U.S. DEPARTMENT OF ENERGY

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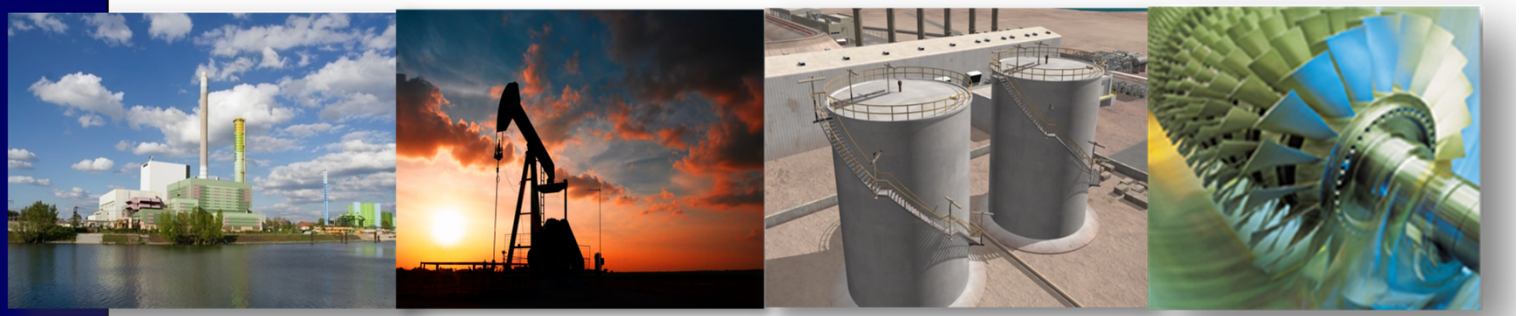
Fossil Energy



Crosscutting Research
Program Overview

Robert Romanosky, Ph.D.
Portfolio Manager

April 18, 2016

NETL

Driving Innovation ♦ Delivering Results

Crosscutting Research & Analysis

Targets Support Across Multiple Program Areas

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National Energy Independence and Reduced Emissions

Key Technologies

- High Performance Materials
- Sensors & Controls
- Simulation-Based Engineering
- Water Management R&D
- Innovative Energy Concepts

Key Drivers

- Higher Efficiency
- Process Intensification
- Improve Design Tools
- Improve Process Control
- Lower Water Use

Crosscutting Research & Analysis

Sensors, Controls & Novel Concepts

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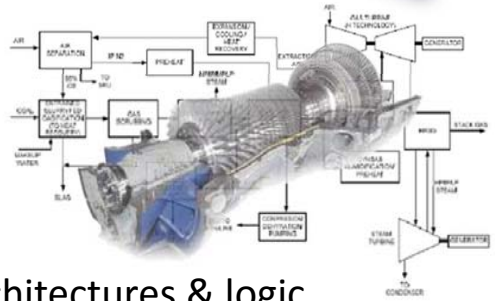
Transformational Development For
On-line Monitoring and Process Control
Faster Response, Improved Knowledge, Better Control

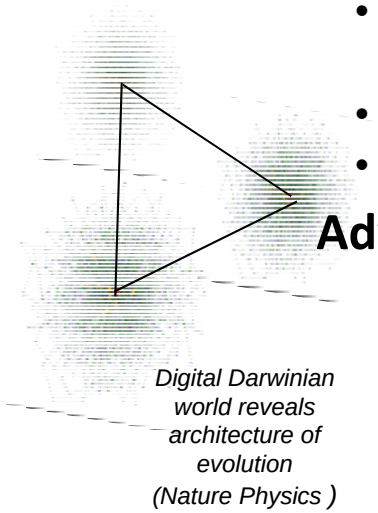
Advanced Sensing and Remote Monitoring

- Harsh environment sensing concepts and approaches for low cost dense distribution of sensors
- Exploration of Sensor Networking using Passive & Active Wireless communication, Thermoelectric & vibration energy harvesting approaches



Distributed Intelligence

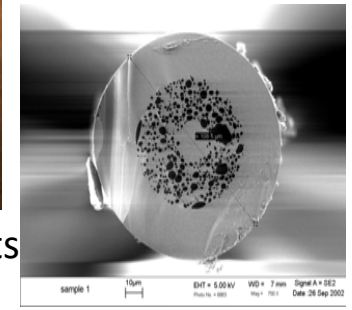
- Computationally driven approaches for novel control architectures & logic, information generation, sensor networking & placement
- Manage complexity inherent to Advanced Systems
- Achieve Performance with Competing Objectives



Digital Darwinian world reveals architecture of evolution (Nature Physics)

Advanced Manufacturing for Sensors

- Pressure, Strain, Temperature, Impedance Defect
- Basis for integrating sensors into systems, &
- Integration of sensors into design and fabrication of components
- AM techniques to lower cost and improve fabrication



Innovative Energy Concepts

- Direct Power Extraction (MHD)

Crosscutting Research & Analysis

Motivation for Sensors and Control Technology Research

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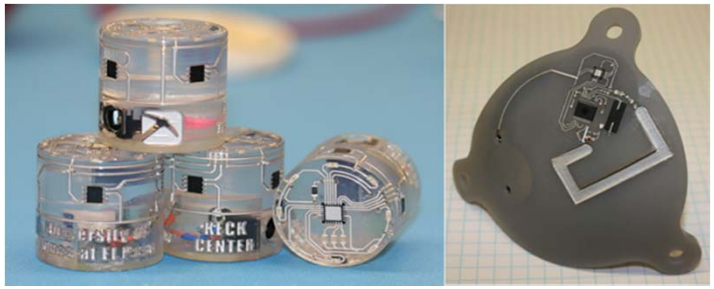
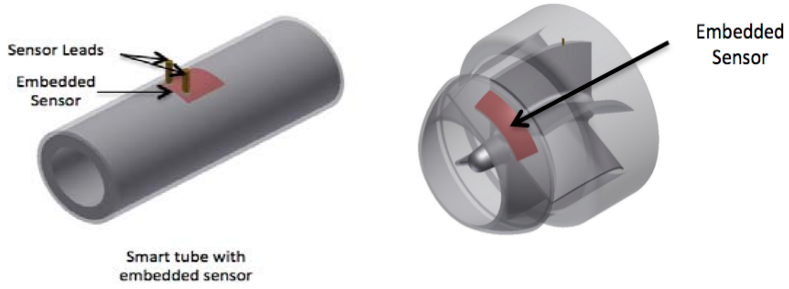
- **Low cost, high benefit technology**
- **Existing technology is inadequate**
  - Sensing in harsh conditions
  - Controls to manage complexities within plant and frequent changes (e.g set point, integration with renewables)
- **Boosts efficiency of existing facilities**
- **Contributes to higher reliability or reduction in forced outages**
- **Enables integration and coordination with all power generation technologies and related infrastructures**
- **Essential for operation of future ultra clean energy plant**





Crosscutting Technology Research

Advanced Process Controls

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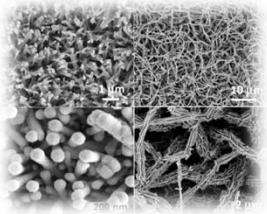
Targeted to be Transformational Development In Process Monitoring and Control

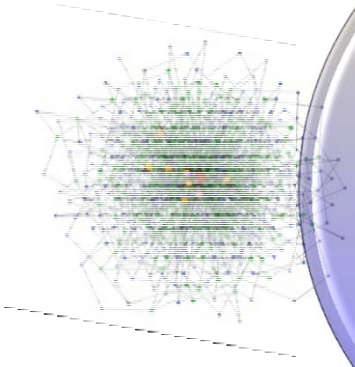


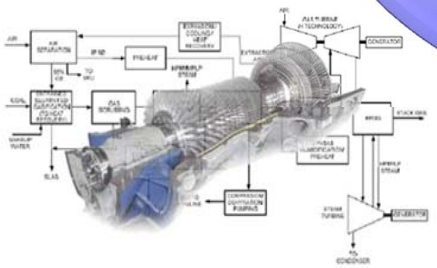
Distributed Intelligence

Computationally driven approaches for novel control architectures and logic, information generation, sensor networking & placement

Advanced Sensing

Harsh environment sensing concepts and approaches for low cost dense distribution of sensors

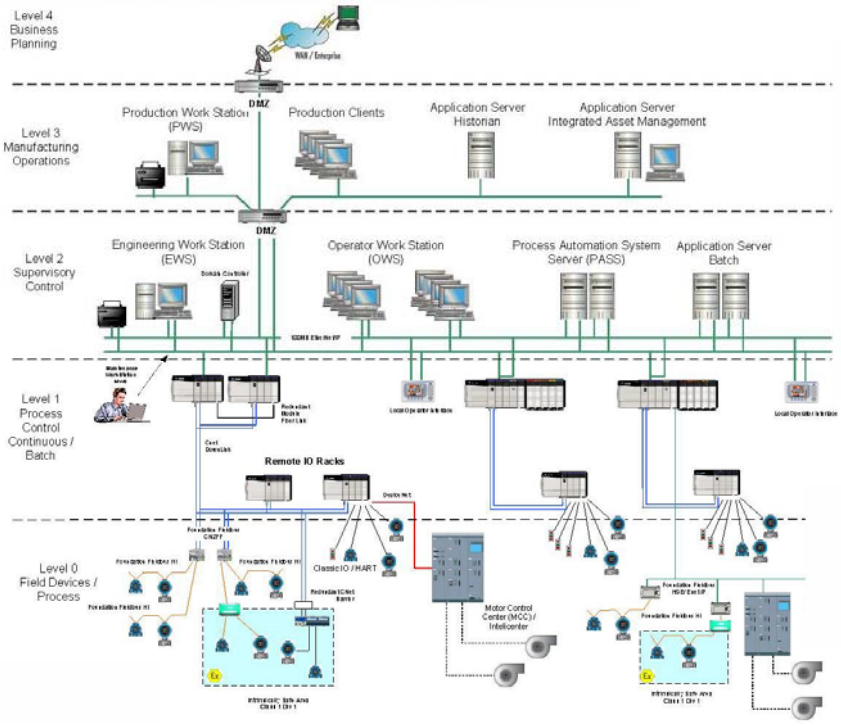




Value derived from an Encompassing Approach, A purposeful applied development effort, and a Clear pathway for transitioning technology

Evolutionary vs Revolutionary Control

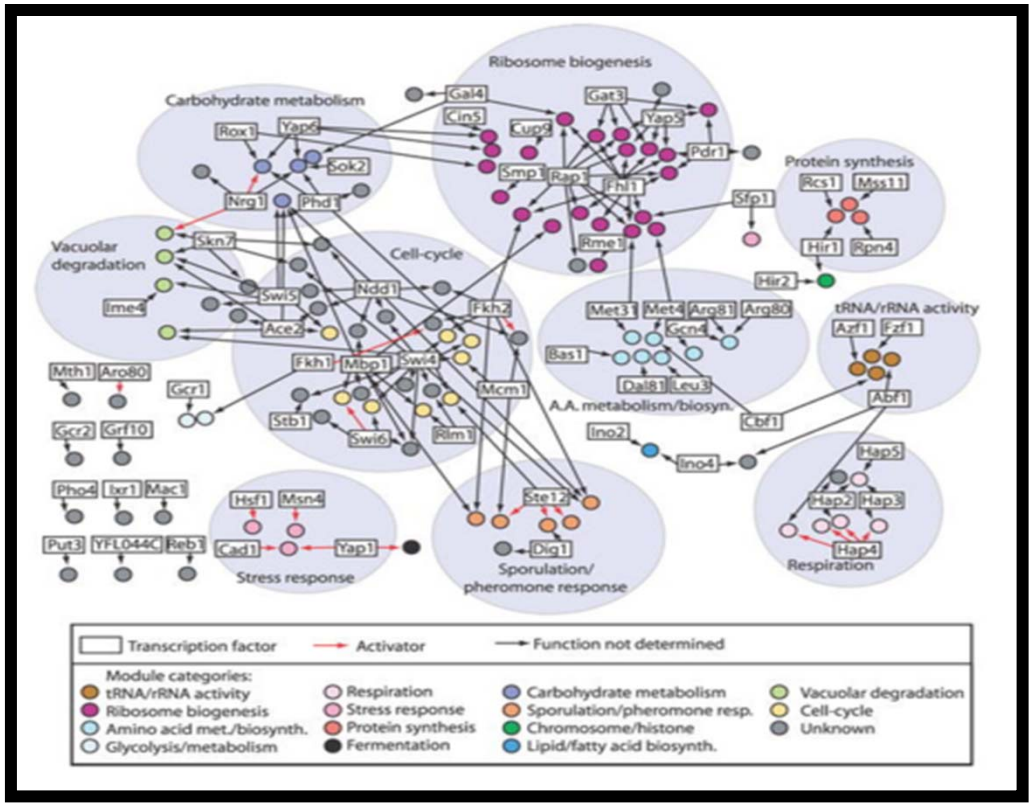
Challenging conventional architectures to support advancements in computational intelligence



Traditional Control Architecture For Distributed Control Systems (DCS)

- Linear and based on minimization of error and set points

New approaches mimic biological systems, utilize distributed intelligence, and designed to handle complexity



Distributed Intelligence Approach

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- Efficient Decision Making
- Actionable Information
- Decentralized Control

- Computational Environments
- Mimic Experimental Facilities
- Smooth Transition
- Mitigate Risk

What should be the location, type and number of sensors for a given unit, objective, decision & action

- Lower-Level Intelligence
- Sensor Communication
- Know When and What to Measure

- Use Local Information
- Reduce Response Time to System Changes

Smart Parts and Embedded Sensing

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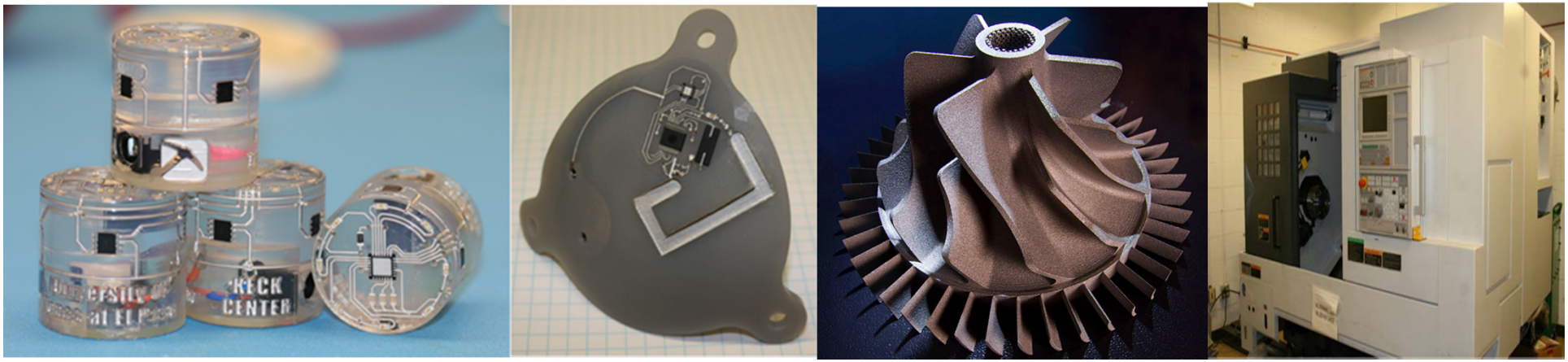
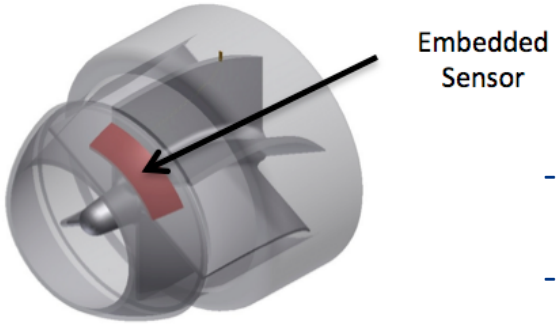


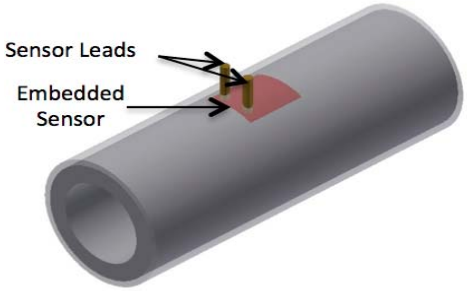
Quantitative Evaluation of Embedded Sensing Capability

- Pressure, Strain, Temperature, Impedance Defect
- UTEP has a world class facility for Advanced Manufacturing
- Minority based Institution with excellent staff and students



Transformational effort

- Basis for integrating sensors into systems, and
- Integration of sensors into design and fabrication of components



Smart tube with embedded sensor

Putting All The Pieces Together

- **Operational and Reliability challenges at full scale…**
- **Start up, Shutdown, Load following and Cycling**
- **Integration of plant operation with grid, water, emissions, CO_2 capture and storage operations**
- **Competing and conflicting objectives for plant operation and control**
- **Complexity in plant design and control objectives is driving advancements in process control**
- **Harsh environments are driving advances in sensing**
- **Need for real time "actionable information" is driving low cost sensor networks**

Computational Modeling: Scale Comparison

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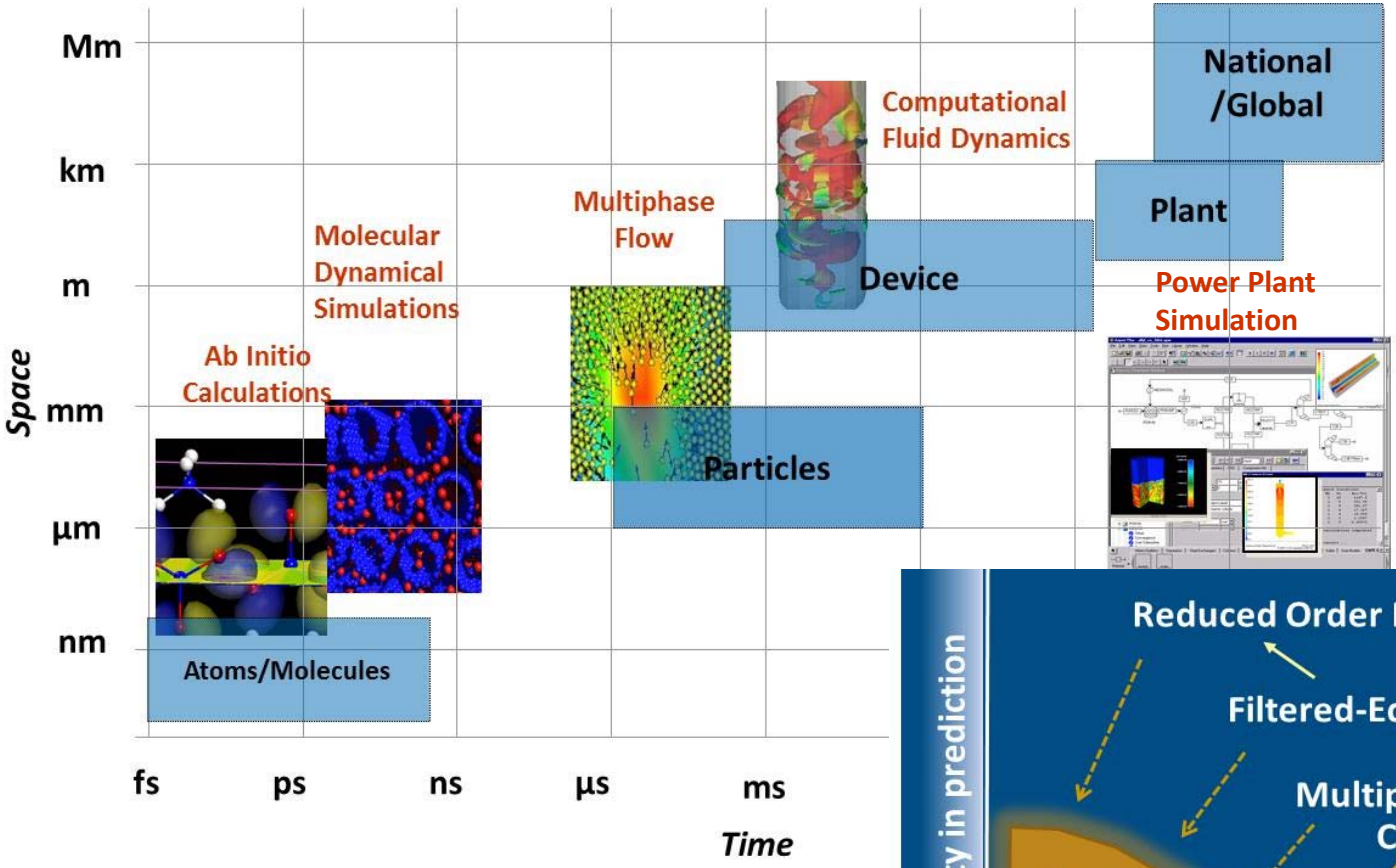
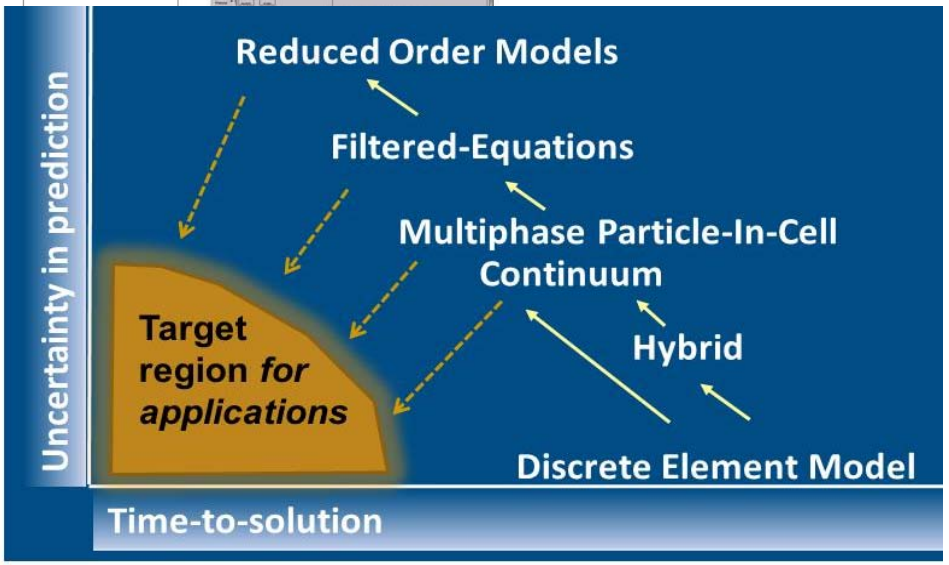


Computational Tools and Analysis for a Broad Set of Applications



All concepts, technologies and systems can and should be described in a computational format.

Crosscutting Research & Analysis

Simulation-Based Engineering

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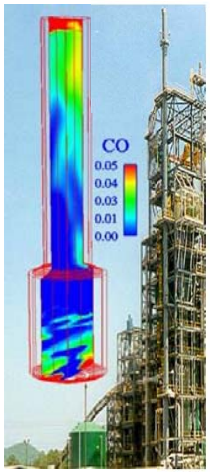
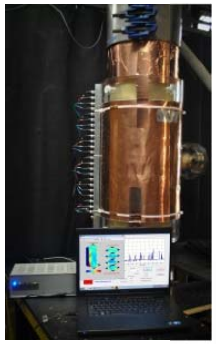
CCSI Carbon Capture Simulation Initiative

NRAP National Risk Assessment Partnership

MFiX

iDAES





C3M™ Carbonaceous Chemistry for Computational Modeling

Institute for Design of Advanced Energy Systems

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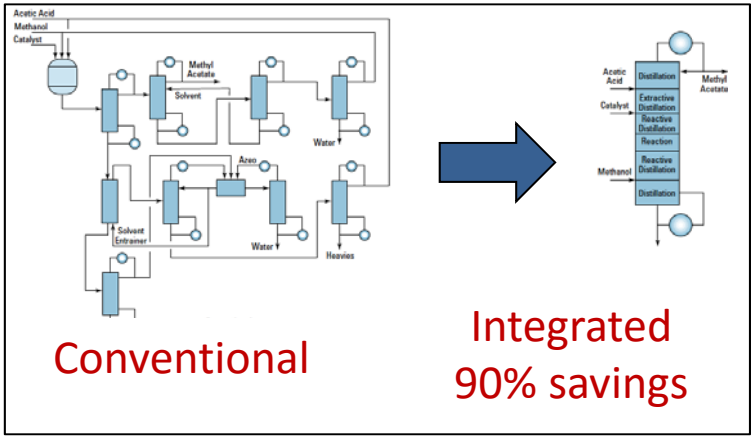
iDAES

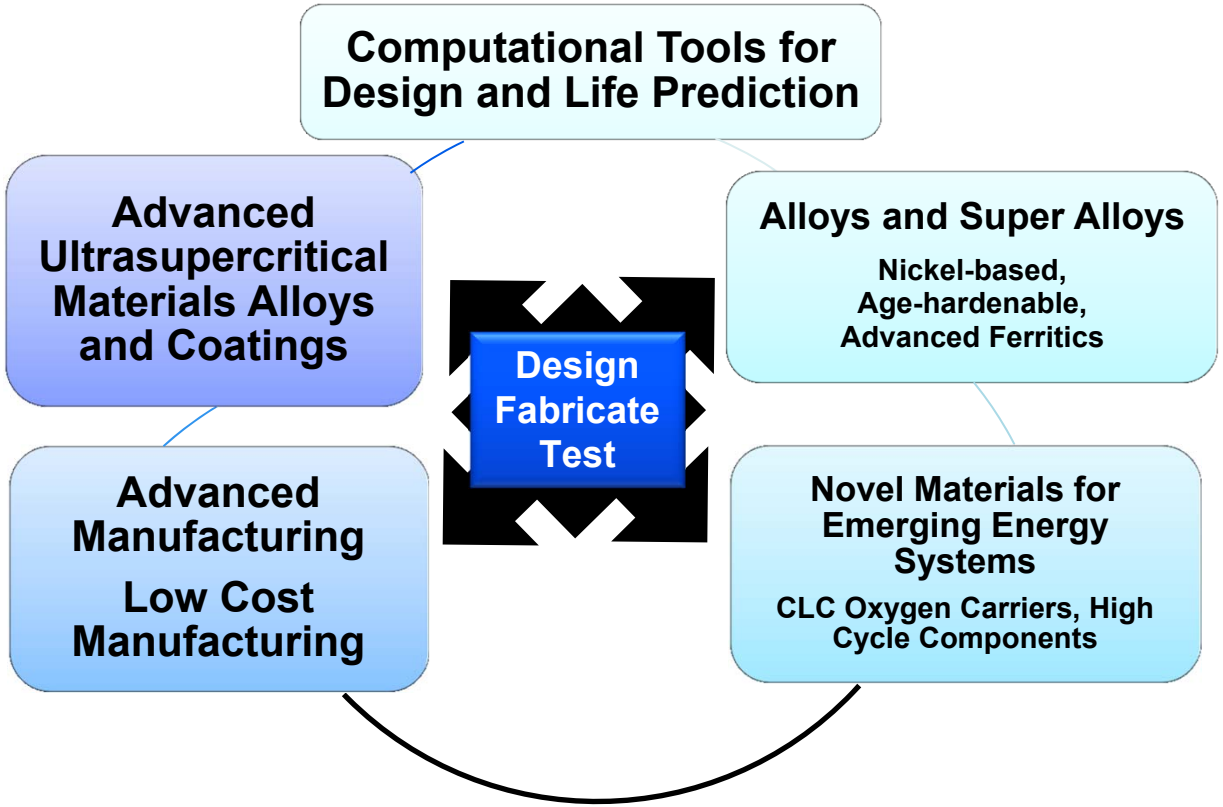
- **Mission**
  - Enable the development of *innovative, advanced energy systems* by developing and utilizing advanced process systems engineering tools and approaches
- **Energy System Applications**
  - Fossil Energy: Chemical Looping, Transformational Carbon Capture Technologies, Supercritical CO_2, Hybrid Systems, Gasification, Natural Gas Processes
  - Other applications: Biofuels, Green Chemistry, Nuclear, Environmental Management
- **Technical Capabilities**
  - Process intensification, conceptual design, process synthesis, optimization, and process integration
  - Multi-scale simulation with uncertainty quantification
  - Simultaneously identify material, equipment and process
  - Dynamic optimization for flexible, resilient processes
  - High resolution submodel development
  - Utilizes supercomputers for large scale simulation

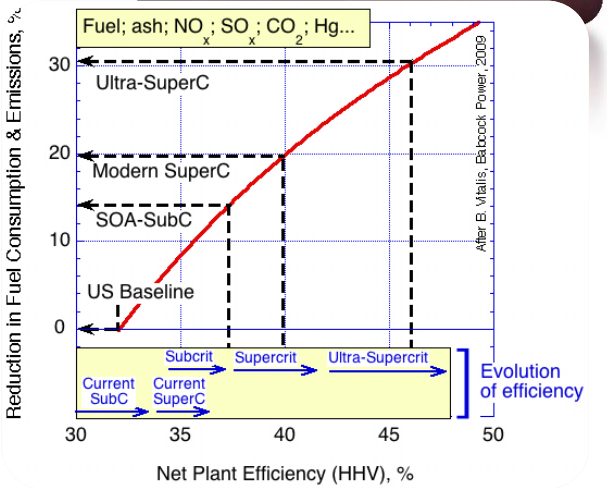


- **Benefits to DOE**
  - Develop entirely new equipment and process designs for advanced energy systems
  - Use advanced process systems engineering to better differentiate new technology concepts
  - Support the development, scale up, and deployment of new energy technologies
- **NETL Leadership**
  - NETL and its partners are recognized world experts in Process Systems Engineering
  - The experience, software and methods developed under CCSI will form the foundation of iDAES

High Performance Materials

- New materials are essential for advanced power generation systems with carbon capture and storage capability to achieve performance, efficiency, and cost goals.
- Materials of interest are those that enable components and equipment to perform in the harsh environments of an advanced power system.





Materials Program

Increasing Power Systems Efficiency

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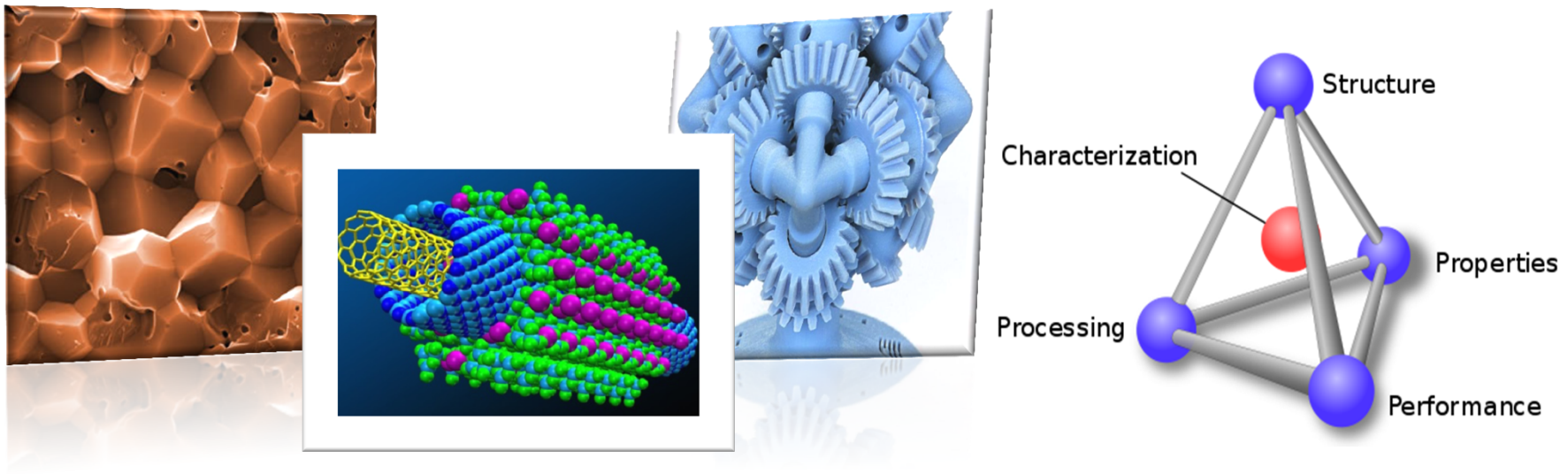
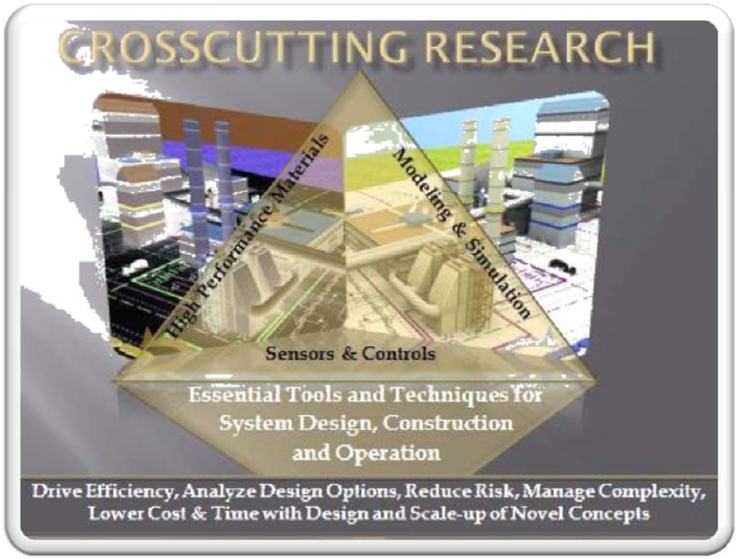
- Evaluate and develop materials technologies that allow use of advanced steam cycles in coal-based power plants operating at steam conditions of up to 760 °C (1400 °F) and 5,000 psi.
- New novel materials can allow for increased temperature and pressure, resulting in power plant efficiencies of 45-47%, and CO_2 emissions reduction of 15 to 20%.
- Developing materials to enable an oxygen fired A-USC plant would lower balance of plant cost due to less coal handling and smaller pollution control components for the same net plant output.
- Computational methods applied to the design, development, and optimization of materials accelerate creation of cost-effective, functional materials deployable with less repetitive testing; advanced plants go operational more rapidly.
- US/UK research collaboration on advanced materials

What's Next in Materials?



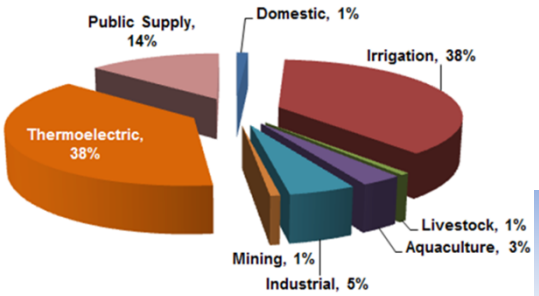
- Supply chain development of materials with greatest market value potential
- High temperature, high cycle materials for fast ramping
- Structured performance evaluation program of materials
- Optimization of Advanced Manufacturing for functional and structural materials
  - Rapid prototyping to support evaluation and design
- Transformational engineering of ceramics for high temperature functional applications
- Magneto Hydrodynamic & Rare Earth Materials



New & Existing Power Plants must Optimize Water Use

- Optimize the freshwater efficiency of energy production, electricity generation, & end use systems for Today's & Tomorrow's Power Plant Systems
- Optimize the energy efficiency of water management, treatment, distribution, and end use systems
- Enhance the reliability and resilience of energy & water systems
- Increase safe and productive use of nontraditional water sources (e.g. MWT, Produced Waters)
- Promote responsible energy operations with respect to water quality, ecosystem, & seismic impacts
- Exploit productive synergies among water and energy systems

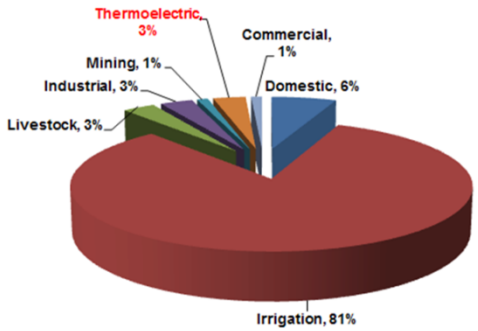
U.S. Freshwater Withdrawal[1]



2010 Thermoelectric Freshwater Requirements:
Withdrawal: ~ 117 BGD
Consumption: ~ 4 BGD

80% Increase in water consumption for CO_2 Capture & Storage

U.S. Freshwater Consumption[2]



Sources: 1USGS, Estimated Use of Water in the United States in 2010, USGS Circular 1405, 2014
2USGS, Estimated Use of Water in the United States in 1995, USGS Circular 1200, 1998

Water Management Research Focus Areas

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- **Advanced / Novel Heat Transfer and Cooling Systems**
  - *Wet, Dry, Hybrid*
  - *Incremental & Step Change Improvements*
  - *Advanced Manufacturing of Recuperators for Combustion Turbines*
- **Water Treatment and Reuse**
  - *Economic Pathways for Zero Liquid Discharge*
  - *Treatment of high TDS Waters (promote greater Water Reuse – collaboration with CS)*
- **Process Efficiency and Heat Utilization:**
  - *Pathways for produce more power per unit of water withdrawn, consumed, and treated*
  - *Utilization of Low-Grade Heat*
  - *Bottoming Cycles*
- **Data, Modeling and Analysis**
  - *Tools to enable regional and plant level decision making*
  - *Develop a National Water Atlas*
- **Breakthrough or Out of the Box**
  - *Low / No water FE based Systems, Distributed Generation, Grid Upgrades*

Innovative Energy Concepts

Direct Power Extraction – R&D Motivations & Benefits

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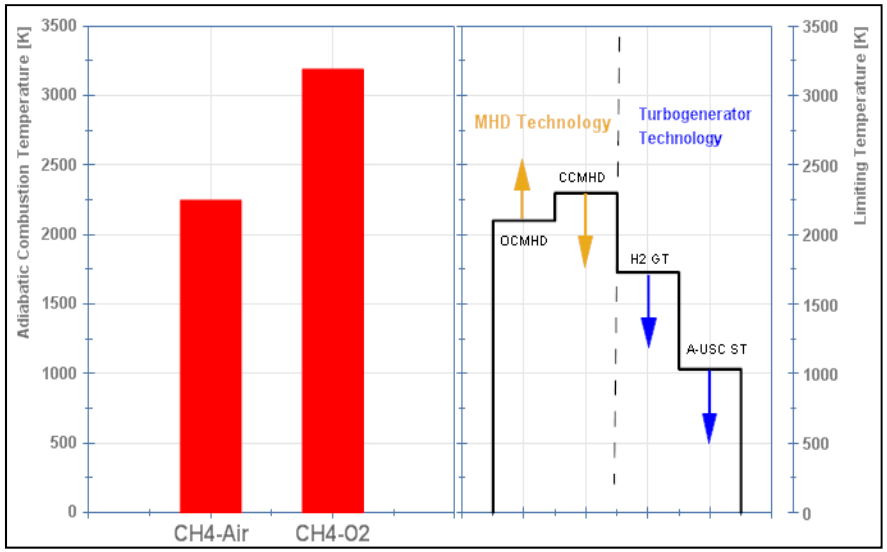
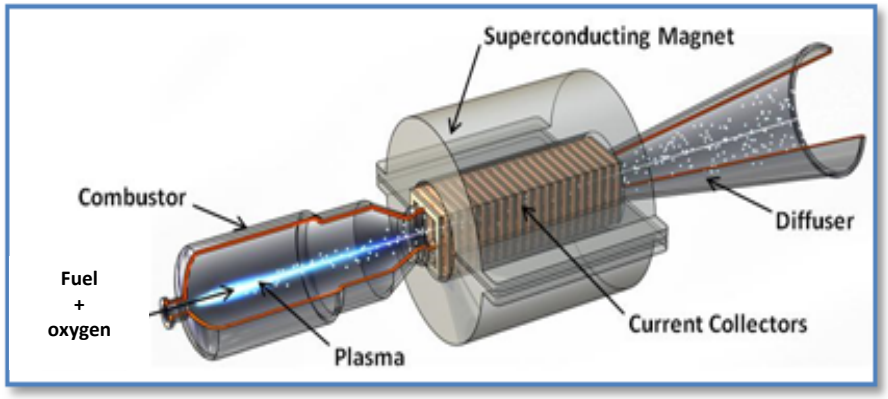
- **To "Step Increase" power generation efficiency**
  - By using much higher cycle temperatures

$$\text{Carnot Limit } n_{th} \leq 1 - \frac{T_C}{T_H}$$

- **Advantageous as topping cycles**
  - Non-disruptive to existing technologies
- **Improved CO_2 capture performance**
  - Synergistic with oxy-fuel approach
- **Flexible systems**
  - Coal + natural gas + bio-fuels
- **Compact systems**
  - Small footprint & potentially portable
- **Ancillary benefits to emerging technologies in**
  - Plasma processing technology
  - Field assisted material processing
  - Aerospace propulsion applications
  - High temperature materials



DPE MHD technology fits the oxy-fuel "temperature spectrum"



Oxy-fuel OCMHD Power Train. 200MW_e channel ~ 0.5x0.5x10m

University Training Research

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University Coal Research

Started in 1979, the program was designed to raise the level of competitiveness of universities in fossil energy research committed to improving the scientific understanding and environmental acceptability of coal while training new generations of research scientists and engineers.

- **Students are expected to present project progress at annual review meetings.**
- **Over 2500 students are estimated to have received degrees while conducting research under the program.**

Historically Black Colleges & Universities

Started in 1984, the program was designed to raise the level of competitiveness of HBCU/OMIs in fossil energy research and tap an under-utilized resource by increasing opportunities in the areas of science, engineering, and technical management.

- **Each grant typically involves 3-5 students throughout the duration of the project.**
- **Students are expected to present project progress at annual review meetings.**

Grants Awarded – By State Period FY95 to FY14

UCR

UCR Program Results:

- ❑ 1000+ Technical Papers
- ❑ 10+ Technical Awards
- ❑ 7 Patents Issued to Date

HBCU Program Results:

- ❑ 500+ Technical Papers
- ❑ 5+ Technical Awards
- ❑ 2 Patents Issued to Date

HBCU

Opportunities for Work with NETL?

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1. NETL Research Program uses the following sites:
   - Fedconnect https://www.fedconnect.net/FedConnect/
   - Grants.gov http://grants.gov/
   - FedBizOpps https://www.fbo.gov/

   to post solicitations/funding opportunity announcements, receive proposals/applications, and disseminate other information for competitive awards.
2. Cooperative Research and Development Agreements (CRADA) allow for joint research and development performed by NETL and CRADA participant researchers. Cost sharing between NETL and the CRADA participant is essential.
3. Small Business Innovation Research (SBIR) is a U.S. government program in which federal agencies set aside a small fraction of their funding for competitions among small businesses only. Small businesses that win awards in these programs keep the rights to any technology developed and are encouraged to commercialize the technology.
4. The Small Business Technology Transfer (STTR) is a program that expands funding opportunities in the federal innovation research and development (R&D) arena. The unique feature of the STTR program is the requirement for the small business to formally collaborate with a research institution in Phase I and Phase II.

It's All About a Clean, Affordable Energy Future

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For More Information, Contact NETL

the ENERGY lab

Delivering Yesterday and Preparing for Tomorrow