Oxygen Supply for Oxyfuel CO$_2$ Capture

1st OXYFUEL COMBUSTION CONFERENCE
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Radisson Hotel, Cottbus, Germany

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Agenda

- Oxyfuel Combustion
- Proven Large-Scale Oxygen Supply: Cryogenic Air Separation Units
  - Industry experience with very large ASU
  - Overview of the process
  - Challenges specific to oxyfuel combustion
- Next Generation Oxygen Production: Ion Transport Membranes (ITM)
- Conclusions
Oxyfuel combustion requires...

- Air Separation Units
- Steam Boiler & Turbine
- CO₂ Purification & Compression
- CO₂ Transport & Sequestration

Diagram showing the process flow of oxygen supply, steam boiler & turbines, CO₂ transport & sequestration, CO₂ purification & compression, and coal flow with flue gas recycle.
Large air separation units (ASUs)
Demonstrated Air Separation Capabilities

- **Technology base**
  - Cryogenic air separation
    - Up to 7,000 t/d
    - plus co-product nitrogen, argon, and other rare gases
    - Nitrogen only configurations
  - Non cryogenic air separation
    - From 2 t/d
    - Adsorption (PSA/VSA)
    - Membrane

- **Experience**
  - Worldwide presence
    - >1,200 air separation units owned or sold
    - >500 units operated and maintained
  - Major pipeline systems include:
    - US Gulf Coast
    - California
    - Rotterdam, Netherlands
    - China
    - Korea
    - South Africa
Experience - Large ASU Projects and Train Scale-up

- Market drives ASU scale-up
- Proven 70% scale-up
- Quoting 5,000+ MTPD today
Overview Of The Process

Main and Boost Air Compression

Air Cooling and Pretreatment

Cryogenic Separation

Storage

Air

Oxygen

Heat

Heat

Heat
Process Cycle Selection Criteria

- Oxygen demand profile
  - Purity
  - Pressure
  - Demand pattern, quantities, duration, frequency

- Argon co-production required?

- Power evaluation criteria

- Capex sensitivity

- Process integration philosophy

- Utility constraints, e.g. steam availability & quality, water consumption

- Operating constraints, e.g. availability, reliability, time to on stream, ramp rate.
A5000 Single Train
Design based on customer’s specific requirements:

- Parasitic load
  - Power vs. Capital costs
  - Purity requirements
  - Co-products
  - Compression integration
- Manufacturing
  - Transport of ASU(s) to site
  - Reducing construction / erection costs and risks
- Operability
  - Fit with customer’s use patterns
    - Turndown / ramping up
  - Advanced control capabilities
- Reliability
Power Costs and Design

Power is the single most important component of the ASU cost.

- Equipment
- Manufacturing
- Construction
- Engineering
- Operations

$0.05 / kWhr
$0.09 / kWhr

Technology and capital improve ASU Power consumption.
Power Consumption Reduction Opportunities

2012 Goal = 150-170 kWhr/ton

Front End Technology
5 kWhr/ton

Heat Exchange Technology & Equipment
20 kWhr/ton

Cycle Improvements
10 kWhr/ton

(*) 1 BAR - GOX only
Advanced Packing for Distillation Technology

- Structured Packing
  - Lower pressure drop – saves air compressor power
  - Better turndown
  - Higher plant capacity

- Sieve trays
  - Shorter columns
Compression: VLASU Design Considerations

- Compression is typically a large component of the cost stack
- We consider power valuation when designing # of trains
  - Multistage or single stage cooling
- Cooling water integration
  - Location of plant
  - Cost of cooling water / Type of systems
- Compression Driver
  - Steam turbines
  - Gas turbines
  - Motor technology / Starting system
- Erection / Packaging strategy
  - Field erect
  - Shop modules (pre-package)
- Cost Impacts
  - Axial vs. In-line cost or integral gear (up to 7000 TPD)
  - Need for soft start as compressor motors increase in size
  - Limited or reverse economies of scale for large vessels, piping and valves
  - Shipping costs or transportation limits
Compression: Design Considerations

Oryx- Qatar – 2x3500 TPD

- MAC—Steam Turbine—BAC
- Air Cooled Condenser
- Shop Skids
- String Test

A5000 and A7000 TPD – Single Train Compression

- Axial main air compressor (no GT integration)
- In-line boost air and nitrogen compressors
- Four large suppliers = GE, MHI, Siemens, MAN

A5000:
- GE Frame 7
- Siemens STC 1000
- MAN AR130-AR140
- MHI M501D

A7000:
- GE Frame 7 - Frame 9
- Siemens STC 1300
- MHI M501F

A5000 and A7000 TPD – (2x Compression – Multitrain)

- Integral gear (GT Copco or STC) or In-line air compressors (RIK)
- Integral gear or In-line boost air and nitrogen compressors (if N2 needed)
Process Integration Goals and Methods

- Reduce cost/improve efficiency without compromising operability

- “Easy” integrations
  - Use of by-product energy (Steam)
  - Combined utility systems (Cooling Water)
  - Air/nitrogen integration with gas turbines

- “Harder” integrations
  - Internal streams between process units
  - Start-up requires other units to be in operation
Reliability

- Air Products operates the majority of plants that it designs and builds

- Thousands of man-years of ASU operating experience includes customers that require 100% availability of products
  - Average plant availability is greater than 99%
    - Average duration of plant trip is ~16 hr
    - Spare parts handling strategies in place
    - Maintenance shutdown once/3+ yrs
      - Coincide with normal power plant maintenance
  - Instantaneous back-up systems in place today in safety-sensitive and electronic applications

Outage Duration 1995 - 2008

- 8 - 16 Hours: 17.1%
- < 8 hours: 38.2%
- >24 Hours: 27.6%
- 16 - 24 Hours: 17.1%
Operability: Plant Ramping, Advanced Controls technology

- Benefits of Advanced Control capabilities
  - Lower power consumption
  - Higher product recoveries
  - Faster disturbance response and mitigation
  - Faster response to changing product demands
  - Higher multi-plant efficiency

- ASU ramping capabilities
  - 1%/min typical
  - 2%/min achievable with advanced control
  - 3%/min possible when “designed in”
  - Higher rates possible by using liquid oxygen backup
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ITM: Revolutionary Technology for Tonnage Oxygen Supply

Goals for ITM in power applications:

- Reduced footprint with lower capital cost
- High-purity, High flux oxygen with lower parasitic power requirement
- High-temperature process has better synergy with power generation systems

0.5 TPD module (commercial-scale)
ITM Oxygen Program

Targeting Reduction in the Cost of Oxygen by One-Third

- Phase 1: Technical Feasibility (0.1 TPD O₂)
- Phase 2: Prototype Testing (1-5 TPD O₂)
- Phase 3: Intermediate Scale Testing (150 TPD O₂)

- Broad, multi-disciplinary team
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 O₂

\[ O_2 \text{Flux} \propto \ln \left( \frac{P'_0}{P''_0} \right) / L \]
ITM Oxygen integrates well with power generation cycles

Previous studies have shown ITM Oxygen requires 30% less capital and 30-60% less energy than a cryogenic oxygen plant.
ITM Oxygen commercial modules continue to be tested in the 5 TPD Pilot Plant

- ITM Vessel Internals
- Flow Duct Installed
- 2 Modules Installed
- Heater
- Make-up Streams
- Control Room
- Vacuum Pumps
- 6 Independent Product Trains
- Heat Exchangers

515 days operation
- Demonstrated Purity
- Demonstrated Flux
- Testing Operations
- Demo’d thermo-cycling
Next stage scale-up is in design: Intermediate-Scale Test Unit (ISTU)

- Forward schedule envisions completion of construction in late 2010

- Goals include:
  - Produce 150 TPD oxygen from an ITM Oxygen system integrated with power co-production equipment
  - Use fuel as primary energy input to the system
  - Use commercial design concepts toward scale-up to the next test platform (~2000 TPD)
ITM Oxygen Enables a Step-change Reduction in the Cost of Oxygen

2500 TPD Oxygen Plant

ITM Oxygen vessel scaled to match cryogenic oxygen plant output
Summary

- There is a major new industry requirement for ASUs from fossil-fuel fired power generation.
- ASUs have changed a great deal in the past 15 years:
  - New cycles
  - Structured packing for distillation
  - More power efficient
- Single train sizes over 5000 tonne/day
- Integration with CO₂ capture unit
- Manufacture/erection approach is project specific
It is about more than just $O_2$...

- **APPLICATION EXPERIENCE:** Supplied large oxygen/air separation equipment to all type of applications and industries:
  - Power
  - Gasification
  - Metals
  - Refining / Petrochemicals

- **INTEGRATION EXPERIENCE:** Air separation plants in all integration modes—
  - Oxygen supply control system
    - Load following, start-up shutdown, peak-shaving
  - MAC heat recovery
  - Off-gas oxygen recovery for boiler blended to LASU $O_2$
  - Standalone, nitrogen integrated, and air/nitrogen integrated (IGCC)

- **MEGA-TRAIN EXPERIENCE:** Operating very large single train air separation plants since 1997 in Rozenburg, The Netherlands (3250 MTPD); also installed a 2x3500 MTPD unit in Qatar

- **RELIABILITY:** First company to supply high-reliability tonnage oxygen for power projects without oxygen backup

- **OTHER GAS PRODUCTS:** Broad industrial gas industry experience creates synergies with H2, CO, and CO$_2$ markets
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