SCO_2 Workshop

Summary of Take-Aways

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Conditions to displace conventional technologies

- Performance and cost target threshold:
  - Cycle efficiency 2-4% over steam Rankine: 600C, ~200 bar, mid-40s cycle efficiency, $700-800 /kW Power Block Capital Cost
    - Notes: LCOE (Cap Cost, Efficiency, Fuel Cost, O&M) bottom line
- Market barriers
  - Steam Cycle Technology will conitne to advance – targets are not static
  - Technology Development at System Fully Integrated Level (i.e. sub-system / component development lacks "vertical" integration / wrapped performance guarantee)
  - Smaller units at larger #'s for de-risking
  - Training of personnel (automation, skill-level for sCO2, etc.)
  - Demonstration facility at the correct T,P's for a broad market needed for market acceptance
  - Non-technical area: Financing will be a barrier unless there is adequate confidence in demonstration
  - For large power applications , solar applications, etc. - need to demonstrate at a 1/5 scale before generating interest
  - Have to have a supply chain ready to support the next step
- Market Opportunities
  - Needs of the utilities are changing. Flexibility is good (lack of clarity on entry-level scale, faster start up times, ramp rates, smaller sizes).

Demonstration (scale / duration / application) needed for market acceptance

Size range and performance targets for a demonstration

- For large power applications , demonstrate at a 1/5 scale demo at **10MW** is at least $60M - $100M incl. combustion
- Need 8,000 hours of operation, both for system but also need to look at component level
- Use Existing Grid tied facilities
- Some key learnings: Demonstrating integration at a smaller scale may be a better strategy. May not learn everything, but maybe enough to demonstrate confidence at a larger scale.

Primary system integration issues for sCO_2 cycles

- No software tools to simulate in fine detail temporarily. Need to move in concert with hardware development.
- No significant electrical integration issues
- Having more validated models is a gap

DOE SCO_2 Tech Team Plan

Contingent on appropriations, the SCO_2 Tech Team is developing an approach for addressing RD&D needs that can lead to the widespread deployment of SCO2-based power systems. This approach is based on the following three pillars as major activities:

1. ***Technology Development Activities***

2. ***Pilot-scale (STEP) Demonstration***

3. ***Pre-commercial Demonstration***

Pilot-scale (STEP) Demonstration

- **Technical Metrics:**
  - Size: 10 MW_e
    - Design point relies on industry needs – what is the end goal?
      - Interest in small (100 MW) scale, but to put significant funding in, need large scale (250-500 MW) applications
      - Marketing study is required to figure out what demand will be – particularly to gauge interest in smaller scale applications (e.g. 10 MW)
        - Smaller scale applications will utilize resources currently not being valued vs. applications for current markets
      - There is no single application – what are the common needs that can be addressed by this pilot?
    - What do the power producers want?
      - Flexibility is important characteristic for any product
        - Competing with DG, but also CHP, fuel cells, et al.
        - Variable sizing (a few MW to 10s of MW) would be very attractive
      - Still unclear what business needs will be
    - Based on 1:5 scaling, 10 MW is appropriate for this stage
      - Therefore, this plant should be designed to answer questions about the 50 MW demo

– Cooling: Dry
– Efficiency: ≥ 40%
– Temperature: ≥ 450˚C - 600˚C
  - Difficult to build 700C larger scale plant if it hasn't been demonstrated yet at this smaller scale
  - At 10 MW, goal is to prove out components *up to* 700C
  - Within context of 10 MW plant, important to design larger scale plant as well – what do you need to learn at the smaller scale to allow building of the larger plant?
– Cycle configuration: RCBC
– Grid connectivity: Maybe
  - Grid connectivity offsets the cost, but permitting could be expensive and difficult
– Hours: ≥ 8000
  - Fuel costs will be huge if not grid-connected
– Cost: ~$60M
  - Difficult for industry to invest until customer market is clear

Pre-commercial Demonstration

Technical Metrics:

- Size: 50 Mw_e
  - Tightly coupled to cost – what's the min size to achieve other metrics?
- Cooling: Dry
  - Wet cooling will still be an option in the future – if you can locate with water resource, why not take advantage of it
  - May preclude 50% efficiency
- Efficiency: ≥ 50%
  - Should have a dry cooling target and wet cooling target
  - 2-4 %pts [net plant efficiency] above conventional may be a more reasonable target
  - Efficiency is output of complex variables – approach could be to fix T,P targets
  - Question is what efficiency is targeted for commercial deployment – that changes efficiency requirements for demo
  - 50% is 10%pts above 50 MW SOA – may be non-viable for commercial deployment
  - Case is indirect fired baseload plant competing against coal plant – these metrics don't necessarily make sense for other applications
  - <550C brayton and rankine cycle efficiencies are identical
  - Efficiency target without considering cost is problematic
  - These targets will not compete with NGCC (~55% efficiency; ~50% at comparable scales)
    - Target could be slightly lower than NGCC, but with 1 plant – lower capital costs
  - Should not specify cycle configuration - encourage industry innovation

- Temperature: ≥ 600˚C - 750˚C
- Cycle configuration: RCBC
  - May not be appropriate for nuclear applications; CSP also
    - More likely that fossil fired heat source will be ready to interface with cycle at the appropriate time
- Grid connectivity: Yes
- Hours: ≥ 8000
  - 45% efficiency would dispatch economically for many hours
- Cost: ~$300M
  - Need smooth transition between paper study and build of demo plant
  - Equivalent to $6000/kW – that seems a reasonable forecast at this point
  - Cost share will only be achievable based on successful outcomes of previous demos

Technology Development Activities

- **Materials characterization**
  - Important to also look at low T materials that we may not fully understand
    - For high T (750 C): 740 inconel, 282
    - Low T (550C): haynes 230, 617, 625
    - Below 550C: stainless steels
  - Current DOE programs have already done a lot of materials testing
    - Need to test CO2 in a flow loop – previous developed methodologies are sufficient
    - Need to look at addition of carbon into the metals from CO2
  - Manufacturing costs need to be taken into account – should be involved in materials characterization
    - E.g. machining on Ni components can take much longer
  - Non-metallics also need to be considered (e.g. seals)
- **Component development/testing**
  - Some off-the-shelf components exist, but may compromise optimization
    - E.g. Dry gas seals only operate at <200C
    - Would like to use high pressure gas bearings, but compatibility is an issue
  - Heater could be a problem if design is not carefully considered
    - For smaller scales cost can be significant
  - Bearings, valves, seals have lots of scaling questions – not always easily translatable between sizes
    - Designs are very dependent on size – important consideration is final intended application size

- **Modeling**
- **Especially difficult to disconnect modeling from component testing and materials characterization**
- **Controls**
- **Other**
  - **Connections between the various topics is important**
  - **Gas properties near the critical point, impact of impurities, etc**
  - **Heat transport –**
  - **Model verification – feeding into operation of subscale plant**
  - **Question about openness of data**
    - **Maybe a component test rig at ~5MW that produces shareable data**
  - **Codes and standards**
    - **Might be result of demo results, but important to consider at early stages**
    - **Design performance test codes**
  - **Inspectability**