ITM Oxygen Development for Advanced Oxygen Supply

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Gasification Technologies Council
October 12, 2011
San Francisco, California USA

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Who Is Air Products?

- **Merchant Gases**
  - **Industrial, medical, and specialty gases supplied to wide array of applications**
- **Tonnage Gases, Equipment and Energy**
  - **Industrial gases supplied via large on-site facilities or pipeline systems; equipment; technologies to serve future industrial and energy markets**
- **Electronics and Performance Materials**
  - **Specialty and tonnage gases/chemicals, services and equipment supplied to electronics markets; performance chemical solutions for a variety of industries**

FORTUNE 500 COMPANY ♦ $9.0 BILLION SALES FY10 ♦ SAFETY LEADER

~ 18,300 Employees ♦ Operations over 40 countries ♦ Sales over 100 countries

Production Operator, Equipment & Plant Sales, Pipelines & Distribution

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Cryogenic Distillation is state-of-the-art for tonnage oxygen

- **Mature, reliable technology**
- **Energy intensive**
- **Requires 100's of equilibrium stages**
- **Represents ~15% of IGCC capital cost**
- **Consumes ~15% of IGCC gross power output**

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Why ITM Oxygen ?

- **Most oxygen is produced using cryogenic distillation**
  - **Cryogenic distillation is a mature technology**
- **Ceramic membranes have the potential to produce oxygen at lower cost, especially in applications where integration with power or high temp processes is possible**
  - **Less parasitic power**
- **Other Benefits of ITM Oxygen**
  - **Less Water Use – can be as little as 50% of cryogenic ASU water use**
  - **Less Plot Area required – approx. 50% less**
  - **Fuel flexibility – natural gas, syngas, liquid fuels**
  - **Excellent integration capability with existing high temperature processes**
  - **Compact design reduces construction costs, easily meets height restrictions, increases overall mobility of the technology**

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What is ITM Oxygen?

A proprietary ceramic membrane to separate oxygen from air

- **Inputs are high pressure air and heat/fuel**
- **Outputs are oxygen and power/steam**

Unique technology gives high oxygen flux and selectivity and good integration with energy applications

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Air Products' ITM Technology

- **Ion Transport Membranes (ITM)**
  - **Extremely selective and very fast transport for oxygen**
  - **Non-porous ceramic membranes**
  - **Multi-component metallic oxide structure incorporates oxygen ion vacancies**
  - **Material formulation is complex and dependent upon application**
  - **Operate at high temperature, typically greater than 700°C**
- **Started R&D in 1988**
- **Currently 84 US Patents and equivalents in other countries**
  - **Materials and catalysts**
  - **Membrane and module structures**
  - **Process cycles**
  - **Applications and integrations**
- **DOE Cooperative Program since 1998**

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ITM Oxygen: DOE Cooperative Program

Targeting Reducing the Cost of Oxygen by One-Third

- **Phase 1: Technical Feasibility (0.1 TPD O_2)**
- **Phase 2: Prototype Testing (1-5 TPD O_2)**
- **Phase 3: Intermediate Scale Testing (100 TPD O_2) – 12 MW IGCC**
- **Phase 4: Reaction Driven Membranes**
- **Phase 5: Ceramic Module Fabrication to supply 2000 TPD O2 facility**
- **Planning next Phase: Energy Scale Development (2000 TPD O_2)**

  - equivalent 250 MWe IGCC or 110 MWe oxycombustion

Broad, multi-disciplinary team

AIR PRODUCTS
U.S. DEPT. OF ENERGY
EPRI ELECTRIC POWER RESEARCH INSTITUTE
NovelEdge TECHNOLOGIES
GE Energy
CONCEPTS NREC
ceramatec
ELTRON RESEARCH
SIEMENS
PENNSTATE
McDERMOTT
SOFCo EFS (McDermott)
University of Pennsylvania
BECHT ENGINEERING
Williams International

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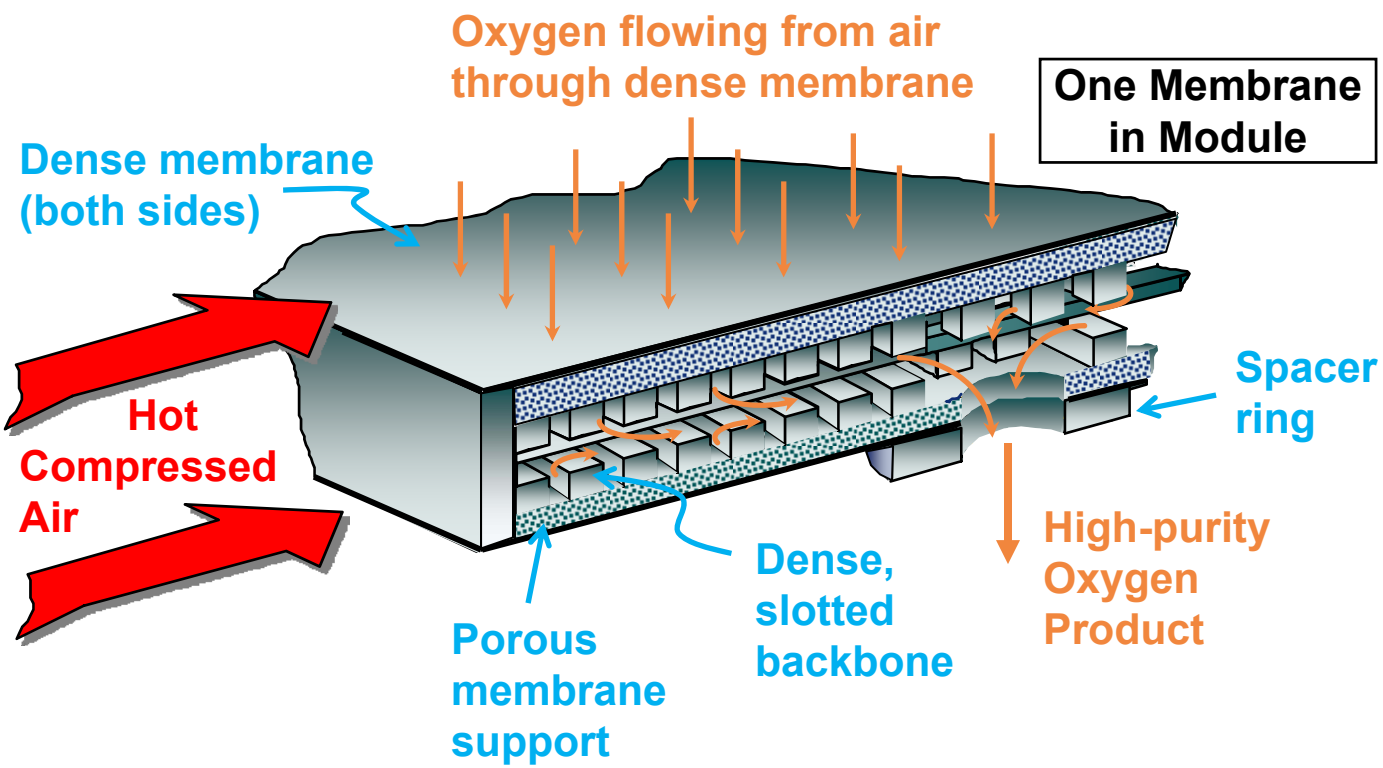
ITM Oxygen membranes are supported thin-film planar devices

- **Very fast transport for oxygen, very compact**
- **Low ΔP on the air side**



One Membrane in Module

½-TPD module

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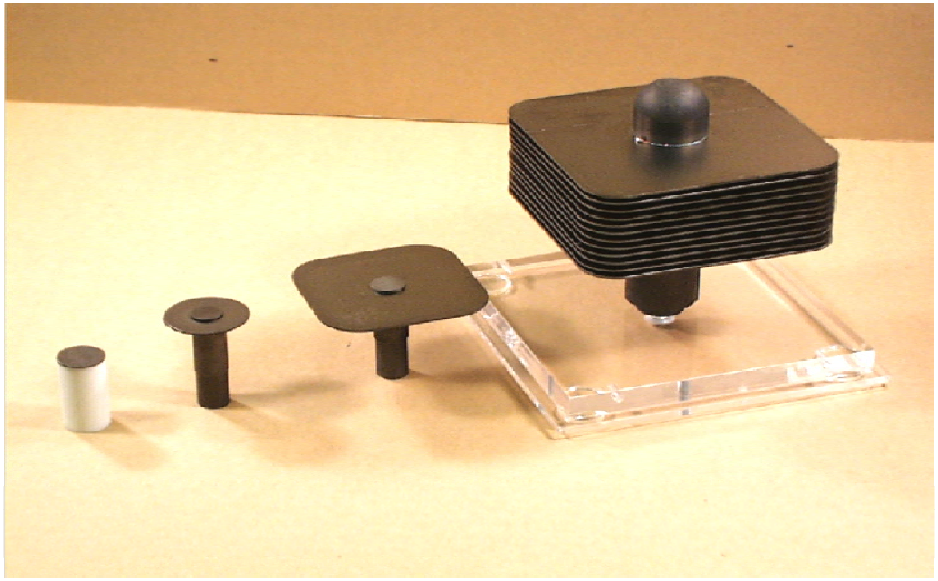
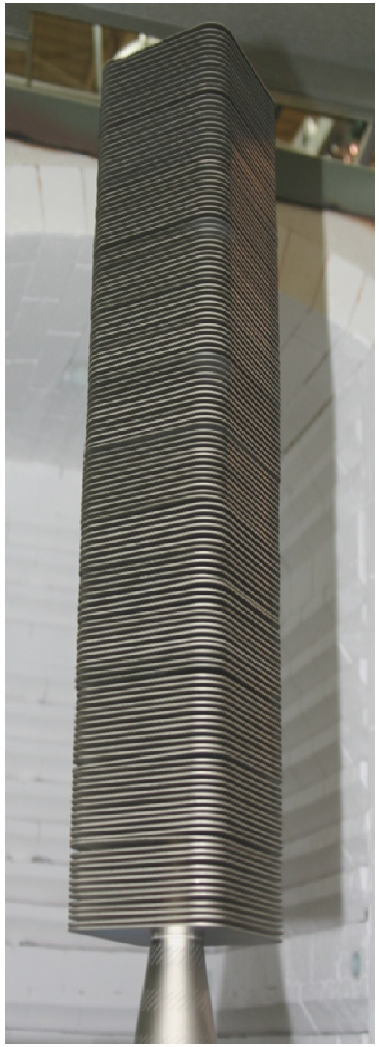
Membrane Fabrication and Scale-up has advanced rapidly

Progression to commercial size wafers



0.5 TPD Stack

1.0 TPD Stack



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Commercial size membrane modules

0.5 TPD Stack

1.0 TPD Stack

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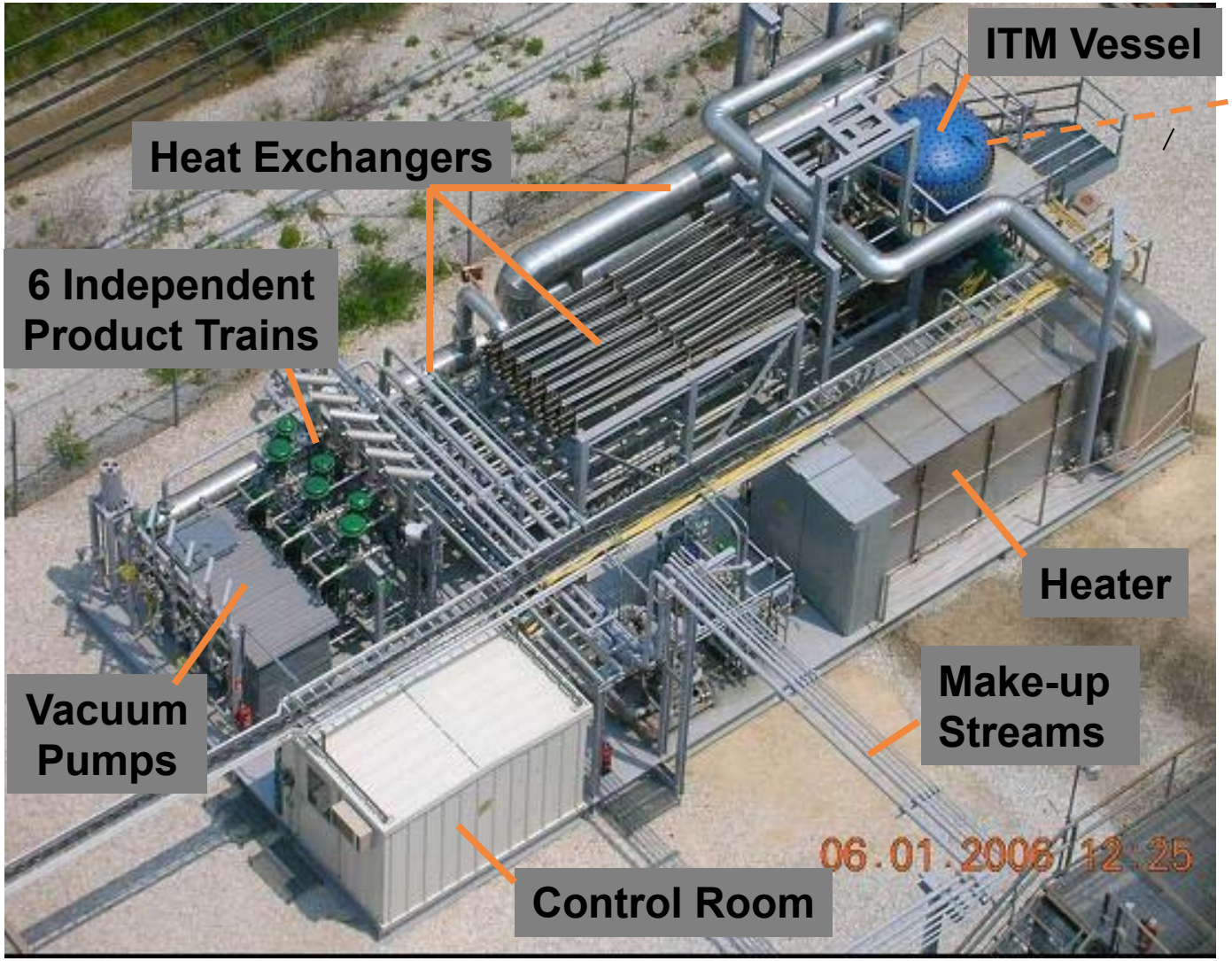
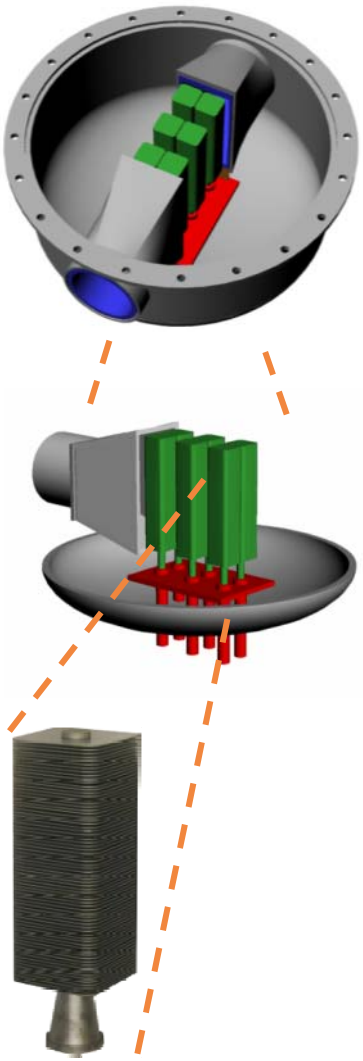
SEP – Subscale Engineering Prototype





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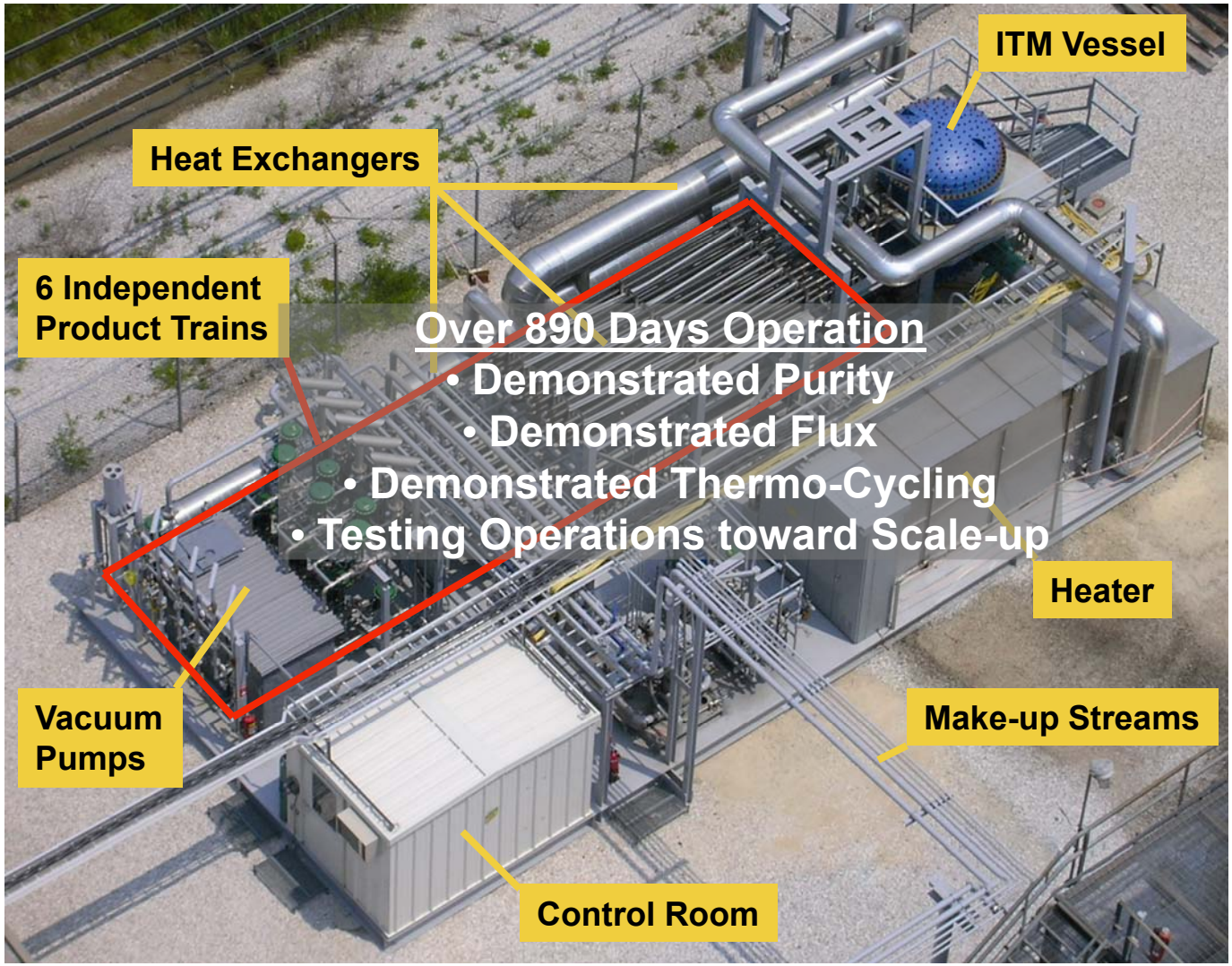
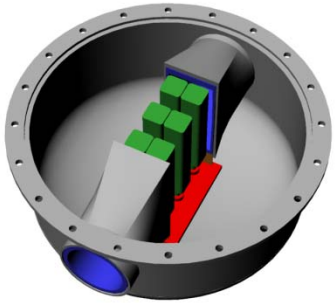
ITM Oxygen commercial modules continue to be tested in the 5 TPD SEP

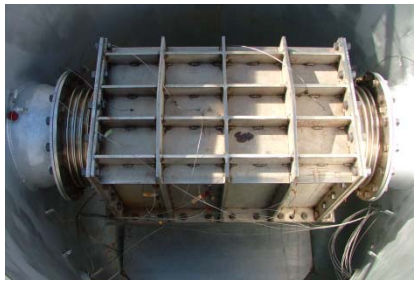


ITM Vessel Internals



6 Modules Installed

Flow Duct Installed



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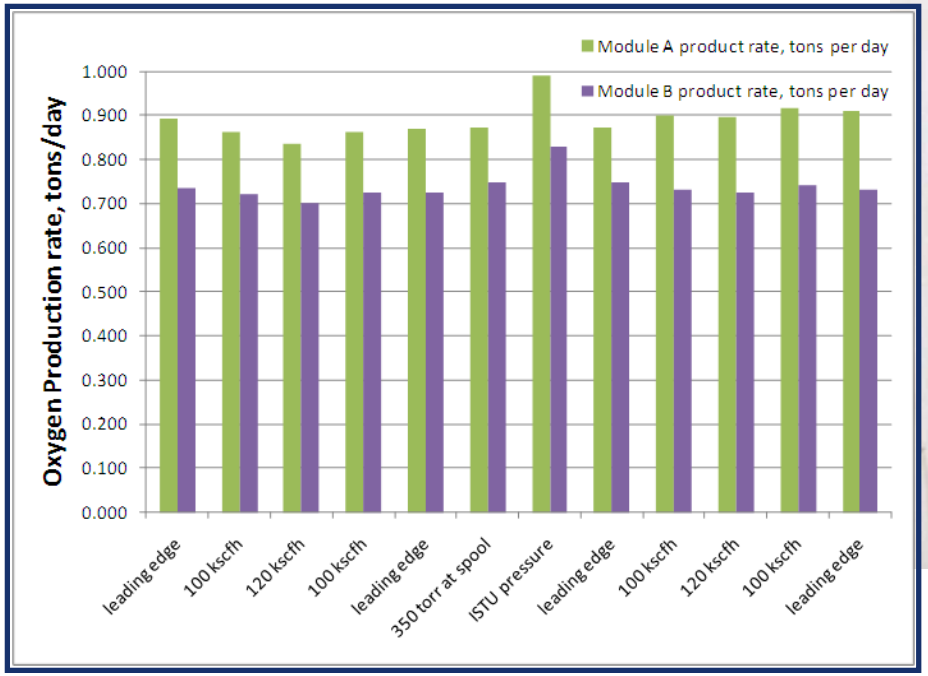
Successfully tested two 1 TPD module stacks, February 2010

- **Minor modifications were made to vessel internals, including taller flow duct**
- **Flow & temperature uniformity confirmed**
- **0.7 to 1.0 TPD capacity demonstrated over 22 days**
  - Modules had thicker membranes resulting in flux lower than typical



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Successfully tested two 1/2 TPD stacks, Oct 2010 – Jan 2011

- **Longest continuous and total flux time at SEP to date: 26 and 40 days**
  - **Two successful thermal cycles**
  - **Survived two significant process upsets caused by power outages and loss of feed air**
- **Tested getter design to remove contaminants that volatilize from system metallurgy**
- **Modified flow duct design toward ISTU scale-up**

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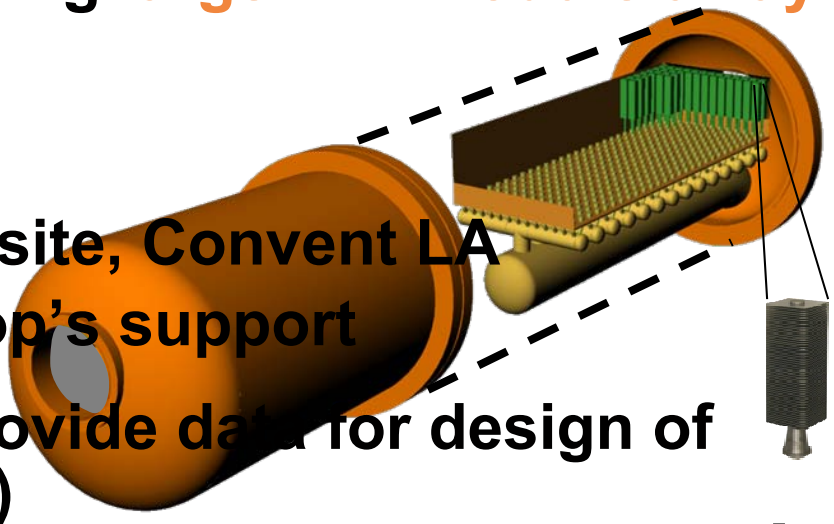
We are building a 100-TPD ISTU (Intermediate-Scale Test Unit)

- **100-TPD ITM Oxygen system integrated with hot gas expander to co-produce power**
  - **Equivalent to 5 MWe oxycoal or 12 MWe IGCC**
  - **Test operation in 2012-2013**
- **Use commercial design concepts to scale-up to the next test platform & first plants**
  - **vessel and internals housing large ITM module array**
  - **process controls**
  - **contaminant mitigation**
- **Located at Air Products ASU site, Convent LA**
  - **infrastructure, logistics, op's support**
- **Provides a test platform to provide data for design of larger scale plants (2000 TPD)**



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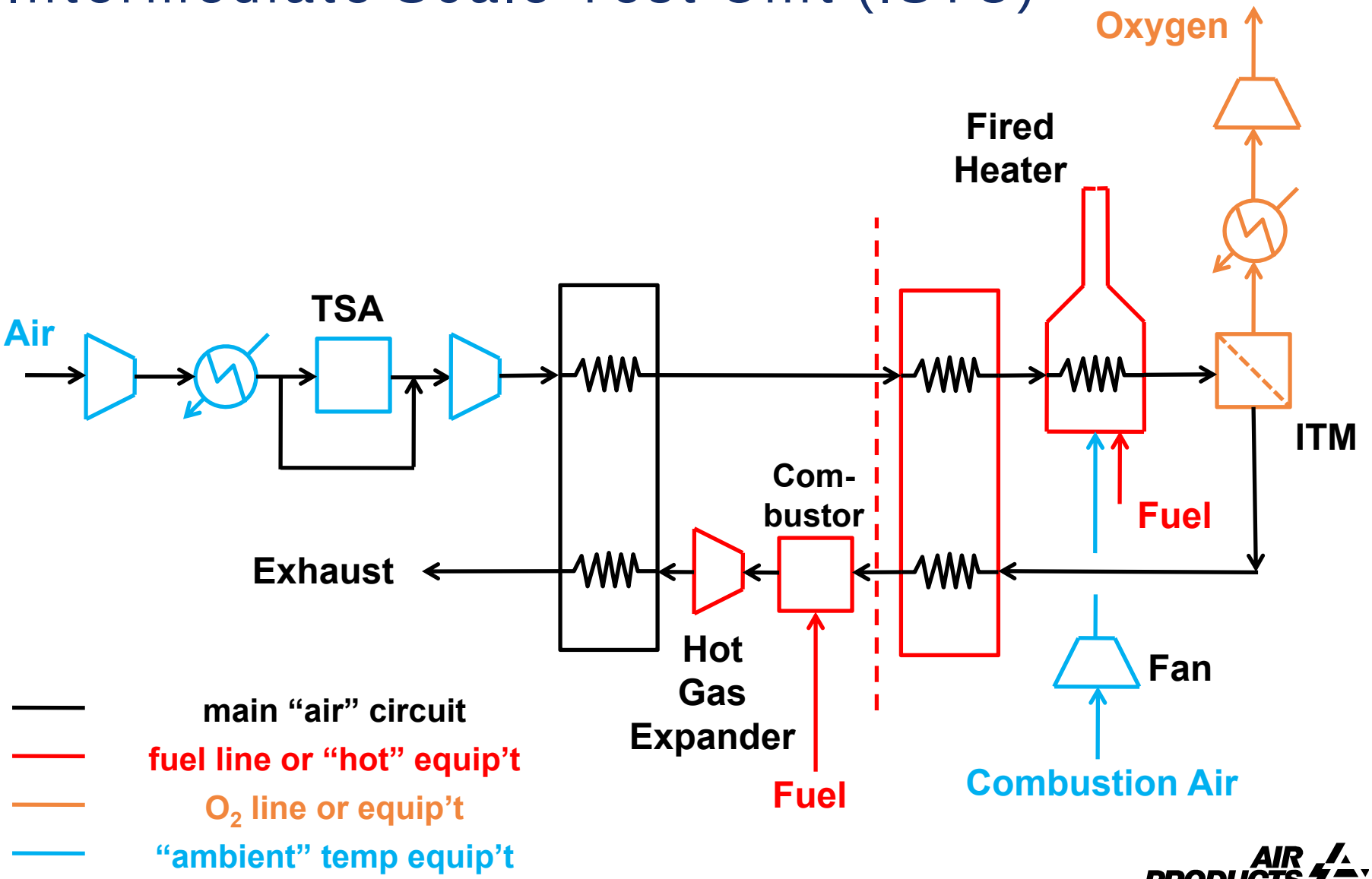
Next stage ITM Oxygen scale-up is in construction: Intermediate-Scale Test Unit (ISTU)



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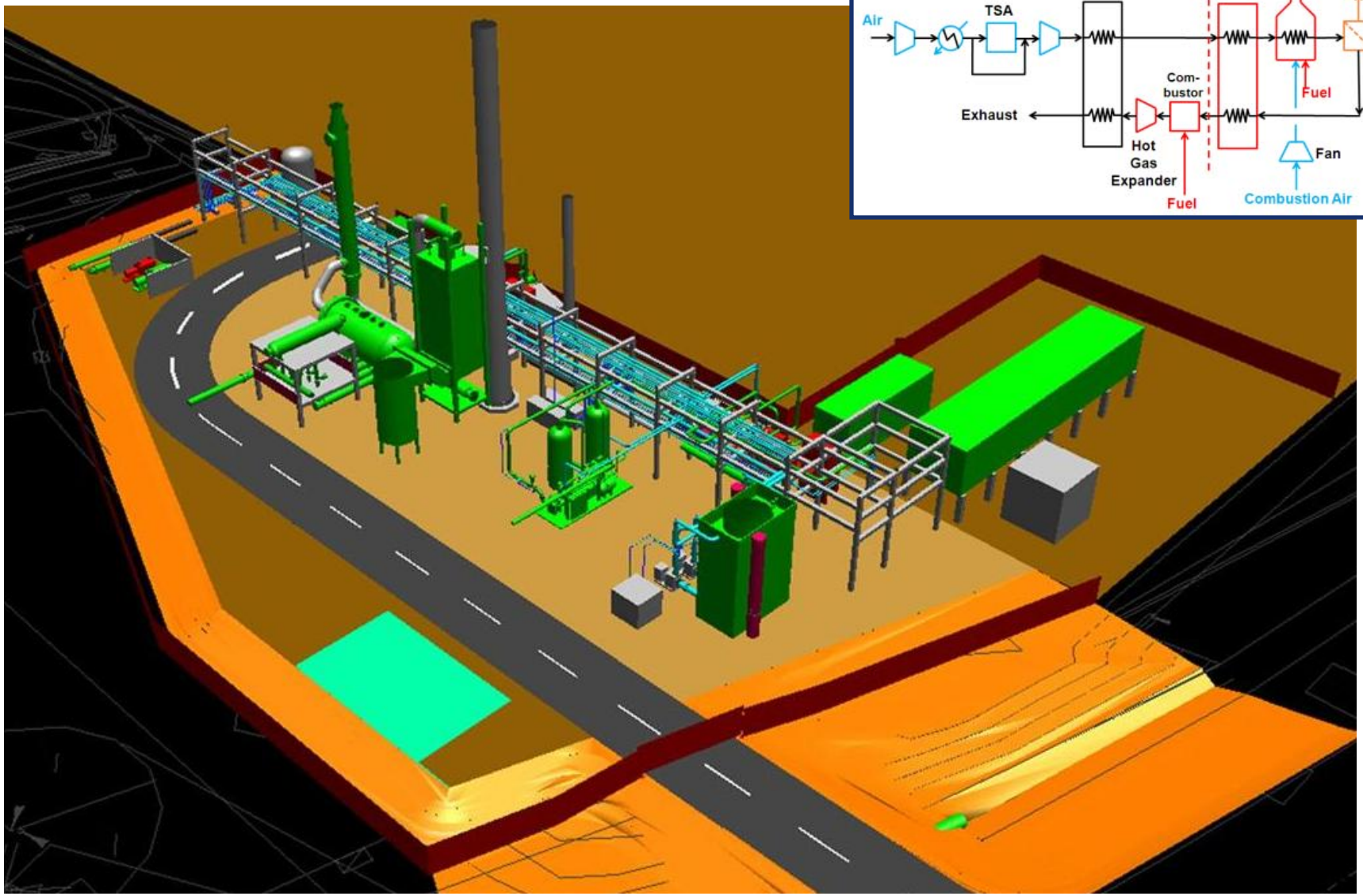
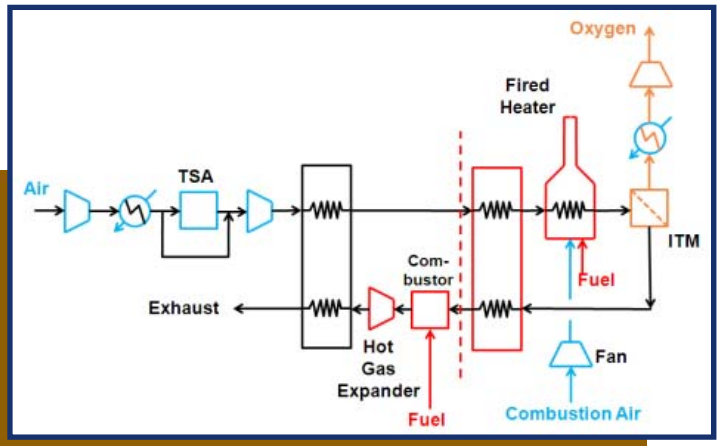
ISTU Plot Layout





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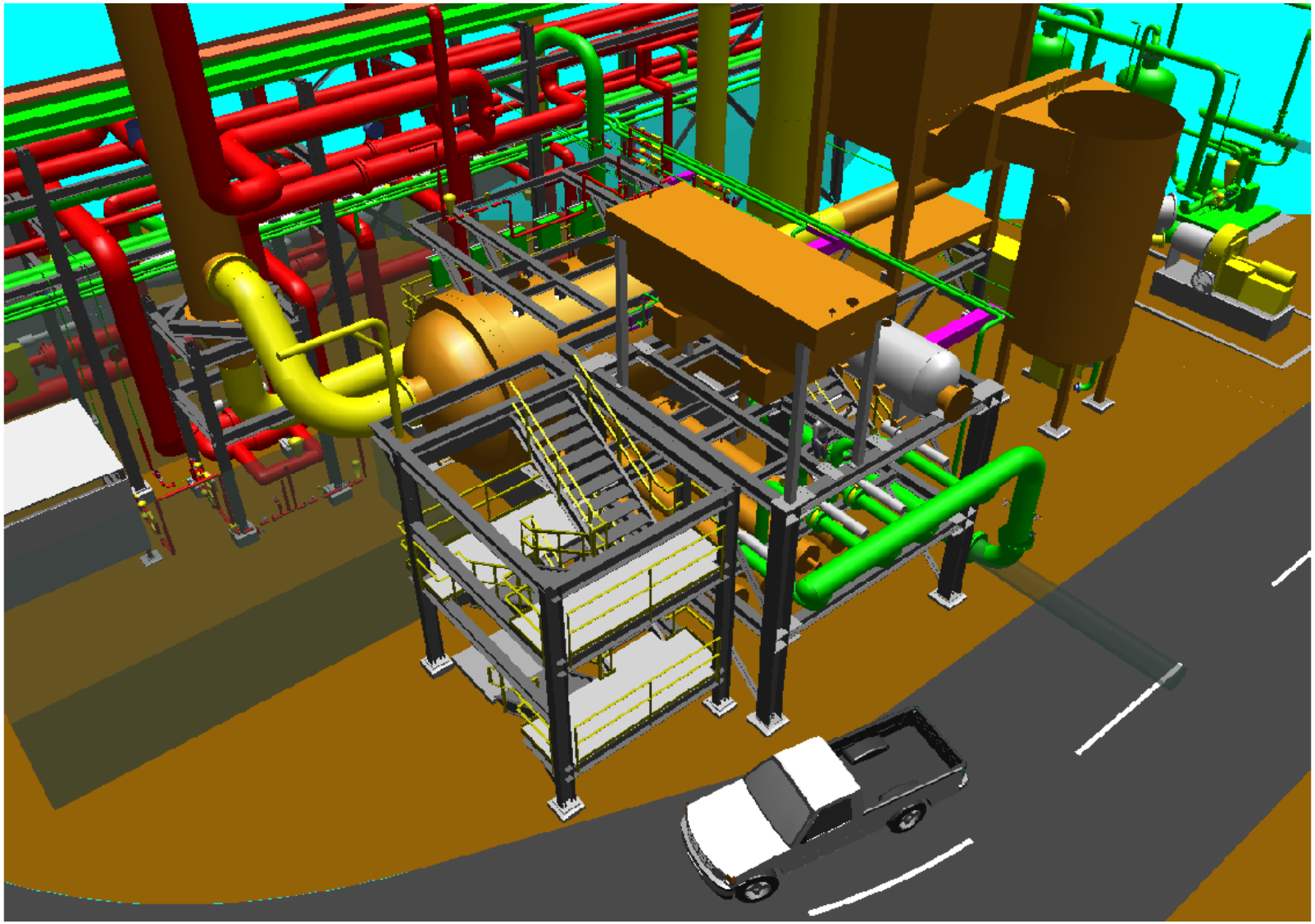
ISTU ITM Oxygen Vessel



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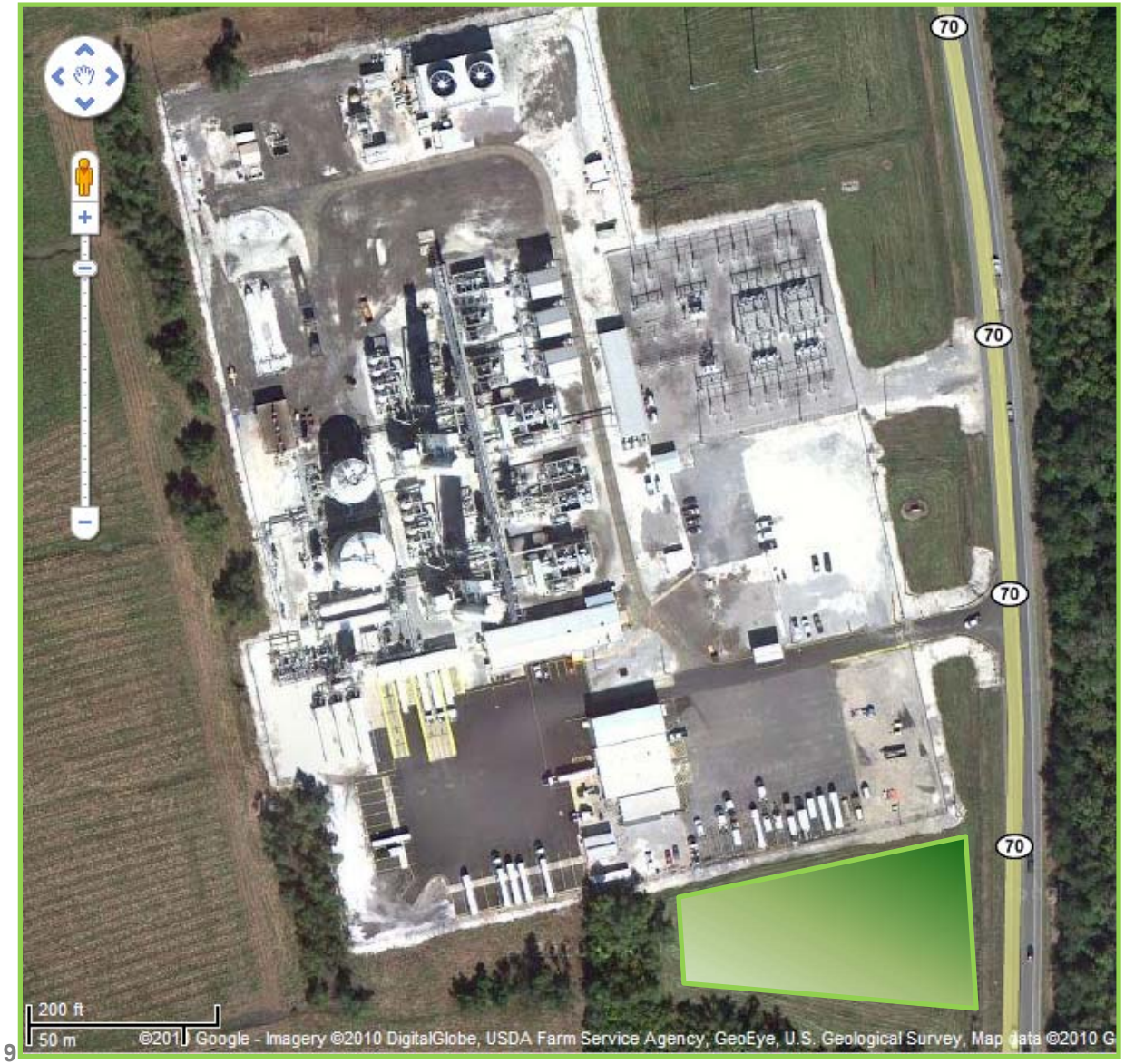
ISTU construction has begun adjacent to Air Products existing ASU in Convent, LA, USA



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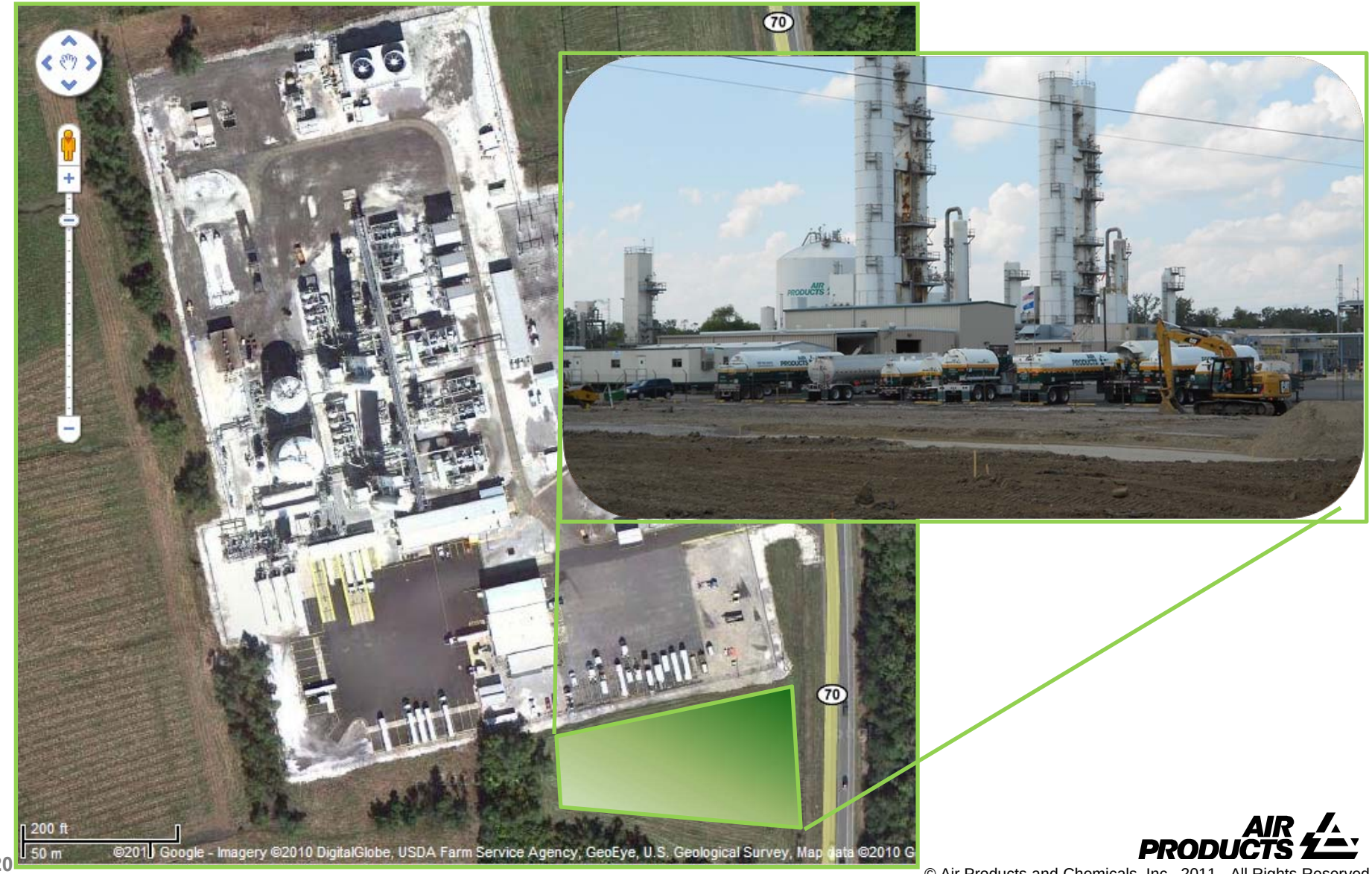

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Ceramic Manufacturing Scale Up (Phase 5)

- **Air Products awarded $71.7 million award as part of the U.S. Recovery Act legislation.**

  Tasks include:

- **<u>Design, build, and operate a ceramic manufacturing facility to supply a 2000 TPD ITM Oxygen test unit by end of 2013.</u>**
- **Supporting R&D in ceramic processing with an emphasis on industrial carbon capture (ICC) applications**
- **Conceptual and detailed engineering of ITM-based facilities for ICC and for testing the ITM Oxygen technology at the 2000 TPD scale**
- **A 2000-TPD ITM test unit might be brought on stream by 2015.**

The ceramic manufacturing facility will be located in Tooele, Utah, near Salt Lake City. Engineering for this facility is underway.

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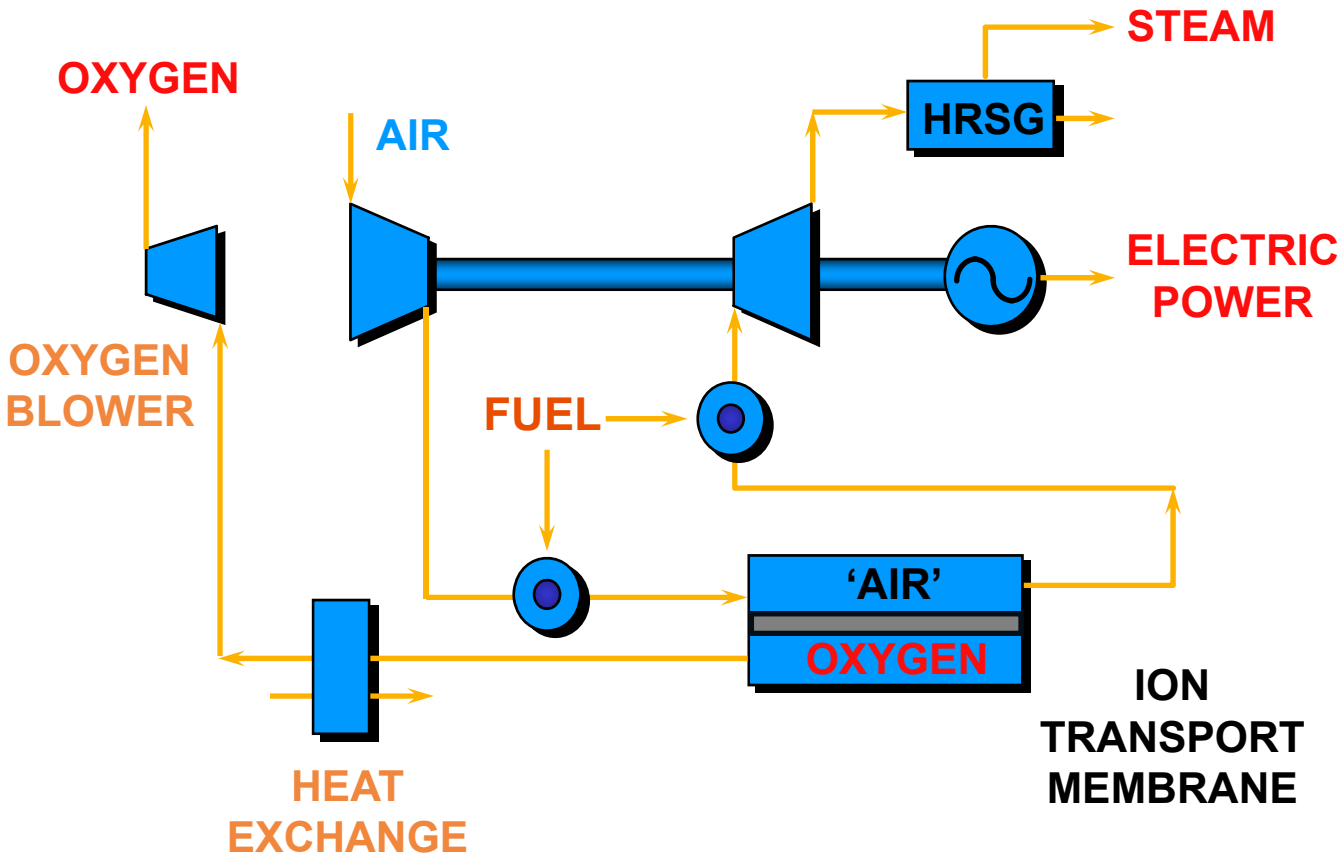
ITM Oxygen integrates well with power generation cycles



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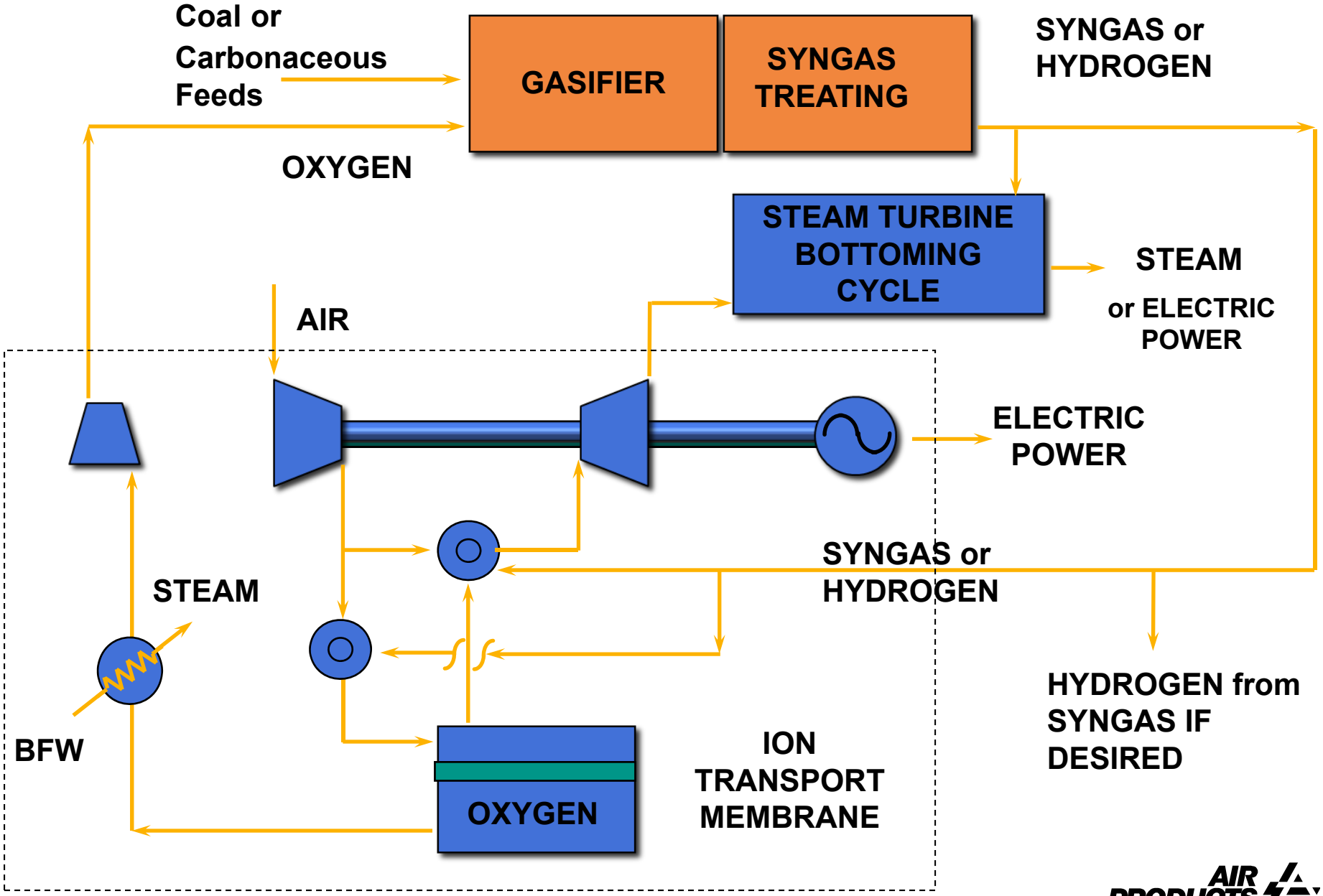
ITM Oxygen / IGCC Integration



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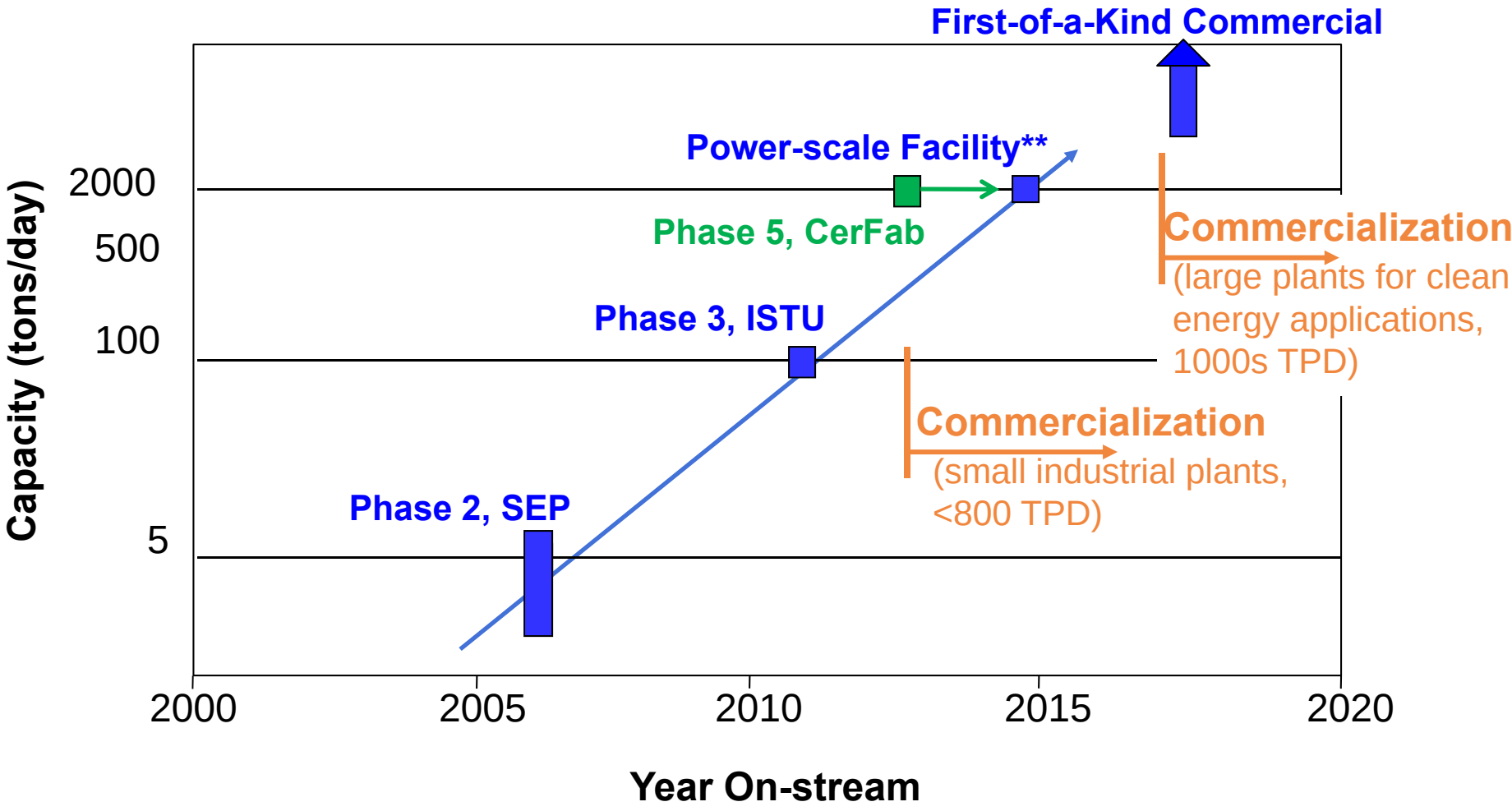
ITM Oxygen Commercialization Timeline For Energy Scale Applications



** equivalent 110 MWe oxycombustion or 250 MWe IGCC

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Significant Progress Made Developing ITM Oxygen Technology

- Excellent progress has been made testing commercial scale ITM Oxygen modules
- Intermediate Scale Test Unit (ISTU) at 100 TPD scale is in construction to operate in 2012
- Ceramic manufacturing scale-up is underway to support 2000 TPD ITM Oxygen facility
  - Next Phase Planning has initiated toward Energy Scale Development (2000 TPD O2)
- Process and economic studies continue to show attractive benefits, both with and without CCS
- ITM Oxygen is well positioned to meet the needs of clean energy applications
- Additional development supporters are welcome

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Acknowledgement

The authors gratefully acknowledge the contributions by the members of the ITM Oxygen team at Air Products, Siemens, Ceramatec, GE Energy Gasification, DOE, EPRI, Concepts NREC, NovelEdge, SOFCo EFS, Eltron Research, Becht Engineering, Williams International, Penn State University, and University of Pennsylvania.

This technology development has been supported in part by the U.S. Department of Energy under Contract No. FC26-98FT40343. The U.S. Government reserves for itself and others acting on its behalf a royalty-free, nonexclusive, irrevocable, worldwide license for Governmental purposes to publish, distribute, translate, duplicate, exhibit and perform this copyrighted paper.

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Thank you

tell me more

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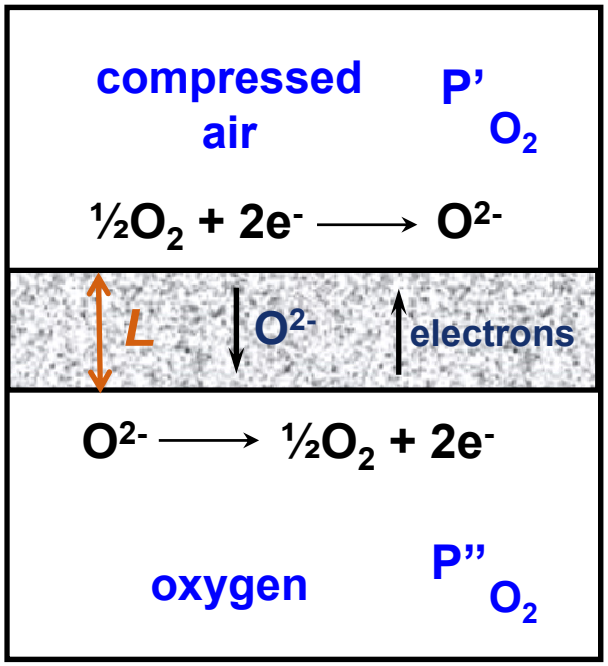
Ion Transport Membranes (ITM) provide high-flux, high-purity Oxygen

- **Mixed-conducting ceramic membranes (non-porous)**
- **Operate around 800 - 900°C**
- **At high temperature, the crystalline structure incorporates oxygen ion vacancies**
- **Oxygen ions diffuse through vacancies**
- **100% selective for O_2**



$$O_2 \text{ Flux} \propto \ln\left(\frac{P'_{O2}}{P''_{O2}}\right) / L$$

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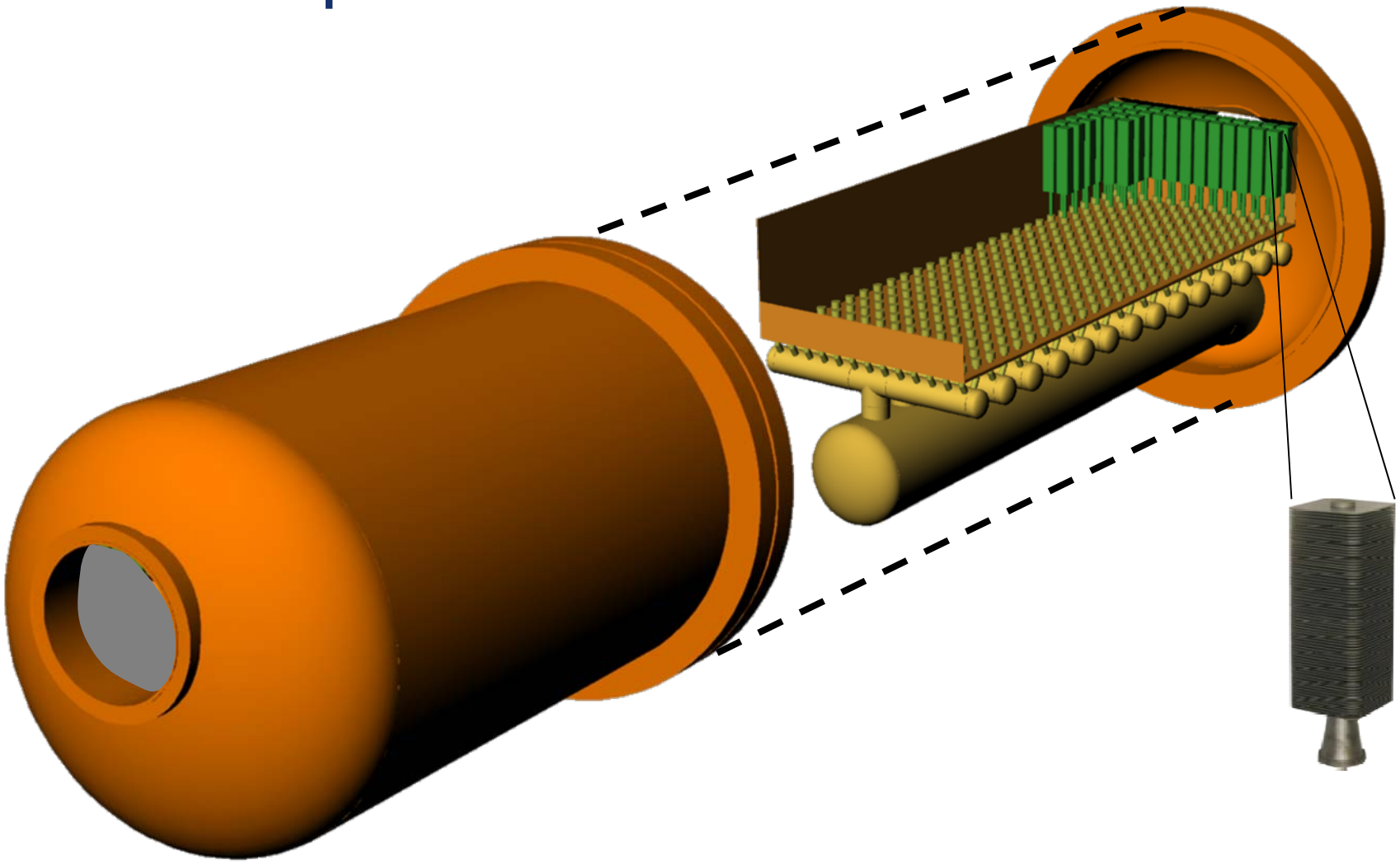
Commercial-scale Vessel Concept



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Flow duct design concepts being tested in SEP for larger plant use

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