AVESTAR Center for Operational Excellence of IGCC Power Plants with CO2 Capture

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Presentation Outline

• U.S. Energy Challenges
  – Power Generation Capacity and Clean Energy Plant Operations

• Advanced Virtual Energy Simulation Training And Research (AVESTAR™)
  – Mission and Goals
  – Integrated Gasification Combined Cycle (IGCC) with CO₂ Capture
    • Process/Project Overview
    • Dynamic Simulator/Operator Training System (OTS)
      • 3D Virtual Immersive Training System (ITS)

• Facilities, Training, Education, and R&D

• Future Simulators/Directions
U.S. Energy Challenges
Power Generation Capacity

Meet increasing demand for clean, affordable, and secure energy by developing a diversified portfolio of power generation plants

- Optimize efficiency of coal-fired plants, while taking full advantage of carbon capture, utilization, and storage (CCUS)
  - Accelerate deployment of post-combustion CO$_2$ capture for pulverized coal plants
  - Exploit pre-combustion CO$_2$ capture advantages and fuel/product flexibility of gasification systems (e.g., IGCC)
- Grow gas-fired generation driven by large increase in shale gas
  - Exploit post-combustion CO$_2$ capture
- Grow share of generation from renewables (e.g., wind, solar)

Source: ExxonMobil-2012 The Outlook for Energy: A View to 2040
U.S. Energy Challenges
Clean Energy Plant Operations

• Improve plant operability, controllability, and flexibility
• Optimize not only baseload operations, but also plant startup, shutdown, and feedstock switchovers
• Respond effectively to process and market disturbances
• Handle faulted operations and abnormal situations
• Increase cycling, ramping, and power demand load following, while minimizing plant derates, emissions, and equipment damage
• Optimize performance by controlling operations closer to economic and environmental constraints, while avoiding any unsafe, wasteful, or inefficient events
• **Mission**
  – Accelerate progress toward achieving *Operational Excellence* for *Clean Energy Plants*
    • 1) Asset, 2) Control, 3) Environment & Safety, and 4) People
• **Goals**
  – Dynamic Simulator Development
    • Develop portfolio of high-fidelity real-time dynamic simulators with full-scope operator training systems (OTSs) and 3D virtual immersive training systems (ITSs)
  – Advanced Computational Research
    • Bring together advanced dynamic simulation-based technologies, state-of-the-art facilities, and leading energy experts
    • Conduct collaborative R&D on dynamics, control/sensors, real-time optimization, virtual plants, smart manufacturing, and modern grid
  – Training and Education
    • Train workforce and educate students using experiential learning
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IGCC Power Plant with CO$_2$ Capture

- IGCC operates at high pressure with oxygen instead of air
- CO$_2$ is removed before combustion
- Increased power plant efficiency
- Lower cost of electricity
- CO$_2$ is easier to capture and is produced at higher pressures

**Plant Section** | **Description**
---|---
Gasification | Entrained-flow Gasifier
Air Separation | Elevated-P Cryogenic ASU (95% vol O$_2$)
H$_2$S Separation | Physical Solvent AGR 1$^{st}$ Stage
Sulfur Recovery | Claus Plant
CO$_2$ Separation | Physical Solvent AGR 2$^{nd}$ Stage
CO$_2$ Compression | Four stage (2200 psia)
Gas Turbines | Adv. F Class (232 MW output each)
Steam Cycle | Subcritical (1,800 psig/1,000ºF/1,000ºF)
Power Output | 746 MW gross (556 MW net)
Status of IGCC Power Plants

**Without/With CO₂ Capture**

**United States**
- **Wabash River Energy**
  - Wabash River, IN
  - 262 MWe, 1995

- **Tampa Electric Co.**
  - Tampa, FL
  - 250 MWe, 1996

- **Duke Energy**
  - Edwardsport, IN
  - 618 MWe, Fall 2012
  - 23% CO₂ Capture Retrofit

**Southern Company**
- Kemper Co., MS
- 65% CO₂ capture

**Texas Clean Energy**
- Odessa, TX
- 90% CO₂ capture (EOR)
- Urea

**SCS Energy**
- Kern Co., CA
- 90% CO₂ capture (EOR)
- Hydrogen

**Europe, Asia, Australia**
- **Nuon**
  - Buggenum, Netherlands
  - 253 MWe, 1994

- **ElcoGas**
  - Puertollano, Spain
  - 298 MWe, 1998

- **Nakoso, Japan**
  - 250 MWe, 2007

- **South Korea**
- **China**
- **Australia**
IGCC Power Plant with CO$_2$ Capture
OTS/ITS Project Overview

• Dynamic Simulator/Operator Training System (OTS)
  – Phase 1: Scoping Study
  – Phase 2: Planning, Functional Design Specification
  – Phase 3: Development (10/08), Model Validation
  – Phase 4: Factory Acceptance Testing (FAT)
  – Phase 5: Deployment, SAT (03/11)

• 3D Virtual Immersive Training System (ITS)
  – Project kickoff in 12/09 with deployment in 07/12

• Development Partners
  \[\text{NETL} \quad \text{West Virginia University} \quad \text{ECS}\]

• Industrial Collaborators
  \[\text{DOOSAN} \quad \text{SOUTHERN COMPANY} \quad \text{AEP} \quad \text{bp} \quad \text{GREATER RIVER ENERGY}\]
IGCC with CO\textsubscript{2} Capture Simulator
Reference Plant (2 Trains)

- Area 100: System Controls*
- Area 200: Slurry Preparation*
- Area 300: Elevated-Pressure Air Separation Unit (ASU)
- Area 400: Gasifiers
- Area 500: Syngas Scrubber System
- Area 600: Shift Reactors Systems
- Area 700: Gas Cooling System
- Area 800: Sour Water Stripper*
- Area 900: Mercury Removal System
- Area 1000: Acid Gas Removal (AGR)
- Area 1100: CO\textsubscript{2} Compression
- Area 1200: Syngas Reheat and Expansion
- Area 1300: Sulfur Recovery Unit*

- Area 1400: Hydrogenation*
- Area 1500: Gas Turbine
- Area 1600: Cooling Water System*
- Area 1700: Boiler Water System
- Area 1800: Circulating Water System*
- Area 1900: HRSG Steam System
- Area 2000: Steam Turbine*
- Area 2100: Selective Catalytic Reduction (SCR)
- Area 2200: Electrical System*

* - Area common to both Trains

Reference
IGCC Plant A – Gasifier Feed & Cooling

Process & Instrumentation Diagram
IGCC Plant A – Gasifier Feed & Cooling

InTouch™ - Human Machine Interface (HMI)
IGCC Dynamic Simulator/OTS
Capabilities and Features

• Full-Scope, High-Fidelity, Real-Time Dynamic Simulator (DYNSIM)
• Modular: IGCC with CO₂ Capture, Process (Gasification), Power (CC)
• Fuels: Coal, Petcoke, Biomass
• OTS: HMI (InTouch), Trends, Alarms
• Instructor: ICs, RFs, Malfunctions
• Controls: Regulatory (PID), Coordinated (Gasifier/Turbine Lead)
• Operations: Normal Baseload, Startup, Shutdown, Load Following, Abnormal Situation Handling

Deployed at AVestar Center in March 2011
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    – Facilities, Training, Education, and R&D
    – Future Simulators/Directors
IGCC Immersive Training System/ Invensys EyeSim

Capabilities and Features

• 3D Virtual Plant Model
  – 3D computer-aided design (CAD)
  – Plant photos for photorealism

• 3D Immersive Interaction/Content
  – Avatar represents field operator
  – Navigation using game pad
  – Remote field functions
  – Collision geometry and sound
  – Popup trends (variables vs. time)
  – Transparent equipment objects
  – Highlighted virtual content/scenarios

• Benefits
  – Added dimension of plant realism
  – Plant familiarization and walkthrough
  – OTS/ITS for control room and plant field operators, promoting teamwork

Deployed at AVESTAR Center in July 2012; Invensys EYESIM software
AVESTAR Center Facilities

• **Locations**
  – NETL: R&D
  – WVU: Education, Training
  – Both in Morgantown, WV

• **Facilities**
  – OTS Room: Control Room
    ▪ Divider for 2 Simulators
  – ITS Room: Plant/Field
  – Local area network

• **Training Systems**
  – OTS
    ▪ 8 Operator Stations
    ▪ 2 Instructor Stations
    ▪ 2 Model Servers
    ▪ 2 Engineering Stations
  – ITS
    ▪ 2 Field Stations
    ▪ 1 Instructor Station
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• Concluding Remarks
AVESTAR Training Program

- Comprehensive, hands-on, dynamic simulator-based training
- Experienced power plant trainers
- IGCC with CO\textsubscript{2} capture courses
  - Orientation to advanced operations
  - Registration inquiries and fees online
  - ITS integrated into training
- Customized courses/programs available for industry
- CEUs through West Virginia Univ.
- Collaborating with regional technical colleges on Power Plant Technology certificate/degree programs

For more information on AVESTAR training, please visit: [www.netl.doe.gov/avestar/training.html](http://www.netl.doe.gov/avestar/training.html)
AVESTAR Education Program

• Leverage integrated OTS/ITS technology
• Enhance engineering education in process simulation, dynamics, control, and safety

• Example courses at WVU include:
  – Process Control for Chemical Engineers
    • 4-6 hours on IGCC dynamic simulator
    • Learn how plant responds dynamically to changes in manipulated inputs, as well as how control system impacts plant performance, stability, and robustness
  – Process and Dynamic Simulation
    • Theory of steady-state/dynamic process simulation
    • Development of operator training simulators
    • 3-4 weeks on IGCC dynamic simulator

• Extend to other NETL-RUA universities
AVESTAR R&D Program

• Dynamics
  – High-fidelity dynamic models
  – S/U, S/D, Load following, Ramp rate

• Controls and Sensors
  – Regulatory and coordinated control
  – Model predictive control (MPC)
  – Optimal sensor placement
    • State estimation, Disturbance rejection
    • Process monitoring, Fault diagnosis

• 3D Virtual Technology
  – Motion-based interaction
  – Interactive Field Operator Controls
Natural Gas Combined Cycle (NGCC) with Post-Combustion CO₂ Capture

• Develop NGCC dynamic simulator/OTS from the combined cycle portion of AVESTAR’s IGCC dynamic simulator/OTS

– Completed steady-state NGCC power plant design
  ➢ 2x2x1 Gas Turbine/HRSG/Steam Turbine design
– Completed modifications and dynamic testing of DYNSIM model
– Future work
  ➢ Update controls and HMIs
  ➢ Leverage in R&D/Training
  ➢ Cycling, load-following, MPC
  ➢ Add hooks for post-combustion CO₂ capture

Typical cyclical duty profile for a “two-cycled” NGCC plant. Source: GE Energy
Supercritical Pulverized Coal (SCPC) with Post-Combustion CO₂ Capture

- DOE’s Carbon Capture Simulation Initiative
  - Multi-year, multi-lab initiative, led by NETL
  - Focused on using modeling and simulation to accelerate deployment of CO₂ capture
- Industrial Challenge Problem
  - Post-combustion solid sorbent-based capture
- Plant Operations and Control
  - SCPC dynamic simulator/OTS with process/heat integration interfaces for post-combustion CO₂ capture
  - Dynamic models of solid sorbent-based CO₂ capture adsorber and regenerator reactors
  - Dynamic model of CO₂ Compression
  - Transient studies under wide range of process disturbances
AVESTAR Center
Future Directions for Virtual Energy Simulation

- **Virtual Carbon Capture Center (VCCC)**
  - Integrate, test, and optimize operation and control of CO$_2$ capture technologies with baseline power plants

- **Carbon Capture, Utilization, and Storage (CCUS)**
  - CO$_2$ Pipeline/Transport, CO$_2$ Utilization, CO$_2$ Injection

- **Shale Gas Processing Facilities**
  - Cryogenation, Fractionation (C3/4/5), and Ethane Cracking

- **Smart/Advanced Manufacturing**
  - Virtual test bed for Smart Manufacturing Leadership Coalition (SMLC)

- **Modern Power Grid**
  - Grid simulations coupled with dynamic simulators for Clean Energy Plants, Variable Renewable Generators, and Energy Storage
  - Grid operations, dynamics, control, and training
Thank You / Questions?

• For more information on AVESTAR’s simulators, facilities, training, education, and R&D, please visit us at www.netl.doe.gov/avestar

• or contact us at:
  • avestar@netl.doe.gov or gprovost@fossilconsulting.com

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