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Oxyfuel Activities in USA & FutureGen Update

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Coal Research Forum – Meeting of Combustion Division
25 April 2012

Contents – Some key US projects / initiatives

- Brief overview of CCS projects in the US
- Overview of US Oxyfuel Activities in US
  - B & W and Air Liquide
  - Alstom, US DOE, NETL
  - Air Products & ITM
- EPRI Activities
- FutureGen 2.0 Update

DOE Large Scale CCS Projects (as of 2011)

Project	Location	Capture rate (ts / yr)	Repository	Start
Oxy-Combustion				
FutureGen 2.0	Meredosia IL	1,150,000	GS	2015
Pre-Combustion Capture (IGCC)				
Summit Texas Clean Energy	Odessa, TX	2,700,000	EOR	2014
Southern Company	Kemper Co, MS	1,800,000	EOR	2014
Hydrogen Energy	Kern Co, CA	1,800,000	EOR/GS	2016
Post Combustion Capture				
Basin Electric	Beulah, ND	450,000 – 1,360,000	EOR/GS	2014
NRG Energy	Thompsons, TX	400,000	EOR	2015
AEP	New Haven, WV	1,500,000	GS	2015
Industrial CCS Solicitation				
Leucadia Energy	Lake Charles, LA	4,000,000	EOR	2014
Air Products	Port Arthur, TX	900,000	EOR	2013

Alstom, US DOE & NETL

- One of 6 R & D Carbon Capture Projects funded by Existing Plants, Emissions & Capture Programme (EPEC)
- Focus on retrofit to T-fired units (500 – 600MWe)
- Optimised demonstration 100 – 200MWe
- Pilot scale tests at 15MWth T-Fired BSF
- Several oxy-combustion system designs to be evaluated
- Will include techno-economic analysis
- Project cost – circa $18m (DOE -$15m)

Courtesy of Alstom

Babcock & Wilcox and Air Liquide

- B & W and Air Liquide have been developing oxy-combustion retrofit technology at their respective test facilities

- Two-phased approach
  - Phase 1 – Effect of coal rank
  - Phase 2 – Engineering & Economic assessment of technology

- Developing a 700MWe Oxy-Coal Reference Plant with EPRI & URS
  - Sub-bituminous coal
  - Steam – 259bar, 593C
  - Wet Cooling
  - Location – Kenosha, Wisconsin

- Technology suppliers to FutureGen 2.0

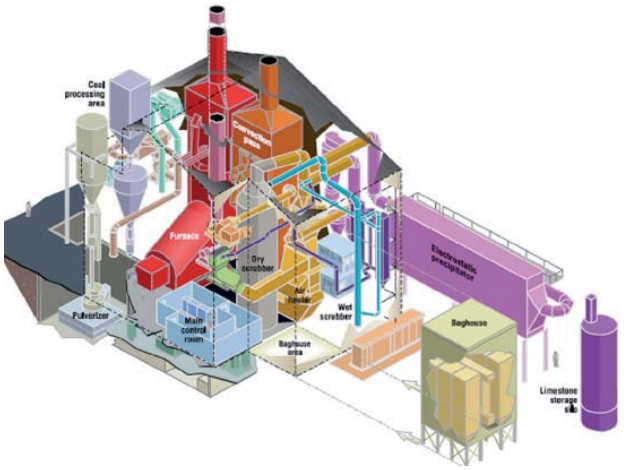
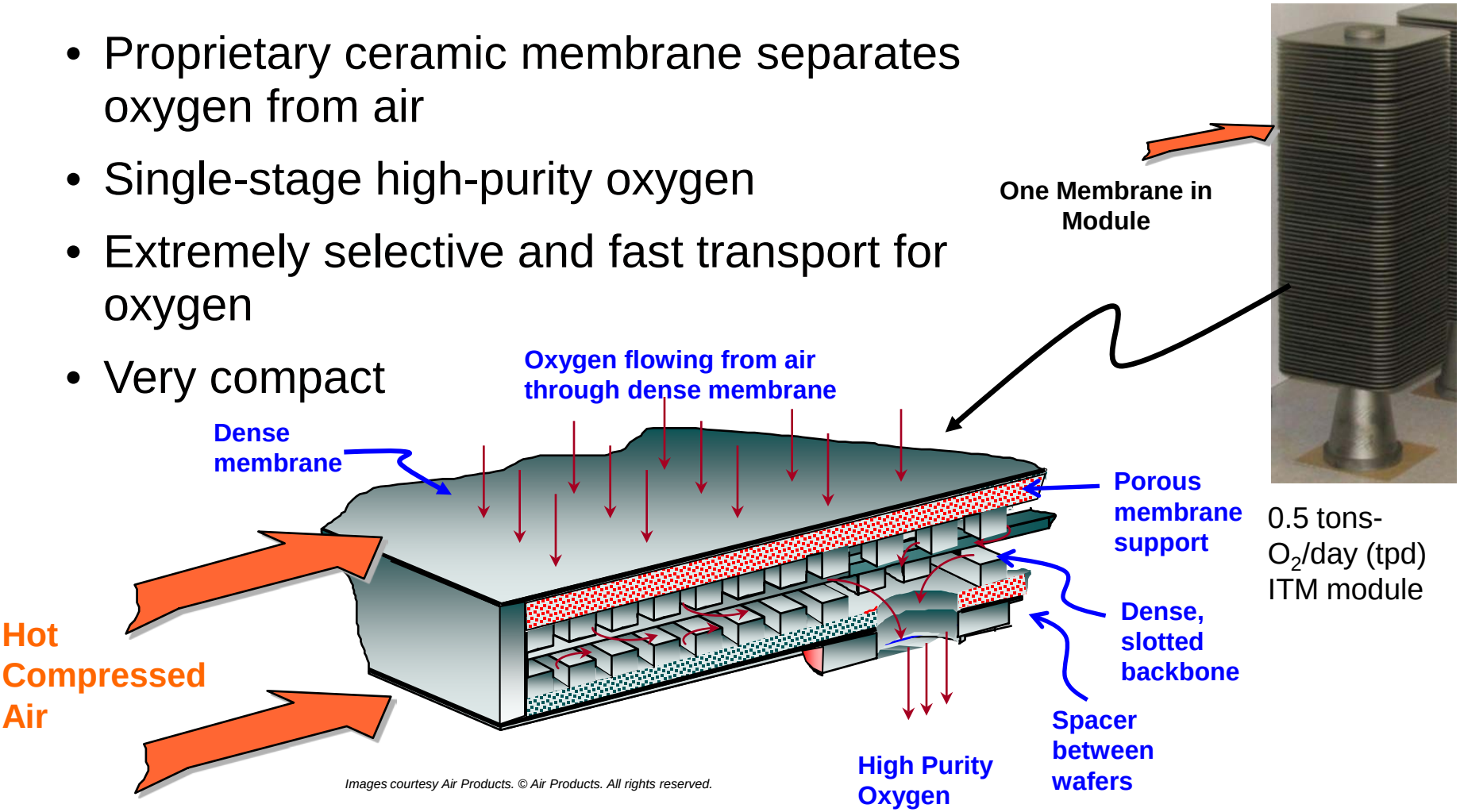


Illustration of B & W's Oxy-combustion Pilot Scale Test Facility

ITM Oxygen Membranes – Air Products

- Proprietary ceramic membrane separates oxygen from air
- Single-stage high-purity oxygen
- Extremely selective and fast transport for oxygen
- Very compact



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1500-1650°F (800-900°C), 200+ psia (14+ bara)

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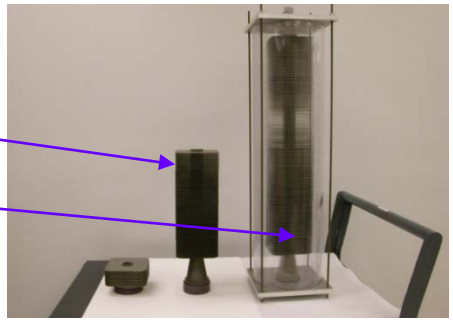
ITM Oxygen Unit

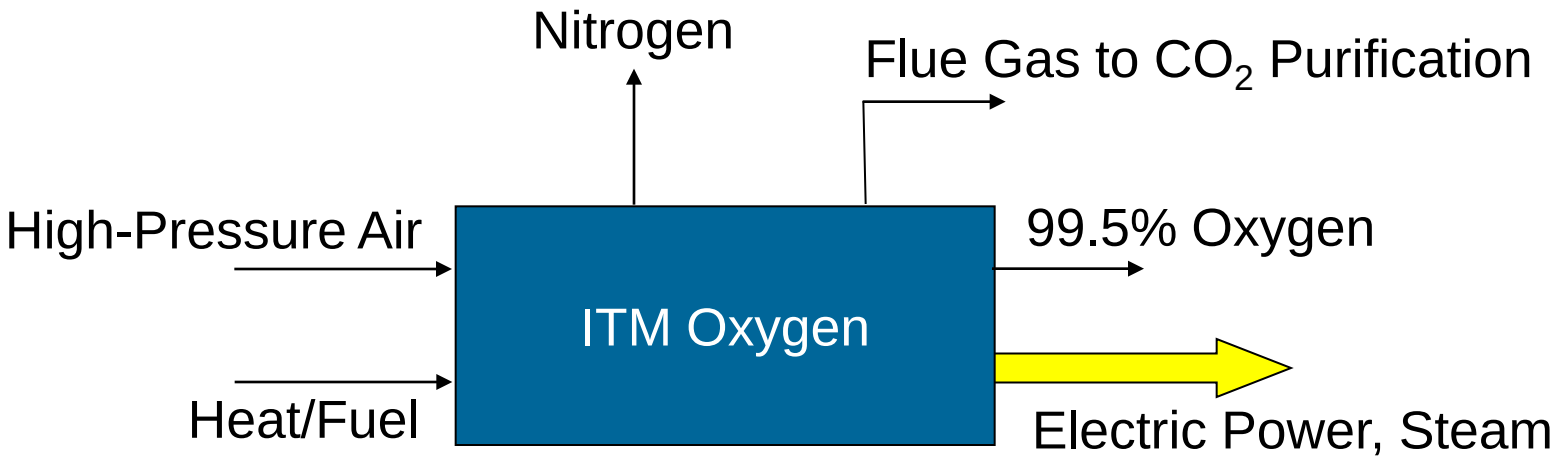
ITM Modules

- 0.5 tpd
- 1.0 tpd



Options for ITM Oxygen Unit Design:

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



EPRI – Generation Sector Focus

Collaborative Bandwidth

Operations and Maintenance

- I&C & Automation
- Maintenance Management & Technology
- Fossil Maintenance Applications Center
- Operations Management & Technology

Major Component Reliability

- Boiler Life & Availability
- Boiler and Turbine Steam & Cycle Chemistry
- Steam Turbines, Generators, & Auxiliary Systems
- Fossil Materials & Repair

Combustion Performance

- Combustion Performance & NO_x Control
- Post-Combustion NO_x Control

Generation Planning

- Technology-Based Business Planning Information & Services
- Power & Fuel Markets & Generation Response

Renewables

- Renewable Generation

Advanced Coal Generation

- **CoalFleet for Tomorrow**
- **CO2 Capture and Storage**

Combustion Turbines

- Combustion Turbine & Combined Cycle O&M
- New CT/CC Plant Design and Technology Selection
- Heat Recovery Steam Generator (HRSG) Dependability

Environmental Controls

- Integrated Environmental Controls
- Particulate and Opacity Control
- Continuous Emissions Monitoring
- Coal Combustion Product Use

Demonstrations

- Industry Demonstrations

Operational integrity of existing assets, regulatory compliance, new build decisions

Advanced Coal Generation

Cost-effective coal-based generation with carbon capture and storage

- **Economics/Planning**
  - Technology knowledge databases
  - Economic analyses of new and retrofit power generation with CCS
- **Retrofit/Repower Existing Assets**
  - Repowering strategies which maximize use of existing coal assets
  - Quantifying and Optimizing CO_2 capture retrofit strategies
- **Future Assets**
  - High efficiency ultra-supercritical PCs
  - IGCC design/cost improvements
  - **Optimization of design and operations with CCS (post-, pre- and oxy-combustion capture)**
  - Accelerated development of advanced CO_2 capture technologies
- **All Assets**
  - Supporting the US Dept of Energy's National Carbon Capture Center

CoalFleet for Tomorrow (66)

Preparing technologies for use in the Coal Power Plant of the 2020s: Advanced Ultrasupercritical PCs, IGCCs and Oxy-Combustion Power Plants

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2012 R&D focus

Identifying and nurturing technologies which can have a significant impact on the cost of electricity from new coal power plants

- Targeting to have reliable and highly efficient new coal plant designs with near-zero emissions and CO_2 capture available to industry by 2025
- Timely and accurate engineering and economic information about advanced coal technologies to support generators' decision-making processes
- Shorten the development time for promising CO_2 capture technologies by co-sponsoring the US Dept of Energy's National Carbon Capture Center
- Validating materials needed for boilers and turbines to operate with steam conditions up to 1400°F (760°C) and 47% HHV efficiency

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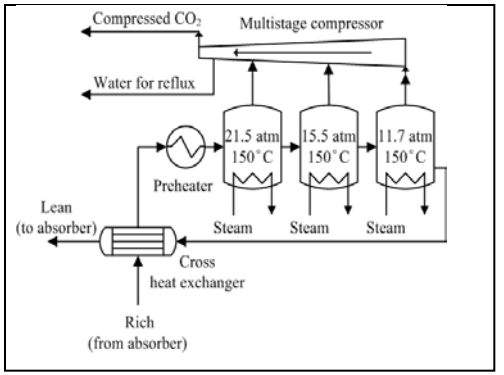
Carbon Capture & Storage (CCS)

Cost-effective coal-based generation with carbon capture and storage

- **Economics/Planning**
  - Technology knowledge databases
  - Economic analyses of new and retrofit power generation with CCS
  - Understanding of fully integrated CO_2 chain – capture to storage
- **Post-Combustion CO_2 Capture Technology Development**
  - Accelerated development of advanced PC capture technologies
  - Carbon capture technologies testing at pilot and sub-pilot scales
  - Industry technology demonstrations
  - Optimization of design and operations with post-combustion CO_2 capture
- **CO_2 Storage**
  - Guidelines for managing storage
  - Advanced reservoir characterization and CO_2 monitoring techniques

CO_2 Capture & Storage (165)

Provide confidence that acceptable capture technologies and storage options will be available when needed



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2012 R&D focus

Develop improved post-combustion capture processes and confirm suitability of transport and storage

- Basis for credible asset planning
- Reduced cost-of-electricity (COE) for post-combustion carbon capture
- Reduced parasitic energy demand
- Knowledge to enable CO_2 underground storage to be understood by government bodies and the public.
- Independent information to develop regulations and legal frameworks for underground CO_2 storage.
- Reduce risk and cost of CO_2 product impurities resulting in increased CO_2 removal requirements, additional injection wells, or unacceptable storage sites

EPRI Oxy-Coal Program Approach

1. **Conduct engineering and economic evaluations of oxy-coal with CO_2 capture.**
   - *Full scale, new-build plant evaluations (published and on-going)*
   - *Oxy-coal retrofit/repowering evaluations (pending)*
2. **Monitor worldwide oxy-coal with CO_2 capture research, demonstration, and deployment.**
   - *Periodic critical reviews of worldwide activities. (published and on-going)*
   - *Pressurized oxy-coal*
   - *Chemical looping combustion*
3. **Conduct CO_2 purification unit technology assessments**
   - *Achieving the zero-emissions coal-fired power plant. (preliminary assessment published)*
   - *CPU process optimization (pending)*
   - *Affect of impurities on transport and storage of product CO_2 (In cooperation with Program 165)*
4. **Provide a platform to put forth industry (utility and vendor) view of oxy-coal with CO_2 capture RD&D needs.**
   - *Working group to produce a white paper (in process)*
5. **Assist in development (and monitoring) of field demonstration projects**

Publications Pertinent to Oxy-Combustion CO_2 Capture

- ***Engineering and Economic Analysis of Oxy-Fired 1100°F Ultra-Supercritical Pulverized Coal Power Plant with CO_2 Capture.*** August 2011. 1021782.
- *Engineering & Economic Evaluations ("EEE") of Advanced Coal Power Plants.* June 2011. 1022025.
- *Oxy-Coal Technology for Carbon Dioxide Capture: Worldwide Development Activity Update.* December 2010. 1019673.
- *Pressurized Oxy-Coal Combustion for Electric Power Generation: A Preliminary Assessment of Field Experience and Prospects.* December 2009. 1021454.
- *Prospects of Oxy-Coal Steam-Electric Power Plants Achieving "Minor Source" Status for Air Emissions Permitting.* December 2009. 1017514.
- *Oxy-Fired Circulating Fluidized Bed with Carbon Dioxide Capture and Storage at Holland Board of Public Works.* December 2009. 1020277.
- *Summary of Test Results from Babcock and Wilcox's 30 MWth Oxy-Coal Pilot Plant.* September 2009. 1017508.
- *Program on Technical Innovation: Oxy-Fired CFB with CO_2 Capture and Storage at Jamestown (NY) Board of Public Utilities.* May 2009. 1018709.

Selected Oxy-Coal Engineering and Economic Evaluation Publications

EPRI

- *Engineering and Economic Analysis of Oxy-Fired 1100°F Ultra-Supercritical Pulverized Coal Power Plant with CO_2 Capture.* August 2011. 1021782.
- *Engineering & Economic Evaluations ("EEE") of Advanced Coal Power Plants.* June 2011. 1022025.

USDoE

- *Pulverized Coal Oxycombustion Power Plants, Volume 1: Bituminous Coal to Electricity.* DOE/NETL-2007/1291, R2, August 2008.
- *Cost and Performance of Low-Rank Pulverized Coal Oxycombustion Energy Plants. DOE/NETL-401/093010.* September 2010.

Consistent conclusions:

- Oxy-Coal power plants (with CO_2 capture) can be built using technologies currently available; a viable technical option to Post-Combustion CO_2 Capture and Pre-combustion CO_2 Capture.
- Oxy-coal LCOE, cost of avoided CO_2 emissions, and cost of CO_2 captured are: at a minimum competitive with Post- and Pre-combustion CO_2 capture and: may have economic advantages over these alternatives.

FutureGen 2.0

Oxy-Combustion w/ CO_2 Sequestration

- Meredosia, IL & Morgan Co., IL
- 200 MWe gross oxy-combustion repowering of Ameren's Meredosia Unit 4 steam turbine (Start 2016)
- 90% CO_2 capture (cryogenic separation) 1,300,000 tons CO_2 /year
- Deep saline sequestration in Mt. Simon formation
- Total Project: $1.3 Billion
  DOE Share: $1.05 Billion (81%)

Key Dates

- **Complete FEED: October 2012**
- **Construction: November 2012**
- **Operation: May 2016**

Status

- **PreFEED – in progress**
- **Sequestration site characterization and validation In progress**
- **NEPA in progress, scoping meetings held, EIS being drafted**

Information courtesy of NETL

FutureGen 2.0 – Project Objectives

To prove the Oxy-combustion process at commercial scale

- Establish a cost and schedule baseline for the technology
- Equipment Design Considerations –Primarily Boiler Reliability – component design, materials of construction
- Maintainability –erosion, corrosion, outage cycles
- Not designed for high efficiency – for flexibility & learning
- Prove basic process and heat transfer parameters – can scale to higher efficiency, larger capacity w/o incremental steps
- Process Design Safety, Functionality, Operability
- Integrated operation of major components
- Understanding Storage Start-up, Shutdown, Load Swing, Capacity Factor, System Dynamics

FutureGen 2.0 – Project Partners

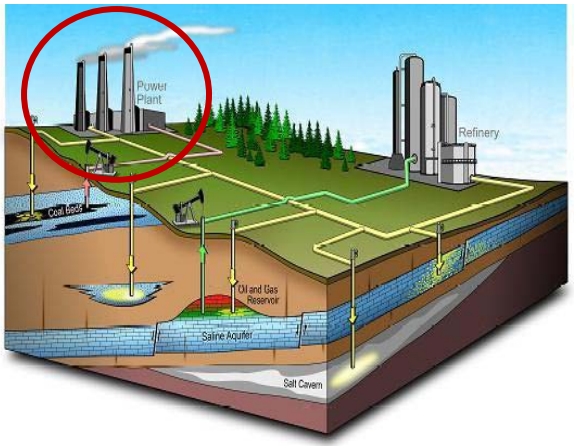
- Ameren (recently decided to pull out)
- Babcock & Wilcox
- Air Liquide
- FutureGen Alliance (non-profit partnership) - includes
  - Anglo American
  - Rio Tinto
  - Peabody Energy
  - Xstrata Coal
  - Consol Energy

- B & W and Air Liquide are the primary contractors

- The FutureGen Alliance is the single entity for the whole project following Ameren's withdrawal and responsible for Project Mgt

FutureGen 2.0: Oxy-Combustion Repowering

A large-scale integrated test to repower Ameren's existing Meredosia Unit 4 with oxy-combustion & carbon capture technology



- ✓ A purpose-built oxy-combustion system
- ✓ Confirmation that oxy-combustion is a viable repowering/new build technology for coal-fueled power plants, incorporating a testing program that will utilize Illinois bituminous coals & other coals
- ✓ Basis for industry acceptance: lowers equipt, operational, reliability & financial risks for future commercial deployments to meet U.S. & world energy needs

Benefits of the Meredosia Host Site

- ✓ Existing site infrastructure conserves capital cost
- ✓ It is the "right size" unit
  - Demonstrates retrofit/repowering potential for existing coal units
  - Large enough test of the technology to support commercial deployment (e.g., 500-800 MWe, supercritical) without another, intermediate, scale-up step
  - Small enough to conserve capital expense for a large-scale integrated test
  - ~3500 tpd CO_2 to storage

Meredosia Power Plant

Information courtesy of NETL

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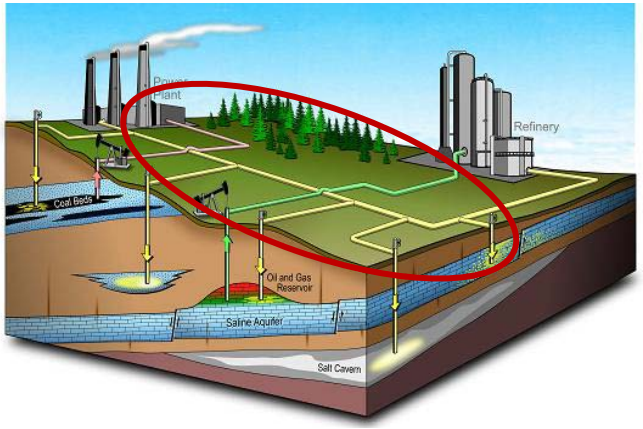
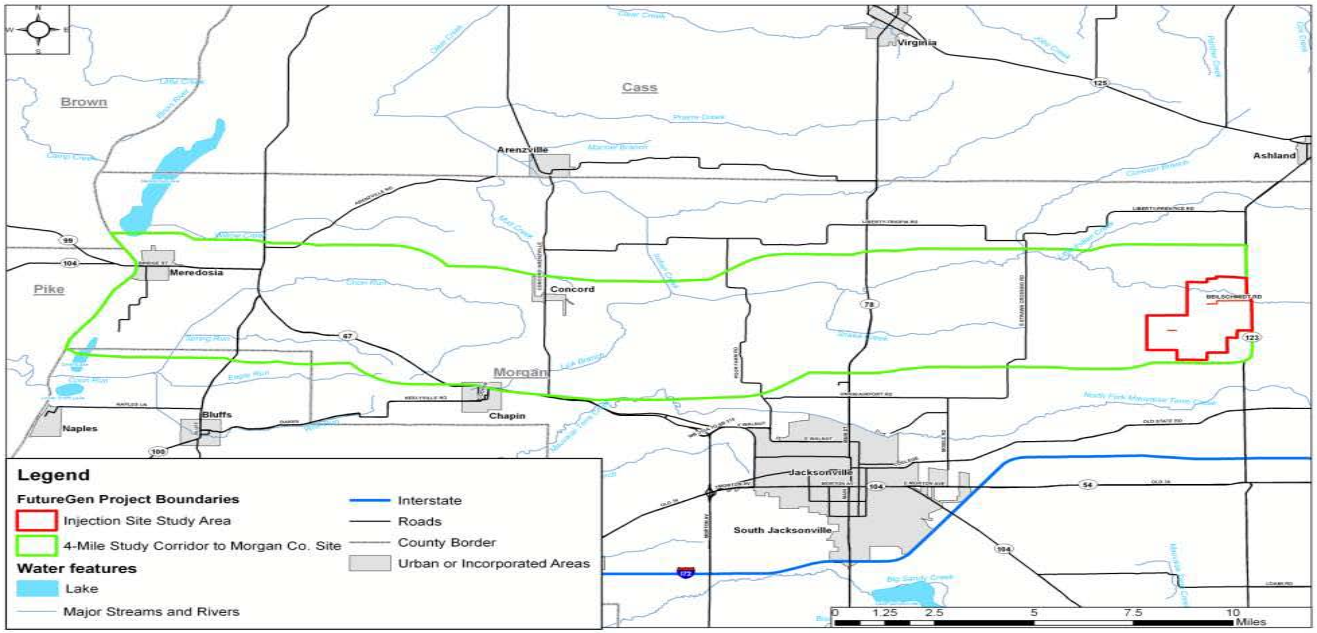
FutureGen 2.0: CO_2 Transmission Pipeline

- Pipeline to transport CO_2 from Meredosia to preferred CO_2 storage site in northeastern Morgan County, Illinois
  - ~30 miles of pipeline from Meredosia to Morgan County site
  - 12-inch diameter pipeline; 2000 psi operating pressure
  - 4-mile wide corridor to be studied as part of EIS



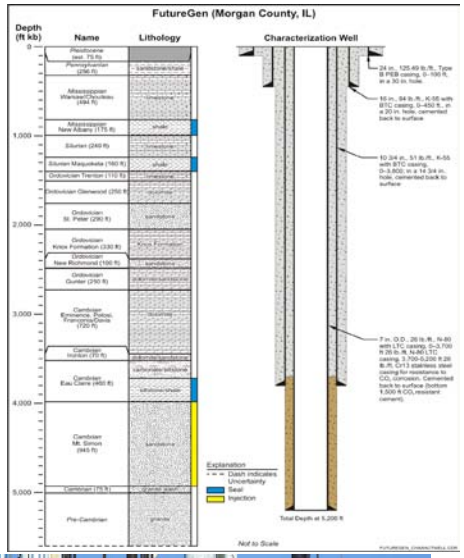


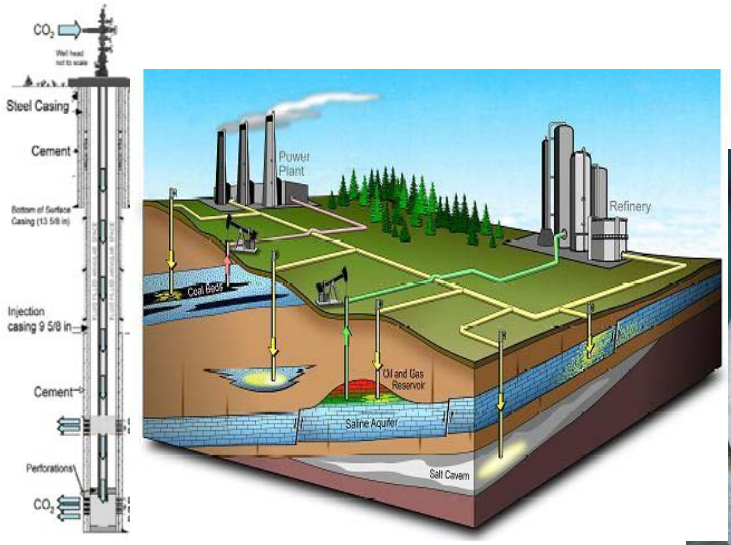
Information courtesy of NETL

FutureGen 2.0: Geological CO_2 Storage

- Design, build & operate geologic storage repository capable of safely permanently sequestering anthropogenic CO_2
  - Site characterization for large volumes to be stored
    - … Modeling, seismic surveys, drilling of characterization wells, injection well design
  - Visitor, education & research facilities
  - Strong community interest, at preferred site & two alternate sites
  - Characterization well completed to depth of 4826’ on December 4, 2011
  - Core sample analyses & reservoir characterization studies being initiated

1. The FGA will not cost share in the visitor, education and training facilities.





Information courtesy of NETL

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FutureGen 2.0 – Progress to date

- Currently 6 – 7 months behind
- Ameren cannot participate as originally envisioned
- Ameren announced plan to close the Meredosia Plant
- Possible FutureGen Alliance may lease the Unit, currently seeking DOE approval
- Preliminary Engineering studies (Pre-FEED) complete
- Test storage well completed
  - Characterisation well indicates suitability of geology
  - Geology data still being analysed
- Project cost estimates up for Federal Review
- The Energy Department remains committed to demonstrating CCS
- Watch this space

Thank you for listening

Happy to take questions

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