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

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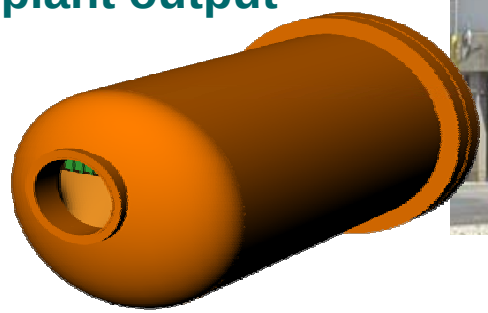
# ITM Oxygen Enables a Step-change Reduction in the Cost of Oxygen


**Conceptual ITM Oxygen vessel scaled to match cryogenic oxygen plant output**



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# 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**

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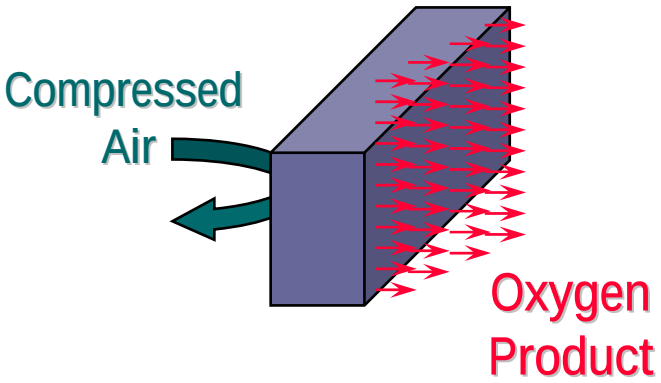
# Ceramic Membranes: Revolutionary Technology for Tonnage Oxygen Supply




**0.5 TPD module (commercial-scale)**

- **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**

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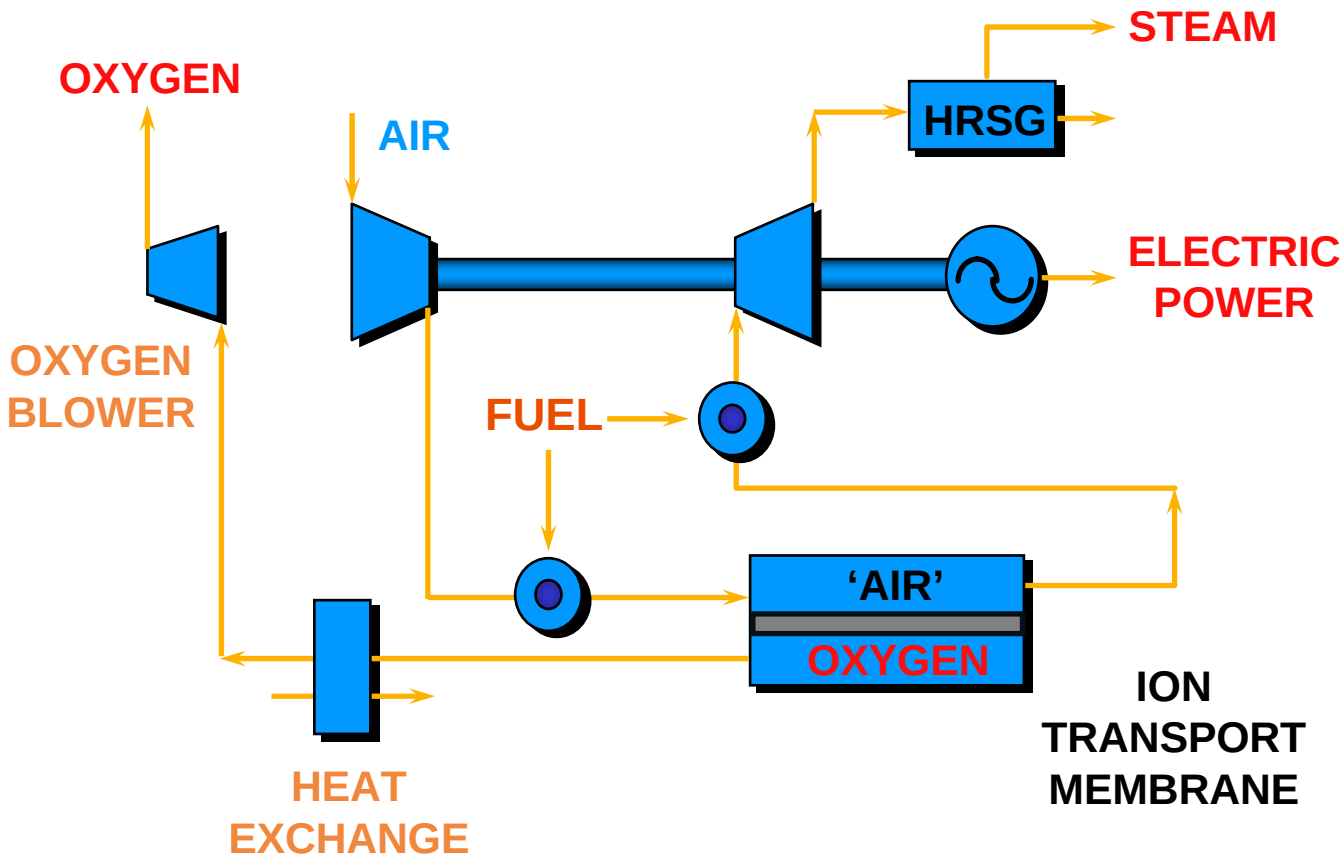
# ITM Oxygen integrates well with power generation cycles




ITM Oxygen separator integrated with a gas turbine-based power cycle



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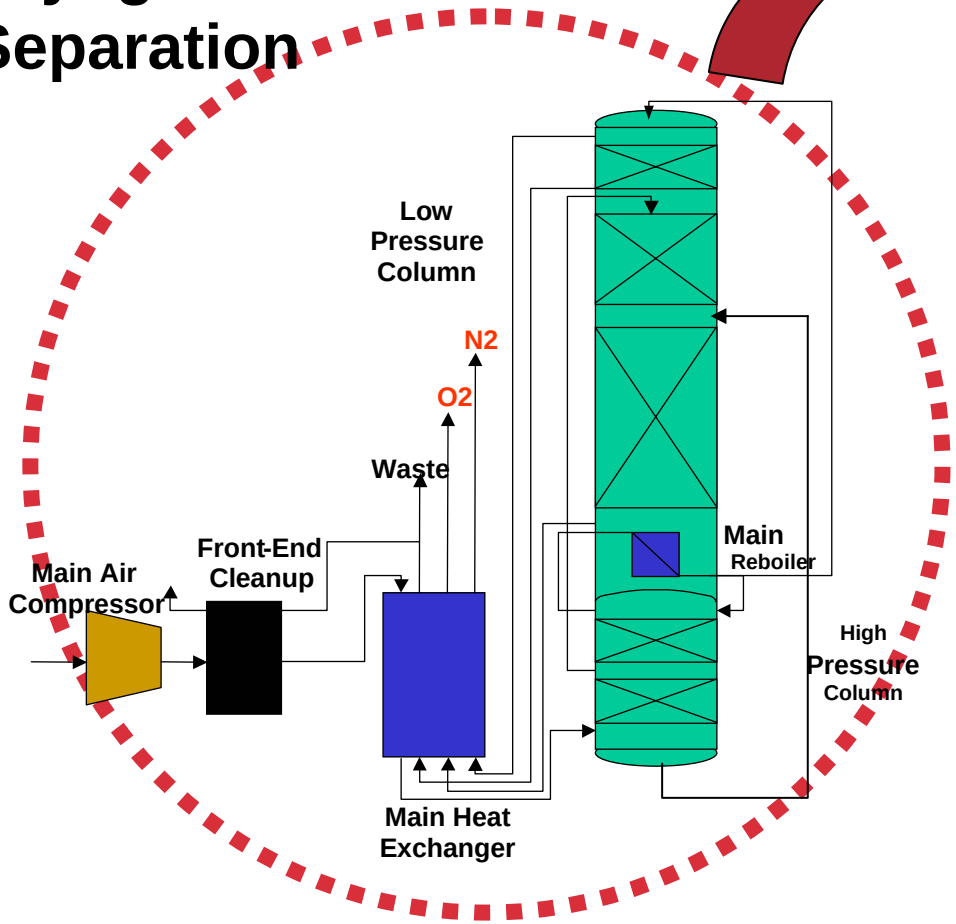
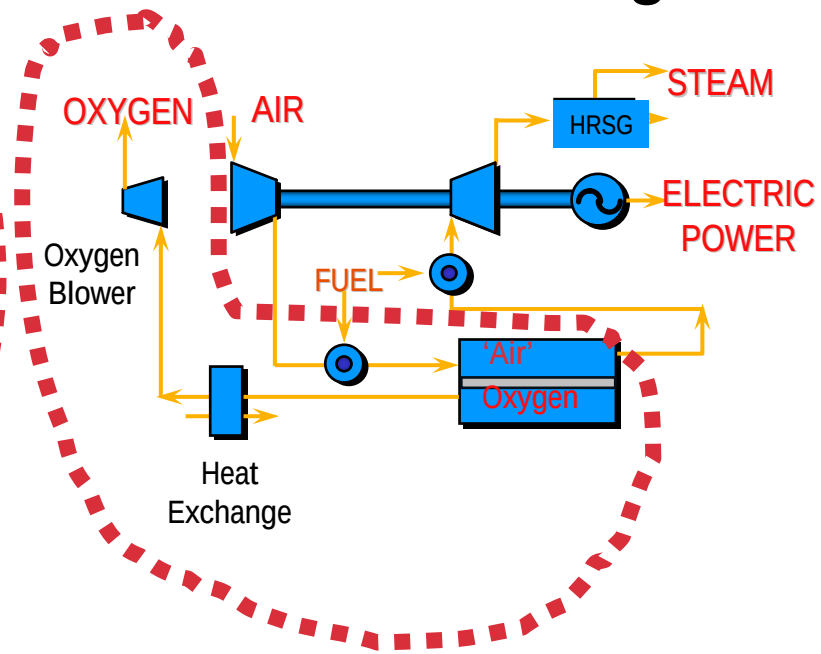
# ITM Oxygen is Simpler and Requires Less Power

## 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



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# ITM Oxygen has Excellent Economic Performance in Many Applications

| | Product | | Savings (% of Cryo ASU) | |
|---|---|---|---|---|
| **Application** | **Oxygen (sTPD)** | **Power (MW)** | **Capital for Oxygen** | **Power for Oxygen** |
| **IGCC** | **3200** | **458** | **35%** | **37%** |
| **Decarbonized Fuel†** | **2400** | **300** | **35%** | **36%** |
| **Enrichment*** | **1500** | **260** | **27%** | **69%** |
| **Oxyfuel†*** | **8030** | **500** | **48%** | **68%** |
| **GTL** | **12,500** | **n/a** | **20+%** | **n/a** |

†enables carbon capture

*uses existing gas turbine offerings



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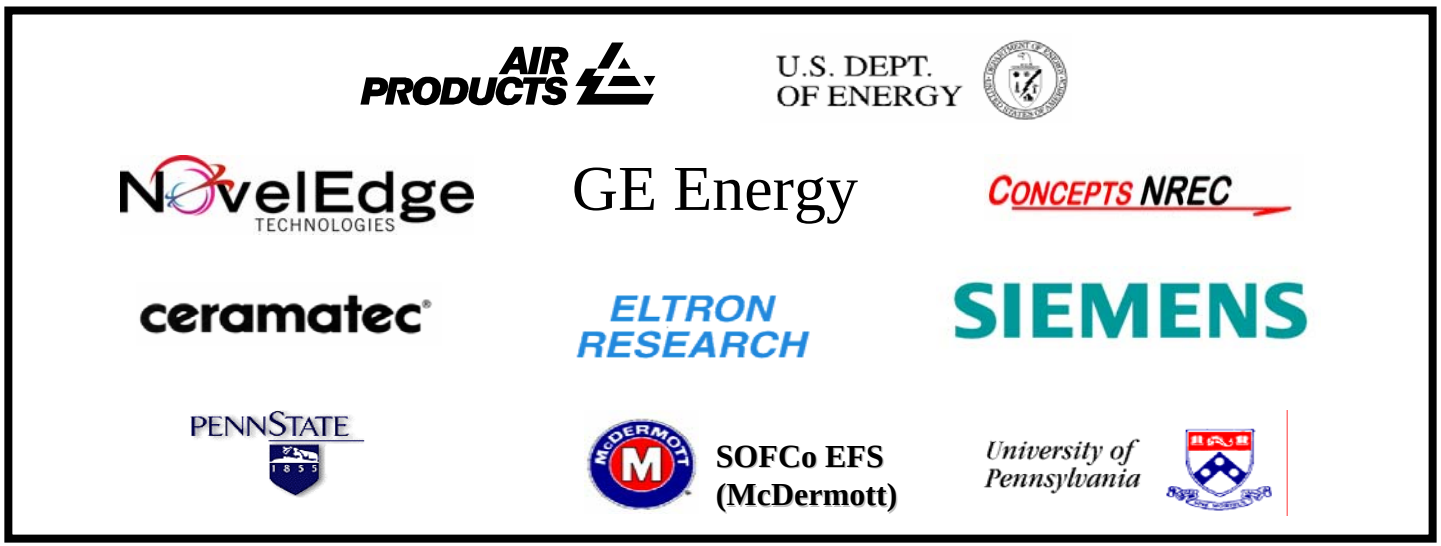
# ITM Oxygen Program

- **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**



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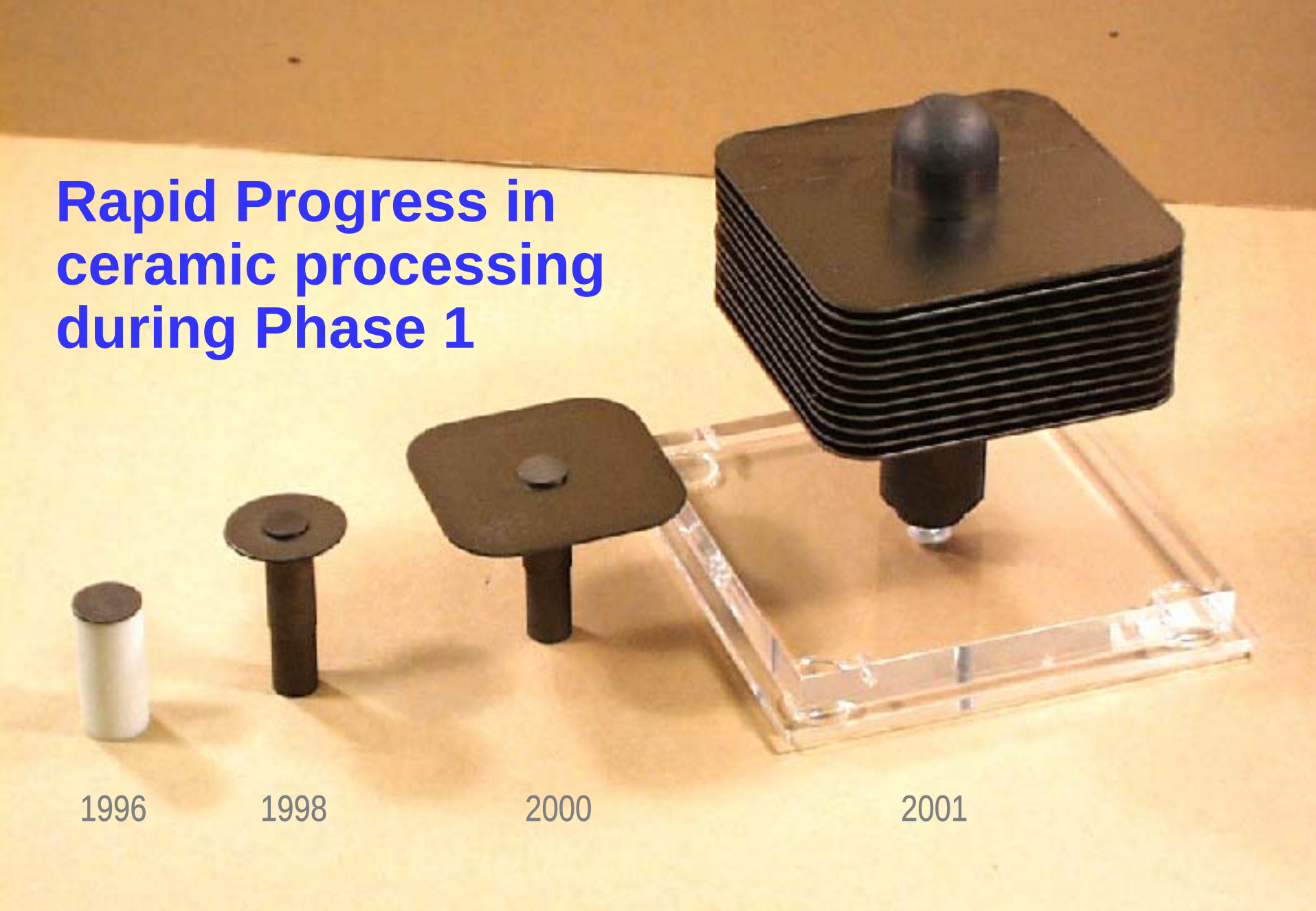
# Rapid Progress in ceramic processing during Phase 1



# Overall Technical Feasibility was established in Phase 1

- ✓ **Materials**
- ✓ **Commercial-size Planar Wafer Architecture**
- ✓ **Stable Flux and Purity**
- ✓ **Economic benefits re-confirmed**



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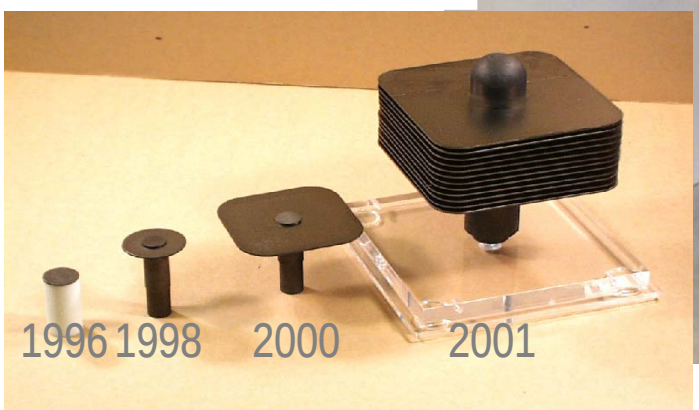
# The feasibility of producing commercial-scale modules was established during Phase 2

# 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)**



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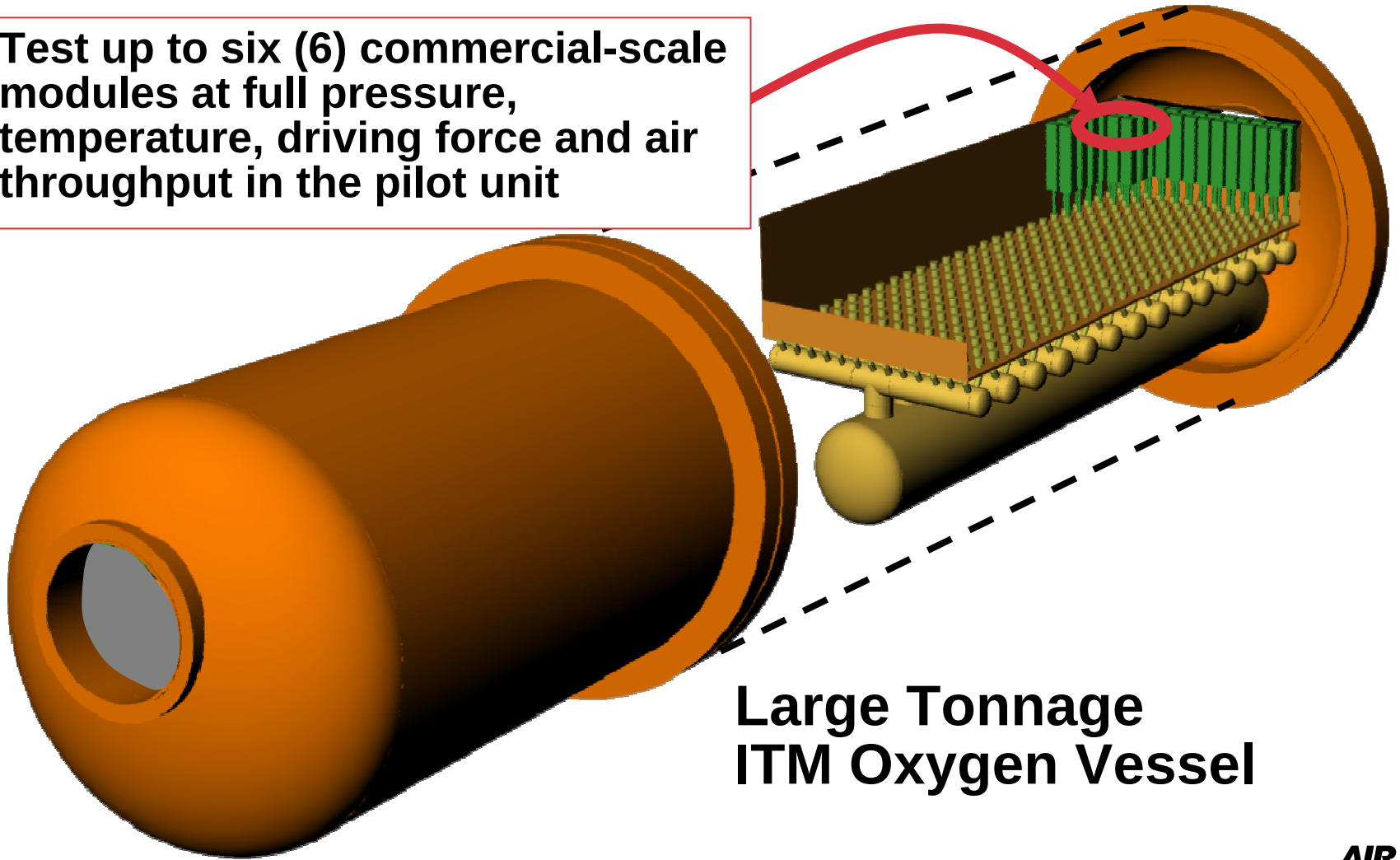
# We wish to test commercial-scale ITM Oxygen modules, simulating a region of a large tonnage oxygen separation unit

**Test up to six (6) commercial-scale modules at full pressure, temperature, driving force and air throughput in the pilot unit**



**Large Tonnage ITM Oxygen Vessel**

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# 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)**



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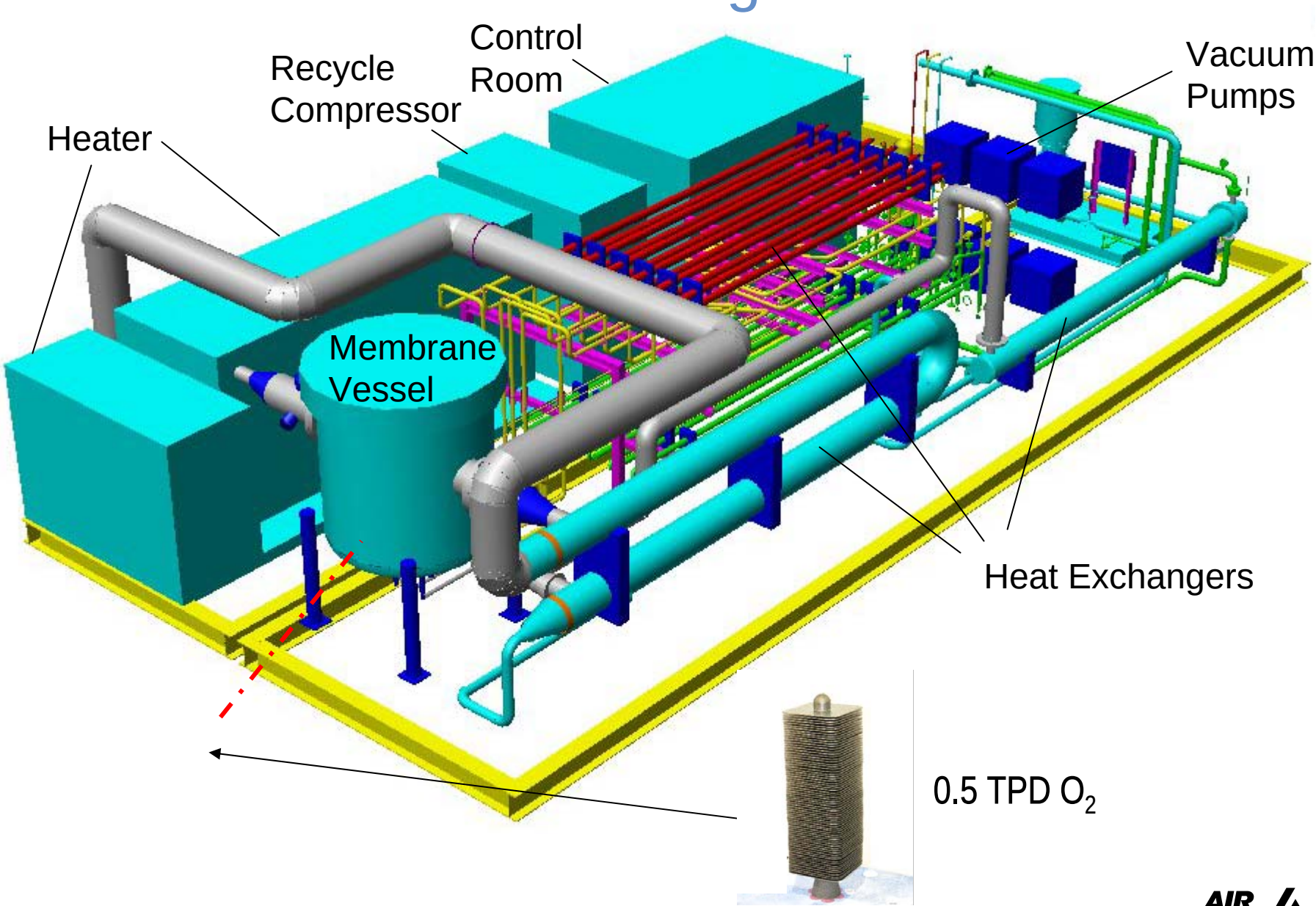
# 5 TPD SEP Skid Design – Isometric



# The SEP was started up in Oct. ’05, commissioned in April ‘06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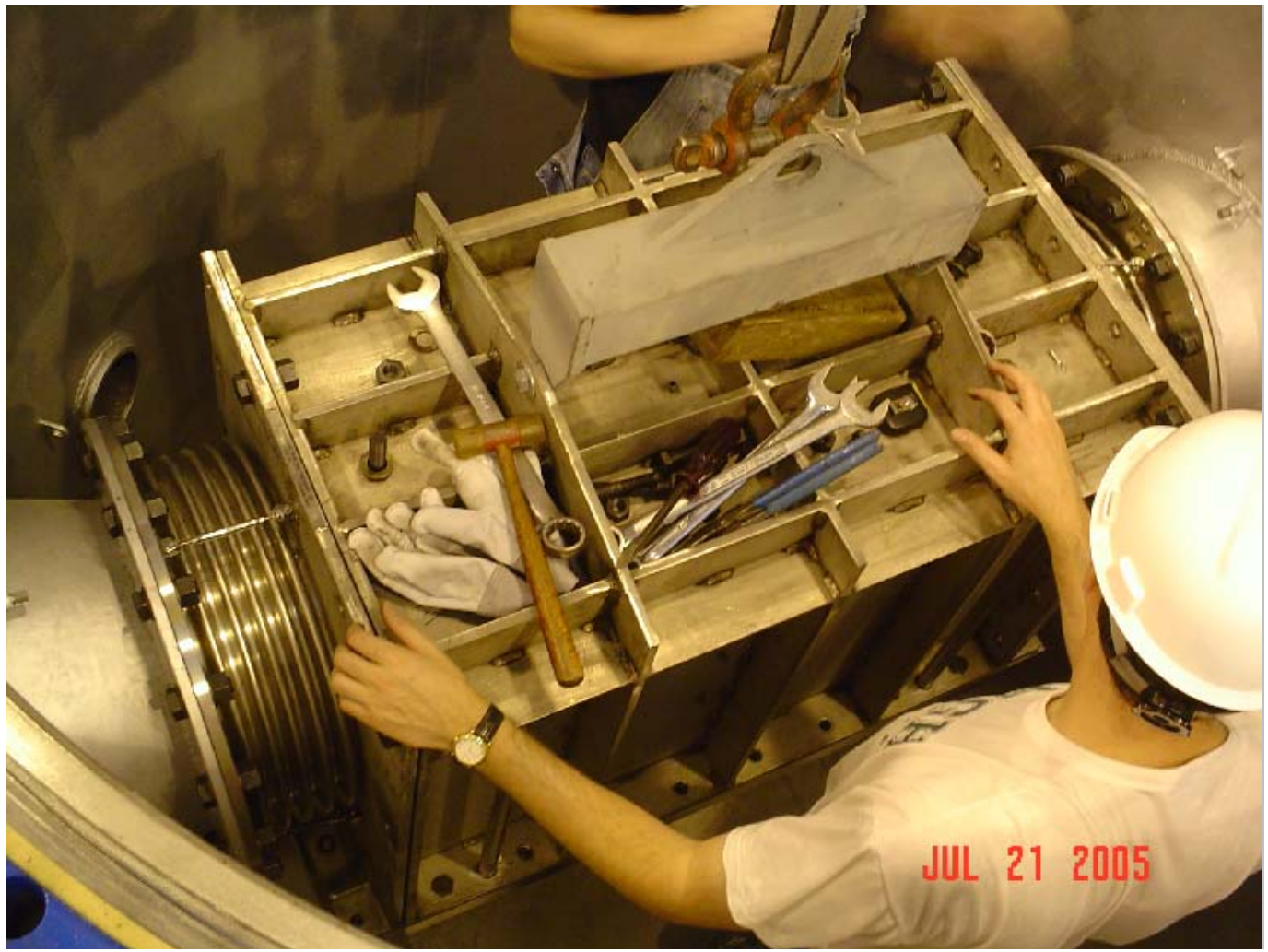
# SEP Flow Duct Houses ITM Oxygen Modules with 3-6 TPD Capacity



# 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



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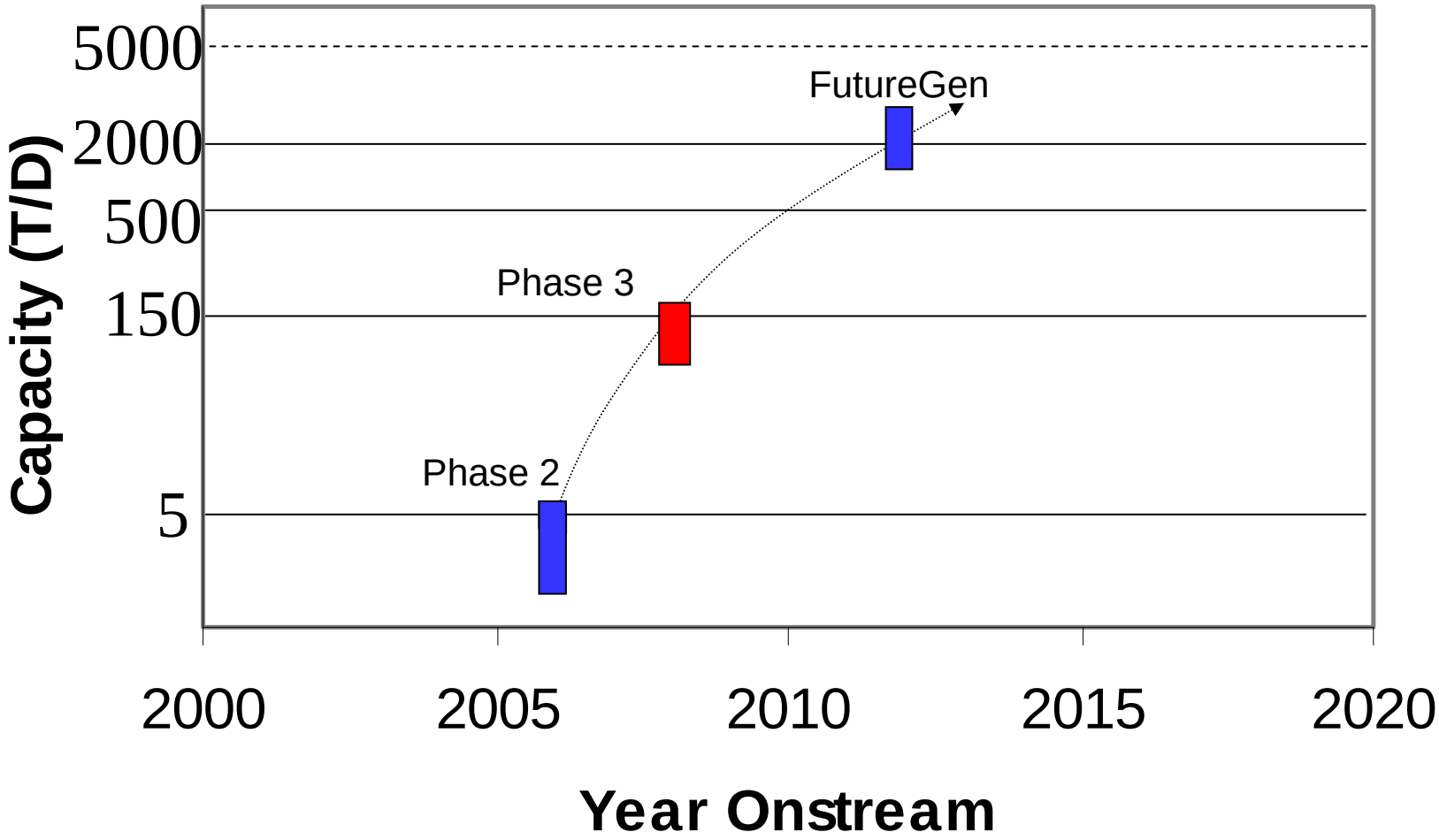
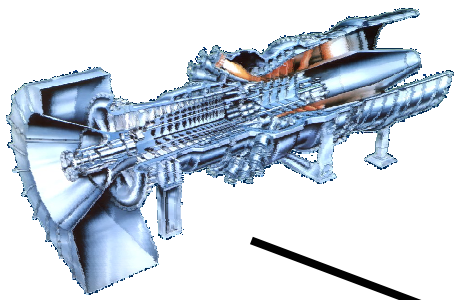
# Future Work: Phase 3 Development Plan meets DOE FutureGen Schedule and Market Timing



# Longer Term: The full benefits of ITM Oxygen are realized in power cycles that are tightly integrated with advanced gas turbines

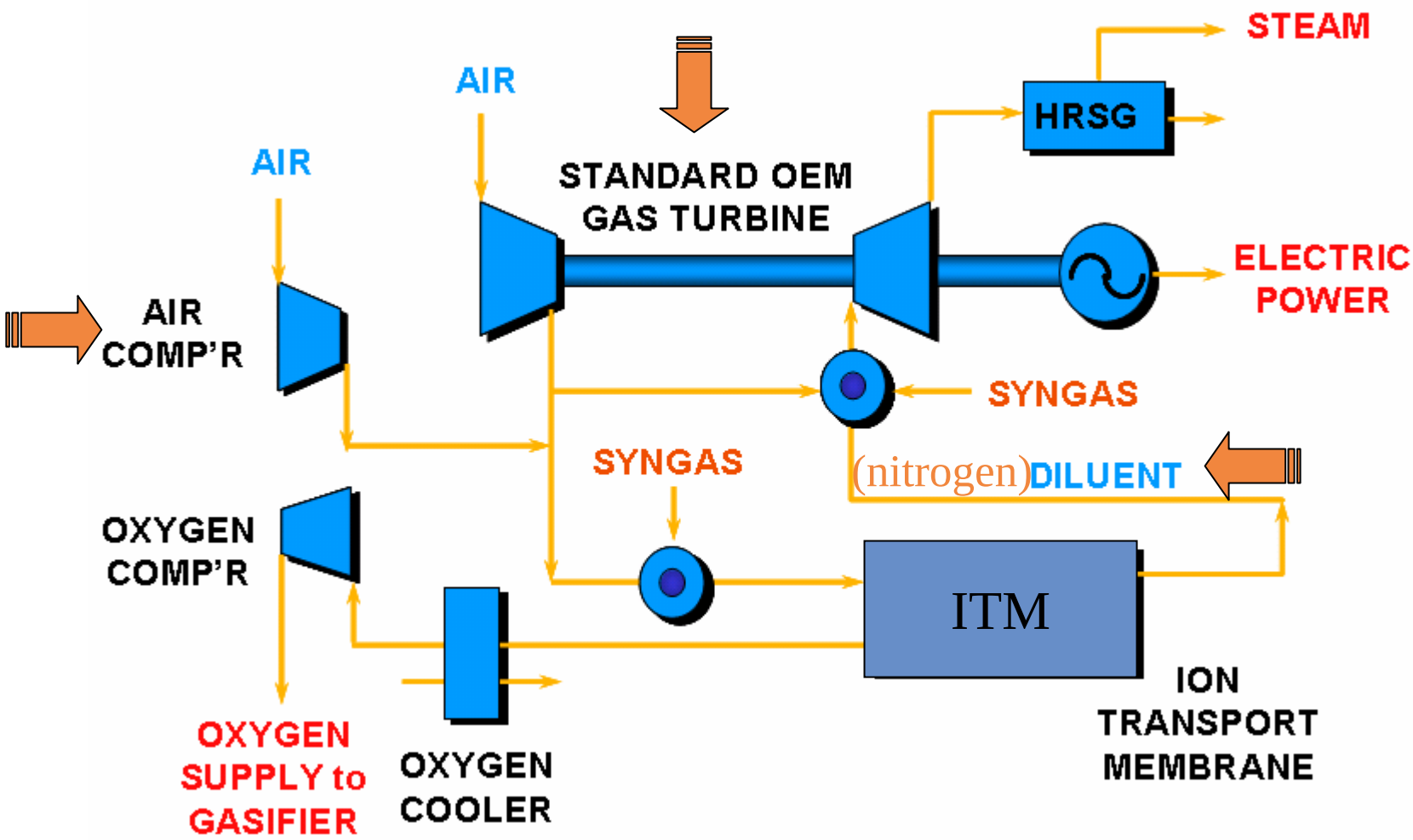


SGT6-6000G-ITM Oxygen Layout




- **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**



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