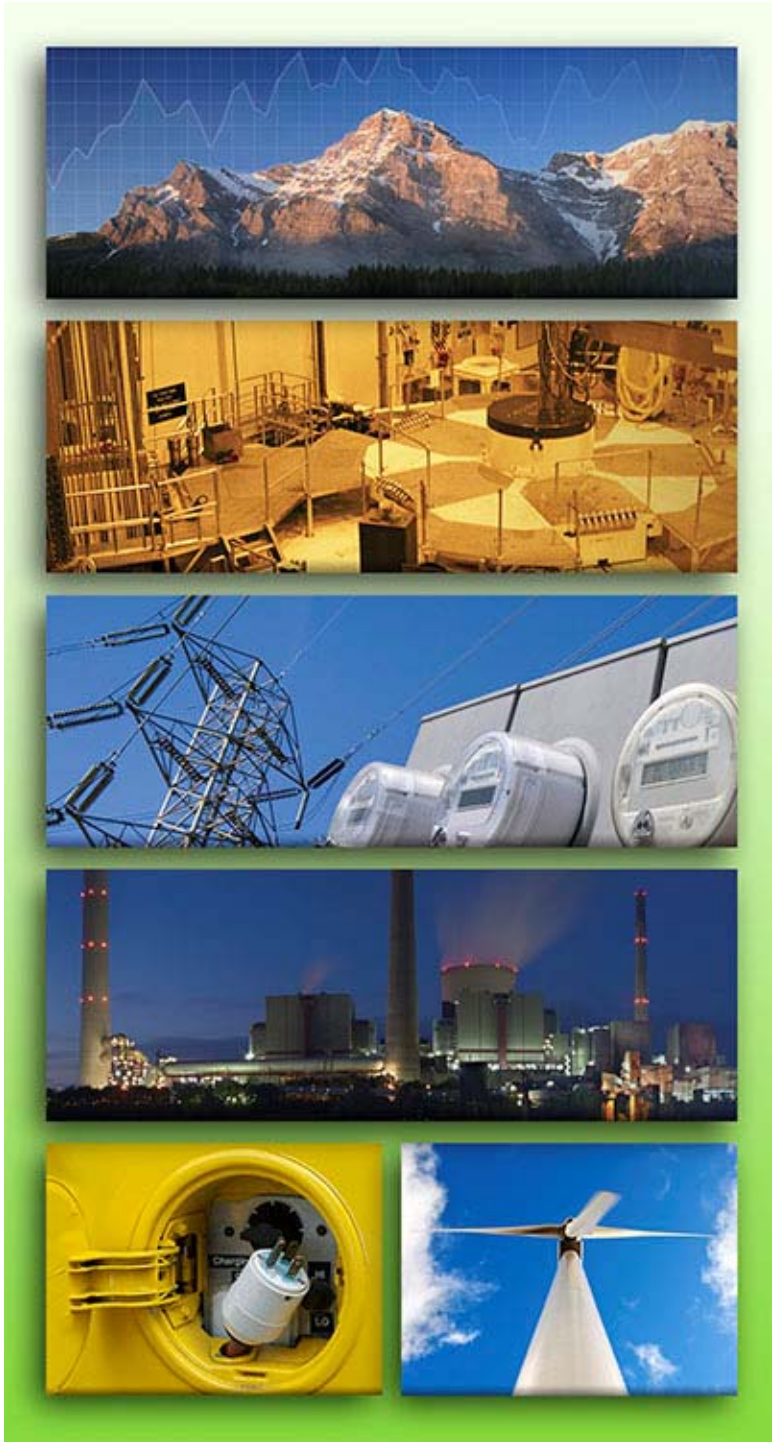

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Ion Transport Membrane (ITM) Technology for Lower-Cost Oxygen Production

Rob Steele – EPRI
(rsteele@epri.com)

Phil Armstrong - Air Products and Chemicals Inc.

Arun Bose – DOE NETL

Gasification Technologies Conference
Washington, D.C.
November 3, 2010

Project Overview and Update

- A ceramic membrane to separate oxygen from air
- A Phase 3 U.S. DOE Cooperative Agreement - to develop the ITM Oxygen technology at the intermediate scale though 2013
  - U.S. DOE NETL, Air Products (AP), EPRI, and others
  - Planned Intermediate-Scale Test Unit (ISTU) 100 ton-O_2/day integrated with 5–15 MW_e turbomachinery system
- A Phase 4 DOE award, $71.7 million, to accelerate
  - Development of ITM module fabrication scale-up
  - 2000 ton-O_2/day pre-commercial scale facility (110MWe oxycoal or 250MWe IGCC)
- EPRI formed seven member power industry collaboration in 2009
  - Additional members are welcome to join

AIR PRODUCTS

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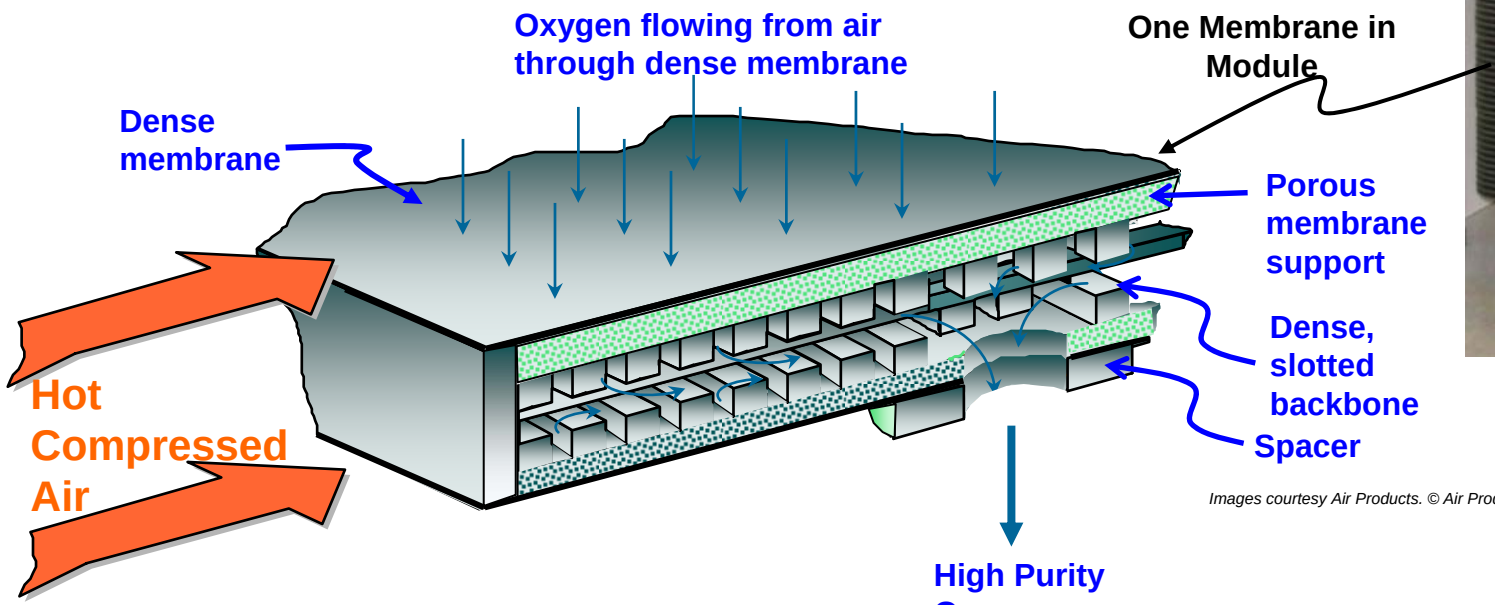
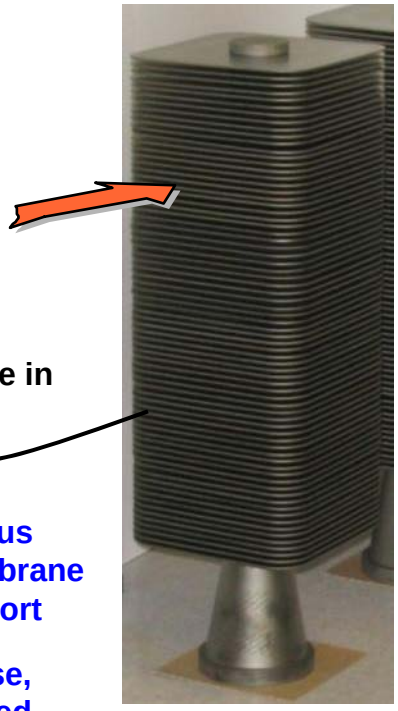
ITM Oxygen Membranes

- Single-stage high purity oxygen
- Extremely selective and very fast transport for oxygen
- Very compact





0.5 ton/day module

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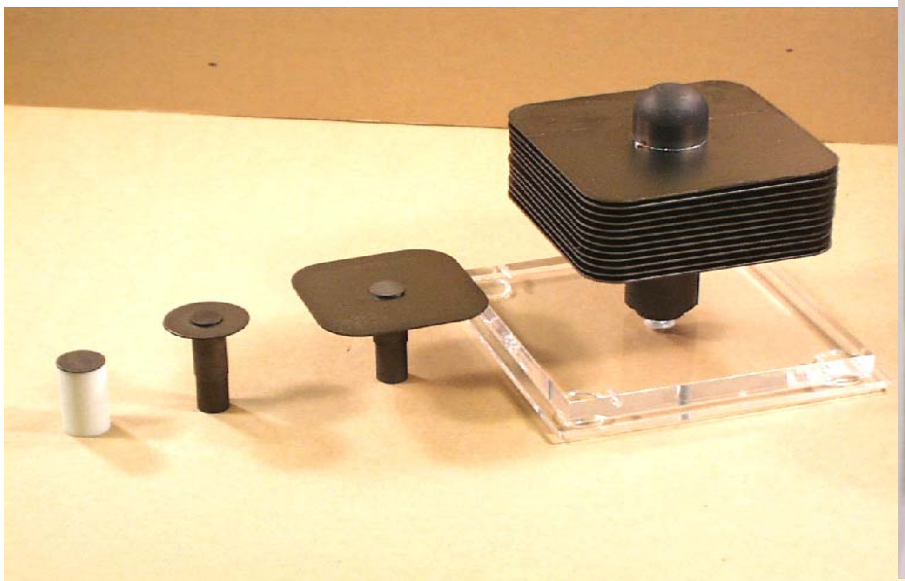
ITM Oxygen – Wafers and Module Scaled-up to Commercial Size

Progression to commercial size wafers



0.5 ton/day Stack

1.0 ton/day Stack

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ITM Oxygen Process

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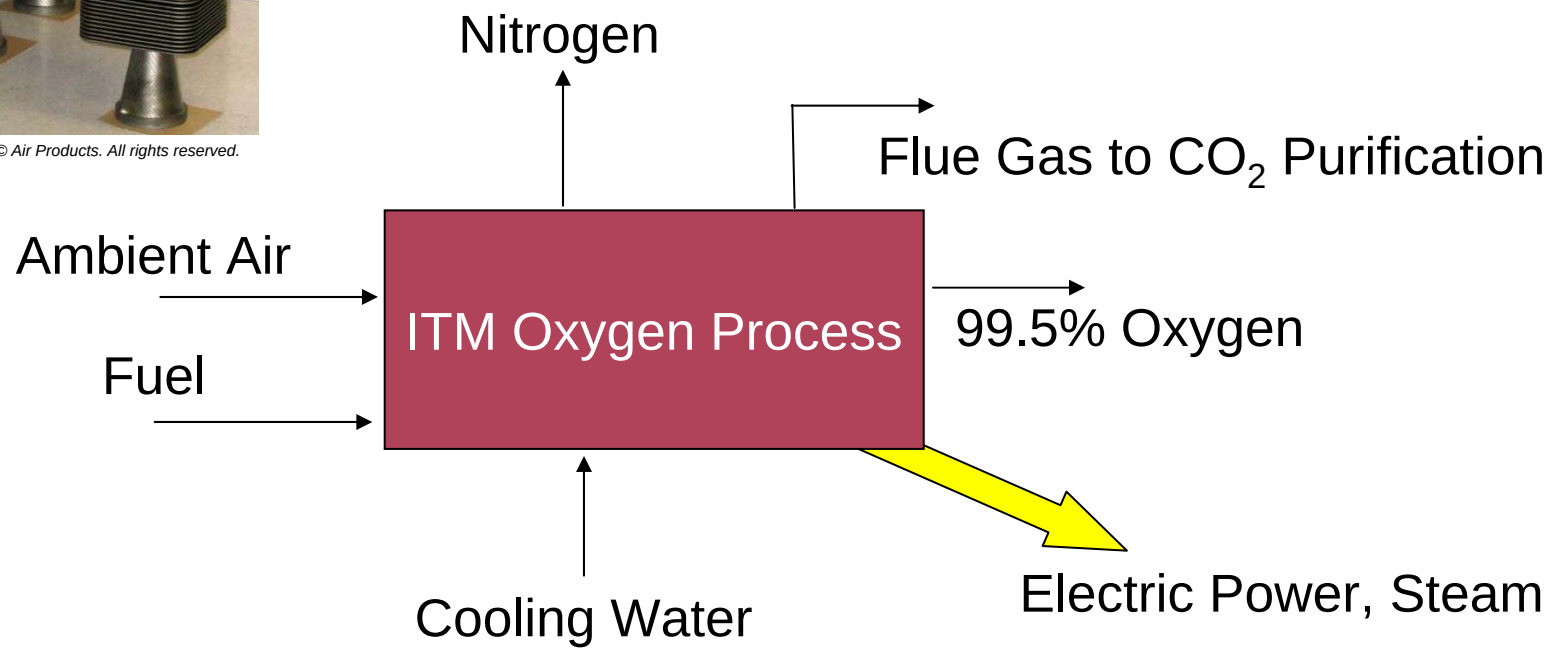
Design options for ITM Oxygen process:

- Power co-production
- Minimum fuel consumption
- Minimum CO_2 emissions



Expansion of Ceramic Processing Infrastructure at Ceramatec, Inc. (Salt Lake City, Utah, US)

- New equipment in operation
- All wafers for planned 100 ton/day test

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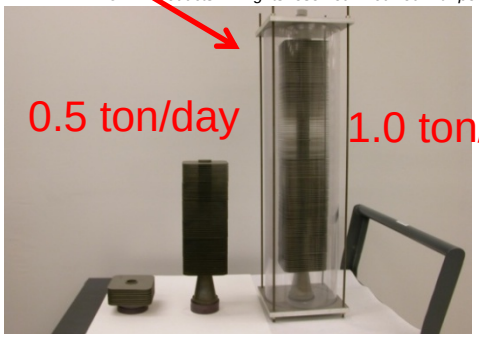
Ceramic Manufacturing Process at Ceramatec Continues to Improve and Scale-up

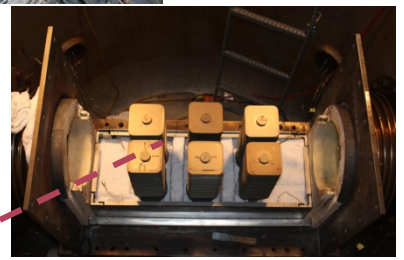
- Large-scale wafer sintering kiln for use in current Phase 3
- Capacity: > 25 ton/day per load
- Currently: Undergoing qualification trials

Multiple Visits to the Subscale Engineering Prototype (SEP) Site

Project progress to date:

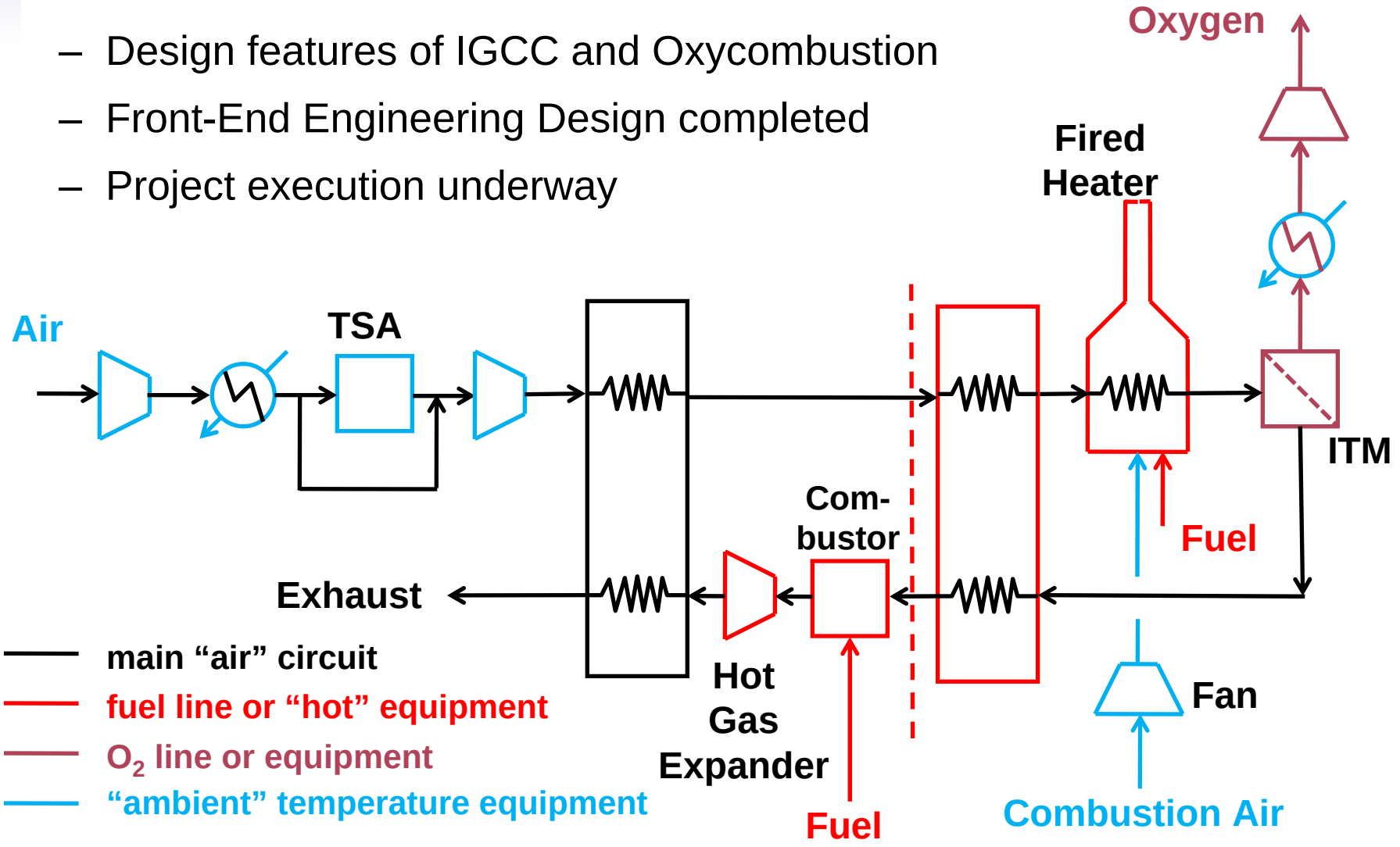
- Initial testing of 0.5 ton/day modules started in 2006
- Over 600 days of cumulative operation in multiple runs
- Initial testing of 1.0 ton/day modules began in February 2010





Intermediate-Scale Test Unit (ISTU)
Block Flow Diagram – 100 ton/day Oxygen

- Design features of IGCC and Oxycombustion
- Front-End Engineering Design completed
- Project execution underway



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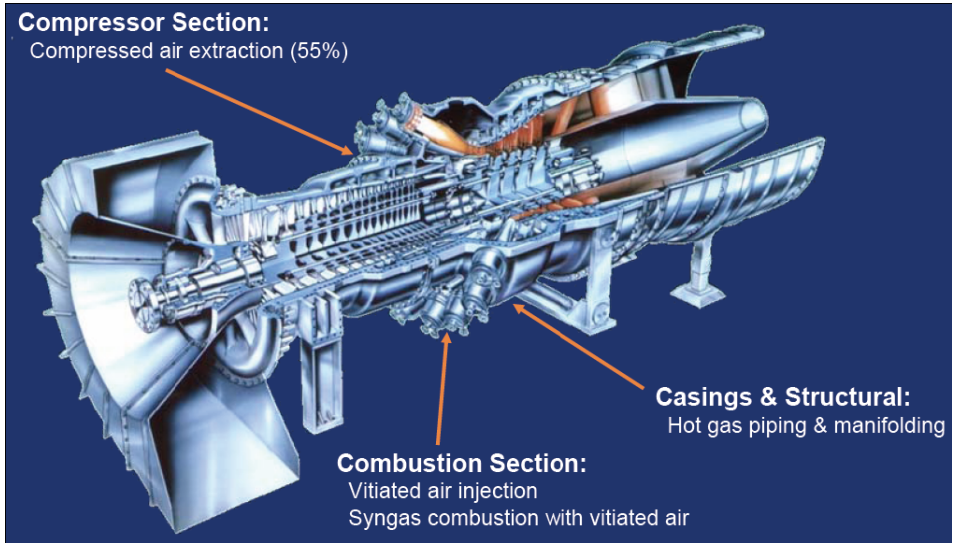
Advanced Gas Turbines

- Firing Temperature Evolution of Gas Turbines
  - F-Class GT: ~2500°F [1370°C] (GE 7F and Siemens 5000F)
  - G/H-Class GT: ~2600°F [1430°C] (GE, Siemens, MHI)
  - J-Class GT: ~2700°F [1480°C] (MHI)
- Increased air extraction
- Higher output
- Higher net plant efficiency



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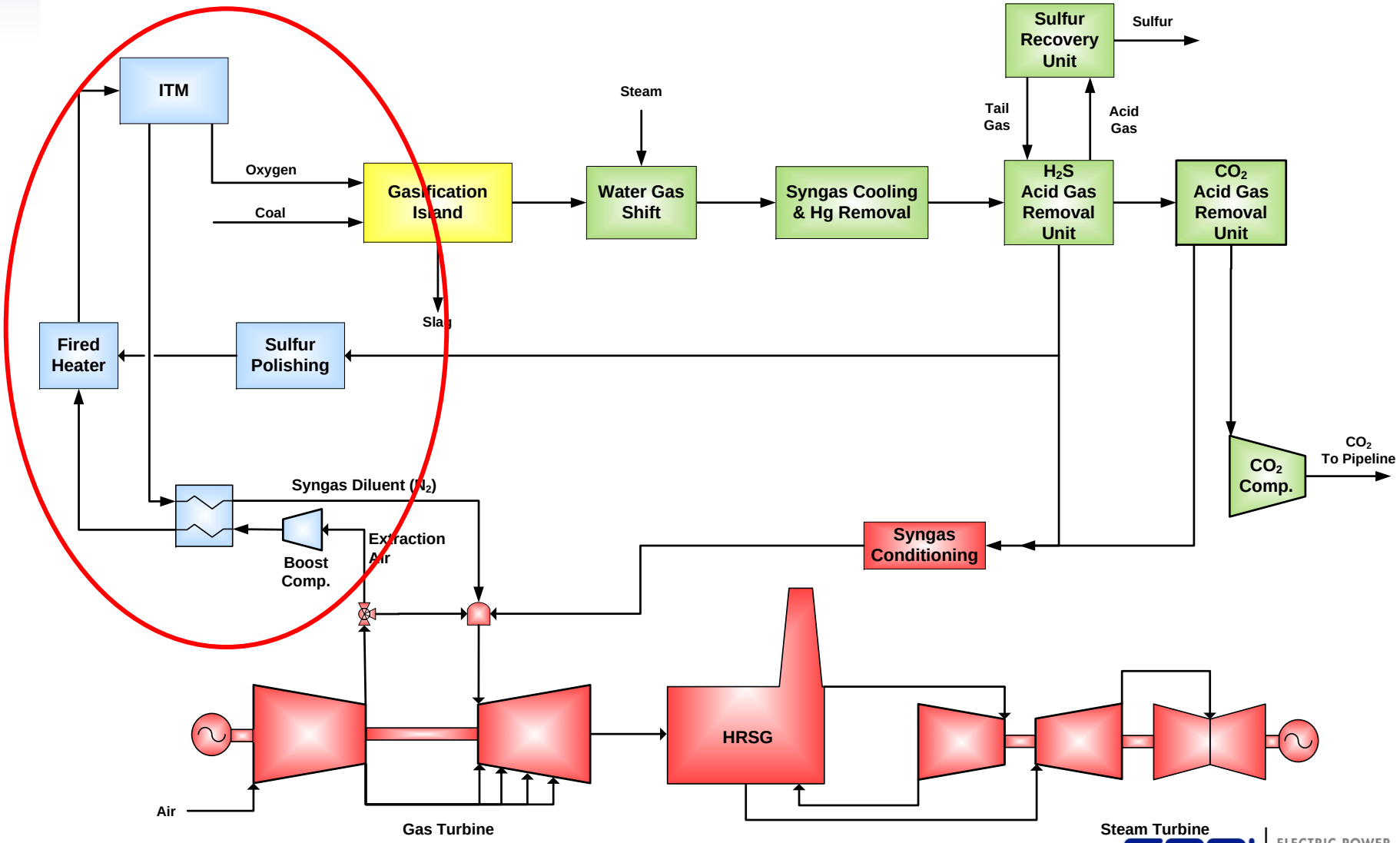
Advanced IGCC with CCS

Process Flow Diagram: IGCC w/ ITM, G-Frame GT w/ CO_2 Removal



EPRI Due Diligence *(TU Report # 1020202)*

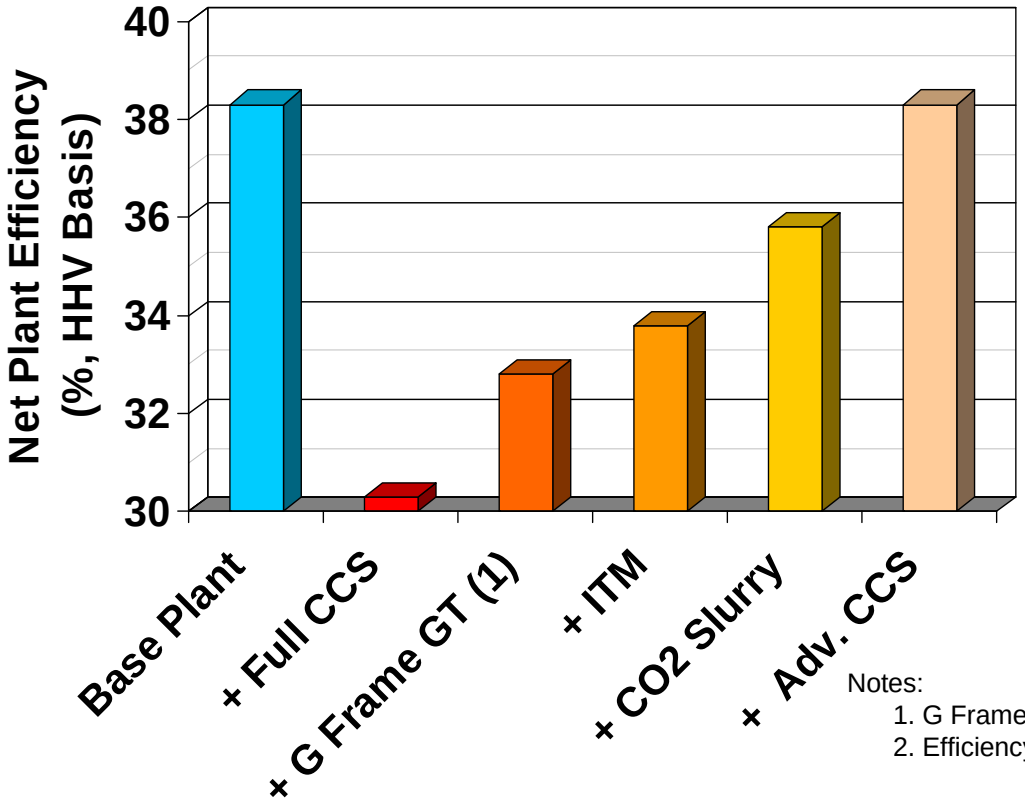
Cryo ASU vs. ITM in IGCC w/ CCS (G-Frame GT)

	Cryo Reference Case	ITM Case
Gas Turbine Power	1.00	1.00
Steam Turbine Power	1.00	1.02
Gross Power	**1.00**	**1.01**
ASU Auxiliary Power	**1.00**	**0.81**
Total Auxiliary Power	**1.00**	**0.94**
Net Power Output	**1.00**	**1.03**
Thermal Input	1.00	1.01
Net Plant Heat Rate, Btu/kWhr	Base	-230
Net Plant Efficiency, HHV	**Base**	**+0.8% point**

- Full air-side integration of GT and ASU
- Reduction in Auxiliary Load
- Positive ITM results warrant further investigation
- Further detailed analyses to be conducted through current project

IGCC Improvement Potential

EPRI Roadmap: Future Potential



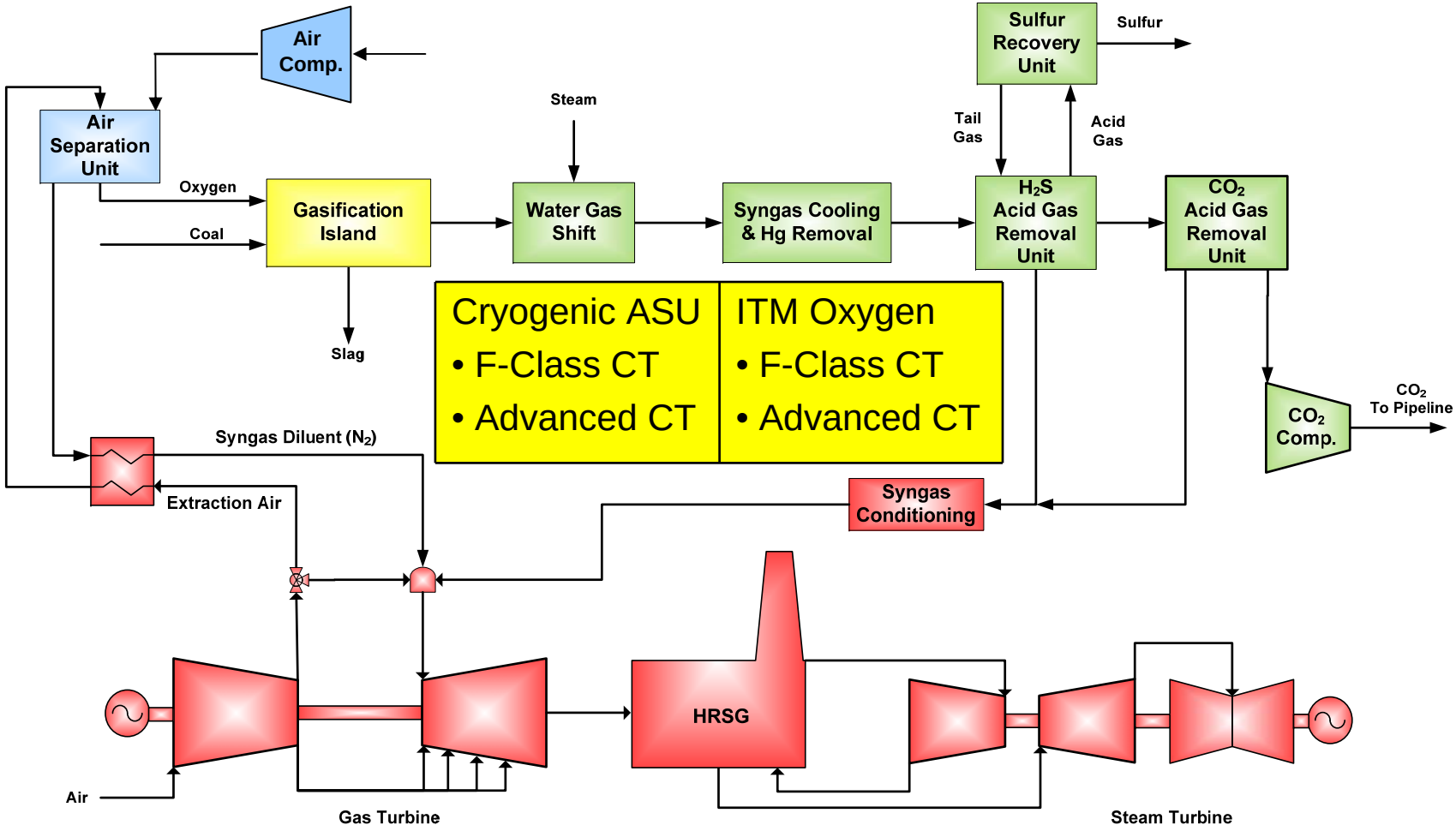
Notes:
1. G Frame GT case includes full air-side GT-ASU integration
2. Efficiency Improvements are cumulative

DOE and EPRI support similar IGCC roadmaps

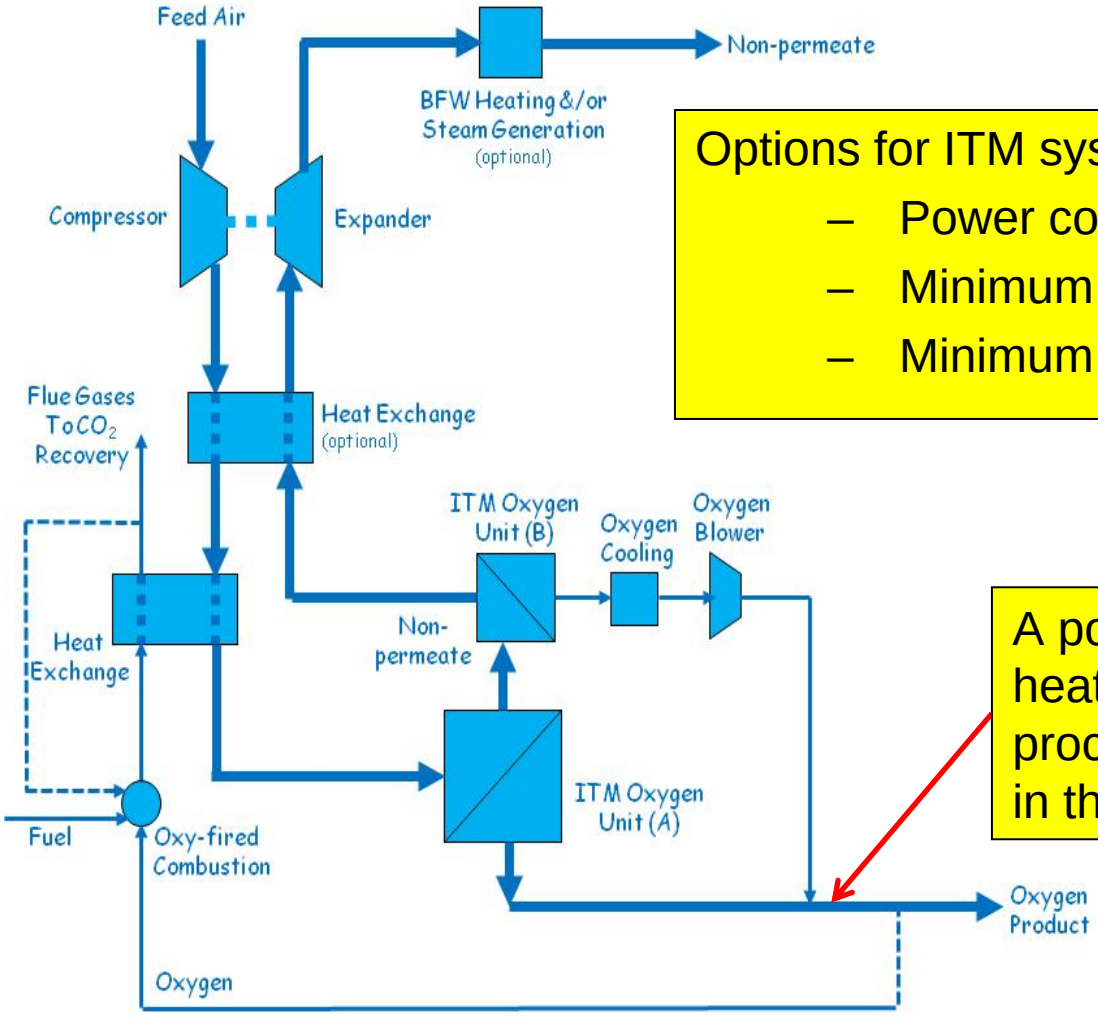
EPRI Tasks

- Plant-wide performance and cost analyses
- ITM operating envelope and design
- Test unit performance evaluation
- Requirements for ITM-based power plants
- Formulation of future development activities

EPRI to Evaluate IGCC with CCS Cases



One ITM-Based Approach to Low-Carbon Oxygen/Power Generation



Options for ITM system design:

- Power co-production
- Minimum fuel consumption
- Minimum CO_2 emissions

A portion of the heat from the ITM process is retained in the oxygen

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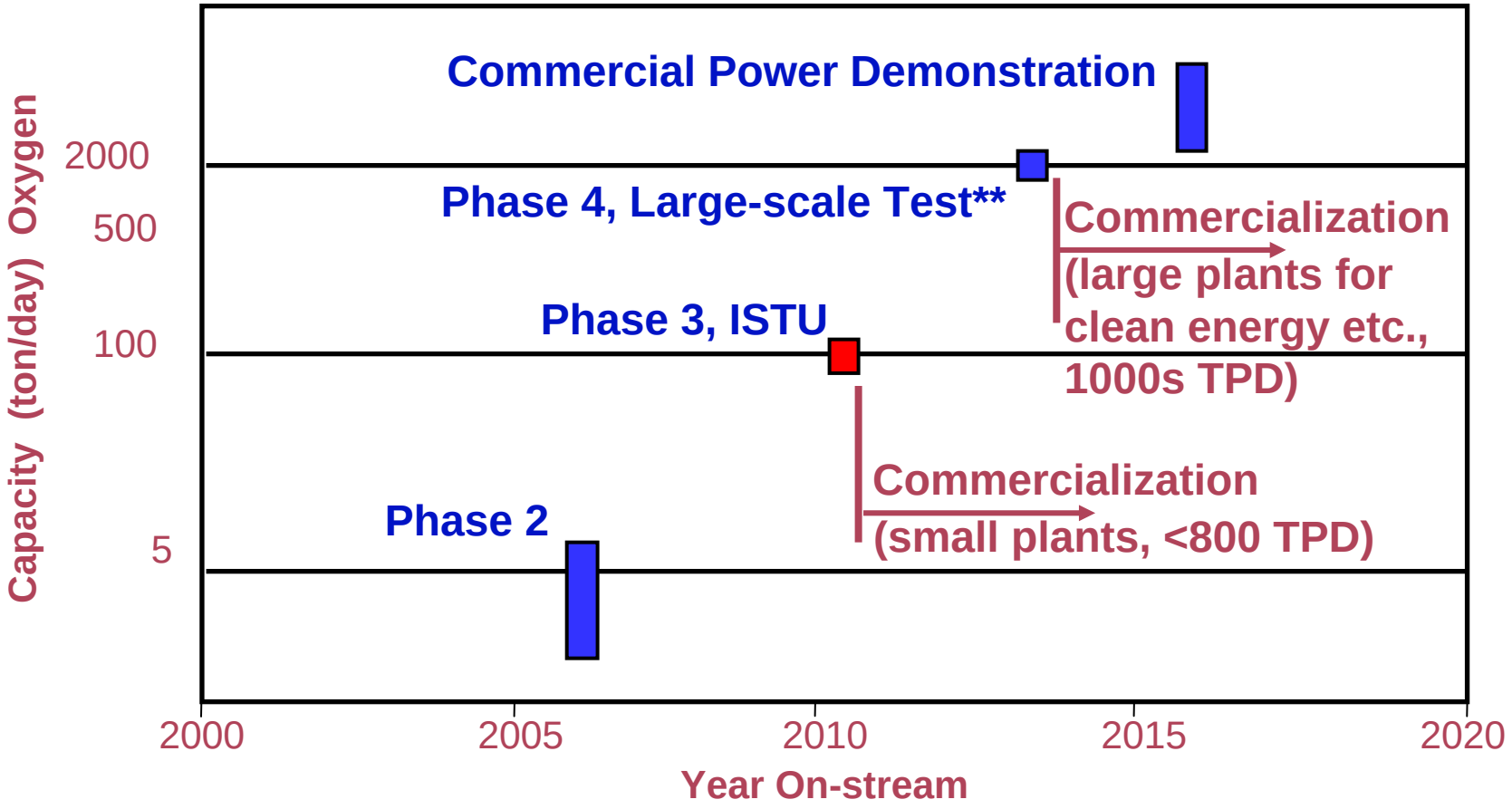
Summary of Technical Program Status

- SEP tests conducted in 2010:
  - 1 ton/day ITM modules
  - Getter for contaminant control
- Advanced module components and automatic shutoff valve proceeding through qualification
  - Early tests indicate the designs are very robust
- 100 ton/day ISTU project fully underway
  - Construction to be complete by Q4 2011
- Significant advances in ceramic processing capability at Ceramatec
- Current oxycombustion study indicates ITM yields significant specific capital cost advantage over cryogenic air separation
- IGCC-CCS study in progress

ITM Oxygen Development Schedule



**Pre-commercial scale facility (equivalent 110MWe oxycombustion or 250MWe IGCC)

Acknowledgment and Disclaimer

Acknowledgment

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Questions ?

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