Turbomachinery Based Cryogenic CO_2 Capture

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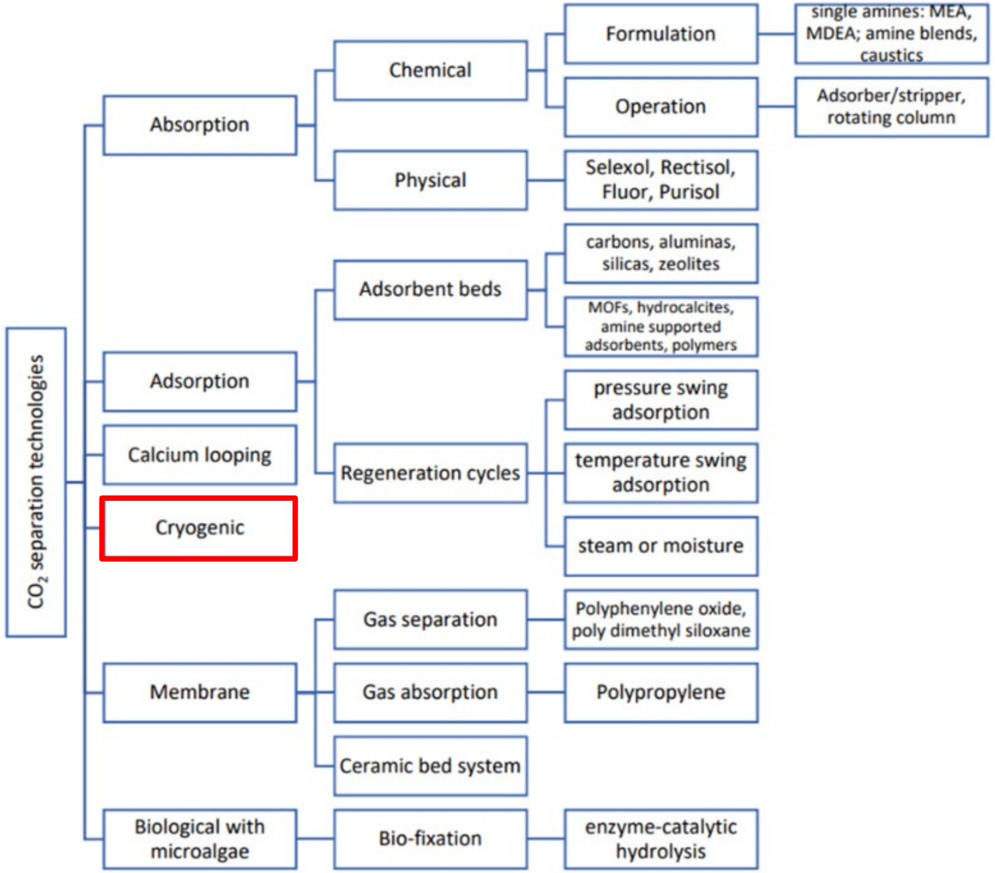
CO_2 Capture Technologies

- Cryogenic Capture is one of several technologies for separating CO_2 from flue gas
- Cryogenic separation has the benefit of using technologies familiar to power plant operators
  - Turbomachinery (compressors and turbines)
  - Heat Exchangers
- CO2 condenses by 'desublimation' going directly from gas to solid and is removed

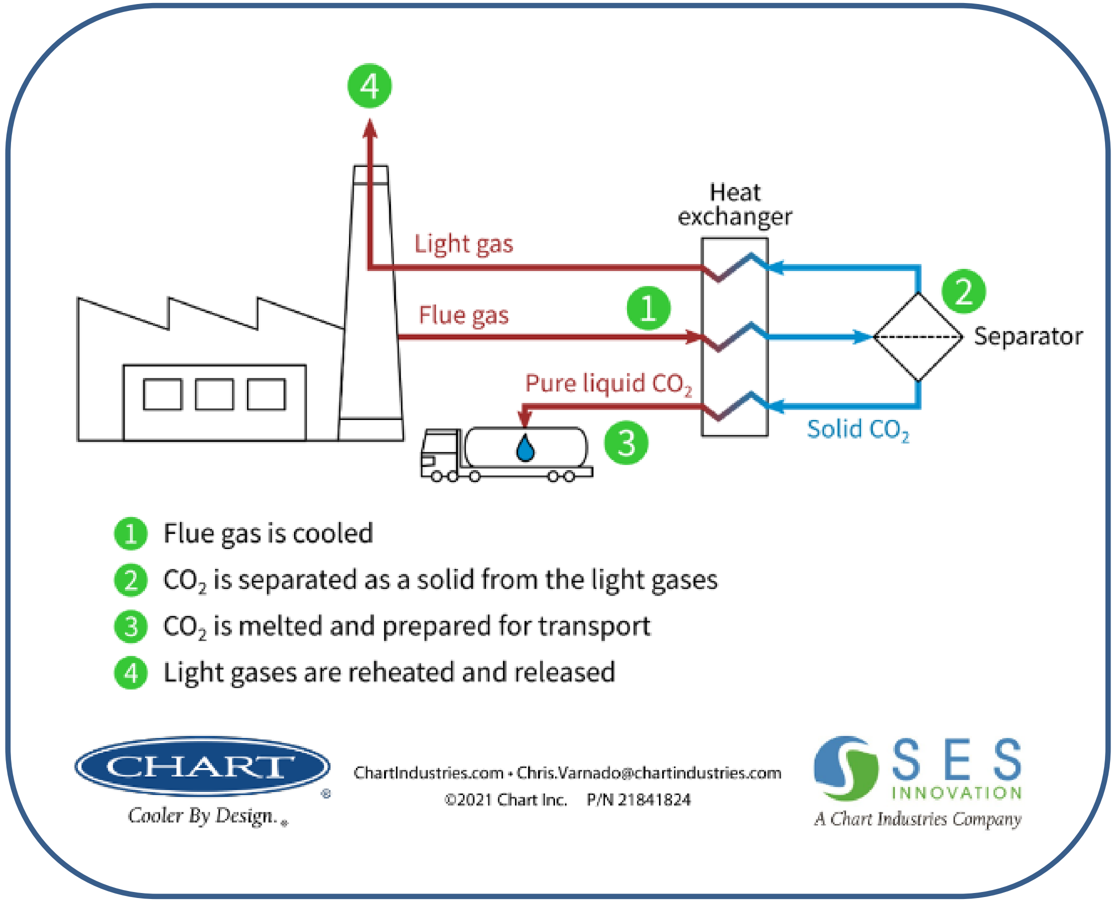


Font-Palma, C., Cann, D., Udemu, C., 2021, "Review of Cryogenic Carbon Capture Innovations and Their Potential Applications," C Journal of Carbon Research, 7, 58.

Two Ways to Cool a Fluid

Heat Transfer

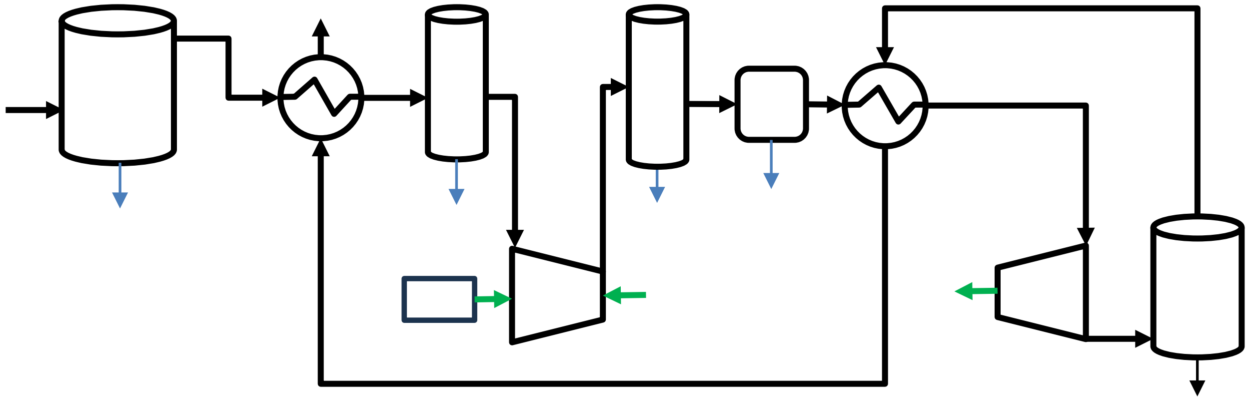
- Energy is removed from the fluid by heat transfer across a boundary
- Boundary surface area determines rate
- Requires a temperature gradient to drive the heat transfer process
- Boundary must be colder than the stream
- Freezing solids accrete on the cold boundary surfaces



Two Ways to Cool a Fluid

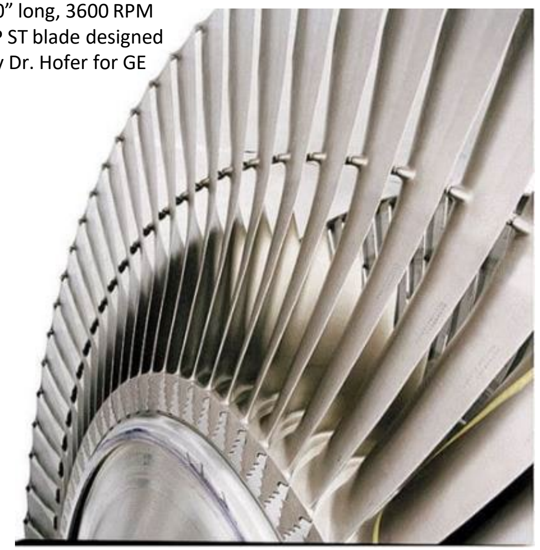
Work Extraction

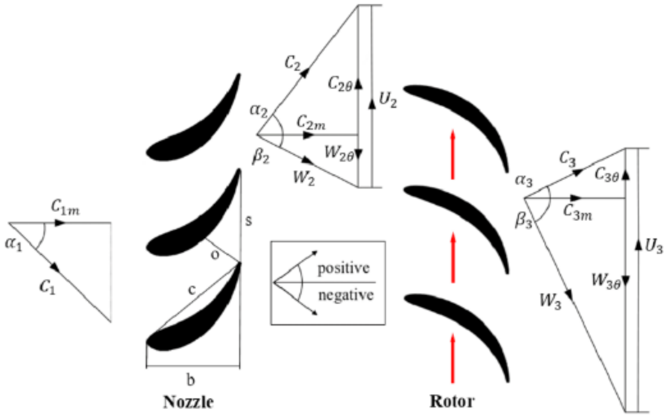
- Energy is removed from the fluid by extracting work through a moving boundary
- Volumetric effect, not dependent on boundary surfaces for better scalability
- Moving boundary can be positive displacement (piston/cylinder) or dynamic (turbine)
- Fluid can be cooled via work extraction even when the boundary surfaces are warmer than the fluid – eliminates accretion.

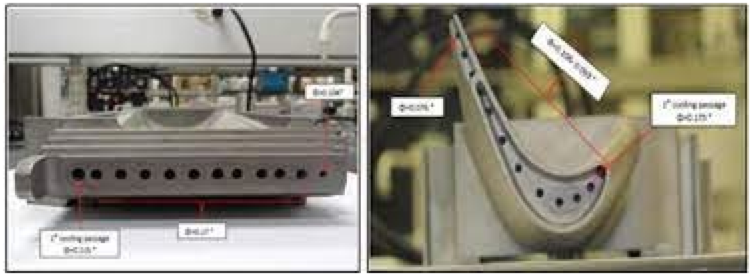


Key Advantage – Condensing Turbine

40” long, 3600 RPM
LP ST blade designed
by Dr. Hofer for GE







LP Steam Turbines have homogeneous condensation of up to 12% liquid

CO2 condensation differs:

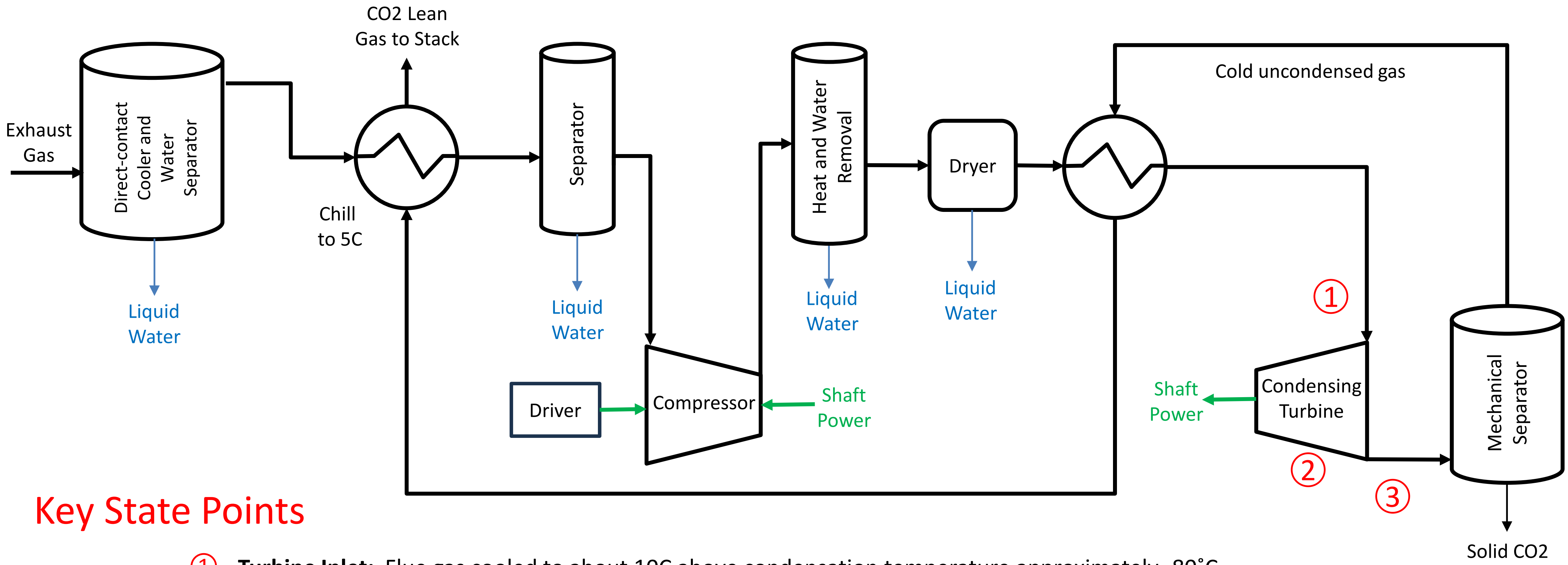
- Solid condensate
- Phases closer in density

Work extraction in turbine lowers enthalpy (cools) via work extraction – not surface heat transfer

Airfoil surfaces can be warmed with internal gas flow to avoid dry ice buildup – reverse of cooled gas turbine blades

These features combine to break the paradox of how to cool flow without buildup of CO2 ice on surfaces

Basic Turbomachinery Based Process



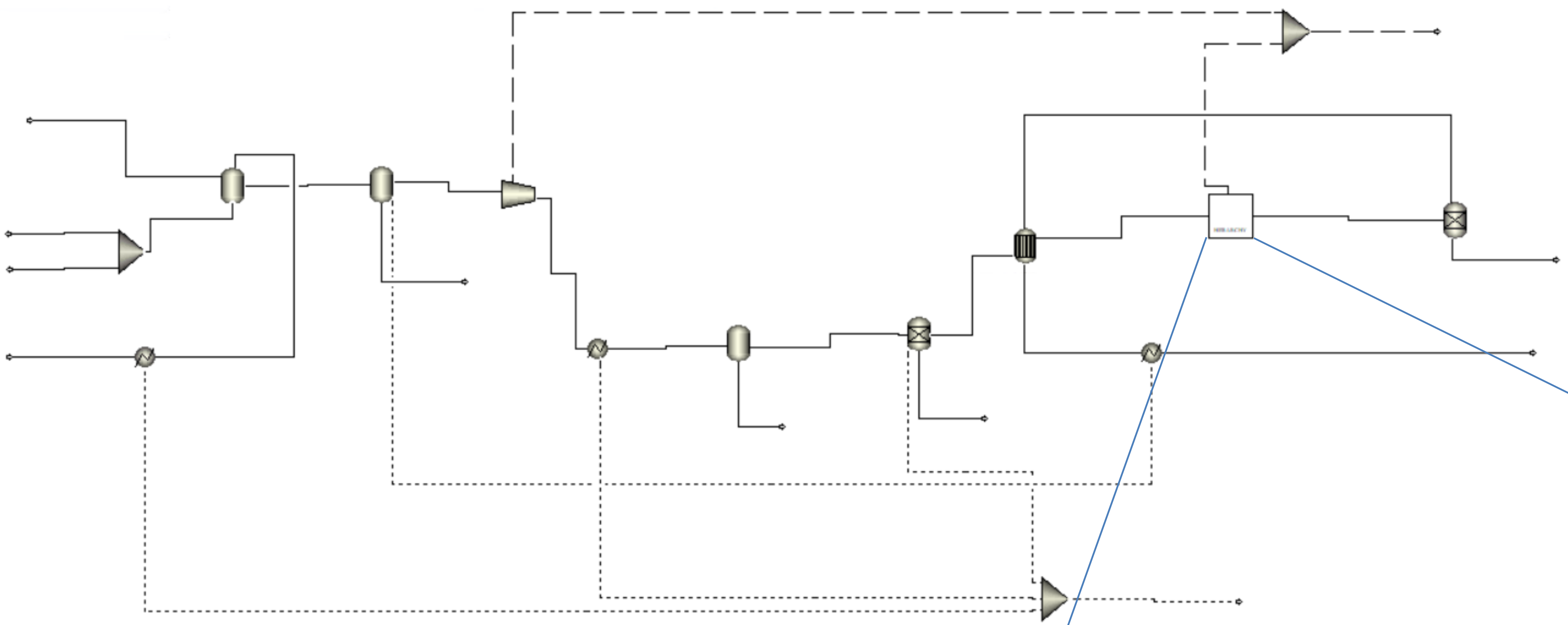
Key State Points

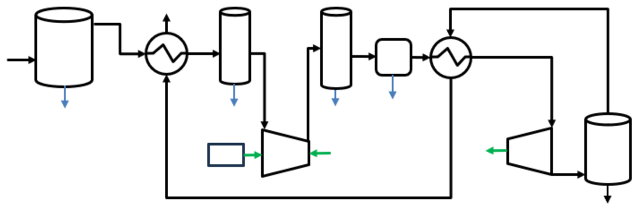
① **Turbine Inlet:** Flue gas cooled to about 10C above condensation temperature approximately -80˚C

② **Multi-phase Turbine:** Flue gas expands with work extraction lowering enthalpy and temperature

③ **Turbine Exit:** Cooled flue gas and condensed solid CO_2 exit turbine at approximately -120˚C

Ongoing Work: Process Modeling in Aspen Plus



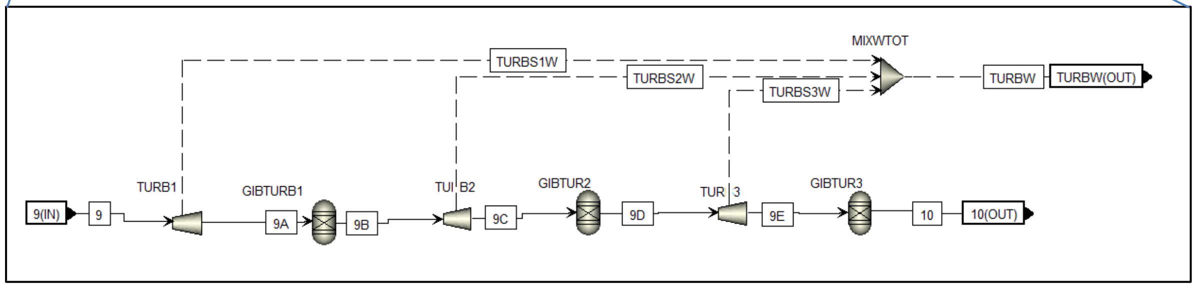


NGCC Baseline Reference
Exhaust Gas Composition (molar)

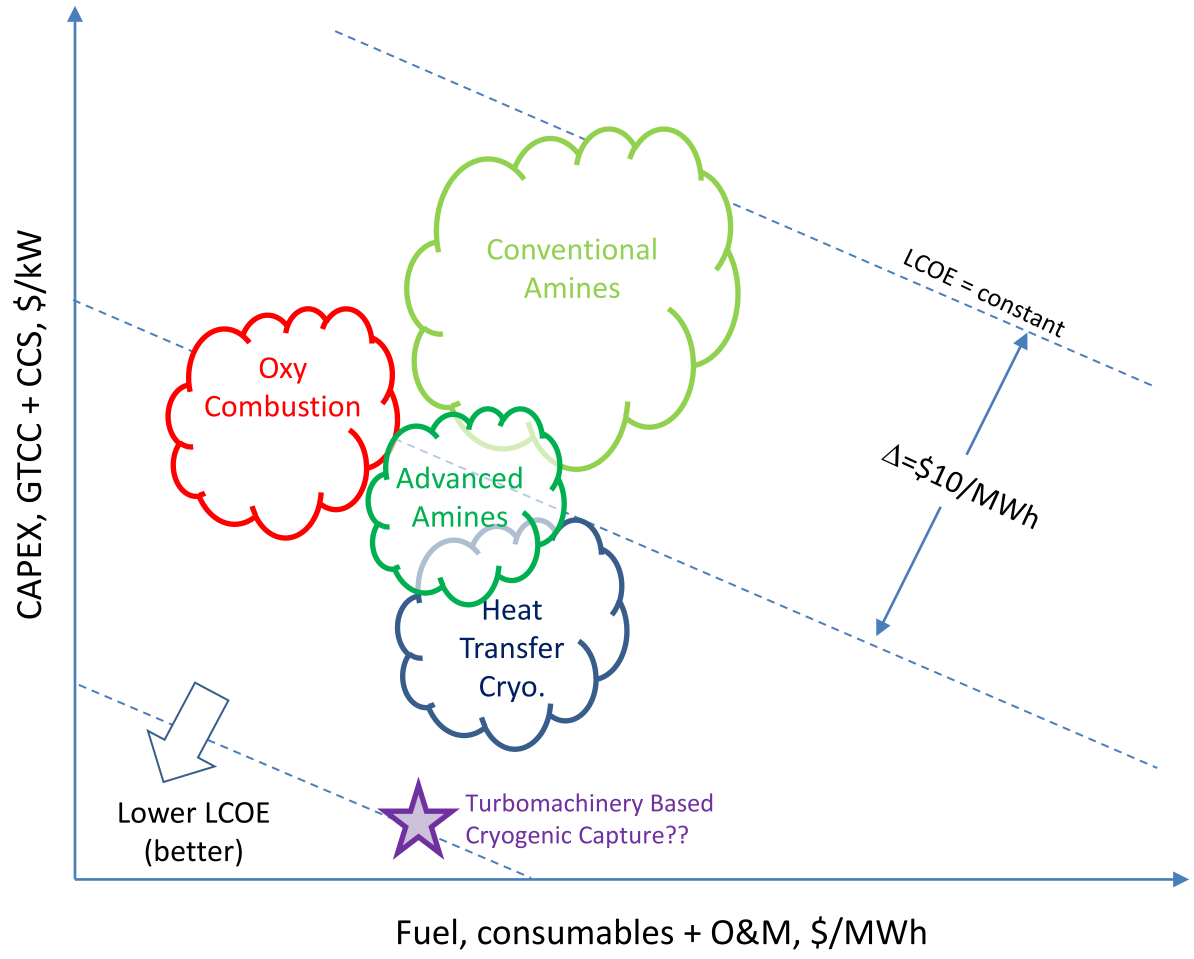
4.1%	CO_2
8.7%	H_2O
12.0%	O_2
0.9%	Ar
74.3%	N_2

1454 kg/s 2xGT

Model Predicts Required Exit Temps of:
- -119.3˚C for 90% capture
- -123.6˚C for 95% capture



Ongoing Work: Techno-Economic Evaluation



Levelized Cost of Electricity, LCOE, for a Natural Gas fired Gas Turbine Combined Cycle is influenced by:

- Capital cost of equipment
- Fuel costs & O&M costs

Models in this study will be developed to include cost and performance to quantitatively populate this chart

Research Program

SwRI Funded IR&D
- Feasibility
- Techno-economics
- Turbine design
- IP in process

Initial Demo
- 1-2 MW engine
- Radial turbomachinery
- Leverage turbochargers

$3-5 MM
24 Months

DOE / Partners

Large Scale Demo
- 10+ MW engine
- Axial turbomachinery
- Bespoke machinery

$10+ MM
36 Months

DOE / Partners

Turbomachinery based Cryogenic CO_2 Capture

- Potential for lower LCOE relative to Amine and oxy-fuel systems
- Solves paradox of cooling without solid CO_2 accretion
- Captures CO_2 with **no** chemicals and **no** consumables
- Inherently Scalable
- All equipment (turbomachinery, heat exchangers) is familiar to power plant operators
- Novel CO_2 condensing turbine opens new solution space

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