ITM Oxygen Supply:
Scaling Up Toward Gasification and Energy/Industrial Applications

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

- Mature, reliable technology
- Requires 100’s of equilibrium stages
- Energy intensive
- Represents ~15% of IGCC capital cost
- Consumes ~15% of IGCC gross power output
Ion Transport Membranes (ITMs) produce high-purity oxygen at high flux

- Mixed-conducting ceramic membranes (non-porous)
- Typically operate at 800-900 °C
- 100% selective for \( \text{O}_2 \)
- \( \text{O}_2 \) flux \( \propto \frac{1}{L} \ln \left( \frac{P'_{O2}}{P''_{O2}} \right) \)

\[
\frac{1}{2}\text{O}_2 + 2e^- \rightarrow \text{O}^{2-}
\]

\[
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\]

\[
L \quad \text{O}^{2-} \quad \text{electrons}
\]

\[
\text{oxygen} \quad P''_{O2}
\]
ITM Oxygen membranes are supported thin-film planar devices

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

Dense membrane (both sides)

Oxygen flowing from air through dense membrane

One Membrane in Module

Hot Compressed Air

Porous membrane support

Dense, slotted backbone

Spacer ring

High-purity Oxygen Product

½-TPD module
ITM Oxygen integrates well with gas turbine power cycles

e.g., Siemens SGT6-6000G ~300 MW

OXYGEN COMP’R

OXYGEN SUPPLY to GASIFIER

OXYGEN COOLING

VITIATED AIR

OXYGEN

ION TRANSPORT MEMBRANE

STEW

ELECTRIC POWER

SYNGAS

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SYNGAS
We are building commercial-scale ITM modules ... 

- **All-ceramic** construction

1/2-TPD Modules

1-TPD Module
... and testing them in a pilot plant

Over 1,000 days cumulative operation
- Demonstrated >99% O₂ purity
- Demonstrated stable flux at target values
- Demonstrated good pressure and temperature cycling
We have fully cycled ITM modules with no performance degradation.
We also test prototype component designs for next phase of scale-up

- advanced control system
- flow duct design and insulation systems
- contaminant mitigation
- automatic shutoff valves (ASOVs)
- advanced architecture module components
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
- Using commercial design concepts to allow scale-up to the next test platform
  - vessel and internals housing large ITM module array
  - process controls
  - contaminant mitigation
- Located at existing Air Products ASU site in Convent, LA, USA
ISTU simplified BFD

- **Air**
- **TSA**
- **Exhaust**
- **Com- bustor**
- **Hot Gas Expander**
- **Oxygen**
- **Fired Heater**
- **ITM**
- **Exhaust**
- **Fuel**
- **Combustion Air**
- **Fan**

**Legend**:
- **main “air” circuit**
- **fuel line or “hot” equip’t**
- **O₂ line or equip’t**
- **“ambient” temp equip’t**
ISTU ITM Oxygen Vessel
ISTU construction has begun adjacent to Air Products existing ASU in Convent, LA, USA
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Williams International is supplying scalable hot gas expander
Design verified for stable combustion in vitiated air

Inlet Temperature (°C)

Oxygen Concentration (Fuel Free) (mole %)

- Ambient Air
- Stable Combustion
- Unstable Combustion

* data corrected for ISTU operating pressure

- Norster C3H8/N2
- Sturgess & Shouse C3H8/N2
- Odgers et al CH4/N2
- Odgers et al C3H8/N2
- Lewis & Von Elbe CH4/N2
- Lewis & Von Elbe C3H8/N2
- Gupta C3H8/Vitiated Air
- Hasegawa et al LPG/N2
- Least Squares Fit
- ISTU Combustor

Combustor Test Rig Setup
ISTU construction status

- All environmental permits issued
- Electrical tie-in to ASU substation complete
- Most major equipment on-site
- >25,000 safe construction hours worked
  - >10,000 hours by mechanical contractor
- Commissioning and startup by late 2012
- Operating through 2013
Ceramic Fabrication scale-up is underway (CerFab)

- Funding awarded from US Recovery Act to scale up ceramic manufacturing in dedicated large-scale facility (CerFab)
  - Design, build, operate by end of 2013 a facility to supply ceramic for a 2,000-TPD ITM Oxygen test unit
  - Engineering for a 2,000-TPD ITM Oxygen test unit
    • Looking for applications and host sites

CerFab will be located in Tooele, Utah, near Salt Lake City. Engineering for this facility is underway.
ISTU and CerFab are critical to commercialize energy-scale ITM Oxygen

Small Scale Test Unit 5 tpd O₂

ISTU 100 tpd O₂

CerFab Facility

modules

Next Scale Test Facility

Future Energy Applications 1000’s tpd O₂, >100MW

Early Industrial Applications 100’s tpd O₂, < 100MW

The future remains bright for ITM Oxygen

- Commercial-scale ITM Oxygen modules are being built and tested successfully
  - flux and purity targets verified
  - good thermal and pressure cycling

- ISTU project at 100-TPD scale under construction

- CerFab facility on track to begin producing modules for 2000-TPD test unit in 2013
ITM Oxygen is well positioned to meet the needs of clean energy applications

- Gasification: IGCC, CtL, XtL, decarbonized fuel
- Oxycombustion with or without CO₂ capture
- Clean energy with or without CO₂ capture
- Traditional energy-intensive industrial production
  - steel, ferrous and non-ferrous metals
  - cement, fertilizer, glass, pulp and paper
  - chemicals, petrochemicals, fuels

- Additional development supporters welcome
- We are actively pursuing early commercial opportunities
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