Techno-Economic Assessment of Direct Air Capture With Microwave-Assisted Regeneration of Sorbent

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1. Background

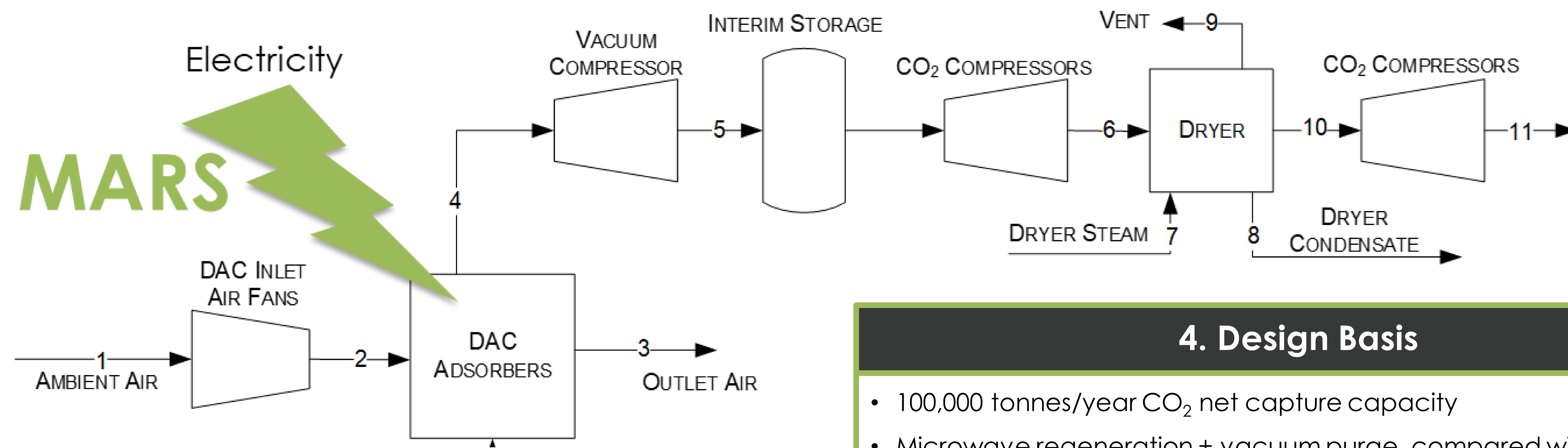
- Direct air capture (DAC) is a key carbon dioxide (CO_2) removal (CDR) technology for removing CO_2 emissions from air.
- DAC technologies commonly use sorbents or solvents to capture CO_2 from air, followed by thermal, mostly steam-based, regeneration.
- There is a recent interest in microwave heating that relies on targeted heating of sorbent, rather than bulk heating as is done in thermal swing regeneration. [1–5]
- Microwave regeneration leads to 2–10 times faster regeneration than thermal heating, resulting in a potential reduction in costs.

2. Objectives

- Perform a high-level techno-economic analysis of microwave-assisted regeneration of sorbent (MARS)-based DAC technology
- Compare the results with a conventional steam-based thermal-vacuum swing adsorption (TVSA) DAC process
- Perform sensitivity analysis on key parameters to identify DAC-specific and microwave-specific variables that impact feasibility

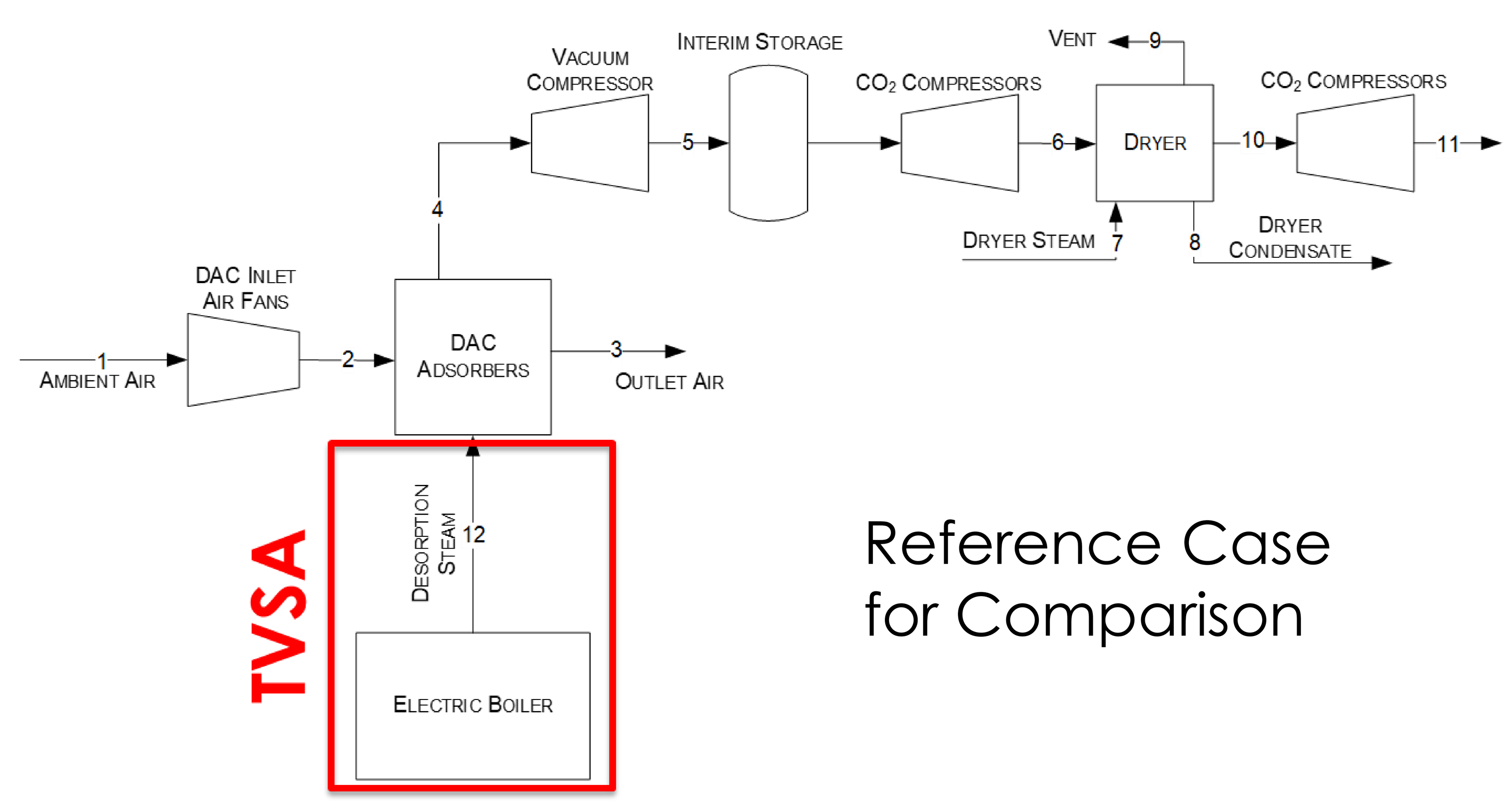
3. Microwave Regeneration

- Desorption mechanism
  - Selective heating of CO_2-adsorption site
  - Indirect heating of CO_2-adsorption site by heating of co-adsorbed water)
  - Bulk heating of sorbent
- Sorbents used for microwave-based CO_2 capture
  - Zeolite 13X, activated carbon, amine-functionalized silica or polymers, etc.
- Relevant sorbent properties
  - Dielectric properties (particularly, "loss factor")
  - Characteristic distance or "penetration depth
- Sorbent structure: powder, beads/pellets, laminate, monolith
- Desorption temperature similar to, or potentially lower than, conventional steam-based heating
- Reactor design
  - Radial fixed/moving bed
  - Fluidized bed
  - Monolith
  - Moving bed reactor design is likely to lead to uniform heating of sorbent, but the microwave waveguides, etc., can be designed to achieve relatively uniform heating even with a monolith design
- Overall efficiency of regeneration depends on a combination of microwave cavity design, power, sorbent, reactor structure, and type



Block Flow Diagram of MARS-based DAC Process

Block Flow Diagram of Steam-based TVSA Process



Reference Case for Comparison

4. Design Basis

- 100,000 tonnes/year CO_2 net capture capacity
- Microwave regeneration + vacuum purge, compared with existing TVSA models that use an electric boiler for regeneration steam
- System design assumptions
  - Generic midwestern U.S. location (15 °C, 1 bar, 420 ppmv CO_2)
  - Monolith contactor
  - Regeneration at 80 °C and 0.2 bar
  - Electricity from the grid
- MARS cycle adsorption time 0.75 hours and desorption time 0.05 hours
  - Compared to 1 hour adsorption and 0.11 hours desorption for TVSA
- Levelized cost of CO_2 capture will be used as a comparison metric

5. Sensitivity Analysis

Parameter	Base Case	Sensitivity
Microwave Generator Efficiency (%)	75	60–90
Microwave Thermal Efficiency (%)	80	60–90
Regeneration Energy (GJ/tonne CO_2)	2	1–3
Sorbent Lifetime (years)	1	0.25–4
Co-adsorption of Water (mol CO_2/mol H_2O)	1	0–2
Sorbent Working Capacity (mol CO_2/kg)	0.8	0.1–2
Adsorption Time (hour)	0.75	0.5–1
Regeneration Time (hour)	0.05	0.01–0.05

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