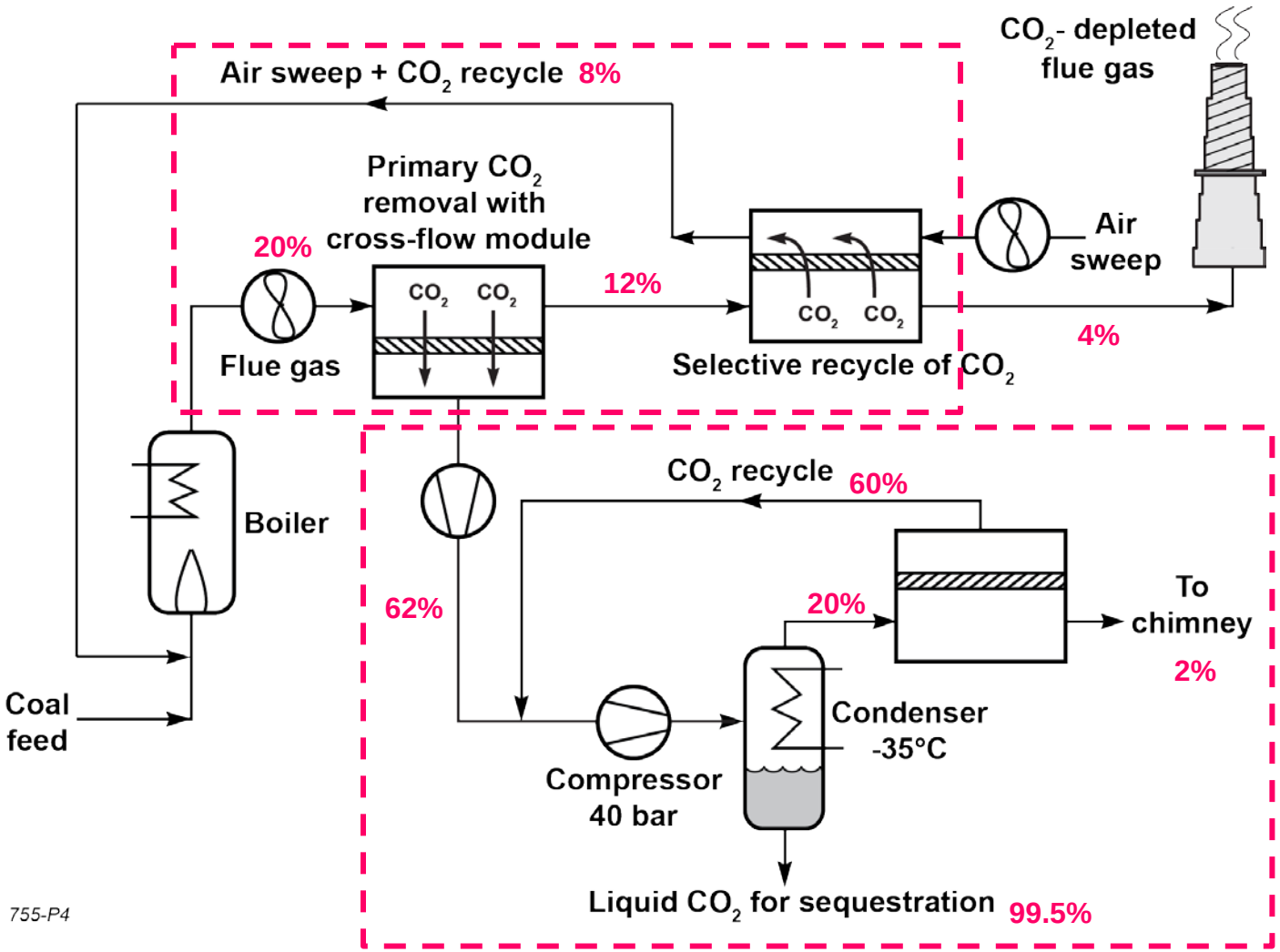
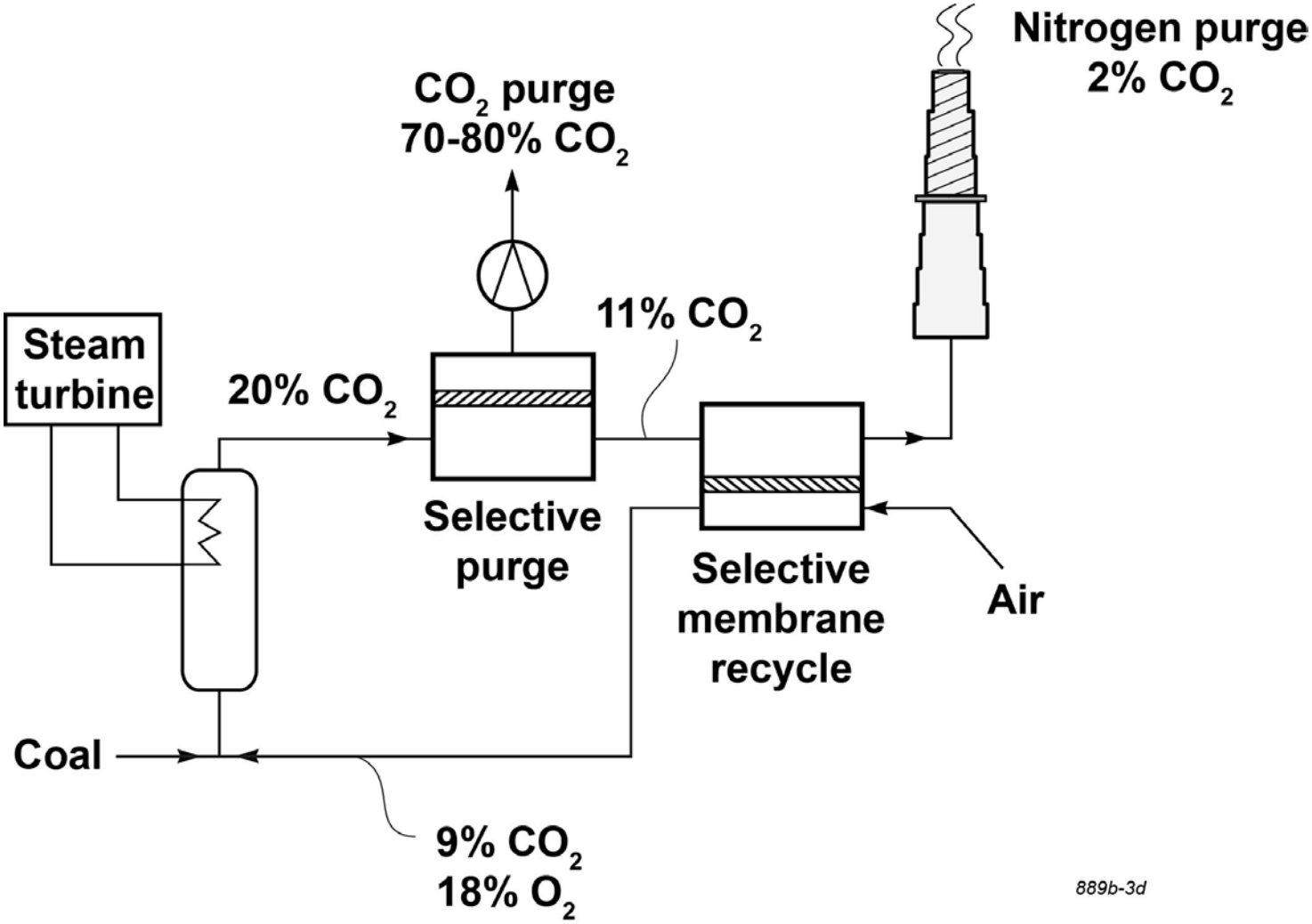
The MTR CO_2 Capture Design

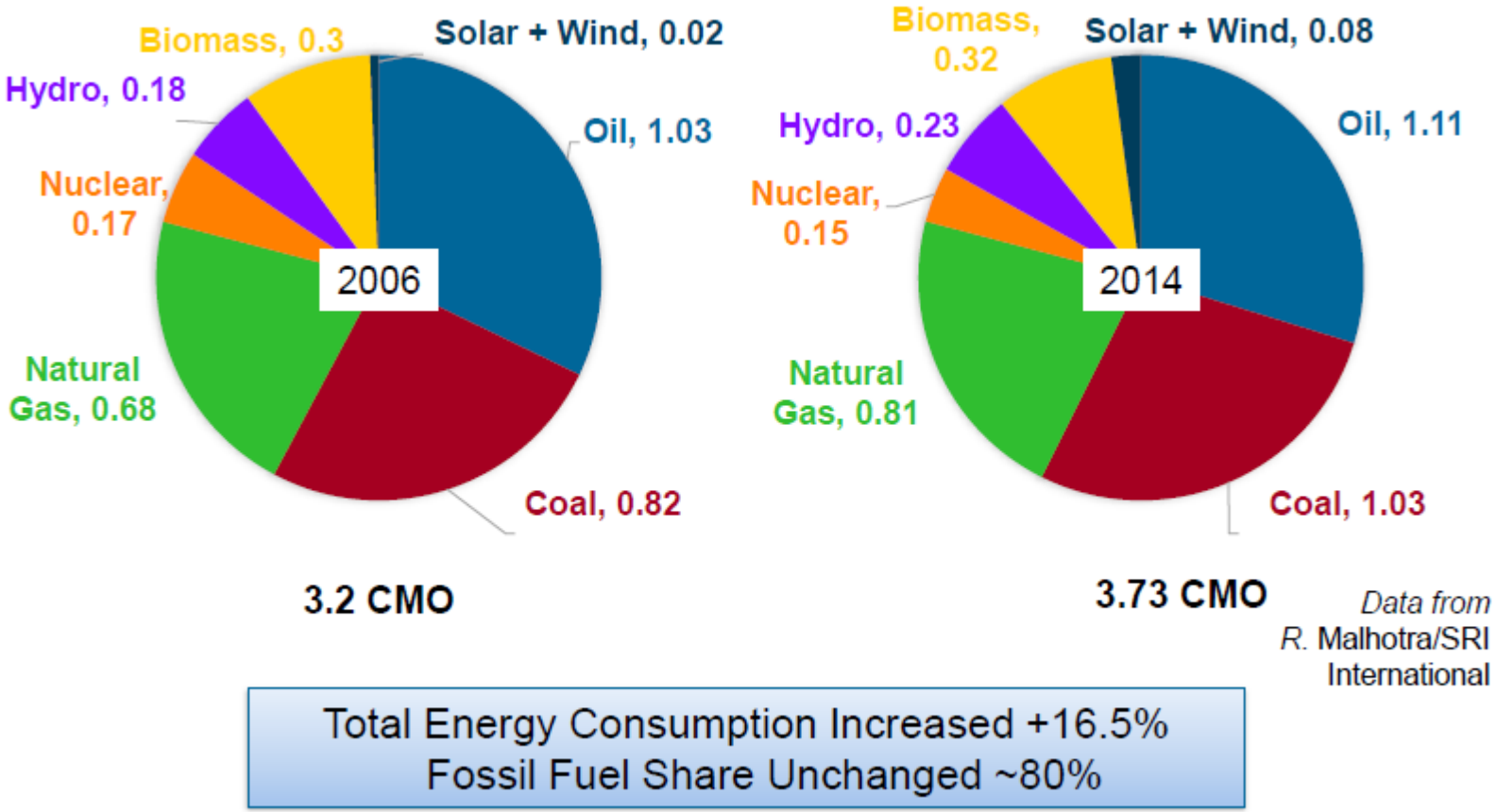


~75% CO_2 capture at 150 bar.

The MTR Process



Global Energy Use Continues to Grow



1 CMO = a cubic mile of oil = 26 billion barrel of oil = 153 Quads energy

Slide from Abhoyjit Bhown at EPRI

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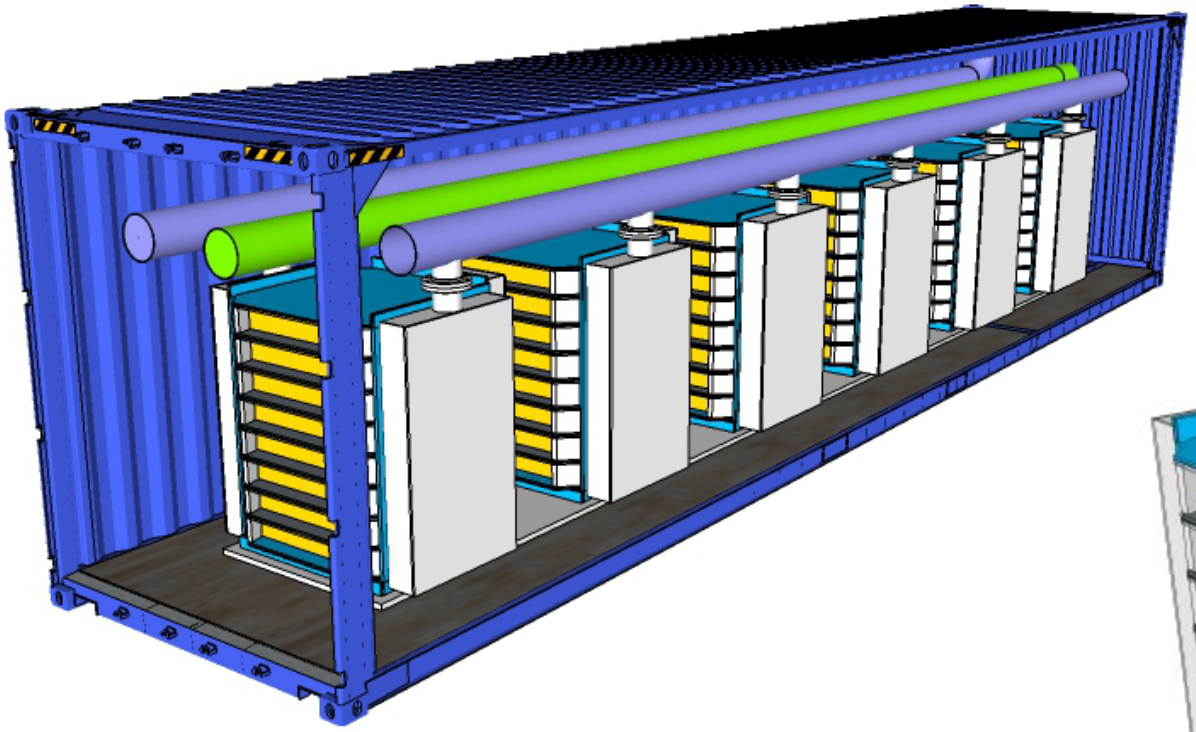
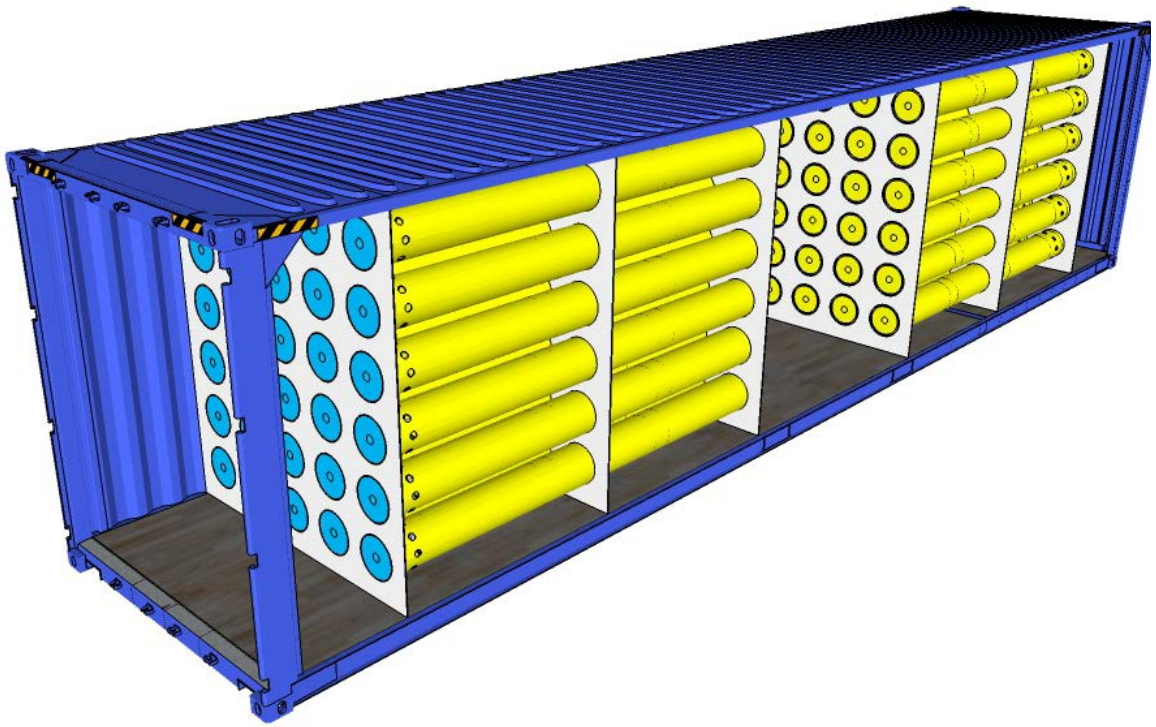
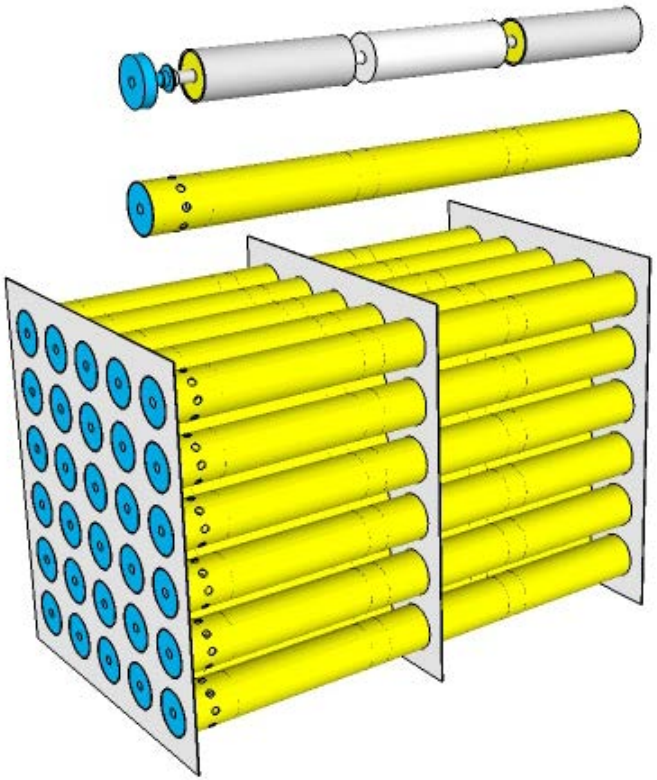
Low-Pressure Containerized Recycle Modules for the 10 MW_e System



Low-Pressure Containerized Capture Modules for the 10 MW_e System





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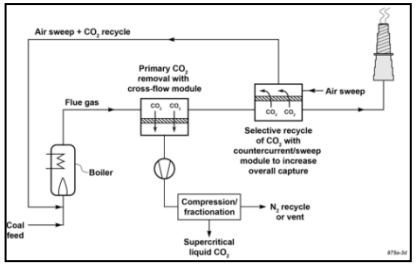
MTR CO_2 Capture Development Timeline

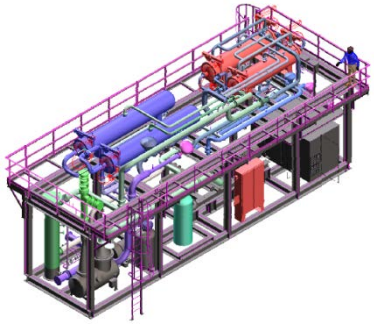
Feasibility study (DE-NT43085)
- Sweep concept proposed
- Polaris membrane conceived



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

APS Cholla Demo (DE-FE5312)
- First Polaris coal flue gas test
- 1 TPD CO_2 captured (50 kW_e)

NCCC 1 MW_e Demo (DE-FE5795)
- 11,000 hours of 1 TPD system operation
- 1 MW_e (20 TPD) system operation



Low Pressure Mega Module (DE-FE7553)
- Design and build a 500 m^2 optimized module

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

B&W Integrated Test

10 MW_e Large Pilot

TRL3 TRL4 TRL5 TRL6 TRL7 TRL8

2006 2008 2010 2012 2014 2016 2018 2020

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System Tests Scaled-Up Membrane Modules

Bundled spiral sweep modules

Bundled Polaris spirals

Polaris plate-and-frame (developed in DE-NT7553)

Advanced modules demonstrate lower cost and pressure drop

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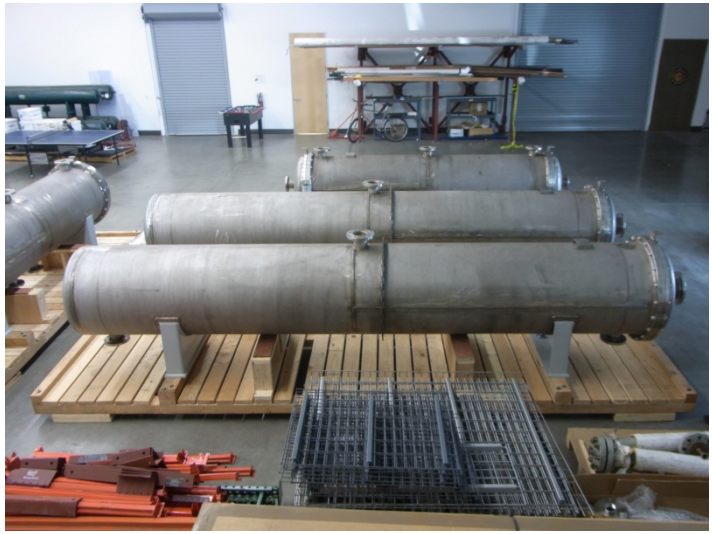
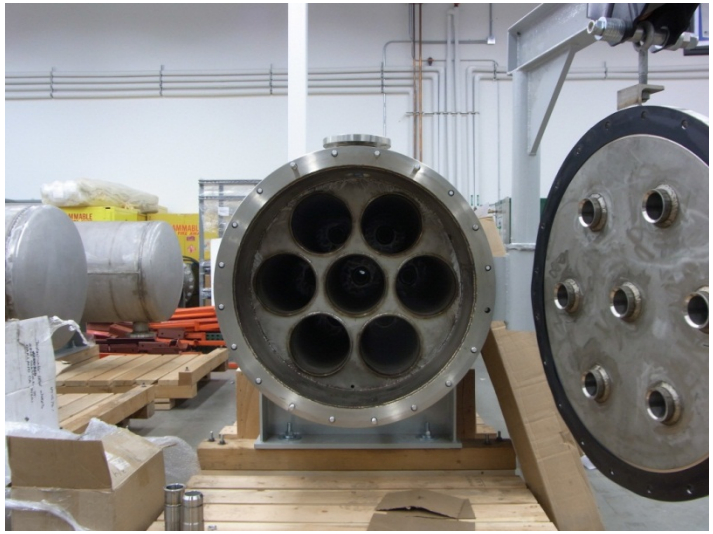
20 TPD Pressure Vessels





20 TPD Pressure Vessels