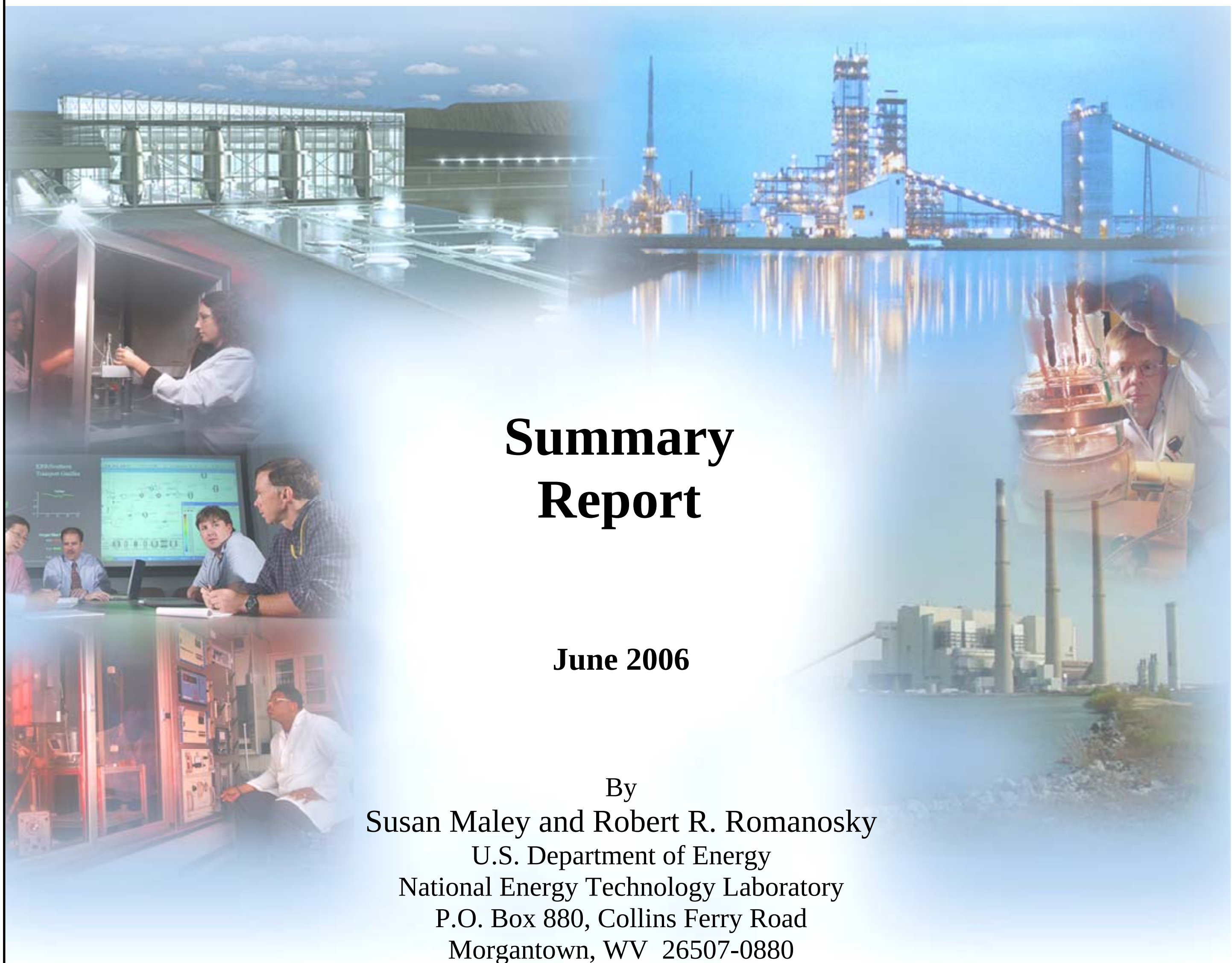
Plant Process Control Workshop



Summary Report

June 2006

By
Susan Maley and Robert R. Romanosky
U.S. Department of Energy
National Energy Technology Laboratory
P.O. Box 880, Collins Ferry Road
Morgantown, WV 26507-0880

Contents

Executive Summary

Today more than ever, the supply and demand requirements within the energy industry are continually evolving; requiring newer and more creative methods in advanced technology to produce power more efficiently with less environmental impacts. Our nation expects the public and private sectors to be at the forefront in providing a safe, reliable, and economical source of energy supply that will meet existing market and forecasted environmental demands to lead us successfully into the 21st century. We must continue to focus our efforts on understanding the current state-of-the-art technologies, operational issues, and emerging trends by monitoring the pulse of the industry through proactive research and development.

As part of an ongoing effort to promote the advancement of power plant technology for future energy requirements, the U.S. Department of Energy (DOE) National Energy Technology Laboratory (NETL), sponsored a one-day workshop entitled "Plant Process Control Workshop" on Wednesday, March 22, 2006. The meeting was held at NETL's Pittsburgh, PA office complex and a total of 24 representatives from the energy community participating in the workshop. The purpose of the meeting was threefold.

- Develop current state-of-the-art understanding for process control applications in advanced power systems.
- Define process control issues and emerging trends via ongoing R&D and forecast process control technology and sensor needs for the next 5 to 10 years, and beyond.
- Identify R&D opportunities for process control to help ensure that key technologies will be available to meet the demands of future advanced power systems.

The workshop was conducted in two sessions and primarily focused on process control technology and methodology rather than on hardware. The morning session opened with an overview of DOE/NETL's Advanced Research Program by keynote speaker Robert R. Romanosky; followed by a series of briefings from process control developers on current-state-of-the-art technology and was concluded with a roundtable discussion. The workshop resumed in the afternoon with presentations from NETL's in-house R&D program, activity updates from the university research community, and a final set of roundtable discussions outlining R&D opportunities and DOE's role.

The participants offered a number of insights regarding current technology issues and trends related to the industry's adoption of advanced process control along with ideas on how the DOE might support research and development in this area. Some of the key points are summarized below.

The external drivers for adoption of new technology will depend largely on end-users in the electric industry, but the catalyst for removing barriers for implementing advanced process control will be dependent upon technology developers and programs sponsored by the federal government. These barriers have been accepted as conventional or standard methods of practice in the industry. Historically, the utility industry has been characterized as conservative/risk adverse. Reluctance to adopt new technologies is based on concerns for increased capital costs, re-educating plant operators, and abandoning existing process control technology that has been proven and warranted for system availability and performance. Also, power plants operated as base loaded may not have the same justification for advanced process control technology as plants that provide peak-load services. Therefore, there must be a fundamental change in thinking if we are to convince end-users of the need for advanced control technology. This change can be initiated by applying external drivers to remove barriers and promote the adoption of advanced technology. Some of those external drivers include lowering operating costs, increasing performance incentives, and integrating a design that is simplistic in operation and user-friendly in application. For near zero emission power plants under development within DOE, it was noted that these external drivers have their greatest impact when they are included in the early stages of planning and design; otherwise, the impact is greatly reduced or may even be totally excluded from the design.

The discussions regarding advanced power plants in the future resulted in several opportunities and recommendations for advanced process control. Some of those issues and trends included designing power plants to be able to handle load variations such as base loading, peaking, or a combination of both operations. They must also be capable of operating at maximum capacity while varying the generation output such as electric, liquid fuels, or chemicals.   Secondly, plant design must integrate a computer framework that allows adaptation to new advances in technology (generic structure, high compatibility with multiple platforms) and focuses on first principles/induction knowledge of operational safety, performance, and maintenance. Thirdly, plant performance must be optimized at the system and subsystem levels by utilizing process control as an enabler to explore benefits derived from improvements in heat rate, plant reliability, and reductions in NOx emissions/water use.

This workshop served as the initial meeting with process control vendors and technology developers. The information summarized in this report will be used to guide NETL's Advanced Research Program in developing a program and projects that will be oriented towards advancements in process control for near zero emission power plants like those conceived under the FutureGen Program.   In addition to process control vendors and technology developers, input from industry, including the power generation, chemical and petroleum industries will be solicited in future forums. This cross section of input is viewed as critical to both the execution of the program and achievement of the goals.

MEETING REPORT

Plant Process Control Workshop
March 22, 2006
Pittsburgh, PA

1.0 INTRODUCTION/OVERVIEW

On Wednesday, March 22, 2006, the U.S. Department of Energy's National Energy Technology Laboratory (NETL) sponsored a one-day workshop entitled "Plant Process Control Workshop." The workshop was held at NETL's Pittsburgh, PA campus. The goals and objectives for this workshop included:

- Develop current state-of-the-art understanding for process control applications in advanced power systems;
- Define process control issues and emerging trends via ongoing research and development (R&D) and forecast process control technology and sensor needs for the next 5, 10 years, and beyond; and
- Identify research and development opportunities for process control to help ensure that key technologies will be available to meet the needs of future advanced power systems.

NETL is using the information gathered during this workshop and from other sources as input for the Sensors and Process Control Technology Roadmap which, in turn, will guide future R&D solicitations and Programmatic efforts.

The focus of this workshop was on process control technology and methodology rather than on hardware (e.g., sensors).

A total of 24 people participated in the workshop (not including individuals from NETL). Representatives from process control/technology development, system integration, and research communities were invited to participate in the workshop. Representatives from the end-user industry (i.e., utility plants) were also invited but were unable to attend. A listing of all attendees is provided in Appendix A.

The workshop was organized around a series of briefings in the morning from process control developers, regarding current state-of-the art technology, followed by roundtable discussions. The workshop continued in the afternoon with presentations from NETL's in-house R&D program, the university research community on their activities, and was followed by a final set of facilitated discussions. A copy of the workshop agenda is provided in Appendix B. A listing of the individual presentations is included in Appendix C.

The balance of this document summarizes those discussions, as well as suggestions for the next workshop session.

2.0 SUMMARY OF DISCUSSIONS

The participants offered a number of insights regarding current technology, issues related to industry's adoption of new process control technology, and recommendations for ways in which the DOE might support R&D. These are summarized below.

2.1 Comments on Current "State-of-the Art" for Process Control

A summary of the comments on current "state-of-the-art" for process control are summarized below.

- In general, the electric utility industry is characterized as conservative/risk adverse; reluctant to utilize new technology or technology that may be unfamiliar with plant operators.

  This is critical because the drivers for adoption of new technology will depend largely on end-users (NOT as a pull but as a push or incentive from technology developers) or as appropriate, from the federal government.

  Barrier: Guaranteed performance relieves operator for need to have advanced control technology (Must have external driver to force adoption).
  - ***Lower cost or performance incentive is required.***
  - ***Load following of feedstock disturbance to electric.***
  - ***Operation may need control (output charge fuel).***

- Technology developers, especially when they are warranting system availability and performance, will be acutely sensitive to using proven process control technology (and developing and/or providing an integrated hardware/process control package).

- Strong recommendations were made towards incorporating system integration and advanced process control very early in the design process; otherwise, its adoption at later stages limits its positive impact.

- There were some discussion/questions regarding the expected higher cost of advanced energy conversion technologies (e.g., oxy-fuel, IGCC, etc.), and whether these plants will be built as base loaded plants rather than for peaking service. Based on past installations, it was noted that base-loaded plants may have less need for advanced process control technology than peakers. However, it is envisioned that advanced power plants will need to be fuel-flexible and will be more complex systems than traditional PC-fired boiler system; hence the need for improving and implementing process control technology. This same need for advancements in process control may also be observed when retrofitting conventional coal-fired systems due to the number of changes in boiler technology and installation of emission control equipment.

- There may be need for process control technology that will enable the facility to operate on fuel-input capacity; however, varying the output (e.g., electricity, chemicals, and fuels) requires more sophisticated process control.

- Recommendations were made to engage cross-industry discussion between the conventional electrical utility industry and chemical/refining industry – which has extensive experience in varying the mix of products to maximize profits. If product switching is viable for newer power plants, then it is also important to consider employing advanced process control for the economic optimization of the plants product mix (e.g. power, hydrogen, fuels).

- Two types of control functions used in current operating systems: (1) modulating, and (2) binary (on/off).
  - Both control functions are handled using either digital control systems (DCS) based on analog or programmable logic controllers (PLC) based on relay.
  - DCS is generally considered a plant wide system controller while PLC is used more at the subsystem level.
  - In modulating control, boiler control is most critical and in nearly all applications is performed with proportional-integral-derivative (PID) controllers.
  - In most plant designs, process is ad hoc, each vendor has de facto standard for most loops. (Tuning is an integral part of plant performance).

- For existing plants, the highest priority in process control design is reliability while efficiency and optimization are of secondary importance.

- It is currently possible to embed advanced control directly into system process and be transparent to the end user with regard to changes in operator interaction.

- Current APC algorithms are designed to address long time delays, multivariable interactions, nonlinear effects, and constraints on I/O. Opportunities to implement more advanced process control (APC) in these areas exist for both existing power plants and future power plants.

- Simulation capabilities and technologies are expanding and the most useful by vendors includes:
  - Operating training: fewer plant trips and improved operator effectiveness
  - Engineering analysis: proposed control strategies can be tried on simulator without jeopardizing plant operation.

2.2 Process Control Issues and Emerging Trends

There were discussions regarding “advanced and future power plants” and some of the opportunities/recommendations for advanced process control. A summary of the issues/trends are listed below.

- New coal plants being built for various applications
  - Base load, peaking service, or a combination of both operations
  - Can a design be created to run at maximum capacity and vary the generation output (e.g., electric, liquid fuel, chemical)?
  - What can be done to add control to the total plant and its subsystem levels?

- Integrated computer framework for control that allows adoption of new technology advances. Technology thrust focuses on first principles/induction knowledge of operation safety, performance, and maintenance.

- Total plant economic optimization (control as an enabler rather than an optimizer)
  - Maximize multi-objective for subsystem and overall system performance
  - Explore complex objectives throughout operational realm by addressing fuel flexibility, parasitic loss, and reducing water use.

- Barriers to emerging trends in advanced process control
  - Benefits are not easily quantifiable
  - Lack of driving need to implement changes
  - Plant operators are not familiar with new technology
  - Power companies are traditionally conservative
  - Requires new software technology

2.3 Future R&D Opportunities

The discussion identified several research and development opportunities that NETL can explore regarding process control technology to ensure key technologies will be available to meet the needs of future advanced power systems.

- What are different drivers for advanced models?
  - Economic performance, planning, operation, and monitoring
  - Sensor placement
  - Controller design and development of model based control (first principles and reduced order)
  - Steady state versus dynamic models
- What are the system issues required for control?
  - Emissions on startup, tripping, and shutdown.
  - Grid and frequency stability
  - Agent based control
  - Availability and quality of measurements (e.g., loss-on-ignition (LOI)/carbon-in-ash)
  - Predict effects of uncertainty
  - Boiler/Gasifier (e.g., fuel, air, feed water, steam temperature, etc.)
  - Turbine (Steam/Combustion)
  - Miscellaneous loops
  - Ash handling system
  - How can the plant design be changed to better control the system?
- Review application of chemical/petroleum industry trends to control interrogation technology to extract state.
- Continue to examine the complexity of integration versus modular build. Consider advantages of standardized plant design (e.g., 600 MW IGCC).
- Continue to develop hardware required for implementing APC. Measurements of interest include: coal flow; size; BTU content; LOI; combustion monitoring; sulfur distribution; and trace contaminants (e.g. mercury).
- What time constants can be controlled / changed?

- For IGCC plants
- For advanced combustion / oxy fired systems

- What R&D should be conducted?
  - Develop standard applications that are user-friendly and configurable
  - Demo technology infusion / lead to acceptance
  - Sensor network / dynamic models, disturbance models
  - Embedding and integrating advanced control algorithms into existing control system architecture
  - Simpler model development with no special testing
  - Capture 50 years of process knowledge
  - Benchmark current control performance
  - Review other industry's approaches to APC
  - Identification and control – integration of signals – robust control
  - Self-tuning control – look ahead.
  - Performance specifications – regime of operation.
- What are the computational power needs?
  - Open architecture
  - 1st principles logic
  - Neural networking
  - Expert systems
  - Inductive reasoning
  - Partial differential equations
  - Spatial/temporal interconnection
  - Sensor networking
  - Different sensing and actuation
  - Adaptive techniques
- Control R&D opportunities for next generation plants
  - Efficiency (e.g., condition based control to raise performance to entitlement)
  - Fuel flexibility (e.g., improved controls for gasifier and turbine such as integration between ASU and turbine; heat integration)
  - Operational flexibility (e.g., managing increased M+E integration for start-up, turndown, emissions, fuel flexibility, unit ops failure)
  - Automation (e.g., increase use of real-time models for optimal operation over manual operation for risk mitigation and efficiency improvement)
  - Bring control system design into plant design stage
- Future R&D Directions
  - Control systems have traditionally been reactive: set point tracking, disturbance rejection
  - Move to "predictive intelligence" technologies
  - Design goals strive to eliminate human error- operations, engineering, maintenance
- Key focal areas
  - Abnormal situation prevention (ASP)
  - Predictive maintenance

There was discussions regarding "advanced power plants of the future" and what might be some opportunities/recommendations for advanced process control. A summary of these are provided below and may be reiterated from prior discussions of the workshop participants.

- Real-time simulation
- Integrate design - Process model reduction
- Models that integrate 1st principles, inductive and expert systems
- Network integration
- Specifications for control system performance
- Bring control system design into design process.
- Make process control an enabling technology
- Requirement for continuous condition monitoring
- Economic versus operation (e.g., supervisory decision making [chemical plants do now])
- Technology transfer
- Dynamic models of combustion process (with fidelity) at the plant or device level
- Identification of complex models / system ID
- Methodology for integration of models
- Methodology for getting to models with sufficient fidelity
- Agent-based control
- Where is the intelligence located (e.g., embedded within the sensor)
- Existing plants / repowering
- Heat rate improvement
  - LOI
  - Smart soot blowers
  - Air preheater optimization
  - SO_3 sensor emissions
  - Parasitic power loss
- SCR improvements
  - Sensors and control system
- Minimize H2O use
- Missing State Information
- Fuel Characterization
  - Pulverized coal flow measurement (e.g., size, distribution, coal quality)
  - Gas composition (e.g., BTU, specific gravity)

2.4 Comments/Recommendations/Next Steps

- Involve representatives from the utility industry in future discussions.
  - Several representatives were invited to the meeting but were able to attend.
- Invite representatives from the chemical, petroleum, utility, and A&E industries because of their extensive experience in making economic (vs. operational) decisions.
- Continue dialogue with an expanded group of participants. NETL plans to conduct another one-day workshop in Fall 2006. The format for the workshop will be determined at a later date. In addition, NETL plans to pursue other forums in which to obtain industry input.
- Have focused discussions on how current and advanced process controls can be used to minimize water usage; particularly for utilities located in the western region of the US.

APPENDIX A

List of Workshop Attendees

Plant Process Control Workshop
March 22, 2006

Joseph Bentsman
University of Illinois
1206 W. Green Street
Urbana, IL 61801
Phone: 217/244-1076
Fax: 217/244-9980
E-mail: jbentsma@uiuc.edu

Kenneth Mark Bryden
Ames National Laboratory
Iowa State University
3030 Black Engineering
Ames, IA 50011-2161
Phone: 515/294-3891
Fax: 515/294-5030
E-mail: kmbryden@iastate.edu

Xu Cheng
Emerson Process Management
200 Beta Drive
Pittsburgh, PA 15238
Phone: 412/963-3608
Fax: 412/963-4519
E-mail: xu.cheng@emersonprocess.com

Dale Cunningham
Sextant Technical Services
National Energy Technology Laboratory
P.O. Box 880 MS J02
Morgantown, WV 26507-0880
Phone: 304/285-0953
Fax: 304/285-0955
E-mail: dale.cunningham@sextant-technical.com

Jeff Grott
Emerson Power & Water Solutions
200 Beta Drive
Pittsburgh, PA 15238
Phone: 412/963-4694
Fax: 412/963-4519
E-mail: jeffrey.grott@emersonprocess.com

Sachindra Dash
Honeywell International
2500 West Union Hills
Phoenix, AZ 85027
Phone: 602/313-4914
Fax: 602/313-3353
E-mail: sachi.dash@honeywell.com

Ali Feliachi
West Virginia University
CSEE Department
P.O. Box 6109
Morgantown, WV 26506-6109
Phone: 304/293-0405 x2529
Fax: 304/293-8602
E-mail: alfeliachi@mail.wvu.edu

Dan Feliz
Connected Energy
306 Linden Shade Court
Millersville, MD 21108
Phone: 410/693-1263
Fax: 410/987-4951
E-mail: dfeliz@dh-inc.com

Thomas Flynn
The Babcock & Wilcox Company
1562 Beeson Street
Alliance, OH 44601
Phone: 330/860-6630
Fax: 330/860-6676
E-mail: tjflynn@babcock.com

William Luyben
Lehigh University
Department of Chemical Engineering
Bethlehem, PA 18015
Phone: 610/758-4256
Fax: 610/758-5057
E-mail: wll0@lehigh.edu

J. Peter Hensel
U.S. Department of Energy NETL
P.O. Box 880, MS C02
Morgantown, WV 26507-0880
Phone: 304/285-4073
Fax: 304/285-4403
E-mail: j.hensel@netl.doe.gov

Rick Kephart
Emerson Process Management
200 Beta Drive
Pittsburgh, PA 15238
Phone: 412/963-4937
Fax: 421/963-4937
E-mail: richard.kephart@emersonprocess.com

Thomas Logan
GE Energy
1 River Road Lane
Building 40-330CC
Schenectady, NY 12345
Phone: 518/385-8002
Fax: 518/385-0404
E-mail: thomas.logan@ge.com

Carl Neuschaefer
ALSTOM Power, Power Plant Labs
2000 Day Hill Road
Windsor, CT 06095
Phone: 860/285-9290
Fax: 860/285-4033
E-mail: carl.h.neuschaefer@power.alstom.com

Steven Ostheim
Technology & Management Services, Inc.
626 Cochrans Mill Road
P.O. Box 880, MS E02
Morgantown, WV 26507-0880
Phone: 412/386-6485
Fax: 412/386-6404
E-mail: steven.ostheim@netl.doe.gov

Udaya Rao
U.S. Department of Energy NETL
P.O. Box 10940, MS 922-273C
Pittsburgh, PA 15236-0940
Phone: 412/386-4743
Fax: 412/386-5917
E-mail: rao@netl.doe.gov

Susan Maley
U.S. Department of Energy NETL
P.O. Box 880, MS C04
Morgantown, WV 26507-0880
Phone: 304/285-1321
Fax: 304/285-4403
E-mail: susan.maley@netl.doe.gov

Russell G. May
Prime Photonics, LC/ Prime Research, LC
1750 Kraft Drive
Suite 1000
Blacksburg, VA 24060
Phone: 540/961-2200 x450
Fax: 540/961-2300
E-mail: rmay@primephotonics.com

Don McLaughlin
West Virginia University
Dept. of Computer Science & Elect. Eng.
P.O. Box 6109
Morgantown, WV 26506
Phone: 304/293-0405 x4258
Fax: N/A
E-mail: don.mclaughlin@mail.wvu.edu

William Rogers
U.S. Department of Energy NETL
P.O. Box 880, MS N06
Morgantown, WV 26507-0880
Phone: 304/285-4272
Fax: 304/285-4403
E-mail: william.rogers@netl.doe.gov

Robert Romanosky
U.S. Department of Energy NETL
P.O. Box 880, MS 922-188C
Pittsburgh, PA 15236
Phone: 304/285-4721
Fax: 304/285-4777
E-mail: rroman@netl.doe.gov

Thomas Sarkus
U.S. Department of Energy NETL
P.O. Box 10940, MS 922-342C
Pittsburgh, PA 15236-0940
Phone: 412/386-5981
Fax: 412/386-4775
E-mail: thomas.sarkus@netl.doe.gov

George Richards
U.S. Department of Energy
National Energy Technology Laboratory
P.O. Box 880, MS N05
Morgantown, WV 26507-0880
Phone: 304/285-4458
Fax: 304/285-4403
E-mail: george.richards@netl.doe.gov

Lucio Soibelman
Carnegie Mellon University
Dept. of Civil & Environmental Engineering
118 N. Porter Hall
Pittsburgh, PA 15213-3890
Phone: 412/268-2952
Fax: 412/268-7813
E-mail: lucio@andrew.cmu.edu

Peter Spinney
NeuCo, Inc.
Hancock Tower, T-31
Boston, MA 02116
Phone: 617/320-0039
Fax: 617/425-3500
E-mail: spinney@neuco.net

Cyrus Taft
EPRI Instrumentation and Control Center
714 Swan Pond Road
Harriman, TN 37748
Phone: 865/717-2017
Fax: 865/717-2020
E-mail: ctaft@epri.com

Jimmy Thornton
U.S. Department of Energy
National Energy Technology Laboratory
P.O. Box 880, MS N05
Morgantown, WV 26507-0880
Phone: 304/285-4427
Fax: 304/285-4469
E-mail: jimmy.thornton@netl.doe.gov

Stephen Zitney
U.S. Department of Energy NETL
P.O. Box 880, MS N04
Morgantown, WV 26507-0880
Phone: 304/285-1379
Fax: 304/285-0903
E-mail: stephen.zitney@netl.doe.gov

Minesh Shah
GE Global Research
One Research Circle
Niskayuna, NY 12065
Phone: 518/3876103
Fax: 518/387-5164
E-mail: shah@research.ge.com

Konstantinos Tsakalis
Arizona State University
Electrical Engineering
P.O. Box 875706
Tempe, AZ 85287
Phone: 480/965-1467
Fax: 480/965-2811
E-mail: tsakalis@asu.edu

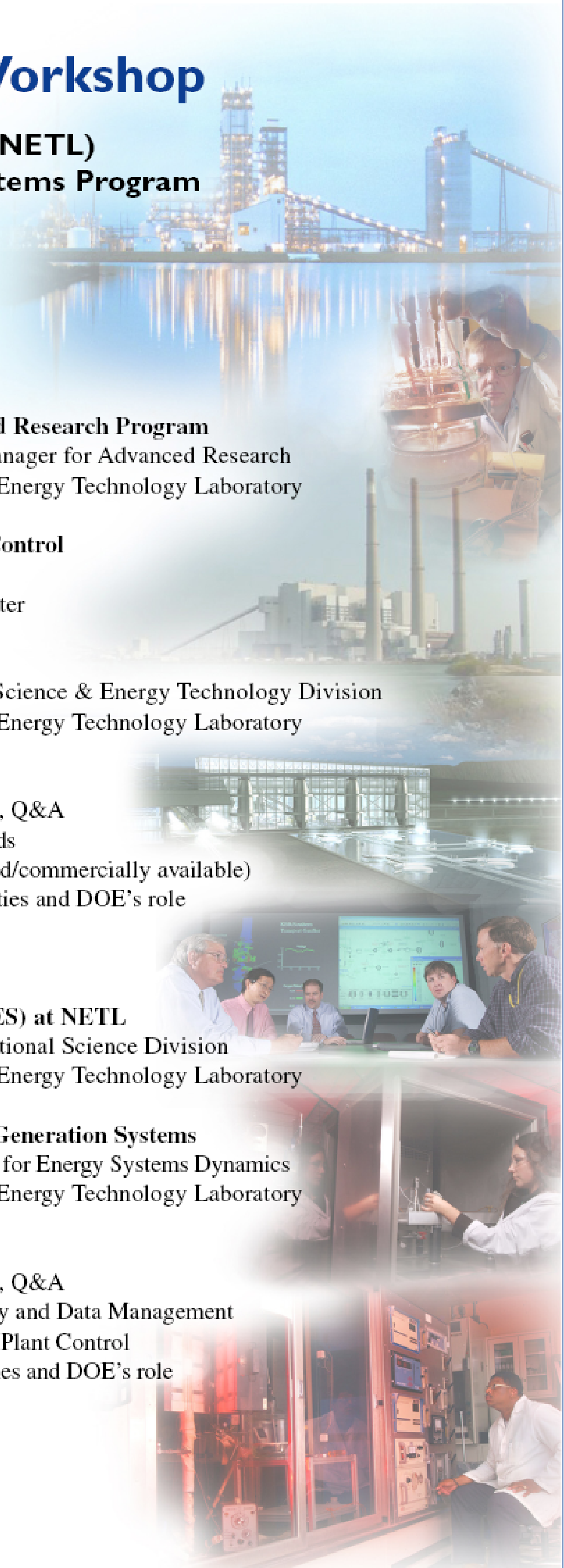
Jeffrey Vipperman
University of Pittsburgh
Department of Mechanical Engineering
648 Benedum Hall
Pittsburgh, PA 15261
Phone: 412/624-1643
Fax: 412/624-4846
E-mail: jsv@pitt.edu

Richard A. Winschel
CONSOL Energy Inc.
4000 Brownsville Road
South Park, PA 15129
Phone: 412/854-6683
Fax: 412/854-6613
E-mail: dickwinschel@consolenergy.com

B. Erik Ydstie
Carnegie Mellon University
5000 Forbes Avenue
Pittsburgh, PA 15213
E-mail: ydstie@cmu.edu

APPENDIX B

Workshop Agenda



Plant Process Control Workshop

National Energy Technology Laboratory (NETL)
Instrumentation, Sensor, and Control Systems Program
Pittsburgh, PA

Wednesday, March 22, 2006

7:30 am	**Registration/Continental Breakfast**
8:30 am	**Welcome** **Overview of DOE/NETL's Advanced Research Program** *Robert R. Romanosky*, Technology Manager for Advanced Research U.S. Department of Energy, National Energy Technology Laboratory
9:00 am	**Current Coal Plant Operation and Control** *Cyrus Taft*, Chief Engineer EPRI Instrumentation and Control Center
9:20 am	**DOE's FutureGen Project** *Thomas A. Sarkus*, Director, Applied Science & Energy Technology Division U.S. Department of Energy, National Energy Technology Laboratory
9:30 am-12:00 pm (with **Break** 10:00-10:15 am)	**Roundtable Discussion** *Participants*, Presentations, Discussion, Q&A • Power Plant Control Issues and Trends • Current Control Technology (installed/commercially available) • Research & Development Opportunities and DOE's role
12:00 pm	**Catered Lunch**
1:00 pm	**Computational Energy Sciences (CES) at NETL** *William A. Rogers*, Director, Computational Science Division U.S. Department of Energy, National Energy Technology Laboratory
1:20 pm	**Control Issues for Advanced Power Generation Systems** *George A. Richards*, Focus Area Leader for Energy Systems Dynamics U.S. Department of Energy, National Energy Technology Laboratory
1:40 pm (with **Break** 2:15-2:30 pm)	**Roundtable Discussion** *Participants*, Presentations, Discussion, Q&A • Current Research Control Technology and Data Management • Control Technology R&D for Power Plant Control • Research & Development Opportunities and DOE's role
4:00 pm	**Conclusion**
4:30 pm	**Adjourn**

APPENDIX C

Workshop Presentation Topics

- **Presentation: NETL Advanced Research Program**
  Bob Romanosky, Advanced Research Technology Manager

- **Presentation: Current Coal Plant Operation and Control**
  Cyrus Taft (Chief Engineer), EPRI Instrumentation and Control Center

- **Presentation: DOE's FutureGen Project**
  Tom Sarkus, FutureGen Project Director

- **Presentation: Plant Process Control Trends and Opportunities**
  Minesh Shah, Mgr Automation & Controls Lab, GE Global Research

- **Presentation: DCS Advanced Control Technologies**
  Rick Kephart, Emerson Process Management

- **Presentation: Advanced Control Systems for Power Generation Systems**
  Tom Flynn, Babcock & Wilcox

- **Presentation: Computational and Basic Sciences Focus Area**
  Bill Rogers, Director Computational Science Division, NETL

- **Presentation: Control Issues for Advanced Power Generation**
  Geo Richards Director, Energy System Dynamics Division, NETL

- **Presentation: Data Mining Complex Data Structures**
  Lucio Soibelman, CMU, Civil & Environmental Engineering

- **Presentation: Trends in Controls Research Relevant To Modern Power Plant Systems**
  Jeffrey Vipperman, Dept of MechE, University of Pittsburgh

- **Presentation: High Density, Heterogeneous, Massive Sensor Nets for Process Systems**
  Mark Bryden, Iowa State University, Mechanical Engineering

- **Presentation: Power Systems Control Issues**
  Joseph Bentsman, University of Illinois

APPENDIX D

Workshop Presentation

Bob Romanosky - NETL

Plant Process Control Workshop

Welcome

National Energy Technology Laboratory
Wednesday, March 22, 2006

Sponsored by the
Advanced Research Program

Workshop Agenda

8:30 am **Welcome and Overview of NETL's Advanced Research Program**
9:00 am **Current Coal Plant Operation and Control**
9:20 am **Department of Energy's FutureGen Project**
9:30 am **Roundtable Discussion**
12:00 pm **Catered Lunch**
1:00 pm **Computational Energy Sciences (CES) at NETL**
1:20 pm **Control Issues for Advanced Power Generation Systems**
1:40 pm **Roundtable Discussion**
4:00 pm **Conclusion**
4:30 pm **Adjourn**

Plant Process Control Workshop - 060322
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Acknowledgements

- **Conference Services**
  – Pamela Stanley and Regina Pride
- **Food and Beverage Services**
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  – Mike Antkowski and Terry Summers
- **Facilitation and Support Services**
  – Steve Ostheim and Dale Cunningham

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Workshop Goals/Objectives

- **Understand current "state-of-art" for process control for application in advanced power systems**
- **Identify process control issues and emerging trends**
  – Understand, via ongoing R&D, where the process control technology and sensor needs will be in the next 5, 10 years, and beyond
- **Identify promising research and development opportunities for process control technology**
  – Understand NETL's/DOE's potential role in supporting R&D of process control to help ensure key technologies will be available to meet the needs of future advanced power systems
- **Develop Sensors and Process Control Technology Roadmap**

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Advanced Research Program

Robert R. Romanosky

Advanced Research Technology Manager

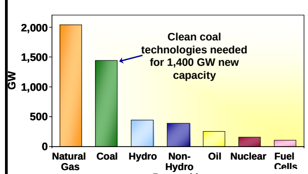
Plant Process Control Workshop

March 22, 2006

National Energy Technology Laboratory

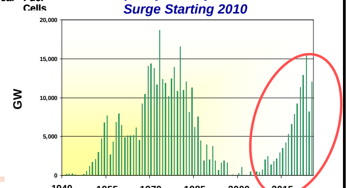
Office of Fossil Energy

World Power Generation Capacity Additions
2000 – 2030



Process Controls Technology has the potential to greatly impact the power generation capacity and plant availability.

Coal Capacity History and Forecast
Surge Starting 2010



Will Nation Be Prepared to Meet This Forecast?

So What?

- **Putting megawatts on grid at required rates means—**
  - Getting absolute most from existing fleet
    - process optimization will play big time!
  - Getting reliable operation from new (more complex) plants
    - process control will play big time!
- **Realizing a reliable power grid is highly dependent on reliability of individual plants**

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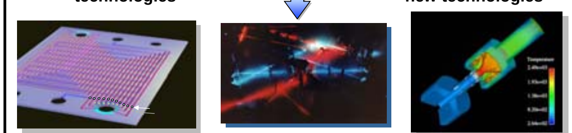
Advanced Research

Mission

Extend state of knowledge in fossil energy technology by supporting development and deployment of innovative systems capable of improving efficiency and environmental performance while reducing costs

Bridge the gap between fundamental and applied technologies

Reflective of industry needs and responsible for driving new technologies



Develop technologies that address critical needs in Fossil Energy Programs

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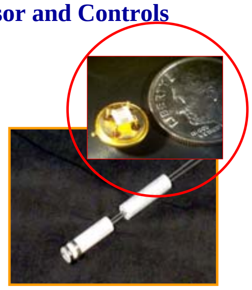
Advanced Research Instrumentation, Sensor and Controls

- **Crosscutting technology**
- **AR is positioned to screen and accept risk**
- **Technology transfer to line programs**
- **Strong stakeholder relationships (developers and users)**
- **Desire to take whole system approach**
- **Time-phased, results driven program**
- **Direction of Program**
  - Continue with development of sensor materials, sensor designs that address a technology gap/stakeholder needs
  - Pursue computational analysis of sensor networking and integration with power systems
  - Identify and initiate advanced control opportunities for advanced power generation in cooperation with CES



SRD Metal Oxide Sensor
NETL Flashback Sensor

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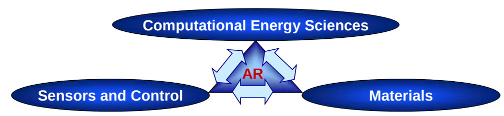
Realignment of AR Technology Focus



- **Essential and enabling technology development programs for the Strategic Center for Coal and Power R&D**
- **Focused effort will contribute to deployment of feasible technologies in the 5-15 year timeframe as well as contribution to the FutureGen Initiative**
- **Enhancement of individual subprograms by expanding collaboration, range of developers, and integrated technology efforts**

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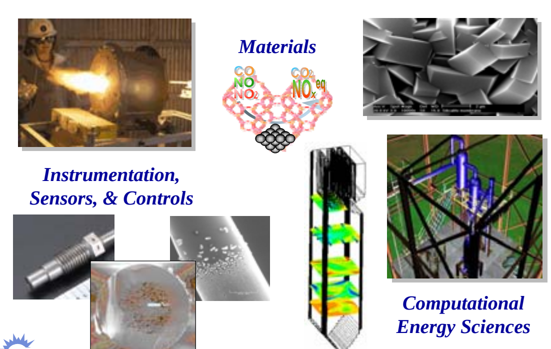
Advanced Research Crosscutting Technologies



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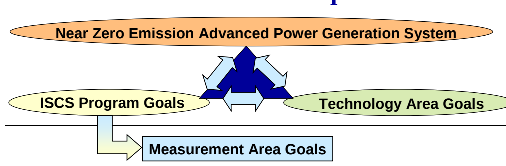
ISCS Roadmap



- **Physical Measurements**	Temperature, pressure & flow for harsh environments
- **Gas and Solid Measurements**	Low cost gas sensors for high temperature environments Trace level contaminant detection Real time solids characterization
- **Control and Condition Monitoring**	Creation of artificially intelligent , integrated controls Information creation & exchange for systems management
- **Infrastructure Security Monitoring**	Measurement and control technology for reliability and security enhancements of related infrastructures

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Motivation for Developing New Sensors and Control Technology

- Low cost, high benefit technology
- Existing technology is inadequate
- Boosts efficiency of existing facilities and significantly contributes to high reliability

- Supports all other power generation technologies and related infrastructures
- Makes operation of future ultra clean energy plants possible
- Enables new paradigms in plant and asset management beyond traditional process control

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Instrumentation and Sensor Needs

(Input from 2001&2002 S&C Workshop)

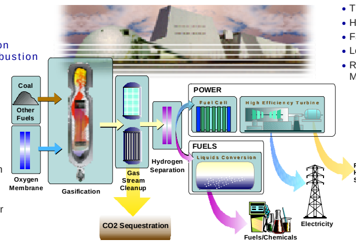
Advanced Materials
- High temperature Micro sensor materials
- Nano-derived materials

Gas Purification / Separation Environmental Control
- Mercury & Trace Metals
- NOx, Sox, Nh3
- CO2 Monitoring

Turbines
- Temperature
- Fuel Quality
- Dynamic Pressure
- Thermal barrier coating
- Hydrogen
- Fast response
- Lean combustion control
- Reliability and Predictive Maintenance Monitoring

Gasification Advanced Combustion
- Temperature
- Gas Quality
- Fuel / air ratio control
- Robust sensors
- Feed flow and Characterization
- Particle Detection
- Standardized signaling
- Corrosion monitor
- O_2 control

Fuel Cells
- Catalyst and anode monitoring
- Sulfur
- Reformate Quality
- Flow & Pressure
- Diagnostic Capability



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Separation and Capture Highlights

Many Advanced Integrated Schemes Emerging

Coal Gasification

CO_2 Hydrates
Membranes
Advanced Scrubbers
Inexpensive Oxygen
Chemical Looping

Pulverized Coal

Oxygen Combustion
Membranes
Advanced Scrubbers
New Sorbents
Inexpensive Oxygen
Chemical Looping

Pathways to Zero Emissions

Process control technology infusion required to optimize the competing dynamics new power plants will face.

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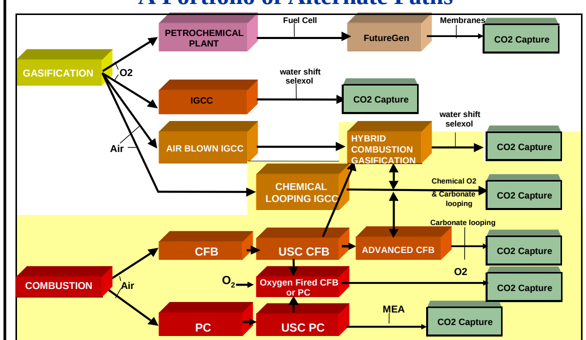
Coal Power Plants A Portfolio of Alternate Paths



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Technology Challenges

- Zero emissions
- Integrated systems
- Controllable and reliable designs
- Tight tolerances & operating margins
- High temperatures & pressures

Near/Zero Emission Advanced Power Generation System

Mid 20th Century Plants

- Plant design
- Process modeling and control
- Operations monitoring (efficiency, emission, equipment)
- Dynamic and transient mode management
- Structural, separation, coatings, and sensing materials for harsh environmental

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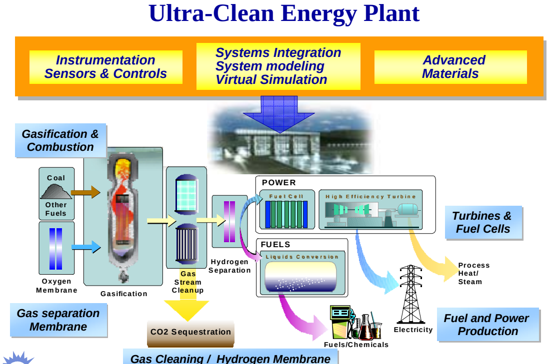
Ultra-Clean Energy Plant



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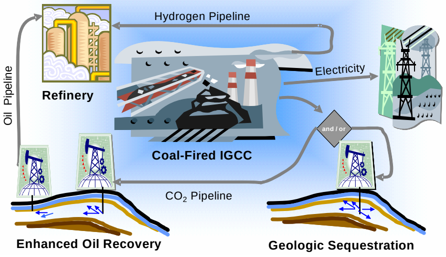
FutureGen - A "Zero Emissions" Plant

- *FutureGen* will test new technologies to capture CO_2 at the power plant
- *FutureGen* will test large-scale injection into oil fields or into deep geologic formations for permanent storage



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Advanced Combustion Program Goals and Objectives

- Develop alternative combustion technologies that allow coal-based utility power plants to implement zero emission and CO_2 mitigation strategies.
- Address technical issues needed to transition existing electric power generation units toward a carbon constrained economy.

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Advanced Combustion Program

- Focuses on CO_2 Management/Climate Change
  - Ultrasupercritical/O_2 Combustion
  - Oxygen Combustion
  - Chemical Looping/metal oxide unmixed fuel processing
  - Ancillary components required for advanced power systems
  - Novel CO2 removal systems

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Advanced Combustion Program Activities

- **Oxy-Combustion**
  - Develop advanced oxygen-fired combustion systems capable of zero emissions and a CO_2-sequestable stream.
- **Chemical Looping/ Unmixed Catalytic Combustion**
  - Complete gas-to-solids heat transfer evaluation of falling solids in a CMB combustor;
  - Complete pilot-scale tests and engineering/economic analysis, and prepare a full-scale conceptual design of the UMC process;
  - Complete pyrolysis and water gas shift testing in small-scale process development facility for calcium oxide and calcium carbonate looping.
- **System Components**
  - Develop system components necessary to implement advanced combustion technologies.
- **Novel CO_2 Removal**
  - Research novel methods of CO_2 removal for combustion systems.

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Ultrasupercritical Program

Goals Were Set For The USC Steam Project

- Materials capable of 760°C (1400°F) and 35 Mpa (5000 psi) in the near term
- Materials capable of >760°C service in the long term
- Increased plant efficiency to 55%
- Reduced emissions by 30%
- Oxygen firing being examined
- Ultrasupercritical Turbine Program Initiated

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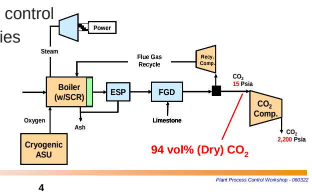
Oxy-combustion in Pulverized Coal Boilers for CO_2 Capture

- **Principle**: O_2 is provided by ASU, N_2 is replaced by re-circulated CO_2

  Coal + O_2 ➡ $CO_2 + H_2O$

  - O_2 is diluted in re-circulated flue gas **for temp. control**
  - **No Nitrogen dilution of the flue gas:** CO_2 rich flue gas **enables easier CO_2 capture**
  - Potential to eliminate NOx control
  - Utilizes existing technologies



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Oxygen Firing in Circulating Fluidized Bed Boilers

O_2 Fired CFB Advantages

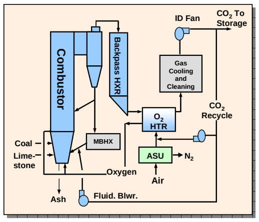
- **Temperature controlled with solids**
- **Lower CO_2 recycle→ Lower parasitic load**
- **Improved capital cost**

Barriers

- **Continuous solids circulation**
- **Cryogenic oxygen is expensive**
  - Consider O_2 membranes

Project Status

- **Proof-of-concept completed in 4-inch laboratory scale CFB**
- **Pilot tests (2.9 MWth) completed May 2004**
- **Work continuing on development of a capture-ready plant design**

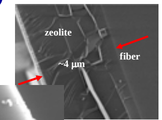


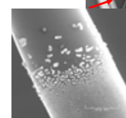
Participants: Alstom Power, ABB Lummus Global, Praxair, Parsons Energy

Fiber-based Sensor Development

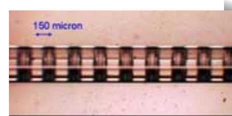
(Materials and Sensor Design)

- **Silica-based fiber sensors**
  - Distributed and selective gas sensing
  - Active sensing layers
- **Sapphire-based fiber sensors**
  - Coating materials
  - Single & Multipoint sensing designs
  - Suitable for ultra high temperatures (1600°C)

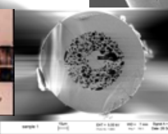




Coated Silica fiber (NMT)



Distributed Gratings in Sapphire Fiber (PSU)



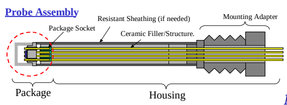
Holey Fiber (VT)

Coated Sapphire Fiber (Prime)

Sensor Packaging

(Design, Materials, Technology Transfer)

Prime OSU



Sporian

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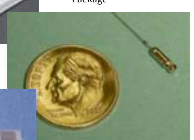
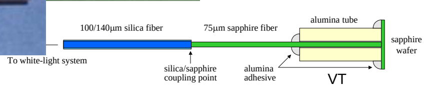
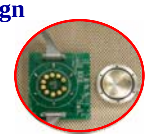




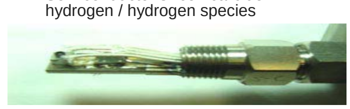
VT

Micro Sensor Design

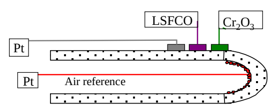
- **Micro Sensors (<600°C)**
  - Metal oxide based sensor arrays for NOx, NH_3, CO, CO_2, H_2, and H_2S
  - Semiconductor silicon carbide for hydrogen / hydrogen species

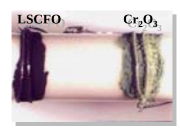


Metal Oxide Gas Sensor Array (SRD)



H_2 Pt/SiC Prototype Sensor (MSU)



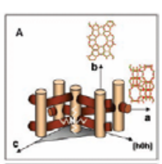


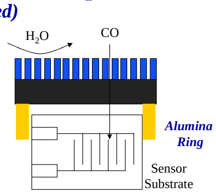
NOX &CO Sensor (OSU)

Micro Sensor Materials Development

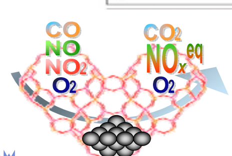
(Nano Derived)

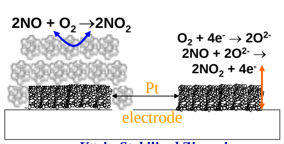
Zeolite Filter w/ Alumina Base





Alumina Ring

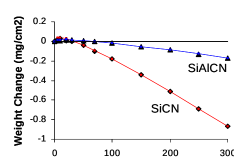




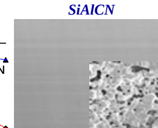
Yttria-Stabilized Zirconia

Micro Sensor Materials Development

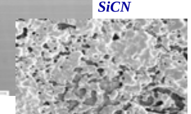
SiCN - Al



SiAlCN



SiCN

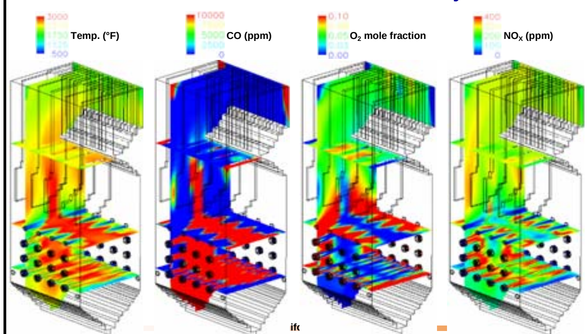


- **Good Corrosion Resistance**
- **High Temperature Stability**
- **Controllable Conductivity**
- **First to make SiAlCN Ceramic Foam**

Visualization Research Group

The Visualization Research Group focuses on developing leading edge visualization software and systems to support fossil energy research

Computational Fluid Dynamics for Burner Flow Control Sensitivity



Conclusion

Energy challenges are daunting

Fossil fuels will continue to play major role for decades

We have used technology to address other major issues facing society

Energy challenges solved easiest with innovative, affordable, low GHG-emitting technologies, especially for electricity and transportation fuels

AR Program Activities for FY06

- **Collaboration and Communication**
  - ISA, EPRI, PIWG, US-UK
  - National Laboratories, Government Agencies
  - Users and vendors
- **NETL Sponsored Workshops and Program Development**
  - Program reviews for all Subprograms
  - Develop or update Technology Roadmaps
- **Solicitations**
  - UCR and HBCU
    - To be Issued in May
    - Grants
  - AR Program Solicitation
    - Under review but targeted for issuance in June 2006
    - Cooperative agreements with 20% cost share
  - www.netl.doe.gov and www.grants.gov

Program Contacts

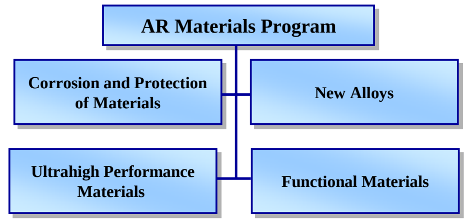
- **Robert Romanosky**
  NETL Advanced Research, Technology Manager
  304-285-4721
- **Udaya Rao**
  Gasification and Combustion Projects Division
  Materials Program / Project Manager
  412-386-4743
- **Susan Maley**
  ISCS Program / Project Manager
  susan.maley@netl.doe.gov
  304-285-1321

Advanced Research Team

External Collaborations

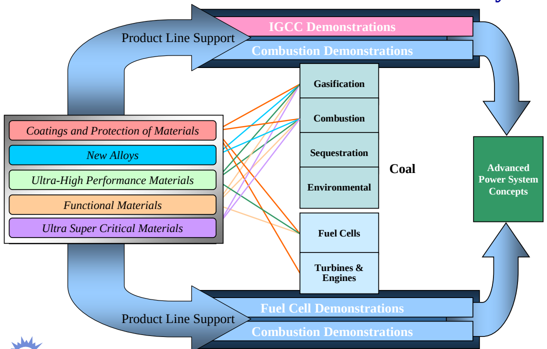
ALSTOM · Sextant · Pacific Northwest National Laboratory · Oak Ridge National Laboratory · Albany Research Center · EPRI · Virginia Tech · Iowa State University · Shell Global Solutions · LSU · NETL · B&W · Argonne National Laboratory · RILEYPower · Foster Wheeler · Energy Industries of Ohio · Reaction Engineering International · Ohio State · Helsinki University of Technology

Advanced Research Materials Program Structure



Do you need? Move to area slide?

Advanced Research Materials Traceability



Estimated Plant Efficiencies for Various Steam Cycles in Coal Fired Boilers

Description	Cycle MPa/°C/°C (psi/°F/°F)	Net Efficiency HHV
Subcritical	16.8/538/538 (2350/1000/1000)	37
Supercritical State of the Art (LEBS)	31.5/593/593/593 (4400/1100/1100/ 1100)	42
Thermie (EU) Ultra-supercritical	38/700/720/720 (5300/1290/1330/ 1330)	46
DOE/OCDO USC Project	38.5/760/760/760 (5390/1400/1400/140)	48

Source: "Materials for Ultra-Supercritical Coal-Fired Power Plant Boilers" R. Viswanathan, 17th Annual Conference on Fossil Energy Materials, April 22-24, 2003.

Tomorrow's Hydrogen

Why is Hydrogen from Coal Important?

- 95% of U.S. hydrogen comes from natural gas
- Future "Hydrogen Economy" must have more diversified sources
- Over longer term, hydrogen will likely come from renewables, nuclear power, fusion, etc.

But coal can also be a major feedstock

- Most abundant U.S. fossil fuel (250-yr supply)
- If hydrogen replaced today's transportation fuel, an additional 1.3 billion tons coal would be required
- Can be environmentally clean source of hydrogen

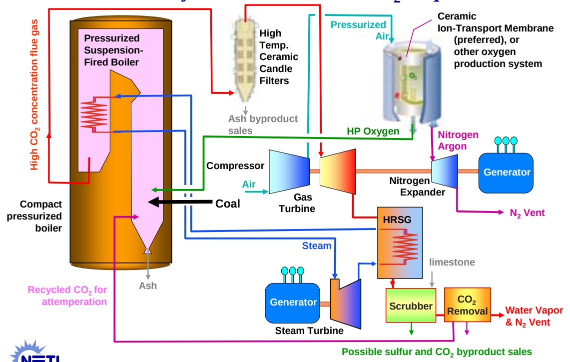
Why IGCC?

Research Reducing Cost & Improving Efficiency
- Gasifier/refractory material
- Low-cost oxygen
- Gas separation membranes

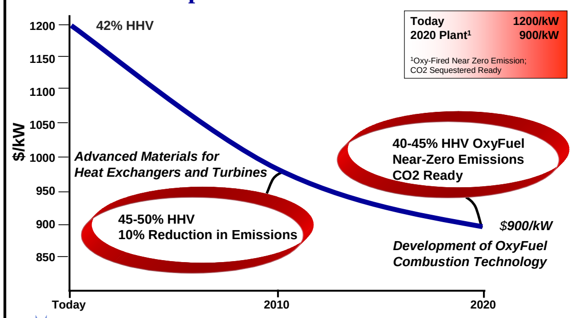
- Fuel and product flexibility
- Environmentally superior
- Easily adapted to be "sequestration ready"
- High efficiency
- Promising "coal to hydrogen" option

Producing concentrated stream of CO_2 at high pressure
- ***Improves sequestration economics***
- ***Reduces efficiency penalty***

Pressurized Oxy-Combustion with CO_2 Sequestration



Driving Down Costs For Ultra Supercritical Coal-Fired Boilers



Oxy-Fuel Ultrasupercritical System

- **Studies have shown that USC unit could be designed to startup on air but operate on oxygen and recirculated flue gas.**
- **Requires little additional equipment.**
- **Oxy-fuel USC would produce a concentrated stream of CO_2 that would be sequestration-ready.**
- **Lower gas flows improve cost of gas scrubbing technologies, such as Amine.**
- **Oxy-Fuel USC technology capable of achieving zero emissions**

R&D Activities and Technical Hurdles

- **High Efficiency Oxygen Combustion Systems**
  - **Currently O_2 based combustion being studied because of potential to greatly reduce emissions**
  - **High efficiency combustion systems will carry sequestration based O_2 concepts to commercial acceptance by coupling them with advances in combustion and O_2 membranes**
  - **The first in a series of combustion systems with 50% or greater thermal efficiency and sequestration potential could be ready by 2010 - 2012**
  - **While these high-efficiency systems are built upon other technical advancements, integration, materials, component design, boiler, burners, manufacturing, and cost barriers must be addressed.**

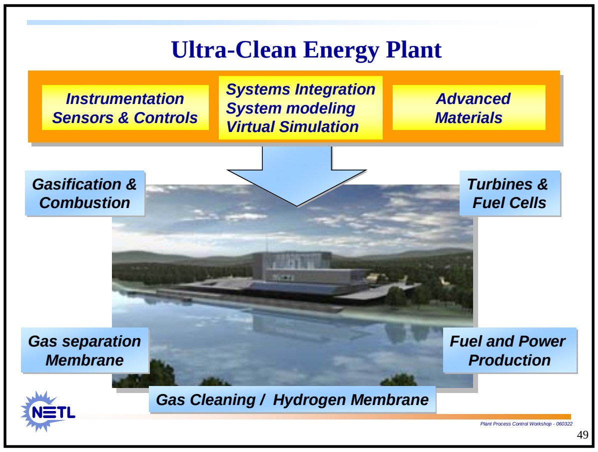
Why FutureGen Is Needed

- **FutureGen is a key step to creating a zero emission coal energy option**
- **Zero Emission Coal will enable:**
  - Countries to meet their growing energy needs
  - Secure an economic and energy future through the clean use of coal, an abundant, strategic energy resource
  - Remove all environmental concerns over coal's use including climate change concerns by sequestering carbon dioxide emissions from coal power plants, and
  - Produce clean low-cost hydrogen with zero emissions for power generation or for transportation.
- **Integration of concepts and components is the key to proving the technical and operational viability as well as gaining acceptance of the zero emission coal concept**

Advanced Low/Zero Emission Boiler Design and Operation

Goal:
- Develop and optimize coal oxy-combustion process for new plants and potential re-powering of existing fleet for CO_2 and NOx controls

Objectives:
- Experimentally demonstrate oxygen-enhanced and oxygen-FGR combustion in a 1.5 MWth Coal Fired Boiler
- Measure and optimize boiler efficiency and emission performance; select oxygen injection and FGR strategies
- Perform an economic assessment comparing combustion mod via oxygen enhancement with alternate approaches


Ultra-Clean Energy Plant
Instrumentation
Sensors & Controls
Systems Integration
System modeling
Virtual Simulation
Advanced
Materials
Gasification &
Combustion
Turbines &
Fuel Cells
Gas separation
Membrane
Fuel and Power
Production
Gas Cleaning / Hydrogen Membrane
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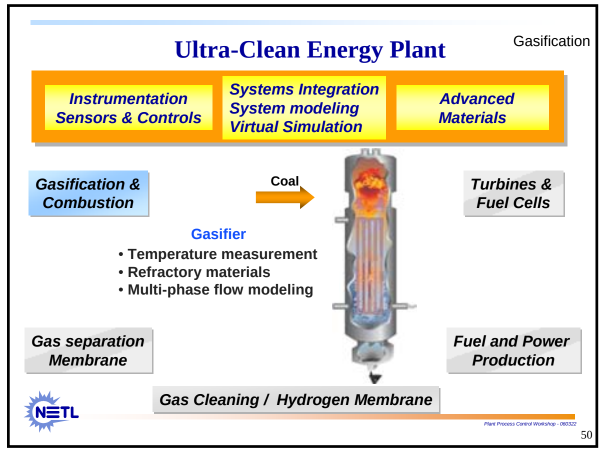
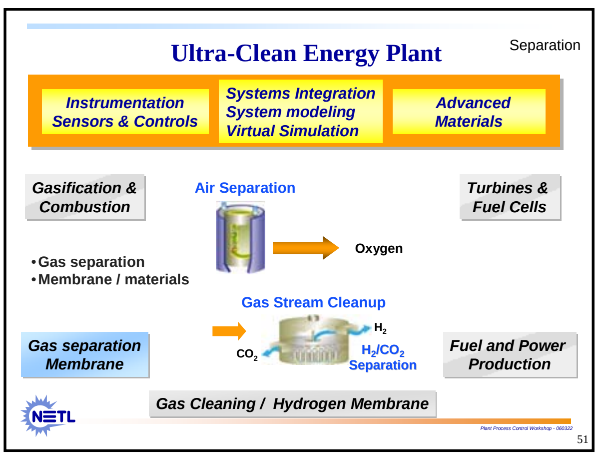

Ultra-Clean Energy Plant
Gasification
Instrumentation
Sensors & Controls
Systems Integration
System modeling
Virtual Simulation
Advanced
Materials
Gasification &
Combustion
Coal
Gasifier
• Temperature measurement
• Refractory materials
• Multi-phase flow modeling
Turbines &
Fuel Cells
Gas separation
Membrane
Fuel and Power
Production
Gas Cleaning / Hydrogen Membrane
NETL
50


Ultra-Clean Energy Plant
Separation
Instrumentation
Sensors & Controls
Systems Integration
System modeling
Virtual Simulation
Advanced
Materials
Gasification &
Combustion
Air Separation
Oxygen
Turbines &
Fuel Cells
•Gas separation
•Membrane / materials
Gas Stream Cleanup
H_2
CO_2
H_2/CO_2
Separation
Gas separation
Membrane
Fuel and Power
Production
Gas Cleaning / Hydrogen Membrane
NETL
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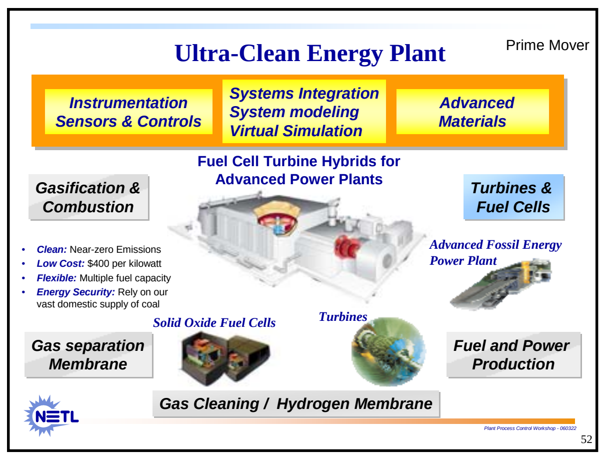
Ultra-Clean Energy Plant
Prime Mover
Instrumentation
Sensors & Controls
Systems Integration
System modeling
Virtual Simulation
Advanced
Materials
Fuel Cell Turbine Hybrids for
Advanced Power Plants
Gasification &
Combustion
Turbines &
Fuel Cells
• Clean: Near-zero Emissions
• Low Cost: $400 per kilowatt
• Flexible: Multiple fuel capacity
• Energy Security: Rely on our vast domestic supply of coal
Advanced Fossil Energy
Power Plant
Solid Oxide Fuel Cells
Turbines
Gas separation
Membrane
Fuel and Power
Production
Gas Cleaning / Hydrogen Membrane
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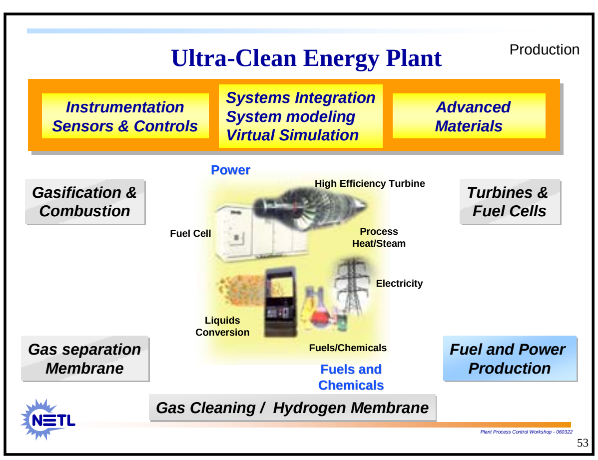
Ultra-Clean Energy Plant
Production
Instrumentation
Sensors & Controls
Systems Integration
System modeling
Virtual Simulation
Advanced
Materials
Power
High Efficiency Turbine
Gasification &
Combustion
Turbines &
Fuel Cells
Fuel Cell
Process
Heat/Steam
Electricity
Liquids
Conversion
Fuels/Chemicals
Gas separation
Membrane
Fuels and
Chemicals
Fuel and Power
Production
Gas Cleaning / Hydrogen Membrane
NETL
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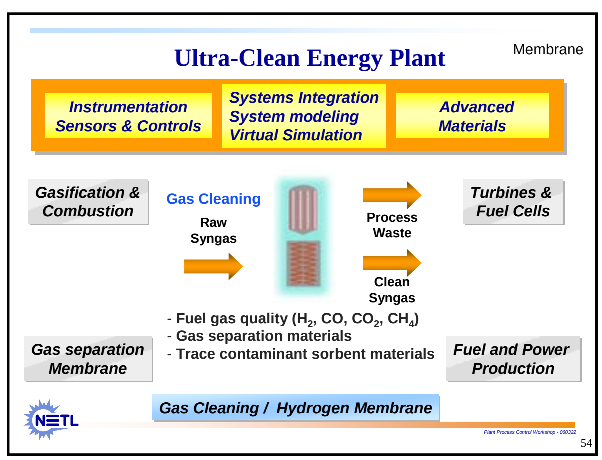
Ultra-Clean Energy Plant
Membrane
Instrumentation
Sensors & Controls
Systems Integration
System modeling
Virtual Simulation
Advanced
Materials
Gasification &
Combustion
Gas Cleaning
Raw
Syngas
Process
Waste
Clean
Syngas
Turbines &
Fuel Cells
- Fuel gas quality (H_2, CO, CO_2, CH_4)
- Gas separation materials
- Trace contaminant sorbent materials
Gas separation
Membrane
Fuel and Power
Production
Gas Cleaning / Hydrogen Membrane
NETL
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FutureGen Uses Cutting-Edge Technologies

- **Can accommodate technology innovations with minimal modifications**
  - Emerging from national or international R&D
  - R&D test beds to be implemented over life of project
- **Some emerging new technologies**
  - Membrane-based O_2 and H_2 separation
  - High-throughput gasifiers
  - High-efficiency hydrogen turbines
  - Fuel-cell systems
  - Monitoring systems

FutureGen will be a global showcase of very best technology options for coal-based systems with near-zero carbon emissions

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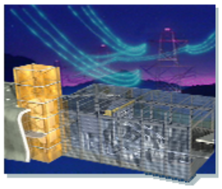
FutureGen

World's first near zero-emission, coal-based power plant to:

- **Pioneer advanced hydrogen production from coal**
- **Emit virtually no air pollutants**
- **Capture and permanently sequester carbon dioxide**
- **Integrate operations at full-scale – a key step to proving feasibility**



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System Components Offering Greatest Potential for Cost Reduction or Performance Enhancement

Oxy-Combustion

- Technical and economic feasibility demonstrated on a PC pilot scale in 2004[1]:
  - ↓ NOx emissions by 70% → No SCR required
  - ↓ Flue gas volume by 80% → Low cost pollutant controls
  - ↑ Fraction of oxidized mercury → Reduced mercury emissions
  - ↑ Flue gas CO_2 from 15 to 80% → Ideal CO_2 capture opportunity
- Potential to achieve 20% increase in COE for 90% CO_2 capture

Chemical Looping/Unmixed Combustion[2]

- Provides a 50% decrease in parasitic load compared to cryogenic oxy-fuel power plant (no ASU required)
- Potential to achieve 15% increase in COE ($11/tonne CO_2 avoided) with near 100% CO_2 capture

References:
1. DOE/Air Liquide Study (2004), DE-FC26-02NT41586, 1.5MWth Pilot Scale
2. DOE/Alstom study (2003). DE-FC26-01NT4116

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UNMIXED CATALYTIC COMBUSTION AND CHEMICAL LOOPING GOALS

Unmixed combustion (UMC) is a GE-proprietary technology that appears to offer superior performance with respect to thermodynamic efficiency and low pollutant emissions.

- Goals
  - Demonstrate in a two-reactor pilot-scale system the unmixed combustion (UMC) of coal with metal oxide catalysts;
  - Conduct lab- and pilot-scale tests;
  - Perform engineering and economic analyses; and
  - Prepare a full-scale conceptual design of the UMC process.

Chemical Looping is a revolutionary combustion technology that includes CO2 mitigation.

- Goals
  - Develop and verify the high temperature chemical and thermal looping process
  - Demonstrate concept at a small-scale pilot facility to verify design, construct, and performance of a pre-commercial, prototype.

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Current Coal Plant Operation and Control

Cyrus W. Taft, P.E.
Chief Engineer
EPRI Instrumentation and Control Center
Harriman, Tennessee

Overview

- Historical perspective
- Current practices
- Obstacles to advanced control
- Research ideas

Coal Plants

- The fleet is old.
- Most units built in 60's and 70's.
- Two major categories
  - Drum type units (subcritical)
  - Once through units (mostly supercritical)
- Size ranges from 50 MW to 1300 MW
- Operating regimes
  - Base-loaded (100% load most of the time)
  - Peaking service (<10% capacity factor)
  - Load regulating (high load during the day, low load at night)

Coal Plants continued

- Production costs vary widely
- Most plants have been upgraded
  - Control systems (due to obsolescence)
  - Emission controls, NO_X, SO_2 etc. (due to regulations)
- Regulated and merchant plants
- Reliability is biggest concern today
- Efficiency and responsiveness secondary

Typical Example

Coal Plant Control Systems

- What needs to be controlled?
  - Boiler (fuel, air, feedwater, steam temperature)
  - Turbine
  - Miscellaneous loops
  - Ash handling system for bottom ash and fly ash
  - Coal handling system
  - Sootblowers
  - Water treatment
  - Precipitators
  - Scrubbers
  - Selective Catalytic Reduction (SCR) systems

Current Control Systems

- Control functions come in two flavors
  - Modulating
  - Binary (on/off)
- Originally modulating control systems were analog, either pneumatic or electronic.
- Binary control was done with relays
- Today both functions are handled by digital systems.
- Two families of systems
  - Distributed control systems (DCS)
  - Programmable logic controller systems (PLC)

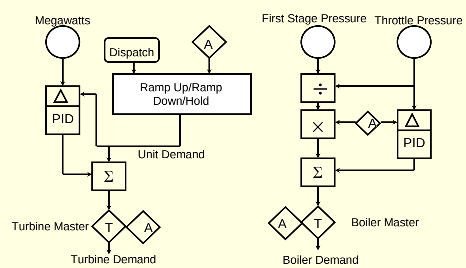
DCS and PLC comparison

- Both are distributed digital control systems.
- DCS evolved from analog control world.
- PLC evolved from relay control world.
- DCS is generally considered a plantwide solution.
- PLC more commonly used at the subsystem level.
- Both can do modulating and binary control.

Modulating control

- Boiler control is most important.
- 99% of modulating control is done with PID controllers today.
- Design is ad hoc, each vendor has de facto standard for most loops.
- Some very capable systems have been developed in the past 30 years.
- Performance can be very good.
- Tuning is very important for good performance

Boiler control example



Who are the vendors?

- Emerson (Westinghouse)
- ABB (Bailey)
- Invensys (Foxboro)
- Metso Automation (Leeds and Northrup)
- Honeywell
- ??

Advanced control

- Means different things to different people.
  - PID with feedforward?
  - PID with gain scheduling?
  - Model predictive control?
  - Optimization?
- Non-PID, multivariable, dynamic control

Obstacles

- Benefits not easily quantifiable.
- Lack of driving need.
- Plant staffs don't understand it.
- Power companies inherently conservative.
- Requires "special" software in DCS, not imbedded.

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Research needs

- Benchmarking of current control performance.
- Develop "standard" applications.
- Imbed algorithms
- Easier model development – no special testing.
- Capture 50 years of process knowledge.

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Questions??

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Tom Sarkus - NETL

DOE's FutureGen Project

Plant Process Control Workshop

March 22, 2006

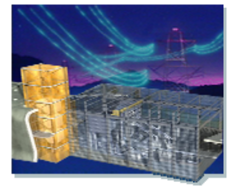
Thomas A. Sarkus, FutureGen Project Director
National Energy Technology Laboratory

NETL

FutureGen Objectives

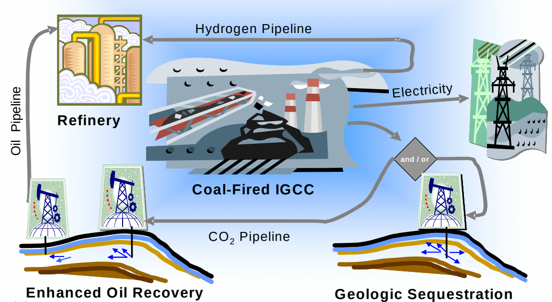
World's first near zero-emission, coal-based power plant to:

- **Pioneer advanced hydrogen production from coal**
- **Emit virtually no air pollutants**
- **Capture and permanently sequester carbon dioxide**
- **Integrate operations at full-scale – a key step to proving feasibility**



NETL TAS 3/14/06

FutureGen Concept



NETL TAS 3/14/06

Size of *FutureGen* Plant

- **Sized to…**
  - Generate nominally 1 million tonnes CO_2 per year, to yield sufficient knowledge re: geologic sequestration
  - Validate sequestration technology
  - Establish cost effectiveness
  - Corroborate scalability of laboratory results
- **Nominal 275 MW (gross power output) of electricity produces 1 million tonnes CO_2 per year**
  - Assumes initial 90% capture

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FutureGen Uses Cutting-Edge Technologies

- **Can accommodate technology innovations with minimal modifications**
  - Emerging from national or international R&D pipelines
  - Slipstream or full-scale tests
  - Over life of project
- **Some emerging new technologies**
  - Membrane-based O_2 and H_2 separation
  - High-efficiency hydrogen turbines
  - High-throughput gasifiers
  - Monitoring systems
  - Fuel-cells

***FutureGen* will be a global showcase of very best technology options for coal-based systems with near-zero carbon emissions**

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DOE Cooperative Agreement with *FutureGen* Industrial Alliance

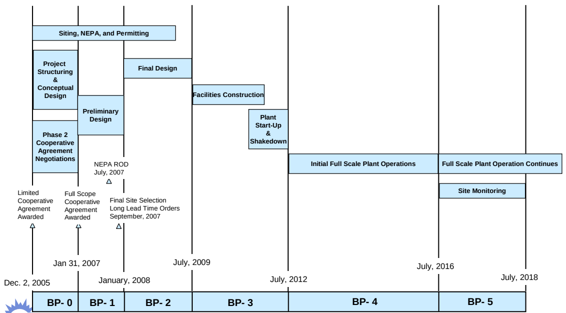
- **American Electric Power**
- **AngloAmerican**
- **BHP Billiton**
- **China Huaneng Group**
- **CONSOL Energy**
- **Foundation Coal**
- **Kennecott Energy**
- **Peabody Energy**
- **Southern Company**

Members represent >15% of U.S. coal-fueled electric generation and >40% of U.S. coal production

NETL TAS 3/14/06

 # Initials Date

FutureGen Project Schedule



TAS 3/14/06

FutureGen Funds / Costs

Cost Elements	$ Million
Plant Definition, Baselining & NEPA	81
Plant Procurement & Construction	480
Shakedown & Full-Scale Operation	188
Sequestration (Design & Construction)	191
Site Monitoring	10
TOTAL	$950

DOE	620
Industry	250
International	80

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Visit the NETL Website at http://www.netl.doe.gov/

- **Coal & Power Systems**
  - Web page for each Coal & Power R&D Program (incl. FutureGen)
- **Also, visit www.FutureGenAlliance.org**

TAS 3/14/06

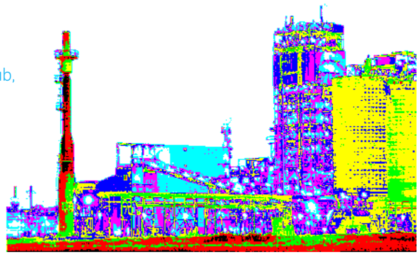
Initials Date

Minesh Shah - GE Global Research

Plant Process Control Trends and Opportunities

March 22, 2006
NETL Plant Process Control Workshop

Minesh Shah
Mgr. Automation & Controls Lab,
GE Global Research

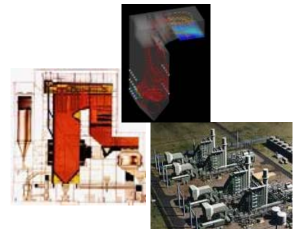


imagination at work

Trends

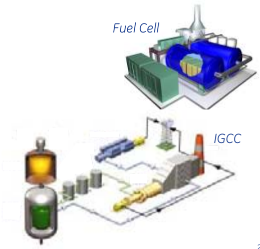
Improving existing plant utilization

- Reliability, Availability, Maintainability
- Efficiency & emissions compliance
- Operational flexibility
- Fuel flexibility



Beyond traditional power island configurations

- Chemical + Mechanical + Electrical
- Reliability, Availability, Maintainability
- COE reduction with system level optimization
- Operational flexibility



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2 / 3/22/2006

Control R&D Opportunities

RAM	Complement hardware sensors with soft sensors for diagnostics
RAM	Managing redundancy for reliability under I/O explosion
Efficiency	Condition based control to raise performance to entitlement
Fuel flexibility	Improved controls for gasifier & turbine
Operational flexibility	Managing increased mass and energy integration for start-up, turndown, emissions, fuel flexibility, unit op failures
Automation	Increase use real time models for optimal operation over manual operation for risk mitigation & efficiency improvement
Robustness	Modeling and adaptation to compensate for plant degradation, variation
Performance Assessment	Robust, reliable, long life instrumentation for harsh environments
First costs	Distributed, wireless control platform

imagination at work

3 / 3/22/2006

DCS Advanced Control Technologies

Rick Kephart
Emerson Process Management
Power & Water Solutions

EMERSON. Process Management

Presentation Roadmap

- Introduction
- Current state of Advanced Power Plant Control
- Philosophy of advanced control
- Advanced control application examples
  - Unit Coordinated Control
  - Steam Temperature
- Simulation Technologies
- Future Directions of Advanced Control in Power Generation

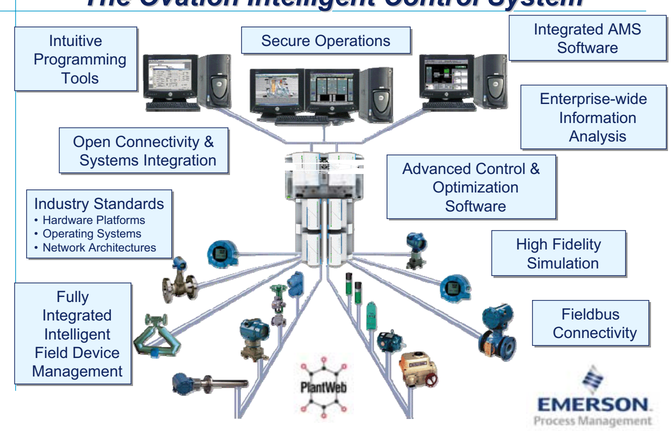
EMERSON. Process Management

Power & Water Solutions Overview

- Headquartered in Pittsburgh
- Former Westinghouse Process Control Division
- Manufacturer of the *Ovation*® Distributed Control System
- Serve the Power and Water/Waste Water markets

EMERSON. Process Management

The Ovation Intelligent Control System



EMERSON. Process Management

DCS-Based Advanced Control Evolution

1990-1994 — *Advanced supervisory control applications implemented on proprietary hardware*

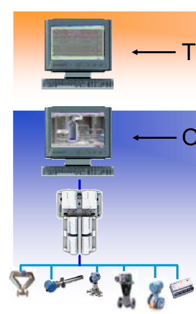
1995-1999 — *Advanced control applications implemented on Unix Workstations*

2000-2004 — *Embedded advanced control functions implemented as standard algorithm function blocks*

2004-2008 — *Advanced control technologies become an intrinsic part of the total control solution – DCS, sensors, transmitters, actuators etc.*

EMERSON. Process Management

Enabling Better Control: Advanced Process Control



Traditional Advanced Control

Ovation Embedded Advanced Control
- Powerful but easy-to-use function blocks to deal with variability problems like excessive dead time, long time constants, and loop-to-loop interactions
- Allows you to operate closer to operating constraints
- Redundant

EMERSON. Process Management

Ovation APC Technology Goals

- APC algorithms are designed to addresses issues that make control hard
  - Long time delays
  - Multivariable interactions
  - Non-Linear effects
  - Non-minimum phase (inverse) response
  - Constraints on both input and outputs
- Target specific applications
  - Reduce application complexity
  - Reduce total number of algorithms required in a control strategy

EMERSON. Process Management

Advanced Control Examples

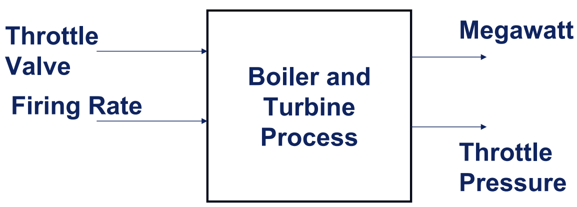
Unit Coordinated Control

Steam Temperature Control

EMERSON. Process Management

Model Predictive Coordinated Control

- Multivariable control improves load ramp rate
- Long time delays are incorporated in the mode



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Steam Temperature Optimizer

- Reduce temperature swings
  - Load Ramps
  - Reject non-linear effects
- Unify superheat and control structures
- Systematically handle disturbances
  - Load Changes
  - Burner tilts / Dampers
  - Sootblower Disturbances

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Simulation Technologies

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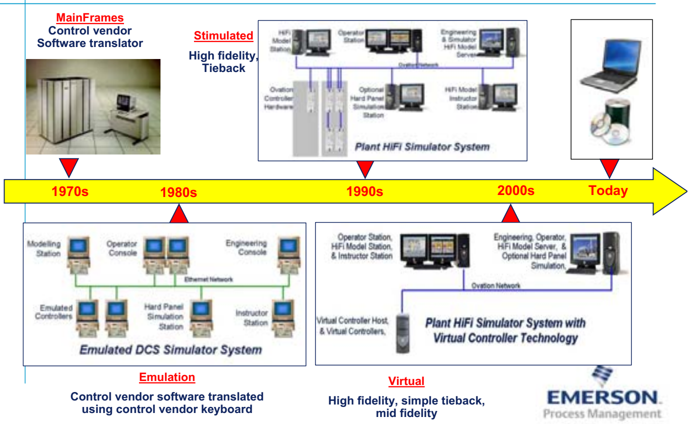
Simulation Evolution

OVATION

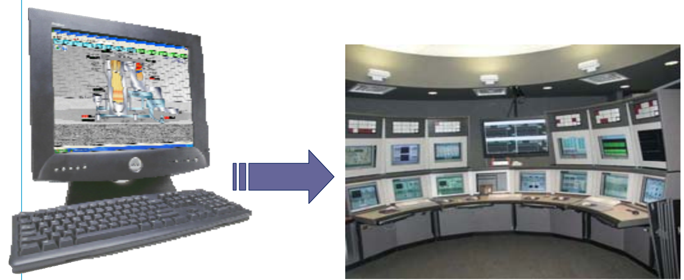


EMERSON. Process Management

Key Benefits of Simulation

- Reduced Startup and Commissioning Times
  - All plant personnel are familiar with the Ovation system prior to startup
- Operator training
  - Fewer plant trips
  - Improved operator effectiveness
- Engineering Analysis
  - Proposed control strategies can be tried on simulator first without jeopardizing operations

Scalable and Flexible Simulator Architecture



- Same software supports all configurations and architectures

Future Directions

Where the market is driving us…

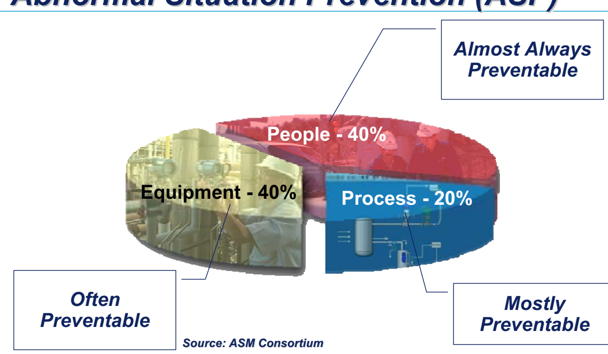
The Evolution of Control Systems

- Control Systems have traditionally been reactive entities
  - Set-Point Tracking
  - Disturbance Rejection
- Current technologies enable a coupling of control functions and process monitoring
- Design goals strive to eliminate human error
  - Operations
  - Engineering
  - Maintenance

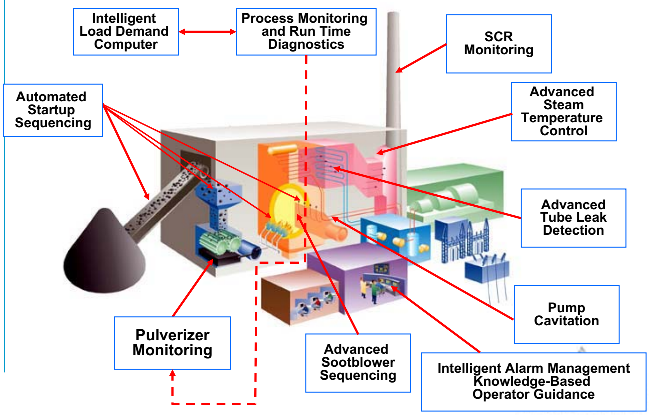
Predictive Intelligence

- Commitment Statement
  - To prevent abnormal situations by predicting the event, alerting the appropriate personnel, and automatically correcting or guiding personnel on how to mitigate the event
- Key Focal Areas
  - Abnormal process situation prevention
  - Predictive maintenance – asset management
  - Predictive operations
    - Load & steam demand/dispatch/commitment management
    - Emissions cap management
  - Expert systems for intelligent response actions/guidance

Abnormal Situation Prevention (ASP)



The Power Plant of the Future



Summary

- Existing state of the art
  - Advanced Control solutions are becoming a standard part of DCS control offerings
  - New advanced control architectures are blurring the distinction between advanced control and base control
- Challenges to Overcome
  - New control technologies require a learning investment
  - Adoption of digital bus technologies to exploit the data available in smart instruments

EMERSON
Process Management

Thank You !!

EMERSON
Process Management

Plant Process Control Workshop

The Babcock & Wilcox Company

Presentation to the DOE National Energy Technology Laboratory

Pittsburgh, Pennsylvania

March 22, 2006

TJFlynn 11/30/05.1

Advanced Control Systems for Power Generation Systems

Existing power generation systems

- Goal: Minimize operating cost
- Optimization
- Condition assessment
- Continuous performance monitoring
- Linking performance data and financial performance

Advanced power generation systems

- Goal: Maximize capacity factor
- Novel operating modes
- Sophisticated control schemes
- New high temperature materials/alloys
- Continuous performance monitoring
- Condition assessment

TJFlynn 11/30/05.2

Babcock & Wilcox Perspective

Support development of sensor and control technology

Integrate B&W proprietary power generation system knowledge

Commercialize integrated tools for performance monitoring and condition assessment

Advanced power generation technologies

- Ultrasupercritical steam cycle
- IGCC
- Oxy-fuel combustion
- Chemical looping

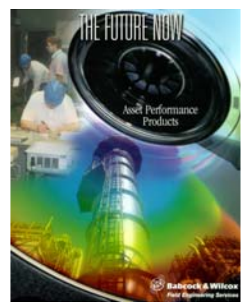
TJFlynn 11/30/05.3

Asset Performance Products

Optimizing Plant Operations

Goals:

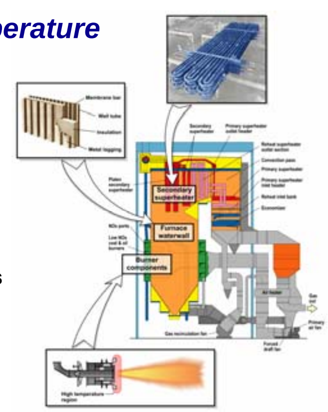
- Focus on products and services that enhance the operation and performance of the boiler island
- Seek related products that complement this objective via development, licensing, alliances and partnering
- Provide on-line services to complement traditional B&W outage support services



TJFlynn 11/30/05.4

High Temperature Sensors

B&W specified areas where fiber optic sensors would enable measurements not previously possible



TJFlynn 11/30/05.5

Backups

TJFlynn 11/30/05.6

Tools for Improved Boiler Performance

Technologies Delivered by B&W

POWER CLEAN — *Optimizing Sootblowing*

Truflux — *Heat Flux Sensor*

FLAME DOCTOR — *Optimizing Burner Performance*

NeuSIGHT™ — *Optimizing Overall Combustion Process*

TJFlynn 11/30/05.7

Powerclean

Intelligent Sootblowing

- Improved control of fouling, slagging
- Better control of furnace conditions – FEGT and NOx benefits
- Improved control of steam temperature in superheat and reheat
- Improved overall operations for gains in efficiency – RH spray, Econ exit gas temperature, etc.
- Consistency across operating shifts with closed loop SB control

POWER CLEAN

TJFlynn 11/30/05.8

Flame Doctor

Advanced Burner Flame Diagnostic System

- Provides absolute individual burner assessment
- Determines root cause of burner problems and offers operator guidance for tuning
- Utilizes existing flame scanners for rapid installation
- B&W tuning service available as option

FLAME DOCTOR

** technology licensed from EPRI*

TJFlynn 11/30/05.9

NeuSIGHT

Neural Network Combustion Optimization

- Empirically models unit operation
- Works with DCS to continuously optimize boiler performance
- Focuses on NOx reductions and/or efficiency improvements with existing plant hardware
- B&W is a value-added reseller and implementer for Pegasus Technologies
- B&W expertise enhances neural network implementation

NeuSIGHT™

TJFlynn 11/30/05.10

Truflux

Waterwall Heat Flux Sensors

- Non-intrusive alternative to tube based heat flux sensors
- Low installation cost
- Reliable measurements
- Easy integration with existing control systems
- Developed and patented by B&W

Truflux

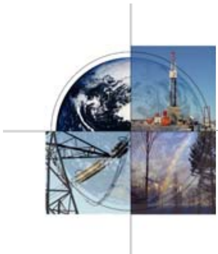
TJFlynn 11/30/05.11

Babcock & Wilcox

a McDermott company

TJFlynn 11/30/05.12

Computational and Basic Sciences Focus Area



NETL Plant Process Control Workshop

March 22, 2006

William Rogers
Director - Computational Science Division

NETL

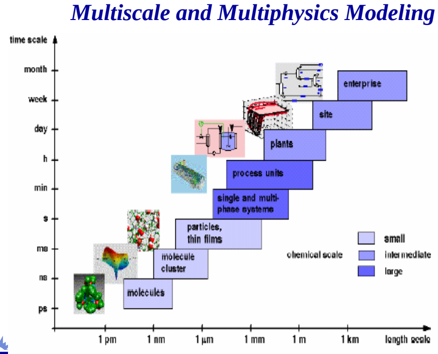
Computational and Basic Sciences Focus Area

Integrate physical, chemical, and computational models as the preferred method for understanding, predicting, and developing advanced materials and multiscale energy systems from molecular-scale to device-scale to plant-scale.

NETL

Computational & Basic Sciences Focus Area

Multiscale and Multiphase Modeling



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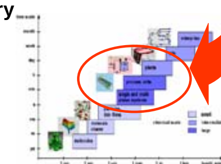
Computational and Basic Sciences

Research Group Organization

- Multiphase Flow
- Process and Dynamic Systems Modeling
- Device Scale Modeling
- Gas-Solids Reactor Systems Research Group
- Energy Infrastructure and Security
- Computational Chemistry
- Hydrogen Separation
- Hydrogen Materials
- Gas Hydrates
- Defense Fuels



NETL

Multiphase Flow Research Group

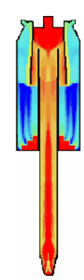
Develop and apply mathematical and computer models of multiphase flows important to fossil energy and chemical processes. These models include both dilute and dense multiphase mixtures and can include chemically reacting flows. Fundamental research is also performed in the modeling of multiphase flow physics.

- *Conduct fully resolved simulations of circulating fluidized beds using MFIX*
- *Validate continuum models with test cases for which accurate experimental data are available; e.g., rotating drums, inclined planes, spouted bed*
- *Develop, validate and apply coal gasifier models*
- *Develop and implement discretization schemes and systems for numerical error estimates.*
- *Develop next generation of multiphase flow code: MFIX-NG*

NETL

Multiphase Flow - MFIX

- **M**ultiphase **F**low with **I**nterphase e**X**changes (www.mfix.org)
- MFIX is recognized internationally as the pre-eminent software for modeling gas-solids flow, which occurs in most energy conversion processes central to fossil fuel (coal) technologies.
- Open source software downloaded by over 200 institutions/500 researchers worldwide
- This software was primarily developed by NETL and has spurred collaboration with several universities, national labs and power plant designers.
- Technology transfer to software and technology developers; e.g., Fluent, Kellogg, Brown & Root, …
- Application in other areas
  - fluid catalytic cracking, polyethylene production, volcanology, nuclear fuel particle coating, solar energy, …

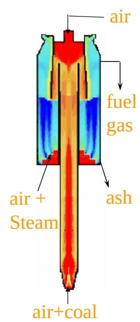


PyGAS gasifier: CO mass fraction

NETL

MFIX Applications

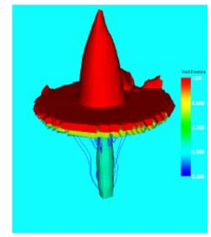
- **NETL Applications**
  - Carbonizer, Foster Wheeler (1992-95)
  - PyGAS™ gasifier, Jacobs Sirrine (1992-93)
  - Ultra pure silicon production, MFDRC/Dow-Corning (1999-2003)
  - PSDF gasifiers, KBR/Southern (2002-)
  - Black liquor gasifier, Georgia Pacific (2003-04)
  - Entrained flow gasifier, Boeing Rocketdyne (2005-)
  - Chemical Looping (2005 -)



PyGAS gasifier: CO mass fraction, Syamlal and Venkatesan 1993

MFIX Applications

- **External Applications (known)**
  - FCC stripper (U. Saskatchewan)
  - Polyethylene (Iowa State U.)
  - Volcanology (MichiganTech, U. of Washington)
  - Yucca mountain nuclear repository (Los Alamos)
  - Nuclear fuel particle coating (ORNL)
  - Solar energy (Sandia)
  - Municipal waste incineration (ABB)



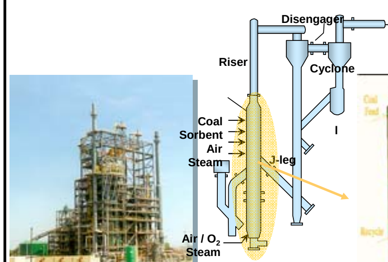
Nuclear fuel particle coater: Void fraction iso-surface (red 0.99; green 0.75) showing the boundary of the internal gas pocket and the surface of the particle fountain in spouted bed. Blue lines are solids tracer path lines. Pannala et al. 2004

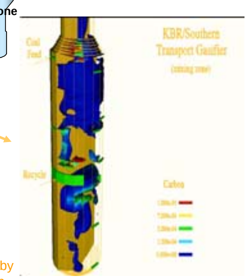
Device Scale Modeling Research Group

Develop, validate, and apply device and equipment models important to fossil energy and chemical processes

- *Development of detailed custom and CFD models for devices and equipment items including, but not limited to: gasifiers, combustors, syngas coolers, gas turbines, steam turbines, heat recovery steam generators (HRSG), and fuel cell stacks*
- *Development of dynamic device and equipment models for IGCC power plants*

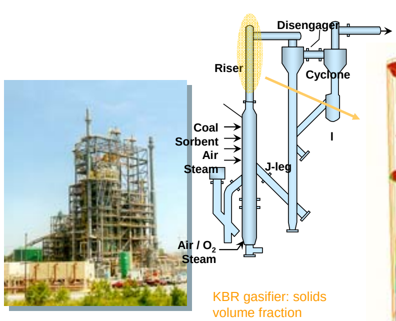
Device Scale - Gasifier Model

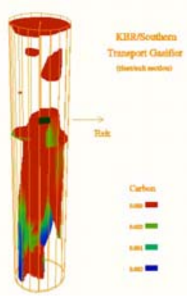




KBR gasifier: solids volume fraction isosurfaces colored by carbon mass fraction

Device Scale - Gasifier Model



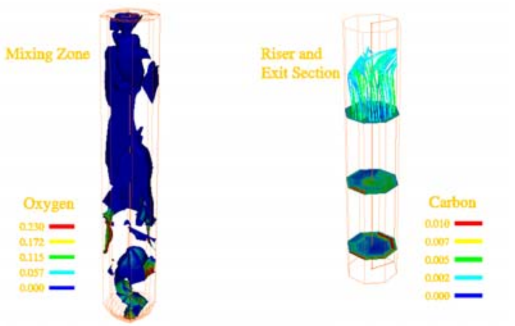


KBR gasifier: solids volume fraction isosurfaces colored by carbon mass fraction

CFD Simulations of a Commercial Scale Transport Gasifier

- Conceptual KBR/Southern Design of a Clean Coal Power Initiative (CCPI) Transport Gasifier
  - Transient, three-dimensional, 1.2 million cells
  - Chemistry model developed from PSDF simulations

KBR/Southern Commercial Scale Transport Gasifier



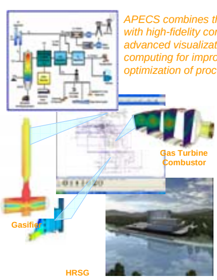
Process and Dynamic Systems Modeling Research Group

Develop, validate, and apply advanced process models of fossil energy power systems for both steady state and dynamic simulations

- *Utilize the NETL Advanced Process Engineering Co-Simulator (APECS)*
- *Dynamic models of fossil energy processes will be developed using Simulink, Aspen Dynamics, and other dynamic process simulation tools*

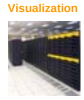
Advanced Process Engineering Co-Simulator (APECS)

APECS combines the power of process simulation with high-fidelity computational fluid dynamics (CFD), advanced visualization, and high-performance computing for improved design, analysis, and optimization of process engineering systems

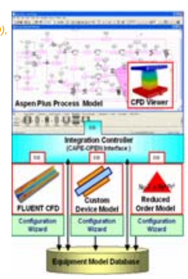


APECS Power Plant Simulation

Advanced Visualization



High-Performance Computing



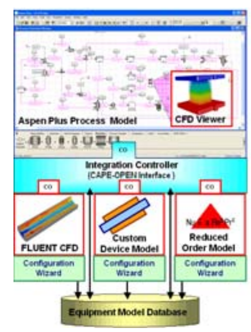
APECS Software Architecture

NETL Cooperative Partnership – 2004 R&D 100 Award

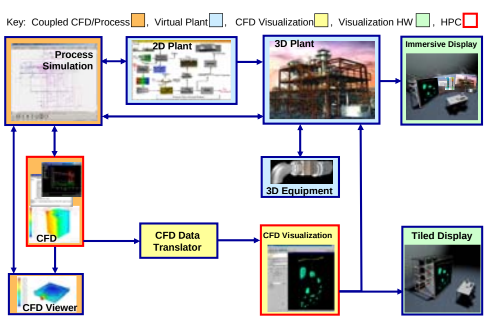
Advanced Process Engineering Co-Simulator (APECS)

Major Components and Features

- **Process Models**
  - Aspen Plus®
- **Equipment Models**
  - FLUENT®
  - Custom Device Models
  - Reduced-Order Models (ROM)
- **Integration Controller**
  - CAPE-OPEN (CO) Interfaces
  - Unit Operations, Physical Properties, Reactions
- **Configuration Wizards**
  - FLUENT*
  - Custom Model** and ROM**
- **Model Database**
- **CFD Viewer**
- **Solution Strategies**
  - Speed (ROM)
  - Accuracy (CFD)
- **Remote Execution**
  - Windows/Linux
  - Serial/Parallel

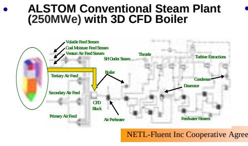


NETL APECS for Virtual Plant Simulation

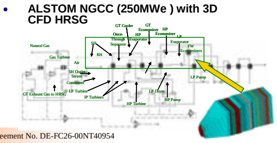


APECS Power Generation Applications

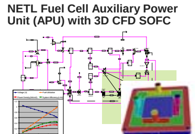
- **ALSTOM Conventional Steam Plant (250MWe) with 3D CFD Boiler**



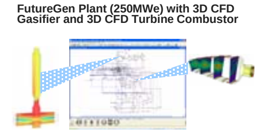
- **ALSTOM NGCC (250MWe) with 3D CFD HRSG**



- **NETL Fuel Cell Auxiliary Power Unit (APU) with 3D CFD SOFC**



- **FutureGen Plant (250MWe) with 3D CFD Gasifier and 3D CFD Turbine Combustor**



IGCC Dynamic Simulator
Goals and Objectives

To meet the emerging need for advanced IGCC systems analysis and training, NETL will:

- **Develop a generic full-scope IGCC dynamic simulator**
- **Establish a Simulator & Training Center**
- **Implement strategic collaborations with simulator vendor and technology partners**
- **Form industry advisory panel**

Simulator Requirements

- **Rigorous, real-time, IGCC dynamic model**
  - Gasifier
  - Air Separation Unit
  - Gas Cleanup
  - Combined Cycle
  - Fuel Handling
- **Full-scope OTS capabilities**
  - Malfunctions/Trips, Alarms, Scenarios, Trending, Snapshots, Data Historian, Trainee Performance Monitoring (TPM)
  - Startup/Shutdown
  - Load Following, Load Shedding
  - Analyzing control strategies (turbine lead, gasifier lead)
  - Response to fuel and ambient variations
- **Suitable for systems analysis and engineering studies**

Training Center Requirements

- **NETL-sponsored and University-hosted**
- **Potential Users**
  - Companies considering IGCC technology
  - Existing IGCC and gasifier companies
  - DOE/NETL system analysts
  - University engineering and training R&D community
  - Those interested in learning more about IGCC plant operations and control
- **Demo and Training Services**
  - IGCC plant operation and control demonstrations
  - Computer-based training program
  - Intelligent tutoring system
  - On-site "Train the Trainer" program

Industry Advisory Panel Requirements

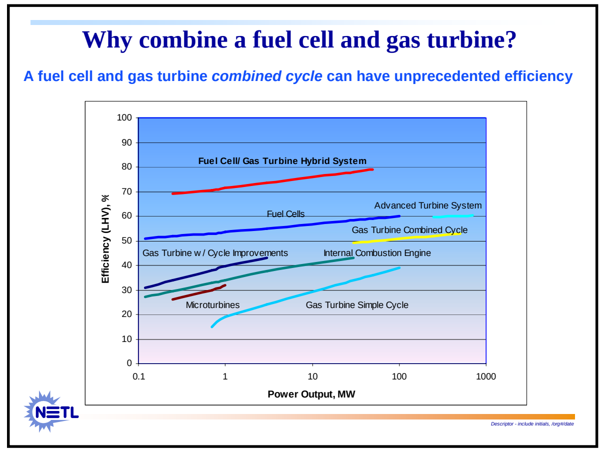
- **Promote collaboration between project team and industry**
- **Provide feedback to ensure project team is meeting industry's needs**
- **Promote awareness to power and energy industry**
- **Target members from:**
  - Electric utilities
  - Engineering, procurement & construction (EPC) firms
  - Gasifier suppliers
  - Research institutes
  - Academic researchers

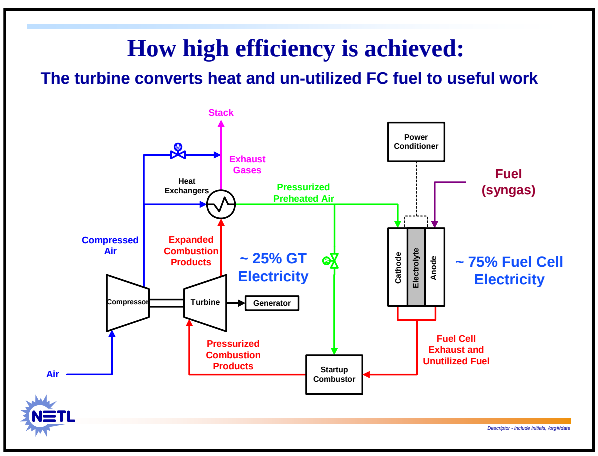
Gas-Solids Reactor Systems Research Group

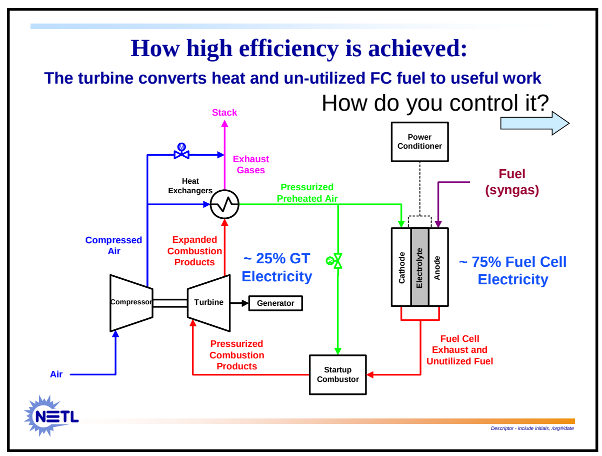
Advanced energy systems involving solid fuels, sorbents, or oxygen carriers most commonly employ fluidized bed and pneumatic transport components. Selection of a suitable gas-solids reactor system is typically based on its ability to achieve the appropriate time temperature profile with sufficient gas-solids contact and mixing.

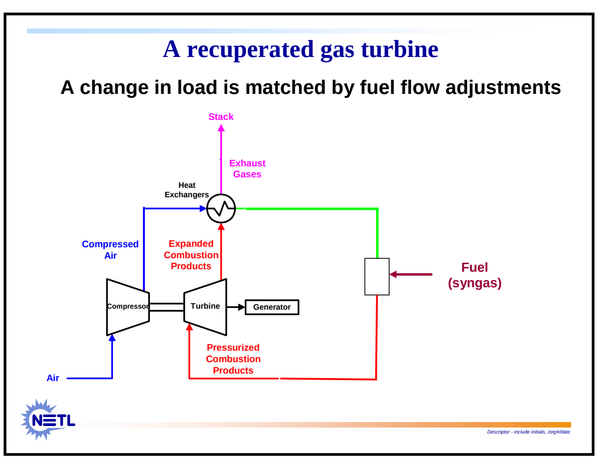
- *Improve measurements of key hydrodynamic parameters in circulating fluid bed systems including solids circulation rates, transport properties such as solids viscosity and granular temperature, as well as separation indices and gas and solids dispersion rates*
- *Experimentally verifiable methodologies and algorithms are sought to improve the reliability and accuracy of designing and scaling gas-solids reactors, non-mechanical valves, gas-solids separators, and solids transfer components.*
- *Methods and algorithms are sought to identify and predict incipient solids flow transport properties and frictional flow regime transitions for materials of interest in energy systems*
- *Generate data for validation of multiphase flow models*

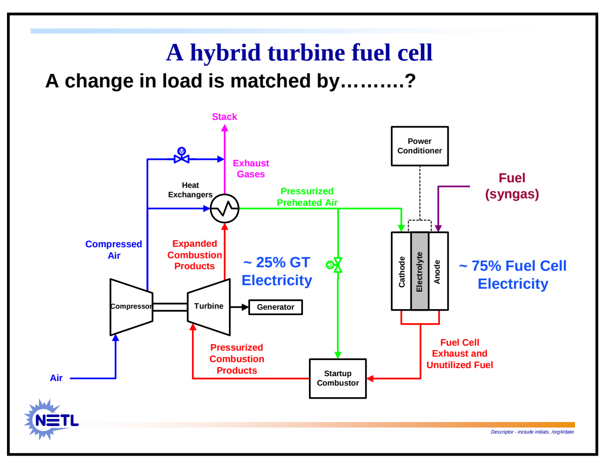
Geo Richards Director - NETL





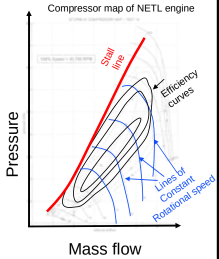






Turbine Engine Dynamics

- **Compressor stall and surge occur when:**
  - The downstream pressure rise is too high for mass flow at a given rotational speed (see "map", crosses the stall line).
- **The best efficiency occurs near the "stall line".**
  - If efficiency is a goal, a hybrid plant will operate "near" the stall line.
- **Compressors stall and surge are significant considerations in conventional engine design and operation.**
  - E.g.: IGCC diluent addition limits, start-up bleed strategies, etc., see Walsh

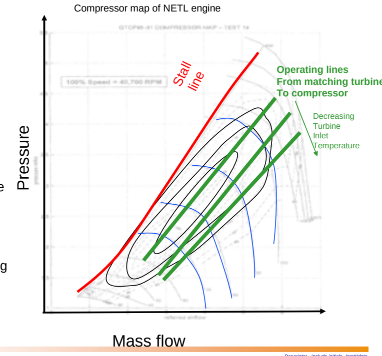


An example of steady operating lines

What happens if you reduce load on the fuel cell?

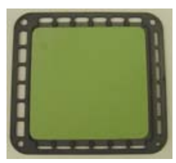
Un-utilized fuel raises the turbine inlet temperature (oops?).

How do you transition between steady operating points?



Unique issues for hybrids

- **The fuel cell flows must be managed during all transients.**
  - Anode reducing, cathode oxidizing.
  - Temperature and pressure transients
- **The addition of cathode volume may lead to surge during some events.**
  - Anode gas combustor flameout (inadequate power to spin compressor + stored cathode gas = surge)
  - Loss of load on the fuel cell (spill anode fuel = inadequate power to spin compressor….or turbine overspeed, surge if burn anode fuel)
- **Approach to load sharing (FC/GT) is to be defined.**



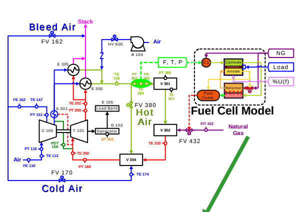
Control Requirements for Different Systems

- **Different hybrid applications may have different architectures:**
  - <1MW: asynchronous generator, variable speed?
  - <10MW: synchronous power turbine?
  - >200MW on coal gas: synchronous generator?

The NETL Hybrid Project

Develop efficient approaches to couple a fuel cell and a gas turbine in a hybrid power generation facility.

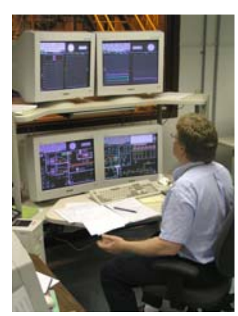
- **Public Domain Facility**
- **Model and Process Validation**
- **DOE Program Support**
- **Integration Issues**
- **Controls Development**



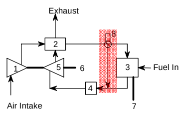
The fuel cell response is (currently) generated by a real-time model controlling a burner.

NETL on-site hybrid research

- **Objectives:**
  - Identify options to control hybrid power flows, mass flows over load range, load shed that:
    - Don't penalize system efficiency
    - Avoid fuel cell material degradation (cathode/anode reduction/oxidation)
    - Avoid thermal limitations of hardware
  - Define optimal system architectures based on validated models, esp. for coal-based hybrid.
  - Quantify sensor requirements for adequate control.



Example of one control architecture



1 Compressor
2 Heat Exchanger
3 Fuel Cell
4 Start-up/Aux Combustor
5 Turbine
6 Engine Shaft
7 Electrical Load
8 By-pass flow valve

- **Bypass flow valve is one option to control load split.**
  - What state variables need to be measured to control FC inlet?
  - Is this practical, cost effective?
  - Does this work differently for synchronous versus asynchronous turbines?

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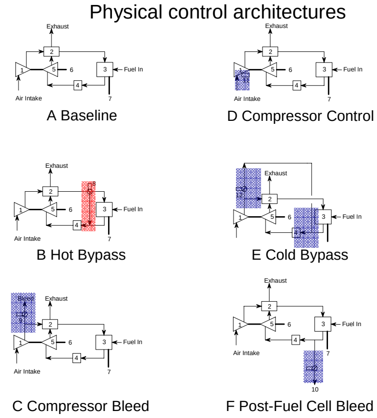
Physical control architectures



1 Compressor
2 Heat Exchanger
3 Fuel Cell
4 Start-up/Aux Combustor
5 Turbine
6 Engine Shaft
7 Electrical Load
8 Hot Bypass
9 Compressor Bleed
10 Post Fuel Cell Bleed
11Compressor Control (IGVs)
12 Cold Air By-pass Flow Valve

Fill in the matrix!

- **Identify configurations, sensor input for observability, and controllability.**
- **Experiments and models used together.**
- **Models used to extrapolate to new configurations.**

Inputs: electrical load demand

Control Actuation ↓	← State variables →								← Figures of Merit →		
	Temps T1.......TN	Press P1....PN	Speed	Mass flow M1...MN	FC load	Turbine load	FC stoich		Cost	Complexity	Tech Development
Electrical load split											
Hot bypass flow	"+...-....+"						" - "				
Cold bypass flow											
Fuel cell fuel flow											
Aux firing fuel flow											
Compressor bleed											
Post FC bleed											
Inlet Guide Vanes*											
Overspeed relief											

Example

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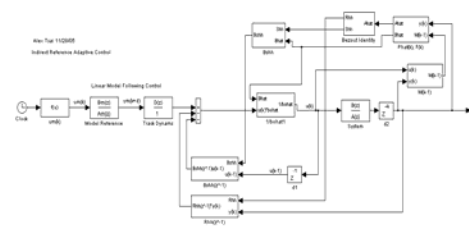
Status of Controls Development

- **Lab testing of various physical control architectures in process**
- **State space model being developed right now**



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Summary

- **Control of advanced power systems introduces new challenges.**
- **NETL hybrid turbine fuel cell facility used to:**
  - Study pros/cons of physical control architectures
  - Validate dynamic system models
  - Develop new control strategies

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Data Mining Complex Data Structures

Data Management and Analysis Team (DMAT)
for Advanced Infrastructure Systems

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KDD and Data Mining

- Growth in our capability to generate, collect, and store data outpaced our ability to interpret and digest available data
- Need for automated and intelligent database analysis to assist humans in analyzing the mountains of data for nuggets of useful knowledge

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KDD and Data Mining II

- KDD is the overall process of finding and interpreting patterns from data
- Interactive and iterative
- Multi-step process
- Nontrivial process of identifying valid, novel, potentially useful, and ultimately understandable patterns in data. (Fayyad,1996).

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Case Study

- Fort Wayne – IN: Flood Control Project
  - Phase I: CTRL-EAST, $4,488,450.21, 11/1/95-10/23/98
  - Phase II: East-North, $12,107,880.46, 1/6/97-11/5/98
  - Phase III: CTRL, $ 6,018,981.54, 9/14/98-8/6/99
  - Phase IV: West, 5/28/99-

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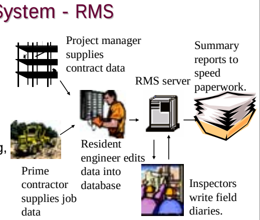
Case Study II

Data Collection and Extraction:

Resident Management System - RMS

- Manages Civil Works projects.
- Was developed by US Corps of Engineers (1996)
- Consists of about 80 database tables, each of which has about more than 20 attributes.
- Contains data on construction project planning, contract administration, quality assurance, payments, correspondence, submittal management, safety and accident administration, modification processing, and management reporting.



RMS in a construction project

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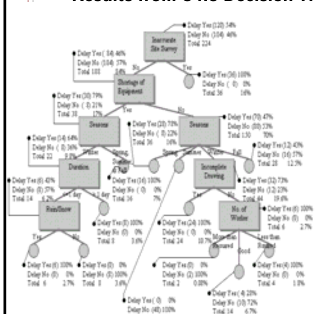
Case Study III

- **Results from C4.5 Decision Trees**



- Weather considered responsible for delays by site managers, appear not to be the most important cause in determining delays.
- Activities with "Inaccurate Site Surveys" are always delayed in the schedule.
- Shortage of Equipment, Seasons, and Incomplete Drawing are also very significant factors compared to other factors.

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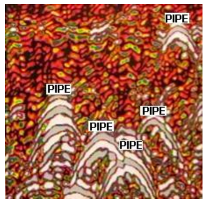
Case Study IV

- Ground penetrating radar is a good investment



Case Study V

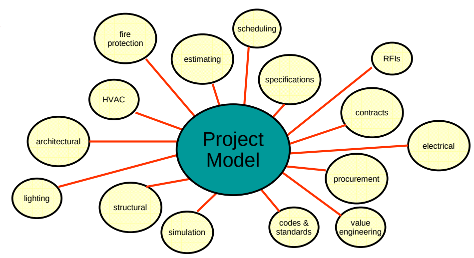
Validation with a construction project manual, RSMeans

- Activity:
  - Drainage Pipe – 320 units – 10 workers
- RS Means 00
  - Output: 10 units worker/day
  - Duration: 3.2 days
- NN
  - Duration: 4.96 – 6.86 days
    - Factors affecting the duration are not considered in RS Means

Case Study VI

- Cost/Benefit
  - According to the result of this case study, the main cause of schedule delays was "Inaccurate Site Survey" rather than the weather related problems initially assumed by site managers.
  - Discussions with site managers confirmed the importance of equipment, such as Ground Penetration Radar (GPR) with $5,000 investment for the equipment.
    - Potential savings at the 4th stage:
      = $587,391
      [$9,436 (daily construction cost) *
      75 (expected number of instances) *
      0.83 (the number of days to be saved through using GPR)]

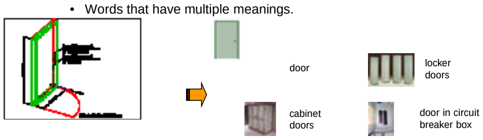
Data Integration - Text



- Project Model-Based Information Systems:
  - A shared project model is used to integrate project information.
  - Based on product, process, or organizational model.

Data Analysis and Industry Feedback

- Project Websites:
  - User-driven folder-based document organization.
- Integration Challenges:
  - Multiple words with the same meaning.
    - e.g.: elevator and lift.
  - Words that have multiple meanings.

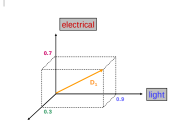


  - Documents that don't contain object terms, but are relevant.
    - e.g.: IfcElectricalElement, IfcLightFixture, and IfcTransportElement

Document Representation

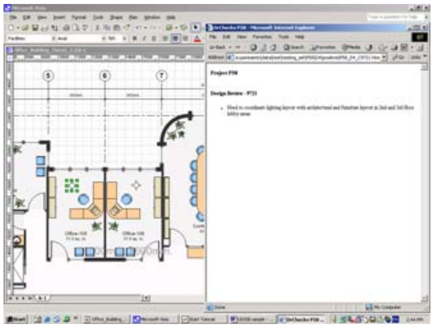
- Project documents are represented as vectors in a multi-dimensional space.
- Vector coordinate values are defined by the index terms weights.
- Project document collection can be represented as a *m x n* matrix.
- Project document collection is parsed and indexed.

$\vec{d_1} = (0.9, 0.7, 0.3, \ldots, 0.0)$



	document 1	document 2	document 3	...	...	document n
term 1	0.9	0.0	0.1			0.0
term 2	0.7	0.0	0.7			0.9
term 3	0.3	0.3	0.0			0.0
...						
...						
term m	0.0	0.3	0.0			0.1

Illustrative Example



Validation

• Recall

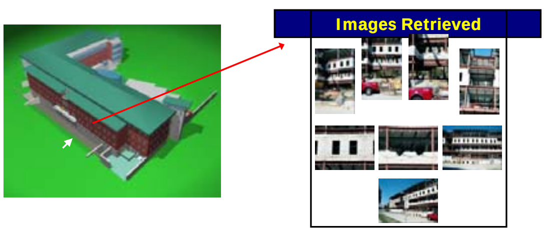
Sample	Mean
UDIS - Model Created from Previous Projects	66.86%
PROJECT CONTRACT MANAGEMENT	44.17%
PROJECT WEBSITE	30.68%
IR SYSTEM 1	42.92%
IR SYSTEM 2	32.99%

• Precision

Sample	Mean
UDIS - Model Created from Previous Projects	46.33%
PROJECT CONTRACT MANAGEMENT	28.55%
PROJECT WEBSITE	28.81%
IR SYSTEM 1	31.45%
IR SYSTEM 2	29.58%

Data Integration - Images

- Checking the progress of the "Building wall" activity of the south east section of Siebel Center



Motivation – Can we link manually or label?

- Number of Objects visible in a picture is large
  - Construction of Perelman Theater, 2002
    - Range: 0 to 300, Mean: 45.4 (objects/picture)
    - Mode: 20, Standard Deviation: 71
    - Average number of links/project > 45,400
- Labeling is not enough

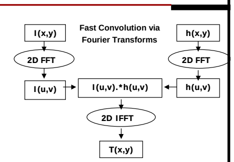
- Example
  - W.E. O'Neil Casino Project image
  - 53 objects
  - Engineer's labeling: domesticwatermains.jpg
  - Complete label: steel_column13+steel_column22+steel_beam09+steel_beam10+steel_beam11+…+concrete_column05+concrete_column08+…+steel_roof02+…

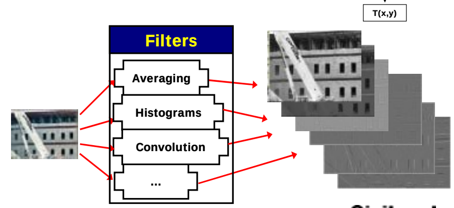
Proposed Solution

- Analyze image into basic features
- Divide image into regions – clusters
- Compute the signatures of each cluster
- Identify construction objects – materials by comparing image cluster signatures with material sample signatures in a knowledge base
- Assign identified materials to original image
- Retrieve images and link them with objects using the identified materials and the temporal and spatial information

Proposed Solution – Analyze image into basic features

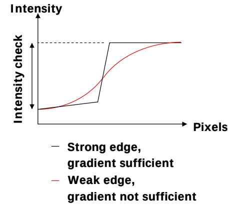
- Apply several filters to the picture using:
  - averaging (intensity),
  - histograms (color),
  - convolution (filter banks) and other techniques
- Extract the corresponding transformations

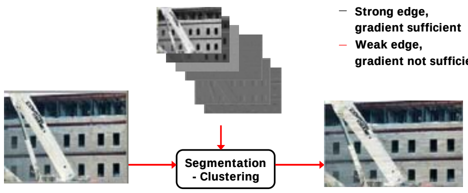




Proposed Solution – Divide image into regions

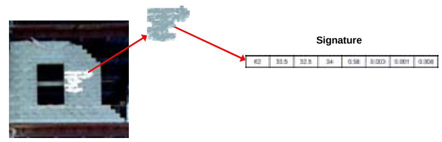
- Use bottom – up approach to avoid missing objects
- Utilize transformations (segmentations + intensity) to group pixels
- Merge clusters (if necessary) using texture related transformations





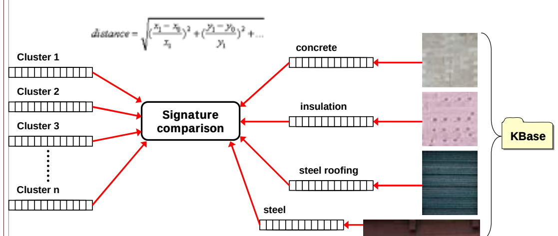
Proposed Solution – Compute the signatures

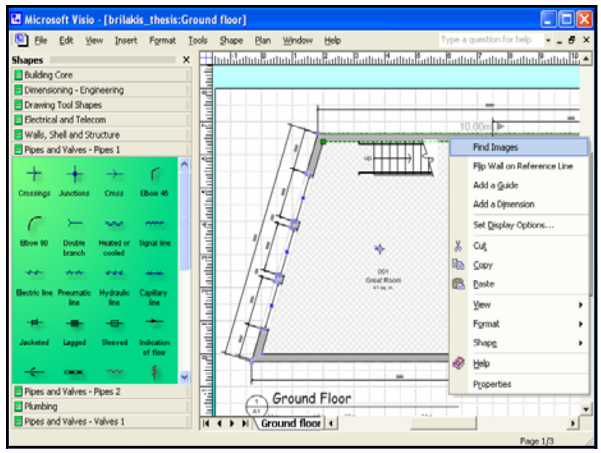
- Use quantifiable, descriptive, compact and accurate signature representations (like mean, mode, variance, etc.)
- Compute signature vector for each cluster (De Bonet, 1997)

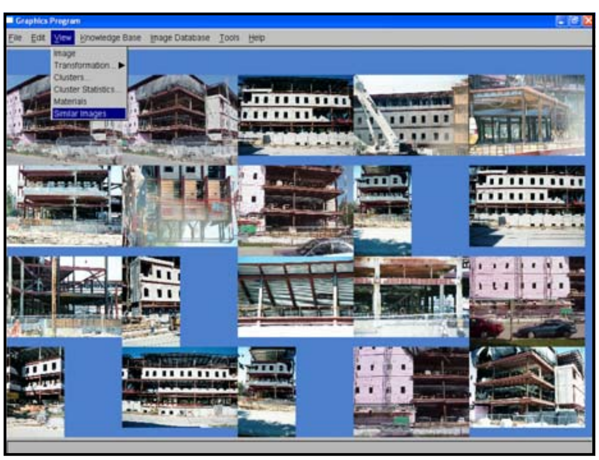


Proposed Solution – Identify construction objects

- Create or acquire a material knowledge base by computing the signatures of images that contain a single object (or part of).
- Compare the signatures of each cluster with the signatures of each material sample in the knowledge base

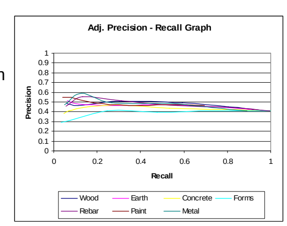




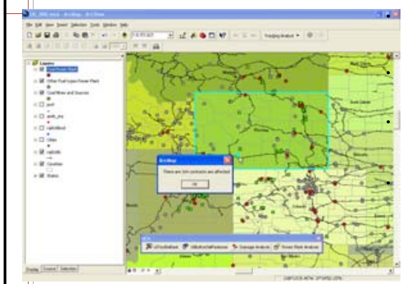


Validation

- The final evaluation indicates robust performance of the proposed method
- Precision averages 50% even at high scopes
- Recall is not sacrificed
- Queries performed on higher level concepts (materials instead of color, texture, etc)



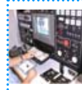
Existing Data – NETL/DOE



- Coaldat
  - Coal transaction records, Coal transportation information, contact information
- Coal Transportation Rate Database (CTRDB)
  - Coal transaction records
- National Transportation Atlas Database (NTAD)
  - Railroads , ports, stations information
- PowerMAP
  - Power plants, mines information

RedZone Pipe Defect Detection

Existing Pipeline Inspection Techniques → Quality / Flexibility → RedZone Robotics



Close Circuit Televised (CCTV) inspections

Sewer Scanner and Evaluation Technology (SSET)

⋮

Existing Pipeline Inspection Robots

Responder

Renovator

A New Generation of Robotic Crawler

CarnegieMellon
Civil and Environmental ENGINEERING

RedZone Images

CarnegieMellon
Civil and Environmental ENGINEERING

Advanced Pipe Asset Management System with Automatic Pipe Defect Classification for Data Acquired by the Autonomous Robotic Sewage Pipe Crawler

Automatic Data Acquiring Robotic Crawler

Automatic Pipeline Defect Troubleshooting System

- Defect Detection
- Defect Classification
- Defect Grading
- Pipe Rating

Positioning System
Deterioration Models
Tradeoffs (power, representation
Compression, speed)

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Type of Defects

- Structural Family of Defects
- Operational & Maintenance Family of Defects
- Construction Features Family Defects
- Miscellaneous Features Family

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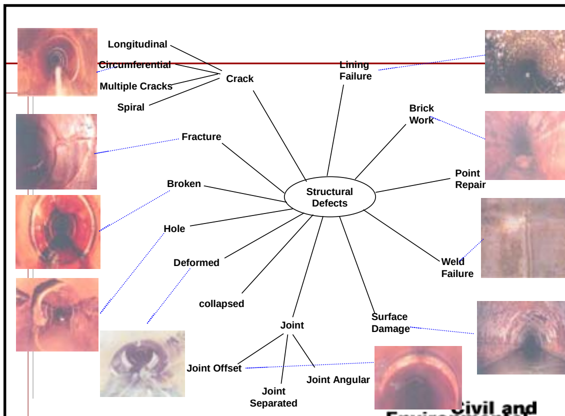

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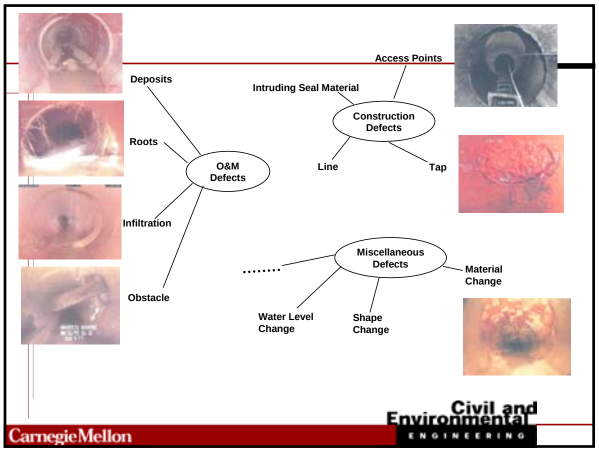
Deposits
Roots
Infiltration
Obstacle
O&M Defects
Access Points
Intruding Seal Material
Construction Defects
Line
Tap
Miscellaneous Defects
Material Change
Water Level Change
Shape Change
Carnegie Mellon
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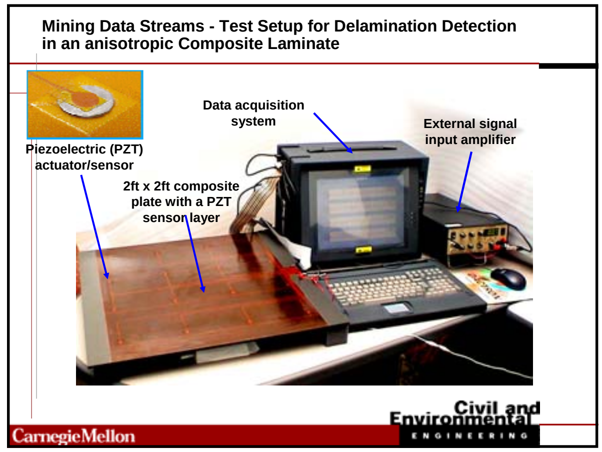
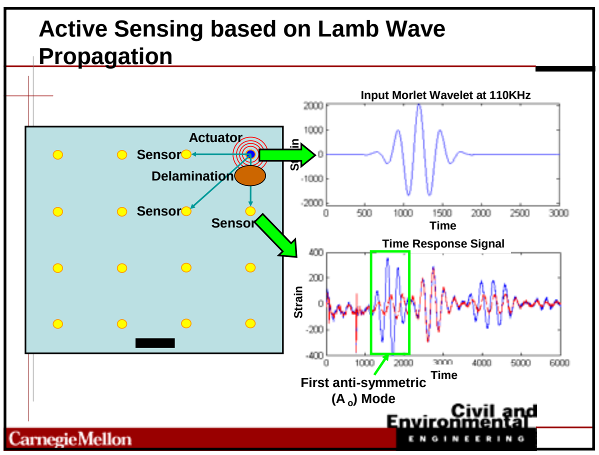

Mining Data Streams - Test Setup for Delamination Detection in an anisotropic Composite Laminate
Data acquisition system
External signal input amplifier
Piezoelectric (PZT) actuator/sensor
2ft x 2ft composite plate with a PZT sensor layer
Carnegie Mellon
Civil and Environmental
ENGINEERING


Active Sensing based on Lamb Wave Propagation
Actuator
Sensor
Delamination
Sensor
Sensor
Input Morlet Wavelet at 110KHz
Time
Time Response Signal
Strain
Time
First anti-symmetric (A o) Mode
Carnegie Mellon
Civil and Environmental
ENGINEERING

Trends in Controls Research Relevant To Modern Power Plant Systems

Jeffrey S. Vipperman
jsv@pitt.edu
Dept. of Mechanical Engineering
University of Pittsburgh
NETL Plant Process Control Workshop
Mary 22, 2006

Outline

- Intro
- Overview of Control Research Trends
- Recommendations for Power Plants

Controls

- Theoretical vs. Applied (80/20 Rule)
- My Background (Worked on smart systems and structures for 16 years)
  - Active noise, vibration, and structural-acoustic control
  - Adaptive FF, robust and optimal FB, adaptive FB, hybrid control approaches
  - Developed new FF and FB algorithms and transducers for collocated control
  - Autonomous system health monitoring
  - Developed data classifying algorithms (ANNs)
- Best solution is the simplest one that works

Challenges to Control: A Collective View (1986 IEEE Workshop)

- Integration of numerical and symbolic data into a single model
- Further theory development for the control of uncertain or unknown models (Robust Control – more mature)
- Development of fault tolerance within multivariable systems
- Further development of non linear control
- *These are issues that are still being addressed today*

Workshop on Future and Emerging Control Systems (Europe, 2000)

- Need Theory to encompass complex/hybrid systems made up of subsystems of varying type (discrete, continuous, probabilistic)
- Further development of the cognitive and nonlinear procedures (fuzzy control, neural networks, and biological paradigms)
- Development of fault diagnostics
  - Smart actuators and sensors
  - Fault tolerance / false triggering protection
- More computational power to enable faster optimization
- Merging numerical and symbolic methodologies
- Unified Control theory for complex uncertain distributed systems
  - Heterogeneous systems analysis, and micro –macro level integration
  - Decentralized, co-operative autonomous/holonic large scale systems
  - Adaptive control of evolving /reactive systems
  - Issues of analysis, estimation and control of (highly) non-linear systems

Richard Murray – Future Directions in Control (2003)

- Move from single system / controller to "heterogeneous mixture" of related systems
- Develop more theory to handle the mixing of decision making control and continuous signals
- Develop systems that can reconfigure as parts fail so systems degenerate instead of stopping abruptly
- Largest areas of future growth – Aerospace / transportation, information / networks, robotics, bio / medicine, and materials / processing

Recommendations: Algorithms

- Model-Predictive (Constraints, multivariable, nonlinearities, can be adaptive)
- Biologically inspired algorithms (ANNs, Fuzzy Control)
- Other Intelligent Control
  - Bayesian probability
  - Machine learning
  - Evolutionary computation
  - Genetic algorithms
- Revisit optimal control
  - Develop cost functionals to balance efficiency, emissions, and other performance goals
- Robust Control Methods (Perf. & Stab.)

SOUND, SYSTEMS AND STRUCTURES LABORATORY

University of Pittsburgh
Department of Mechanical Engineering

Issues to Address

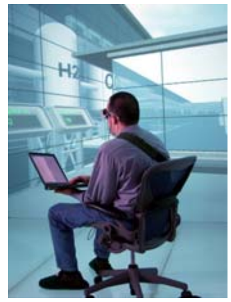
- New Sensors, New Actuators, and possibly New Algorithms (remove time/phase delays and inference)
- Sensor Data fusion
- Integrate the sensors/controllers/actuators into the design from the start
- Blending of on/off and modulating control systems
- Nonlinearities
- Adaptive Algorithms
- Hierarchical control and networks
- Decentralized control
- Integrate monitoring into controls
- Modeling, Model Validation, System ID

SOUND, SYSTEMS AND STRUCTURES LABORATORY

University of Pittsburgh
Department of Mechanical Engineering

High Density, Heterogeneous, Massive Sensor Nets for Process Systems

The Future



- Sensors are:
  - Small
  - Inexpensive
  - Thinking
- Computing is:
  - Highly capable
  - Ubiquitous
- Complexity is:
  - Almost unmanagable
  - The new frontier

Complex Systems Virtual Engineering Group

- 12 doctoral students
- 3 masters students

- 3 post docs
- 1 research scientist

- 4-6 undergrads

- 1 professors

25 - 30 researchers

Current Research

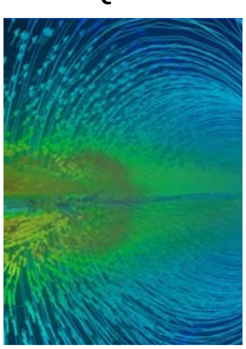
- Develop an experimental basis for investigation and validation
- Develop a mathematical model
- Explore the questions of interest

Current Project

- Developing an integrated hierarchy of models
- Integration of models, simulations, and sensors
- Creation of object based engineering
- Virtual Engineering

Other Projects

Questions of Interest



- How many sensors?
- What capabilities?
- Information share? Local/global?
- Models for sensor use?
- Heterogenous synchronization?

Power Systems Control Issues

Joseph Bentsman
University of Illinois

Basic Controller Design

- "Standard" PID – no such thing – they are complex nonlinear controllers:

1. Ad-hoc modifications: dead zones, nonlinearities – gain scheduling, loop coupling compensation via feedforward
2. Under this set of "spoilers" tuning of P, I, D knobs is problematic
3. Global objective – local tuning?

Basic Controller Design: Time to Move On

- NEW PID: Multi-Input-Multi-Output (MIMO) Robust Controller Tuning Theory and Software Tools:

1. Too much trial and error,
2. Success not guaranteed,
3. Application of various uncertainty representations is unclear

Basic Controller Design

- Current state of the advanced art: predictive control

1. Robustness is an issue

Basic Controller Design

- Identification of Nonlinear MIMO Systems for Robust Linear Control

1. Nominal model selection
2. Model uncertainty determination
3. Deeper models, apportioning uncertainty between feedback and feedforward

Basic Controller Design

- Robust MIMO Self-Tuning Predictive Control – a more relevant solution – don't have it!

1. Controller adjustment : fast – start-up, shut-down
2. Slow - normal operation
3. Reference sequence accommodation
4. Constraint handling

Complex Controller Design

- Hybrid Robust Control for the Full Operating Range of a Nonlinear Plant

1. Controller switching: steady-state
2. Non-steady-state

Complex Controller Design

- Robust MIMO Predictive Control Networks

System Control: Sensor/Controller Configurations

- Combined Control/Observations Optimization
- Plant controller design with real-time sensor reconfigurability

System Control: Sensor/Controller Configurations

- Combined Failure Accommodation

1. Control/sensing configuration restructuring

Network Sensing/Control

- Fast Hybrid Control for Self-Healing Networks – System Interconnections

1. Strategies for self-healing: multi-stage impulsive control
2. Singular phase control

Network Sensing/Control

1. Topological Reconfigurability
2. dynamics issues
3. reconfiguration feasibility and attainment

Network Sensing/Control

- Fast Directed Graph Based Optimal Topology Selection

1. Reconfiguration sequence generation

Power Plants of the Future: Control-Configured Power Plants

- Agile autonomous plants
- Need to start now

PDE-Based Models, Networks, and Control Methods

- PDE-based process fundamental blocks and their interconnection: spatiotemporal networks
- PDE-based network sensing/control oriented models
- PDE-based process control
- Real-time PDE-based simulators
- Predictive adaptive PDE-network based model-based control systems
- Approximation methods: wavelet-based

PDE-Based Models and Control Methods

- Fast computational platforms

1. very inexpensive
2. interconnected
3. running real-time plant models for state estimation/software sensing that go into control systems

Control-Configured Power Plants