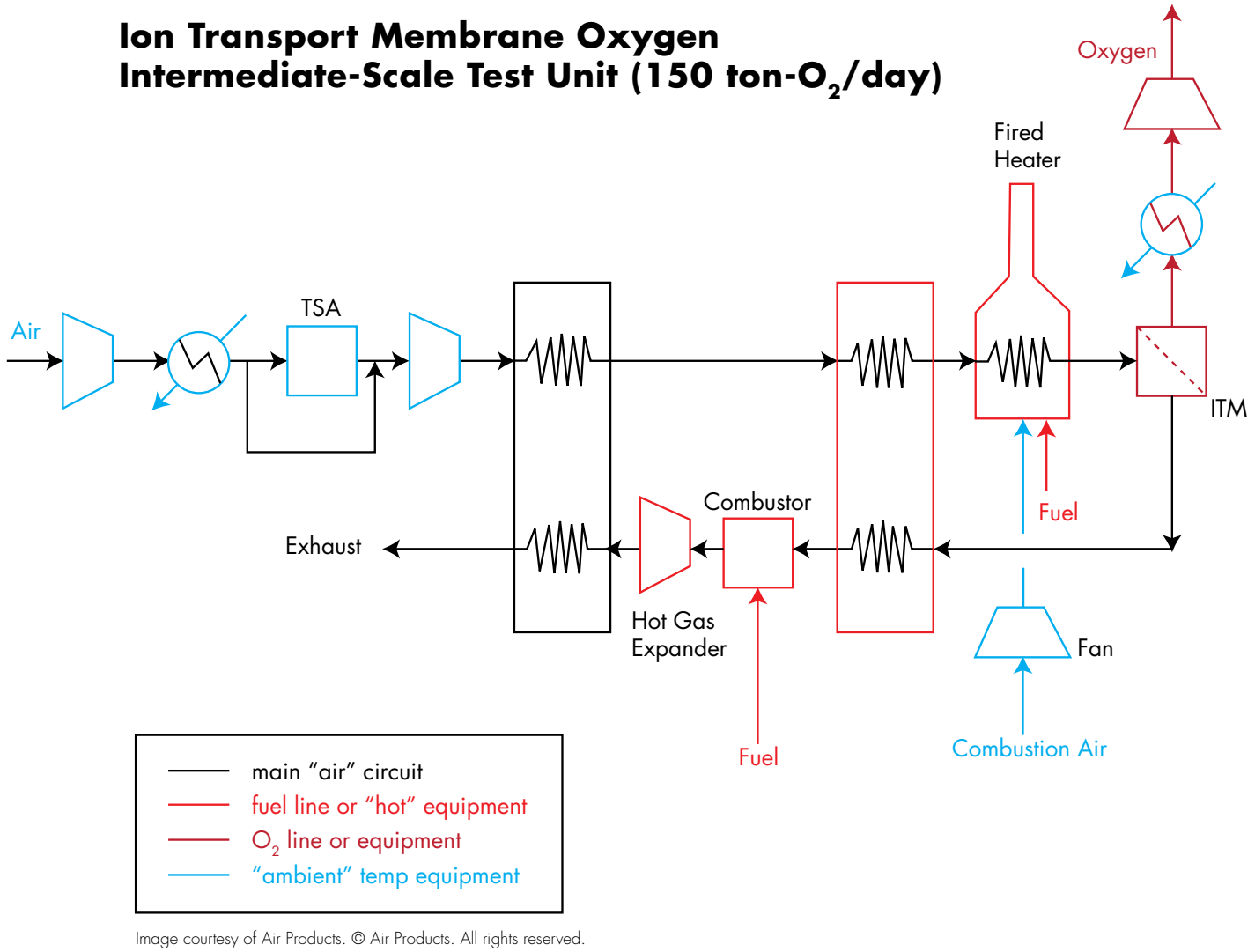
EPRI ELECTRIC POWER RESEARCH INSTITUTE

Ion Transport Membrane for Lower-Cost Oxygen Production

Overview, Value, and Deliverables



Overview

The efficient and low-cost production of oxygen is a pressing need for the coal-fired power generation industry. Coal is the largest source of power in the world but emits CO_2 at high levels. With climate change concerns driving calls for significant reductions in the emission of CO_2 and other greenhouse gases (GHG), the need for advanced coal generation with carbon capture and storage (CCS) is imperative. The Electric Power Research Institute, Inc. (EPRI) has performed an analysis that shows a significant increase in advanced coal power is an essential component of a full portfolio of GHG reductions strategies[1].

Two principal candidates to achieve effective and economical advanced coal generation with CCS are integrated gasification combined cycle (IGCC) and oxy-combustion technologies, both of which require large quantities of oxygen for operation. The anticipated fleet of IGCC and oxy-combustion plants is likely to follow current projections for growth, which will cause the oxygen requirements in power generation to also grow substantially. The current U.S. power generation industry share of the oxygen market is about 4%, but it could become the dominating market driver, accounting for more than 60% of the future market, or approximately 2 million short tons per day (tpd) of oxygen by 2040. Similar projections also apply internationally.

To support the development of lower-cost oxygen production for IGCC and oxy-combustion, EPRI has teamed with the U.S. Department of Energy (DOE) and Air Products (AP) on the ongoing development of a novel oxygen production technology -- ion transport membrane (ITM). The DOE has been funding the ITM Oxygen technology since 1998 and Phase II of its program was completed in 2006. Tasks currently are under way for Phase III of the program, which was approved by the DOE in March 2007, which is providing 60% of the funding.

ITM Oxygen technology has the potential to help produce oxygen more cheaply and efficiently. Estimates by AP, developer of the ITM Oxygen technology, and EPRI by its own analysis, suggest oxygen plant capital costs and operating power consumption could be significantly reduced in IGCC applications by using ITM Oxygen technology. Other potential benefits include reduced cooling water use and plant space used for oxygen separation. AP projects that ITM oxygen plants may have similar economic and efficiency benefits for oxy-combustion power systems.

EPRI has formed a collaborative to support the development of ITM Oxygen technology during the current Phase 3 of the DOE program, culminating in the design, construction, operation, and testing of a 150 tons-per-day (tpd) O_2 test facility integrated with 5- to 15-megawatt (MW) industrial turbo-machinery. This effort builds upon the DOE-funded operation of a 5 tpd O_2 ITM pilot unit. EPRI's role is to provide design features and tests and evaluate project progress and achievements to help bring the technology to a stage in which it can be used to benefit the power utility industry and the public.

0.5 ton-O_2/day ITM Oxygen Modules

Successful completion of Phase III will allow AP to introduce mid-sized commercial-scale ITM units in the rapidly expanding oxygen supply industry. Important from the energy industry perspective, the database derived from operation of the facility will enable the scale-up of a large test unit (thousands of tpd of O_2), a necessary step prior to demonstration at the scale required for power applications. Phase III work is expected to be completed by the end of 2011.

This development activity is part of a larger, power industry-driven EPRI collaborative program of proposed projects for critical-path CO_2-reducing technologies. The interrelated schedule for these projects is included in the document. The schedule shows estimated timelines for: pilot programs, which are early deployments of technology on a smaller scale; demonstration projects, which are larger-scale validations of technology; and integration, when the vetted technology is integrated into a commercial plant at full scale. By managing risk through staged development and shared costs among collaborative funders, EPRI's demonstrations are designed to help usher coal-based technologies into the next phase of commercial deployment.

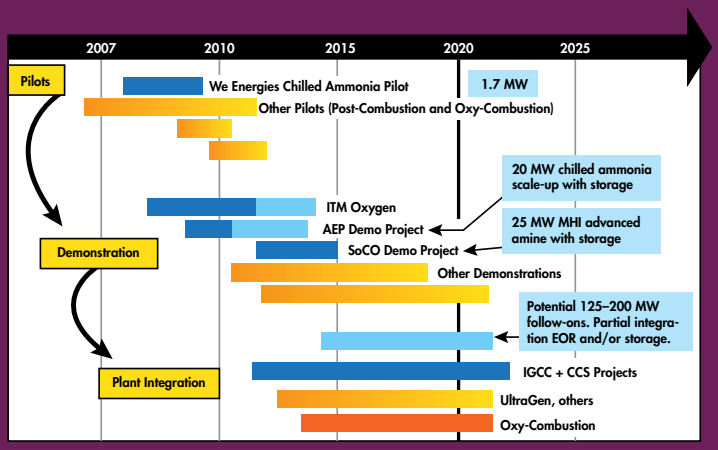
1. *Advanced Coal Power Systems with CO_2 Capture: EPRI's CoalFleet for Tomorrow Vision*, EPRI, Palo Alto, CA: 2008 (EPRI document 1016877) .

This document provides more details about the deliverables and value statements for collaborative funders presented in EPRI Supplemental Project Notice (SPN) 1018956, "Scale up and Integration of Ion Transport Membrane Oxygen Production Technology."

VALUE TO FUNDERS

This demonstration project will provide EPRI's collaborative funders with the benefits indicated below and the opportunity to advise on directing EPRI's involvement in the project. In this way, collaborative funders can gain interactive insights into the status and benefits of the ITM Oxygen technology. They also will have the opportunity to assist EPRI in working with AP and DOE in shaping the objectives, deliverables and timeline of the next phase of development, and focus the overall ITM Oxygen program on early electric power industry deployment. Benefits include:

- Collaborative support means there is greater probability that the ITM Oxygen technology will have been tested beyond the research scale by the time power companies select their oxygen separation technology for the first several IGCC and oxy-combustion installations.
  - — Political observers predict that power companies will begin installing CCS around 2020; hence, selection of oxygen separation technologies en masse occurs around 2017.
  - — Development cycles for such complex equipment are long, so 2017 means demonstrations at this scale (approximately 1/10th full-scale) are needed now.
  - — To EPRI's knowledge, this project currently is the only one in which the evaluating entity is an independent, third-party organization.
- Near-real-time economic and performance results will give collaborative funders early information to help determine which oxygen separation process they will select for their first commercial installations. If the ITM Oxygen process demonstrates the ability to meet project objectives, and a participating power company selects it, that company will reduce its risk of being an early adopter.
- Understanding the development path of the technology and having the opportunity for significant interaction with the process suppliers, grounded in an in-depth understanding of the process, can enable each collaborative funder to proactively evaluate its options and better understand the technology. In addition to learning specifics about the ITM Oxygen process, collaborative funders will gain further insights into the broader area of oxygen separation.



EPRI's Proposed CCS Demonstration Projects Timeline

- Ability to advise EPRI to investigate oxygen separation technologies being considered by a participating company, if different than the technologies already being evaluated by EPRI.

DELIVERABLES

EPRI plans to provide the deliverables and information transfer as summarized in **Table 1**.

Webcasts

EPRI and AP will host quarterly webcasts to provide collaborative funders information on the status of the project and technical updates on (a) the reports being developed by EPRI; (b) any testing issues on the ITM Oxygen system; and (c) performance data from the 150 tpd O_2 test unit when it becomes operational. The actual data provided during each webcast will depend on the activities and tests conducted during that quarter.

Project Review Meetings

Site visits will occur twice per year throughout the project. The site visits will include project updates and tours of particular aspect of the ITM Oxygen development – including the production facility in Salt Lake City, the 5 tpd of O_2 pilot unit in Baltimore, and ultimately the 150 tpd O2 test site. These site visits are expected to provide the opportunity for more detailed technical updates, enabling collaborative funders to watch the ITM Oxygen system in production or actual operation and to interact with EPRI and the AP staff involved with the project.

Table 1. Communication Plan for ITM Oxygen Intermediate Scale Project

Item	Key Content	Timing
Meetings and Webcasts		
Webcasts	Provide status and updates and discuss progress on the project.	Quarterly throughout the project
Individual meetings for collaborative funders	Provide more information for collaborative funders which request more detail tailored for their interests.	Case-by-case basis throughout the project
Project review meetings	Provide access to the key sites related to the ITM Oxygen technology and face-to-face discussions with project experts.	Twice per year throughout the project
Formulation of future development activities	Identification of the critical development activities for subsequent scale-up efforts	4th quarter 2009, 2010, 2011
Test unit performance evaluation	Assessment of the 150 tpd of O_2 test unit	Regular progress will be reported throughout the build, startup, testing and data review
Reports		
Significance of Solid Oxide Fuel Cell Hybrid Development to ITM Oxygen Technology	Assessment of lessons learned from the hybrid fuel cell – gas turbine industry	4th quarter 2009
Integration of ITM Oxygen Technology with Advanced Power Generation Systems	Assessment of real-world operational requirements related to IGCC and oxy-combustion power plants	4th quarter 2009
Plant-wide performance and cost analyses	Economic and performance studies of IGCC and oxy-combustion applications using ITM Oxygen technology	2nd quarter 2010
Equipment and Operational Requirements for ITM Oxygen-based Power Plants	Insights from industrial working group formed to evaluate the operational requirements of ITM Oxygen for real-world plants	3rd quarter 2010
Final report	Summarizes all key activities, test results, findings, and recommendations through 4th quarter 2011	4th quarter 2011

Project Deliverable Reports

Project reports will be published as follows:

- ***Report 1:*** *Significance of Solid Oxide Fuel Cell Hybrid Technology to ITM Oxygen Technology*
  This report documents the history, research and demonstration of integrated pressurized solid oxide fuel cells with gas turbines for power generation. The purpose of the work is to determine the operational similarities between these systems and ITM Oxygen modules integrated with turbo-machinery equipment. The focus of the work is on dynamic flow considerations and real-world lessons learned.

- ***Report 2:*** *Integration of ITM Oxygen Technology with Advanced Power Generation Systems*
  This report will assess the real-world operational requirements related to the integration of ITM Oxygen technology with IGCC and oxy-combustion power plants. The objectives of the report include:

  — Establish a general understanding of the power plant configurations, including layout, functionality and integration features associated with a conventional cryogenic-based air separation unit (ASU).

— Document and assess the current operational practices and concerns related to the integration of cryogenic ASUs. Analyze the interaction and interdependence of the ASU with the other subsystems in the power plant. Describe issues with reliability of equipment, potential failure modes, and resulting effects. The evaluation will address real-world issues associated with startup, shutdown, and dynamic load following.

— Discuss the potential integration issues, opportunities and challenges associated with the replacement of a cryogenic ASU with an ITM Oxygen system. The assessment will look at all equipment requirements upstream and downstream of the ITM Oxygen. Expected reliability issues and potential solutions will be introduced. The anticipated similarities and differences associated with replacing a cryogenic ASU with an ITM Oxygen will be included.

- ***Report 3:*** *Plant-wide Performance and Cost Analyses*
  The objective of the analyses is to increase the fidelity of plant-wide performance and cost predictions of ITM Oxygen-based oxy-combustion and IGCC power plants with carbon capture and compression. The analyses will be based on the most current design, performance and cost information available from the equipment manufacturers. The evaluation will include comparisons with cryogenic ASU-based plants. Modeling software will be used to conduct multiple trade-off and sensitivity studies. The report will include:
  — Design basis document
  — General arrangement and site layout
  — Heat and mass balances
  — Performance and emission estimates
  — Capital, operation and maintenance cost estimates
  — Major equipment descriptions

- ***Report 4:*** *Equipment and Operational Requirements for ITM Oxygen-based Power Plants*
  This report will detail findings from meetings with collaborative funders that allow them to assess project features and request changes or additions to the test plan/tasks. In particular, equipment and operational requirements for ITM Oxygen-based power plants will be discussed. The report will be strengthened with industrial input from a working group made up of the funding organizations and selected experts. The insights and recommendations of the working group will be critical to accelerate future development of the ITM Oxygen technology for the electric power generation industry.

Subscale Engineering Portotype

- ***Report 5:*** *Final Report*
  This report will summarize all key findings, activities and test results from the 150 tpd O_2 test unit through 4th quarter 2011. The report will include test results such as:
  — General arrangement and site layout
  — Heat and mass balances
  — Performance and emission estimates
  The report will also include comments and recommendations from the working group and formulation of specific future development activities.

CONCLUDING REMARKS & CONTACT INFORMATION

This project represents one of several critical near-term actions necessary to achieve substantial CO_2 emissions reductions from the electricity sector. Meeting this challenge will help ensure technology is ready for widespread deployment after 2020 and can be compatible with energy affordability, energy security, and economic goals.

Contact Information

For more information on the **ITM for Lower-Cost Oxygen Production Demonstration**, please contact:

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Together...Shaping the Future of Electricity

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