ITM Oxygen: Scaling Up a Low-cost Oxygen Supply Technology

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ITM Oxygen Enables a Step-change Reduction in the Cost of Oxygen

Conceptual ITM Oxygen vessel scaled to match cryogenic oxygen plant output
What is ITM Oxygen?

- Uses ceramic membranes to separate oxygen from air
- 100% selective to oxygen with extremely high flux (pure, very compact)
- Feed air must be heated (800 – 900 C) and compressed (200 – 300 psig)
  - Energy recovered from depleted air, typically through power generation cycle
  - Integrates well with high temperature and pressure processes
- Can use syngas, gaseous or other fuel to make pure oxygen, power and steam
  - Does not consume electric power
  - Produces net power and steam as desired
- Step-change savings compared to state-of-the-art cryogenic technology
  - 35% less capital
  - 35-60% less power up to 1000 psi product pressure
Ceramic Membranes: Revolutionary Technology for Tonnage Oxygen Supply

- Single-stage air separation leads to compact designs
- Low pressure drop on the high-pressure side
- High-temperature process has better synergy with power generation systems
- Extraordinary flux enables large tonnage production economics

0.5 TPD module (commercial-scale)
ITM Oxygen integrates well with power generation cycles

ITM Oxygen separator integrated with a gas turbine-based power cycle
ITM Oxygen is Simpler and Requires Less Power

Cryogenic Air Separation

ITM Oxygen With Power Integration

ITM O2 Has Much Simpler Flow Sheet and >35% Less Capital

ITM O2 Has 35-60% Less Compression Energy Associated with Oxygen Separation
ITM Oxygen has Excellent Economic Performance in Many Applications

<table>
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<th>Application</th>
<th>Oxygen (sTPD)</th>
<th>Power (MW)</th>
<th>Capital for Oxygen</th>
<th>Power for Oxygen</th>
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†enables carbon capture  
*uses existing gas turbine offerings
ITM Oxygen Program

- **Goal:** Reduce Cost of Oxygen by One-Third
- **DOE/Air Products R&D started 1999 (11 year, $148 million)**
  - Phase 1: Technical Feasibility (0.1 TPD O2)
  - Phase 2: Prototype (1-5 TPD O2)
  - Phase 3: Pre-commercial Development (25+ TPD)
    - Planning 150 TPD

- **Development Team**

![List of Development Team members]
Rapid Progress in ceramic processing during Phase 1
Overall Technical Feasibility was established in Phase 1

✓ Materials
✓ Commercial-size Planar Wafer Architecture
✓ Stable Flux and Purity
✓ Economic benefits re-confirmed
The feasibility of producing commercial-scale modules was established during Phase 2.
We are well on our way to completing the major goals of Phase 2

✓ Fabricate commercial-scale modules
✓ Establish feasibility of Machinery Integration (with Siemens Power Generation, Inc.)

➢ Test commercial-size modules under full driving force conditions
  ➢ Design, build, operate a 1-5 TPD Subscale Engineering Prototype (SEP)
We wish to test commercial-scale ITM Oxygen modules, simulating a region of a large tonnage oxygen separation unit.

Test up to six (6) commercial-scale modules at full pressure, temperature, driving force and air throughput in the pilot unit.
Broad Program Goals of the SEP

- Test concepts for vessel *internal* design
- Test process control strategy
- Assess commercial-scale module performance
  - Phase 2 concludes with successful testing of commercial-scale modules with criteria for performance in:
    - Flux
    - Purity
    - Reliability (Start-up/Shutdown)
5 TPD SEP Skid Design – Isometric
The SEP was started up in Oct. ’05, commissioned in April ‘06
SEP Flow Duct Houses ITM Oxygen Modules with 3-6 TPD Capacity
Initial SEP work **highly successful**

- Several trials with 0.5-TPD modules since May
- Demonstrated >99% oxygen purity from commercial-scale module and seal
- Oxygen flux consistently has met or exceeded expectations, and has been steady
- Currently running modules through start-up/shutdown cycles to test reliability
Future Work: Phase 3 Development Plan meets DOE FutureGen Schedule and Market Timing
Longer Term: The full benefits of ITM Oxygen are realized in power cycles that are tightly integrated with advanced gas turbines.

Siemens/Air Products have concluded that integration with a Siemens’ large-frame gas turbine is technically feasible and achieves the full benefits of ITM Oxygen technology.
However, Integration with Currently Available Baseload Turbines is Also Achievable and preserves Good Economic Benefits
Conclusions

- Major Phase 2 ITM Oxygen development objectives have been met
  - Built and tested commercial-scale ITM Oxygen modules successfully

- Air Products and the U.S. DOE are planning an expanded Phase 3 to enable ITM Oxygen to produce large-tonnage quantities of oxygen in the FutureGen plant
Acknowledgment: DOE/NETL

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