Crosscutting Technology Research Program Overview

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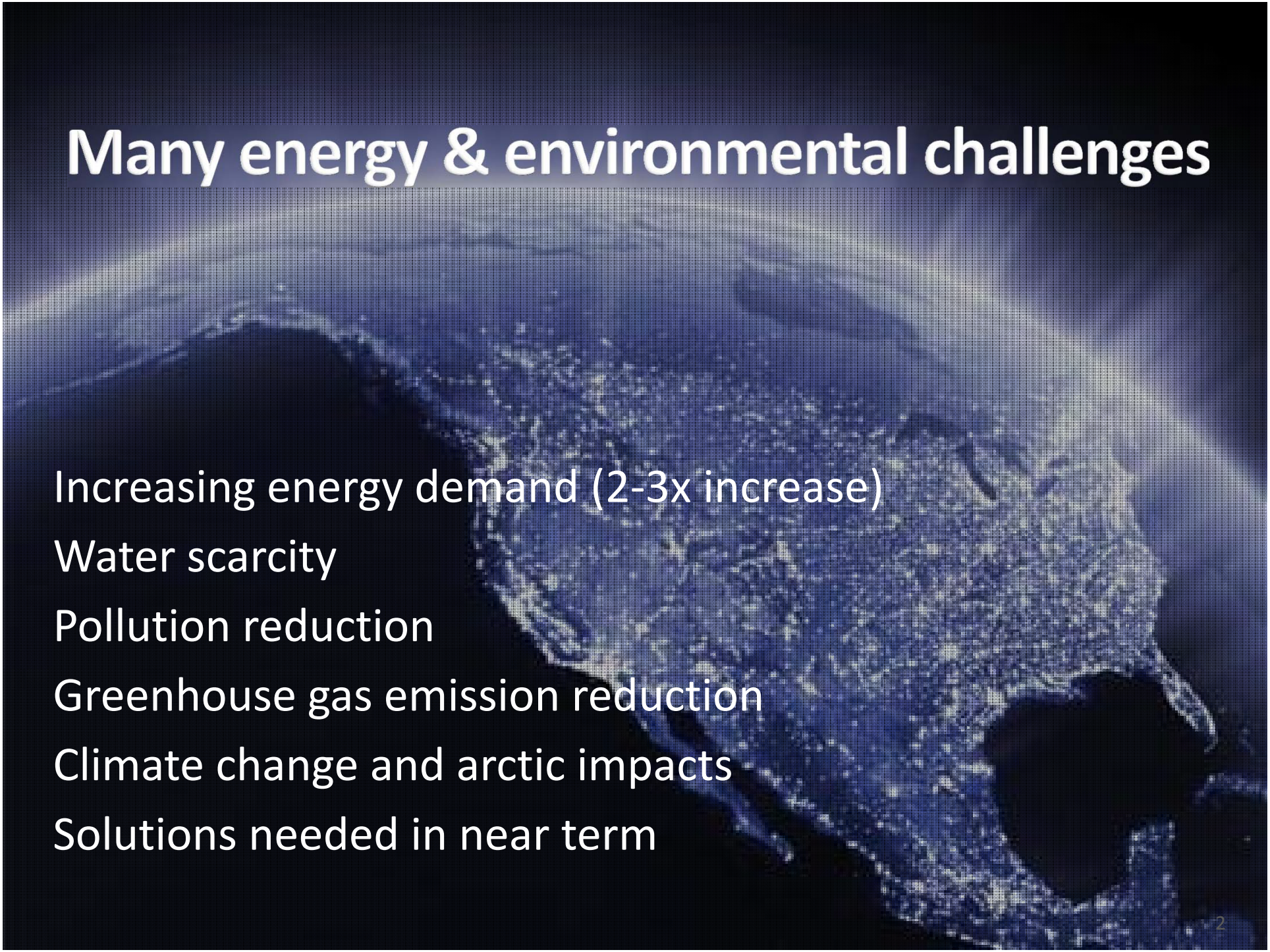
National Energy Technology Laboratory

April 27, 2015

U.S. DEPARTMENT OF ENERGY | National Energy Technology Laboratory

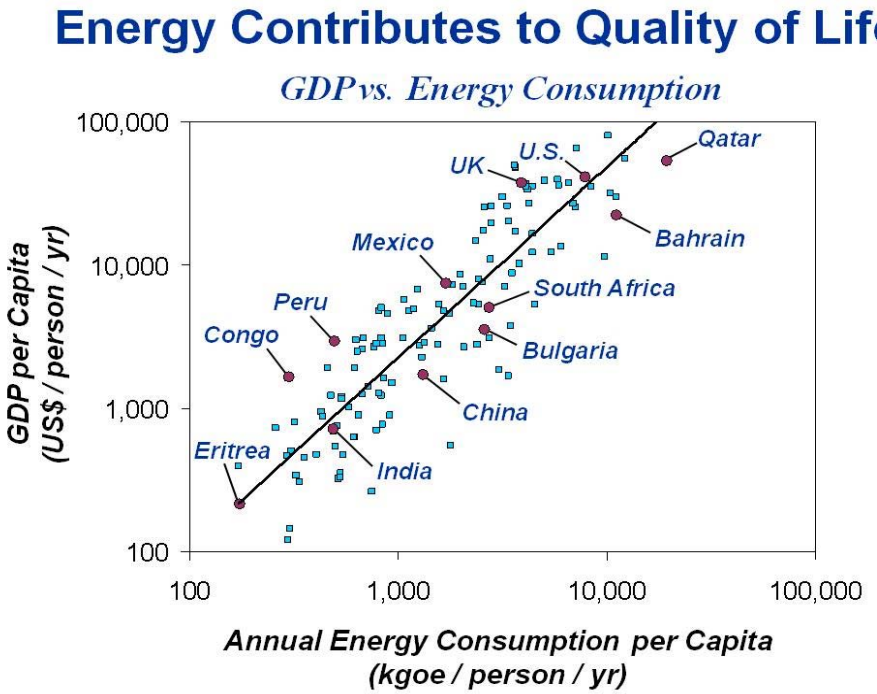
Many energy & environmental challenges



- Increasing energy demand (2-3x increase)
- Water scarcity
- Pollution reduction
- Greenhouse gas emission reduction
- Climate change and arctic impacts
- Solutions needed in near term

Point of Reference

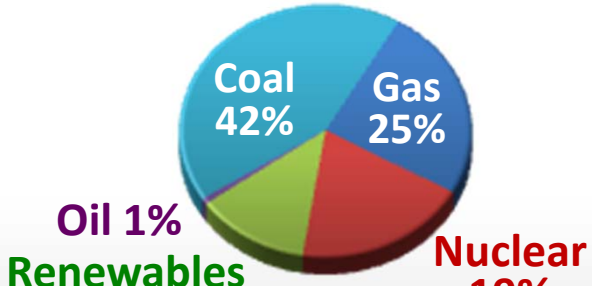
- **Competing demands for reliable, low-cost energy and climate change mitigation**
- **Uncertainty of regulatory outcomes and rising costs impact opportunities for capital investment, production capacity, and other factors in an integrated infrastructure**



- **Carry out research and development to foster new processes that address conflicting energy objectives**
- **Our laboratory's mission is to increase efficiency and mitigate CO_2 emissions in current plants and to develop novel carbon capture ready power generation processes**

Electricity Demand 2011

4,084 BkWh / Year
68% Fossil Energy

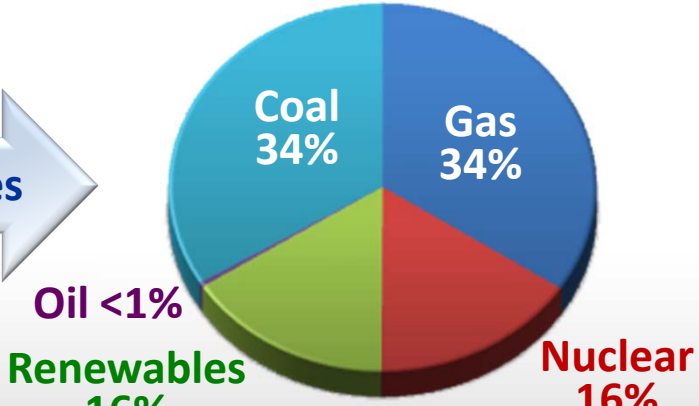


2,171 mmt CO_2

+ 22%
United States

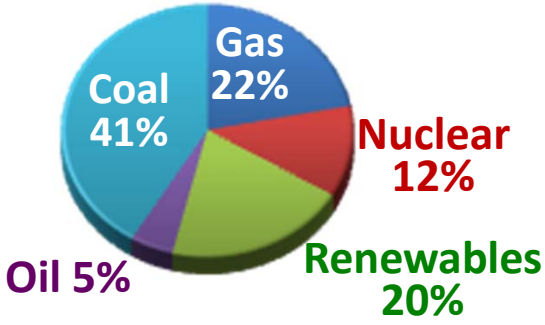
Electricity Demand 2035

4,979 BkWh / Year
68% Fossil Energy



2,247 mmt CO_2

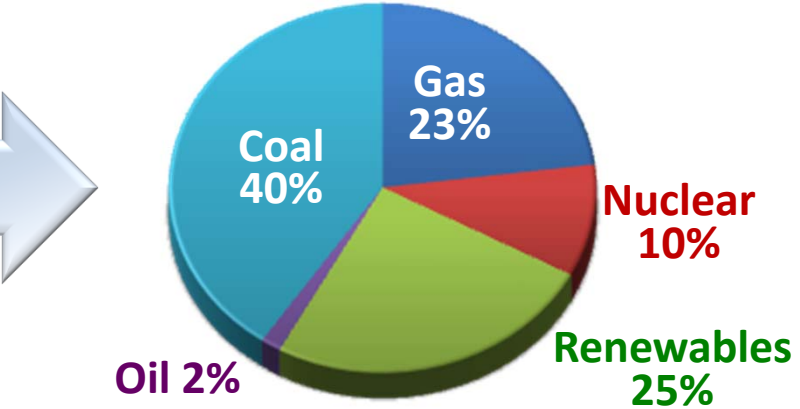
22,113 BkWhr / Year
68% Fossil Energy



12,954 mmt CO_2

+ 80%
World

39,854 BkWh / Year
65% Fossil Energy



19,122 mmt CO_2

U.S. data from EIA, Annual Energy Outlook 2014 early release; World data from IEA, World Energy Outlook 2013

National Energy Technology Laboratory

Where Energy Challenges Converge and Energy Solutions Emerge

- Only government owned & operated DOE national lab
- Dedicated to energy RD&D, domestic energy resources
- Fundamental science through technology demonstration
- Unique industry–academia–government collaborations

Oregon

Pennsylvania

West Virginia

Opportunities for Work with NETL?

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. Entities wishing to participate in these solicitations will need to register at these websites.

Proposals will be accepted only through FedConnect or Grants.Gov which is indicated in the solicitation document. Each website has the ability to send email messages when a new solicitation is posted from NETL.

Additional information can be found at the NETL Business website http://www.netl.doe.gov/business/

Crosscutting Research

Enabling Technology Advancement

Bridging the gap between fundamental research and applied development to support advancement and utilization of domestic energy resources.

- Crosscutting science, tools, and technology development program is supported by Industry
- Has a 15-25 year horizon for technology that supports breakthrough concepts, addresses gaps, develops products with commercial application – ***near-term*** and ***long-term***
- Innovation through fundamental and applied developments that benefit Fossil-based Energy Systems (largely coal focused)

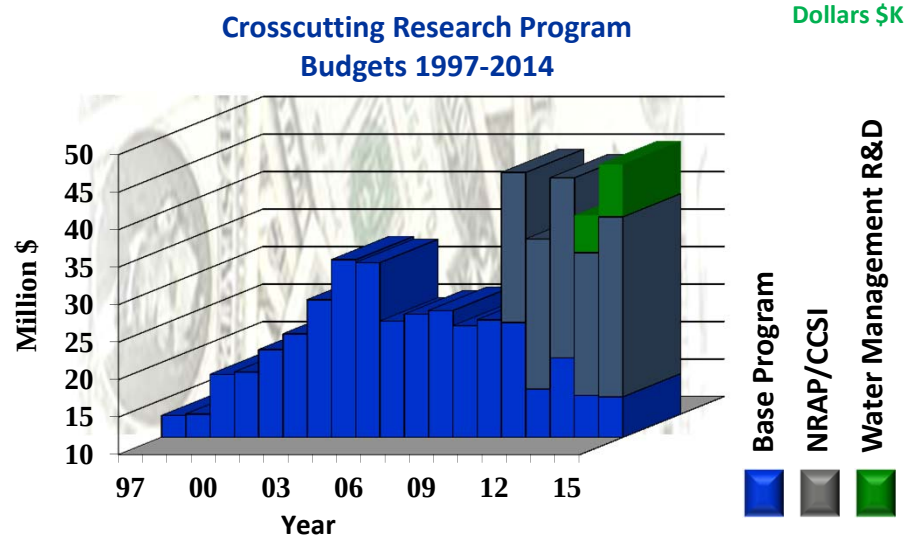
Crosscutting Research Focuses on Enabling Technologies that apply across multiple platforms

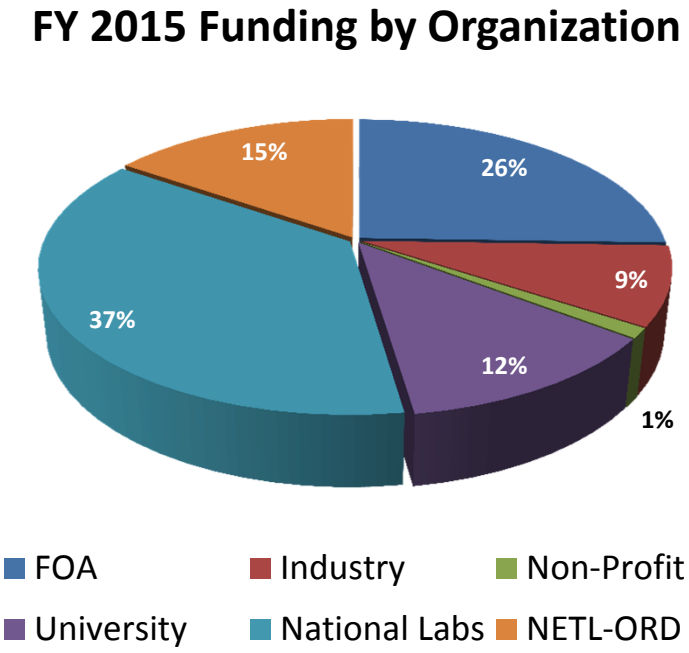
- ❑ **High Performance Materials**
- ❑ **Sensors and Controls**
- ❑ **Simulation-Based Engineering**
- ❑ **Water Management**
- ❑ **Innovative Energy Concepts**
- ❑ **University Training and Research (UTR)**

Fostering transformational developments in power system design, construction, and operation for highly efficient operation and superior environmental performance.

Crosscutting Research Program

Key Activity / Component	FY13	FY14	FY15
Plant Optimization Technologies	12,206	17,025	18,500
Computational System Dynamics	11,230	9,500	12,000
Computational Energy Science	12,752	9,500	12.000
Systems Analysis	3,807	0	0
University Coal Research	2,855	2,500	3,000
Historically Black Colleges & Universities	952	1,100	900
Crosscutting Research TOTAL	**44,599**	**39,625**	**46,400**





Harsh Environment Operation

Common Thread to Technology Development Needs

- **Harsh high temperature & pressure conditions are common to the more efficient use of fossil fuels for combustion and chemical conversion processes**
- **Materials must be flexible, resilient, and maintain longevity of service**
- **Sensors needed to monitor & control processes in real time for improved system performance and reliability**

Solid Oxide Fuel Cells

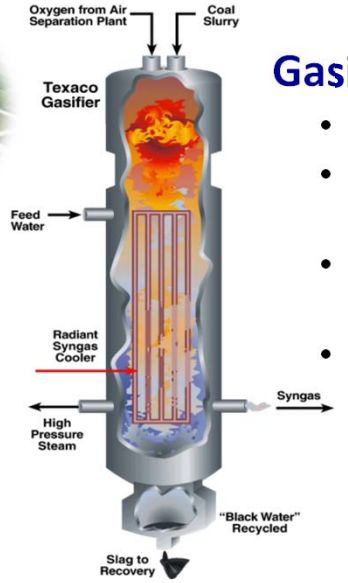
- Utilizes Hydrogen from gaseous fuels and Oxygen from air
- 1200 – 1830 °F temperature
- Atmospheric pressure

Advanced Combustion Turbines

- Gaseous Fuel (Natural Gas to High Hydrogen Fuels)
- Up to 2370 °F combustion temperatures
- Pressure ratios of 30:1

Advanced UltraSupercritical Boilers

- Development of ferritic, austenitic, and nickel-based alloy materials for USC boiler conditions
- Up to 1400 °F temperature
- Up to 5000 PSI pressure



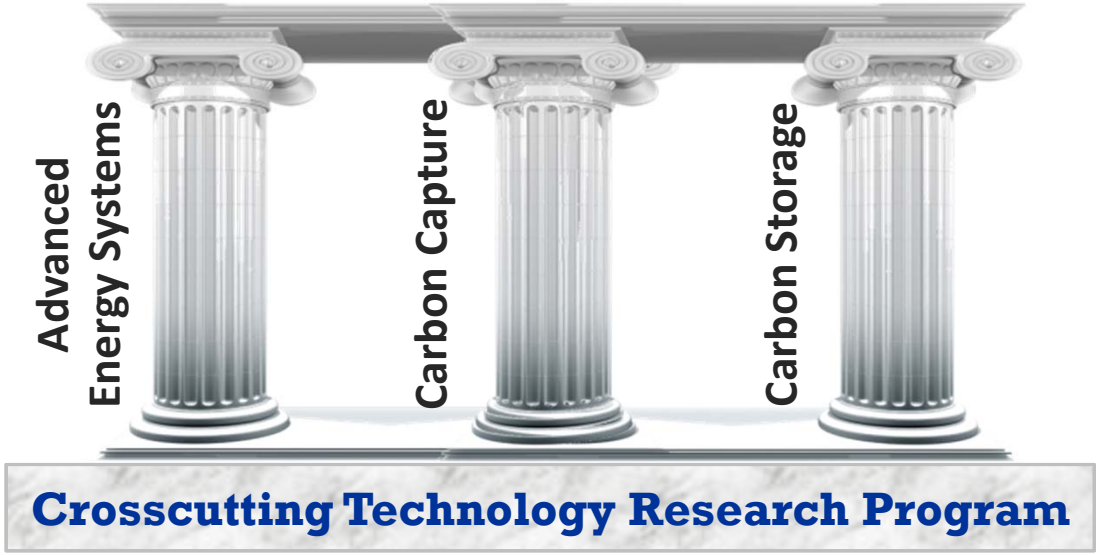
Gasifiers

- Up to 2900 °F, and
- 1000 PSI (slagging gasifiers)
- Erosive, corrosive, highly reducing environment
- Physical shifting of refractory brick, vibration, shifting “hot zones”

NETL's Crosscutting Technology Research

Support for Multiple Program Areas

National Energy Independence and Reduced Emissions



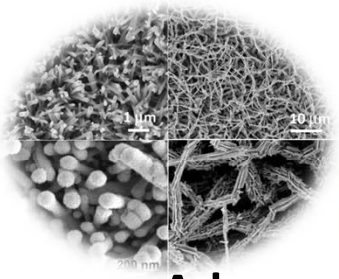
Key Technologies

- Sensors & Controls
- High-Performance Materials
- 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

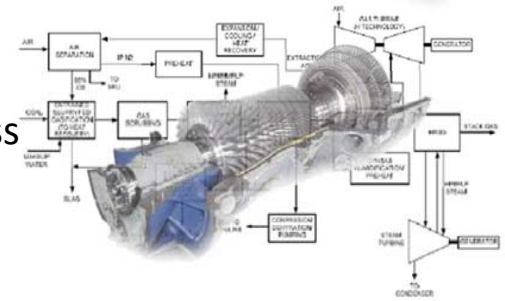
Sensors & Controls



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

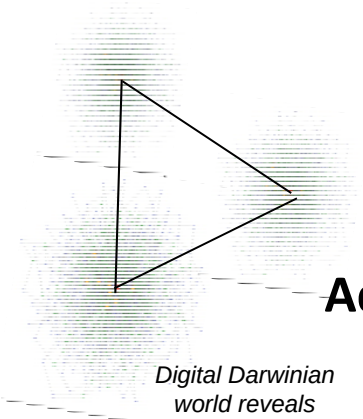
Advanced Sensing and Remote Monitoring

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



Distributed Intelligence

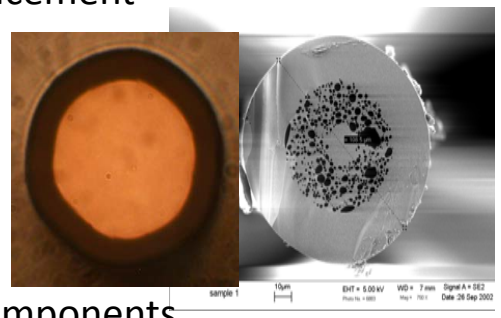
- Computationally driven approaches for novel control architectures and logic, information generation, sensor networking & placement
- Manage complexity inherent to Advanced Systems
- Achieve Performance with Competing Objectives



Digital Darwinian world reveals architecture of evolution (Nature Physics)

Advanced Manufacturing Sensors

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



Drivers for Advanced Sensing

- **Harsh high temperature conditions are common to the efficient conversion of fuels and processes for environmental control**
- **Monitoring/estimating harsh conditions in real time is needed for high system performance and assessing reliability.**

Gasifiers

- Up to 1600°C
- Up to 1000 PSI
- Erosive, corrosive, & highly reducing

Combustion Turbines

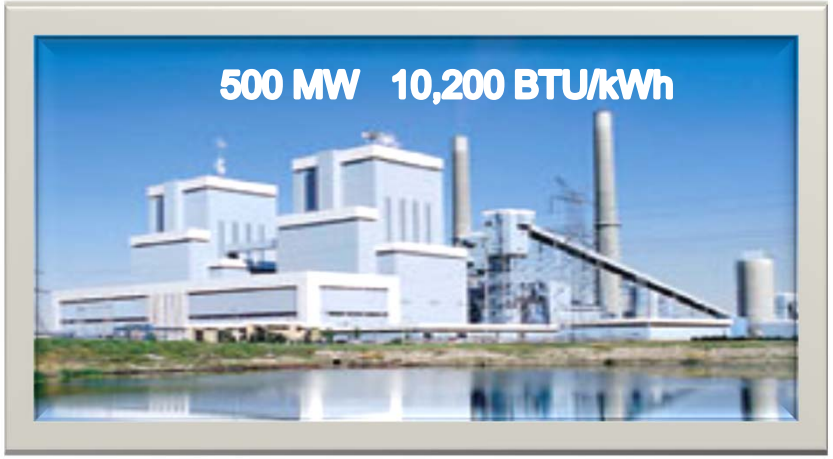
- Up to 1350°C
- Pressure ratios of 30:1
- Thermal shock, highly oxidative
- Complex geometries

Contribution from Sensors & Controls

Value Derived for an Existing Coal Fired Power Plant

Improving HEAT RATE by 1%

- 500 MW net capacity unit
  - $780,000/yr coal cost savings
  - 1% reduction in gaseous and solid emissions
- Entire coal-fired fleet
  - $340 million/yr coal cost savings
  - Reduction of 13.8 million metric tons CO_2 per year



Power
3.5 Billion kWh/yr
@ 80% capacity factor

Improvements and Increases of 1%
Are easily achievable.

Coal
35,700 MMBTU/yr
$70 Million/yr
@ $2/MMBTU

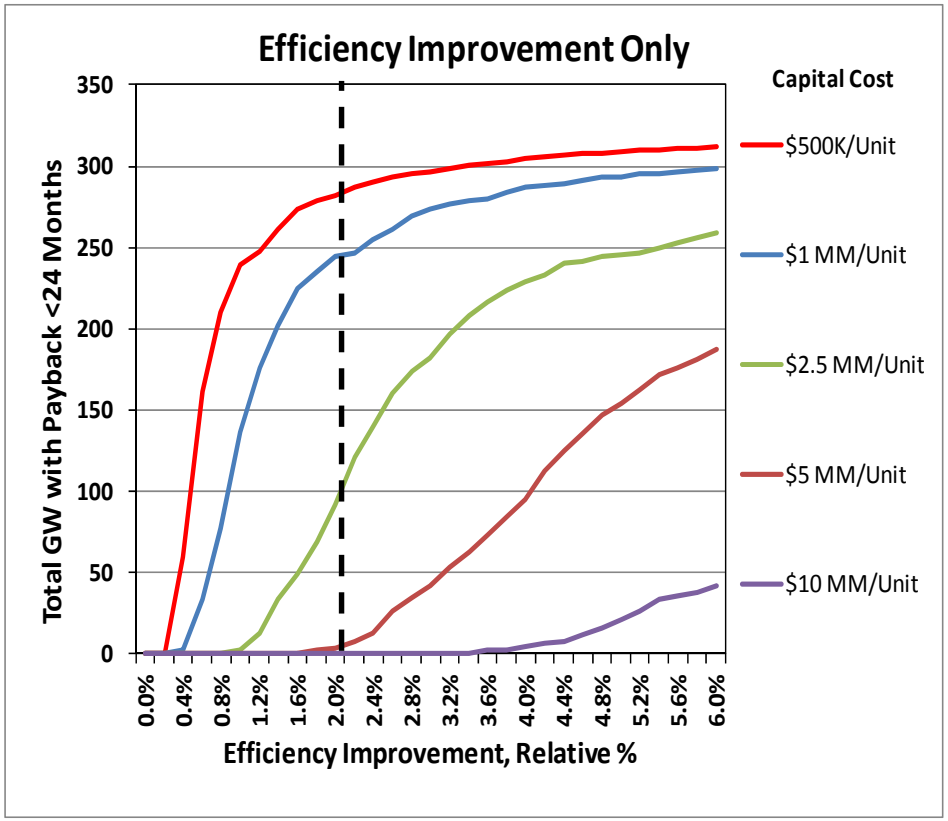
Sensors & Controls can enable improvements to be maintained for long term.

Increasing AVAILABILITY by 1 %

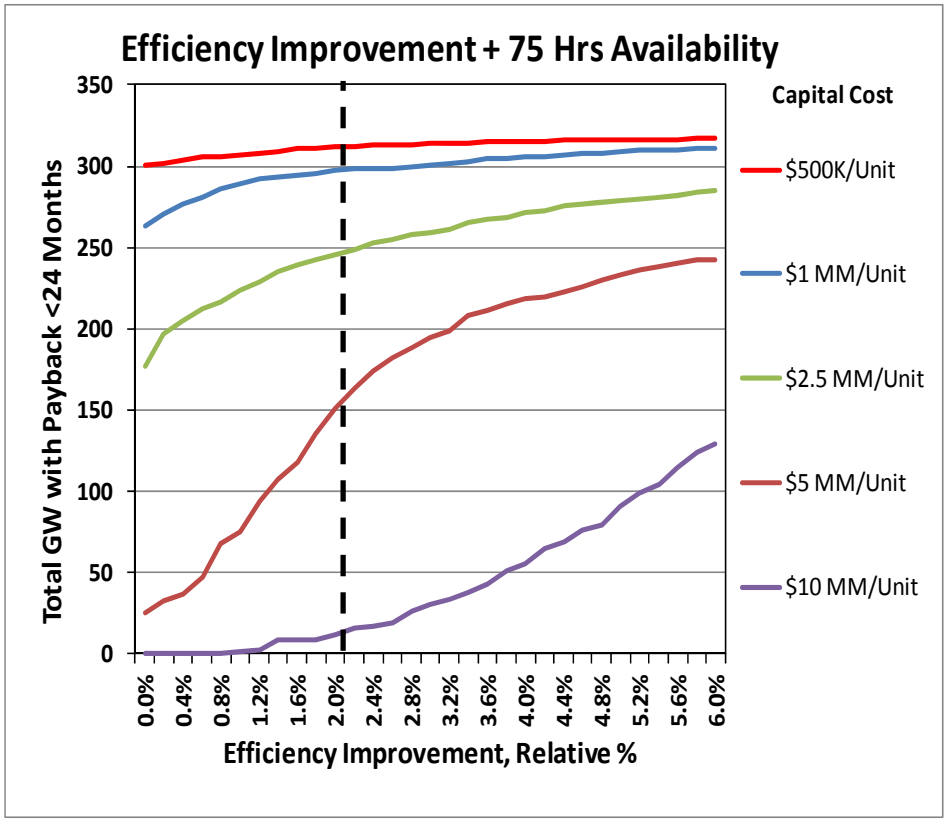
- 500 MW net capacity unit 44 million kWh/yr added generation
  - Approximately $2.6 million/yr in sales (@ 6 cents/kWh)
- Entire coal-fired fleet
  - More than 2 GW of additional power from existing fleet

Analysis based on 2011 coal costs and 2011 coal-fired power plant fleet (units greater than 300 MW)

Net Present Value Analysis – Results



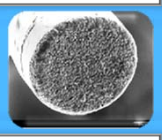
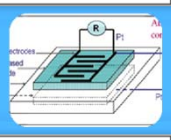
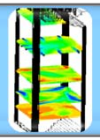
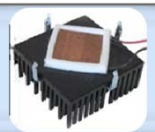
More analysis underway to expand and understand S&C impact



A $5M project would be economically feasible for 150GW of the fleet, roughly half, if it can increase availability 75hrs/yr and improve relative efficiency 2%.

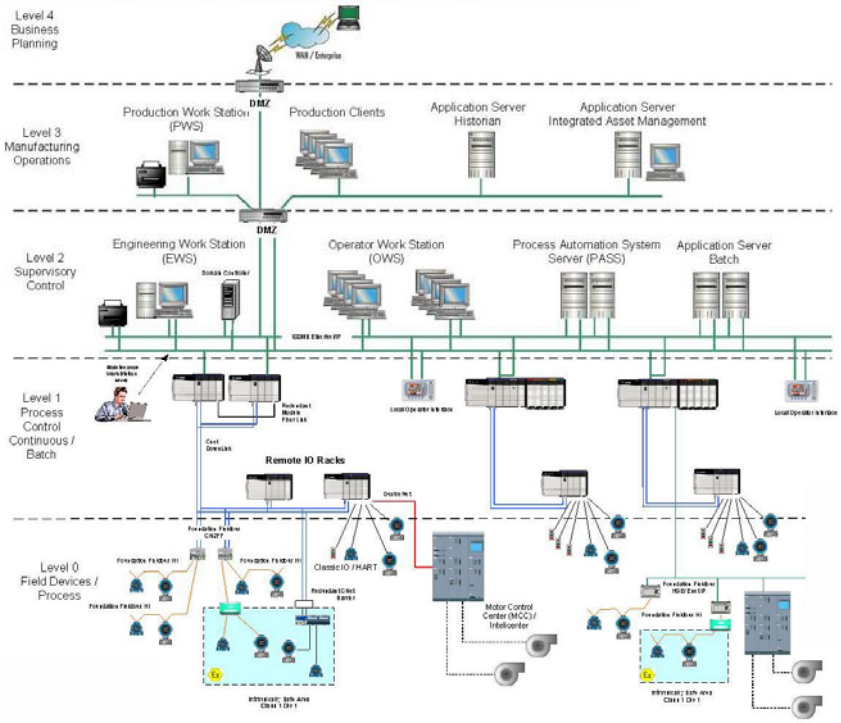
Source: Results based on unit by unit discounted cash flow model. Unit level data taken from 2010 EV database. Cost and performance based on NETL survey of previous sensors and controls projects.

Sensor & Controls R&D Areas

Optical Sensors	• *Spectroscopic* • *Non-contact* • *Fiber based* 	*Optical Access, Interference management* *Single Point, Distributed and Multiplexed Sensors, Coatings for sensing, protection, and attachment*
Micro Sensors	• *Single point* • *Array based* 	*Materials for active sensing layers & protective coatings, Algorithms for Gas Quantification, Sensor Packaging, lead wire & connector improvements*
Other Sensors	• *Embedded sensors* • *Imaging* 	*Active films, direct write sensors, Metamaterials, Capacitance Imaging, Algorithms for image reconstruction*
Enabling Technologies	• *Wireless Energy Harvesting* 	*Passive Wireless, Active Wireless communication, Thermoelectric and vibration energy harvesting approaches, Sensor Networking*
Controls Technologies	• *Distributed Intelligence*	Computationally driven approaches for novel control architectures and logic, information generation, sensor networking & placement
Novel Controls	• *Sensor Placement* • *Control and Optimization*	Biomimetic control, learning algorithms, setpoint optimization, hybrid plant control, and actionable information

Evolutionary vs Revolutionary

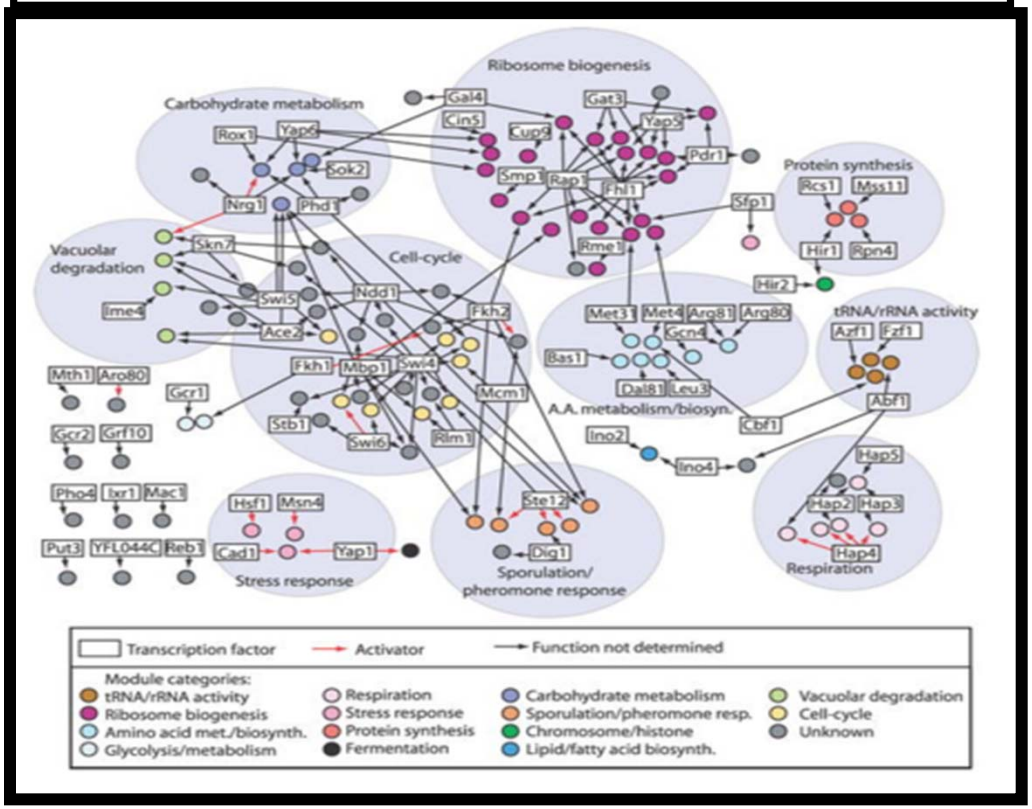
Challenging conventional architectures to
support advancements in computational intelligence



Traditional Control Architecture
For Distributed Control Systems (DCS)

- Linear and based on minimization of error and set points

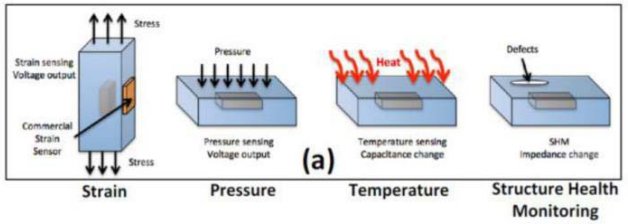
New approaches mimic biological systems, utilize distributed intelligence, and designed to handle complexity

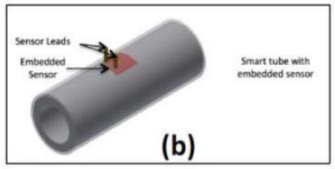


Advanced Manufacturing Technologies

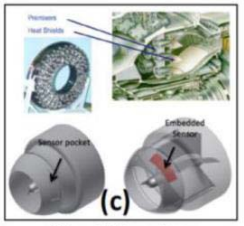
Crosscutting Projects on Leading Edge

- **Next Generation Materials**
  - Advanced Materials
  - Membranes
  - Catalysts
  - Material Genome Initiative
  - Advanced Sensors
  - Advanced Coatings
  - Next Generation Electronics
- **Next Generation Manufacturing Processes**
  - Additive Manufacturing
  - Nanomanufacturing
  - Bio-manufacturing
  - Modular Process Intensification
  - Roll-to-Roll Processing
- **Improved Manufacturing Systems**
  - Smart Manufacturing
  - Automation and Robotics
  - Simulation and Visualization
  - Sustainable Manufacturing

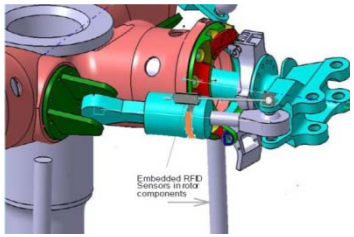


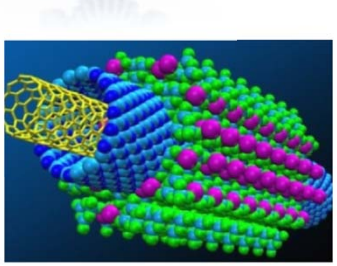


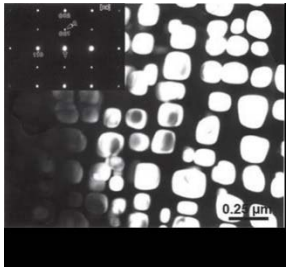
"Smart" Tube



"Smart" Pre-mixer

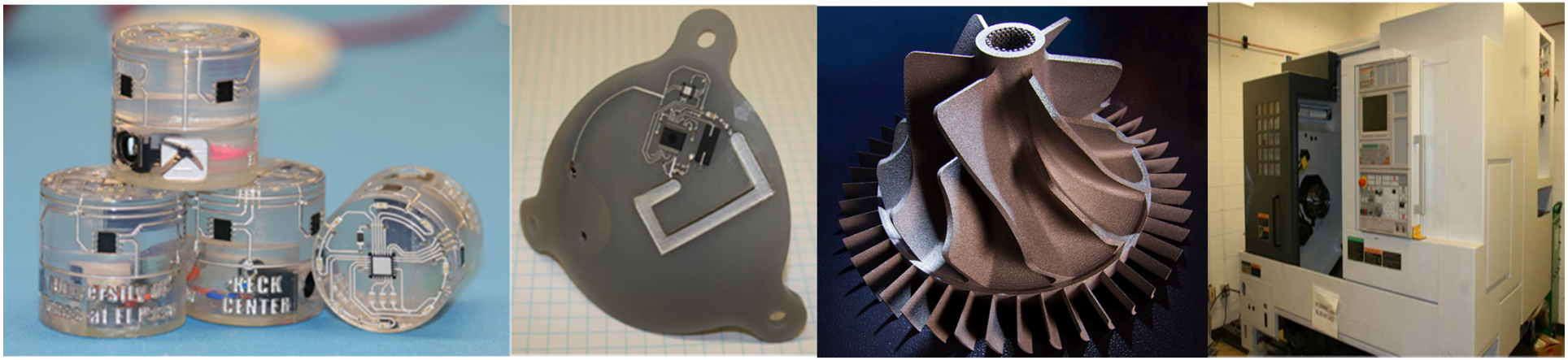






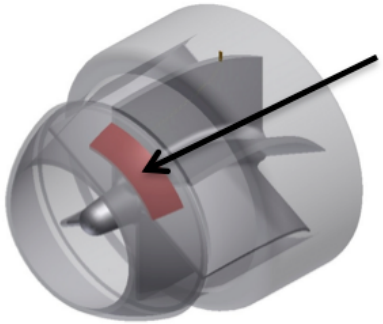
50% of NETL Projects w/Advanced Mfg Concepts are Crosscutting Projects

Smart Parts and Embedded Sensing



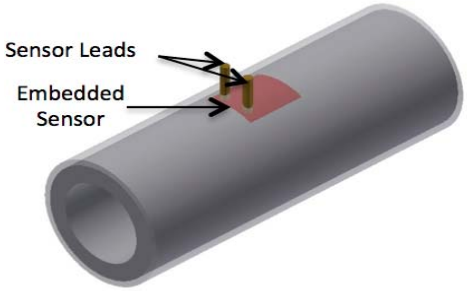
Quantitative Evaluation of Embedded Sensing Capability

- 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

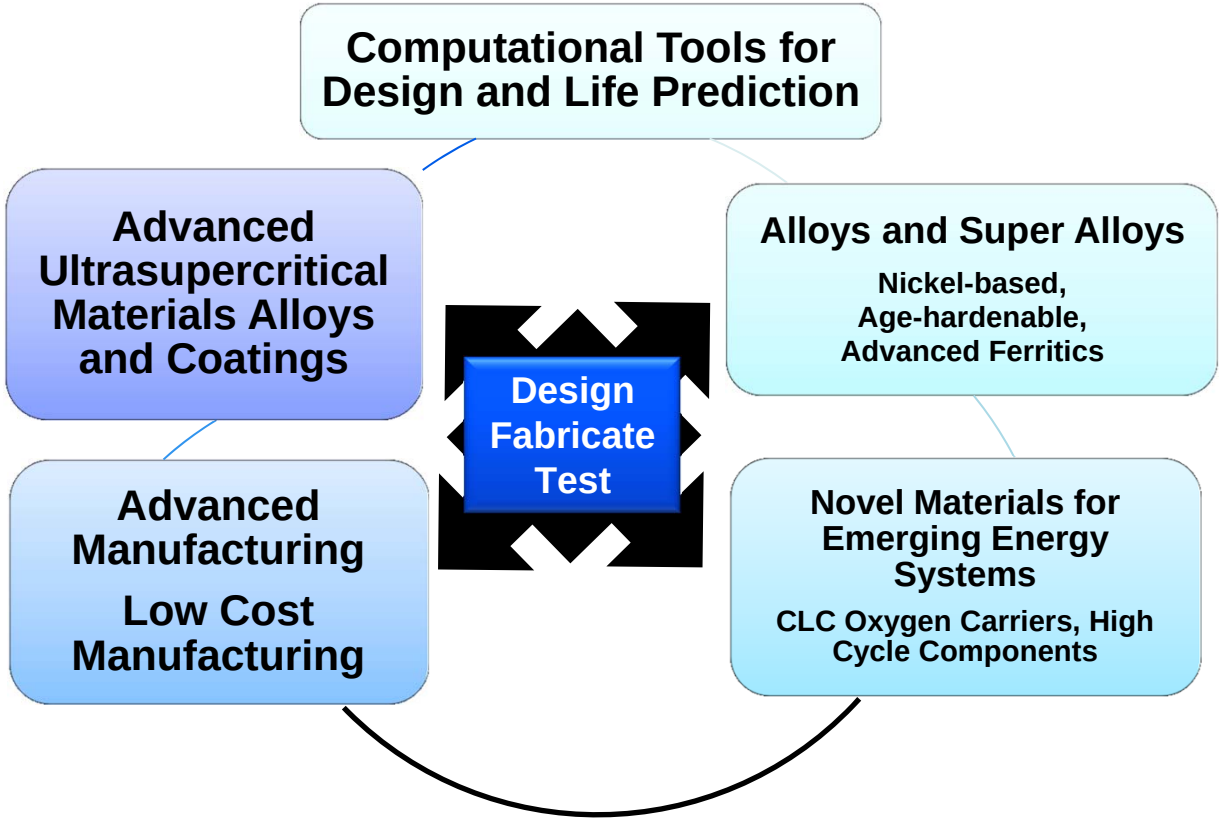
Putting all the pieces together

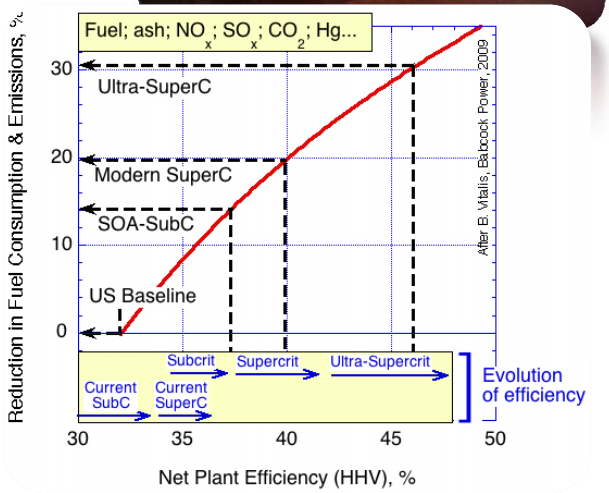
- **Operational and Reliability challenges at full scale…**
- **Start up, Shutdown, Load following and Cycling**
- **Integration of plant operation with grid, water, emissions, CO_2 capture and storage operations**
- **Competing and conflicting objectives for plant operation and control**
- **Complexity 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**

High Performance Materials

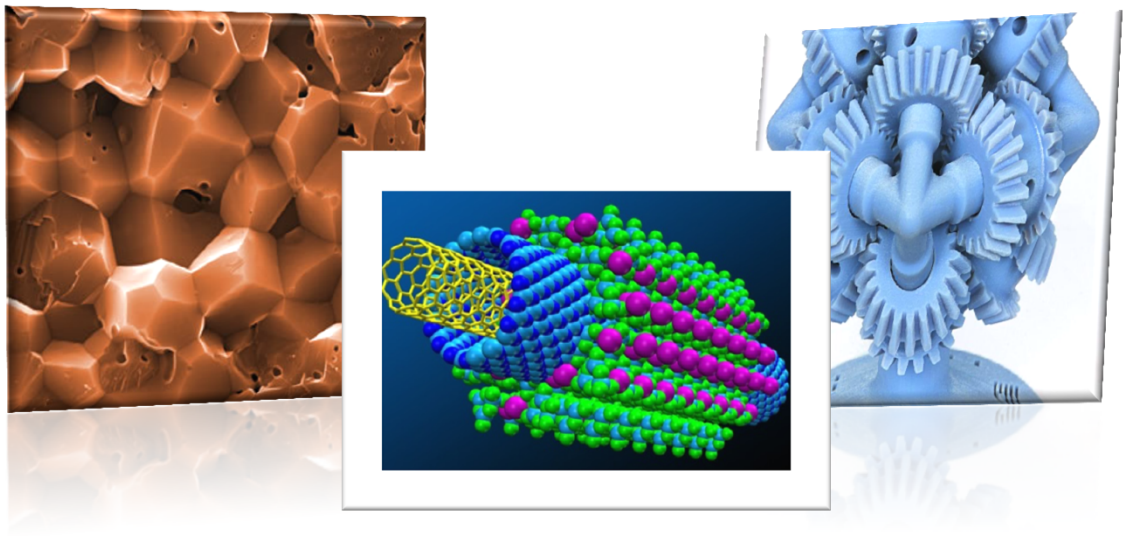
New materials are essential for advanced power generation systems with carbon capture and storage capability to achieve performance, efficiency, and cost goals.

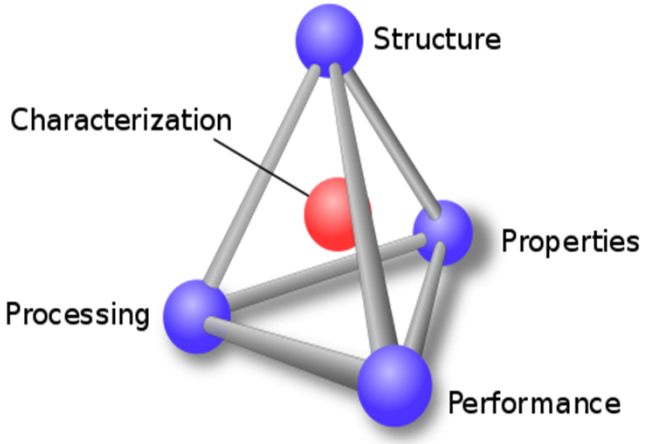
Materials of interest are those that enable components and equipments to perform in the harsh environments of an advanced power system.



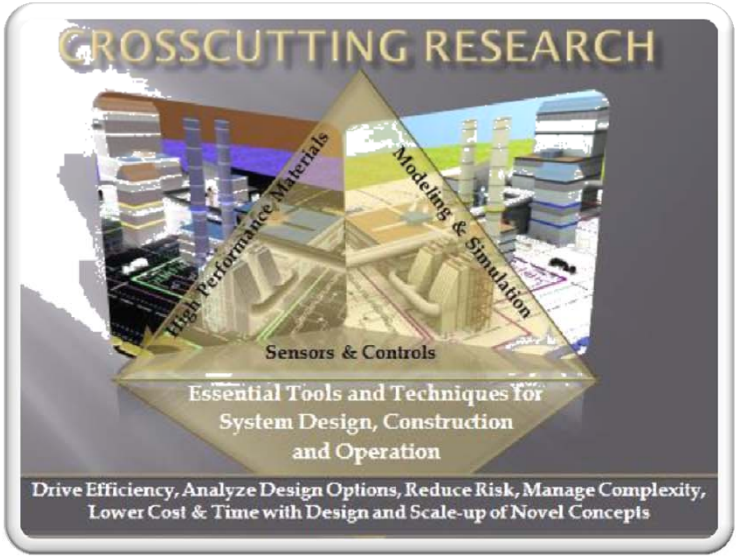


What's Next in Materials?

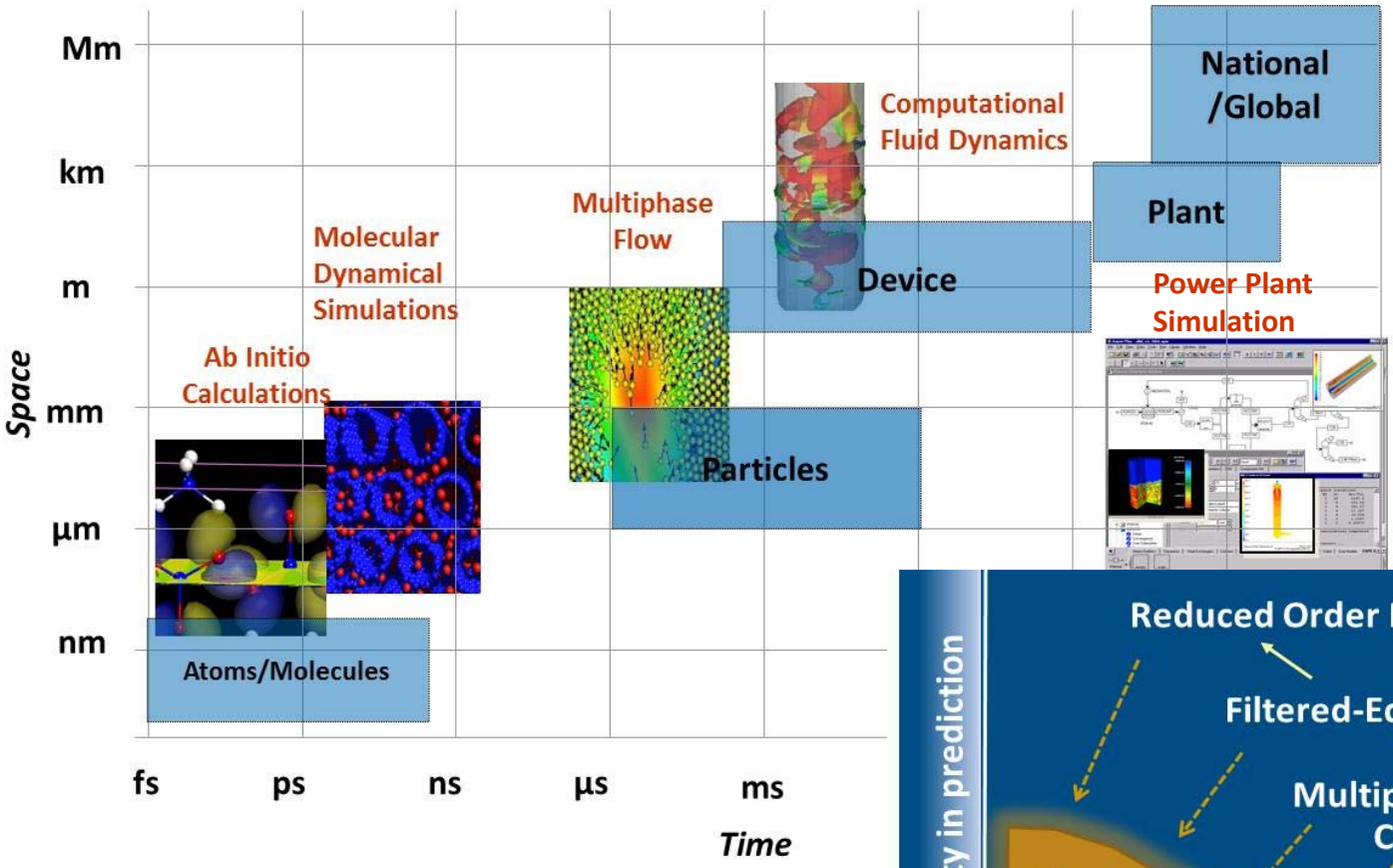




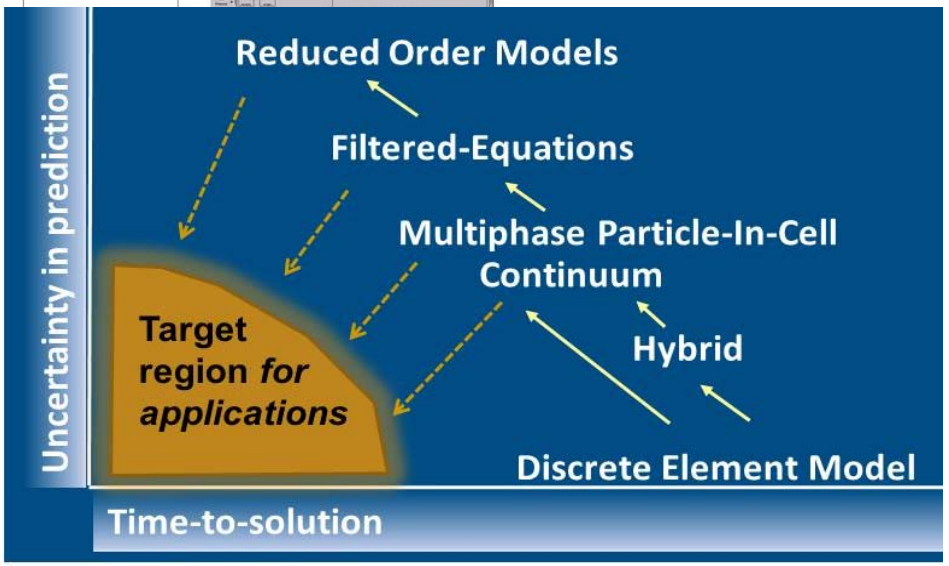
- Supply chain development of materials with greatest market value potential
- High temperature, high cycle materials for fast ramping
- Structured performance evaluation program of materials
- Optimization of Advanced Manufacturing for functional and structural materials
  - Rapid prototyping to support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



Computational Modeling: Scale Comparison



Computational Tools and Analysis for a Broad Set of Applications

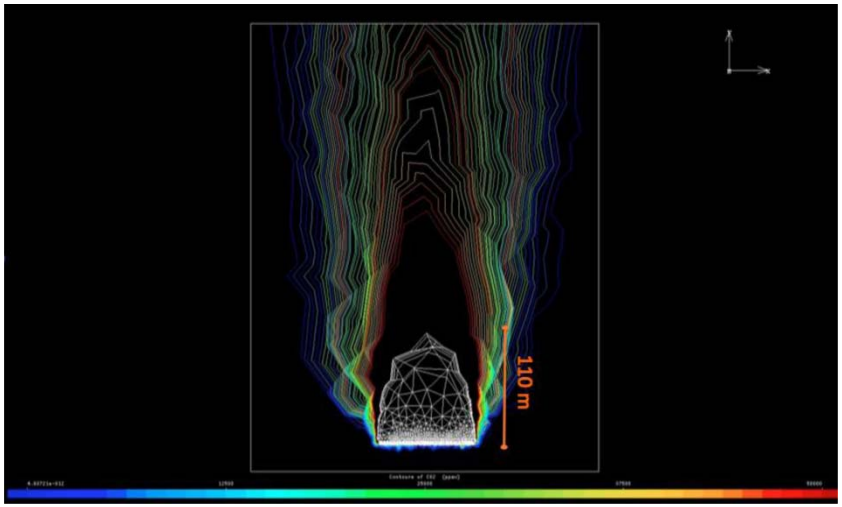


All concepts, technologies and systems can and should be described in a computational format.

Why Simulation-Based Engineering?

Advanced simulation techniques enable more rapid development of advanced highly efficient, low-emission power plants

- **Required by industry to accelerate novel technologies and meet future needs of power generation systems**
- **Speeds design, reduces risk, and saves money thus reduces time to commercialization**
- **System and Component Optimization to reduce construction costs/improve operational efficiency**



- **Barrier issues to technology use can be addressed in a cost effective manner**
- **Safe testing environments for novel control and sensor placement platforms**
- **Orders of magnitude faster solutions through tool integration across scales**

Why Water Management R&D?

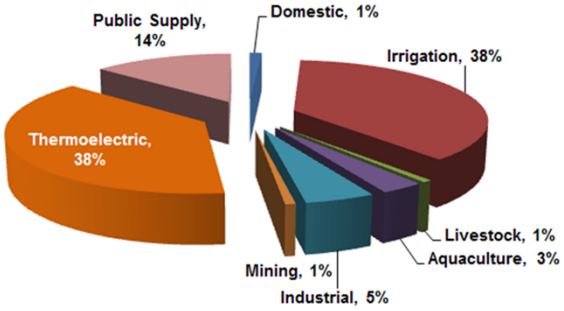
Public Issue: Water Withdrawals and Consumptive Use

Thermo-electric Power Large User of Water, Relatively Small Consumer

New & Existing Power Plants must Optimize Water Use

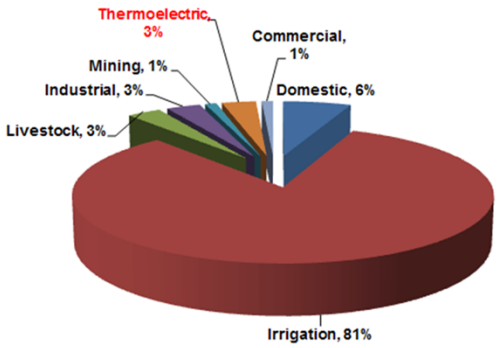
- *Optimize the freshwater efficiency of energy production, electricity generation, and end use systems for Today's and Tomorrow's Power Plant Systems*
- *Optimize the energy efficiency of water management, treatment, distribution, and end use systems*
- *Enhance the reliability and resilience of energy and 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, and seismic impacts*
- *Exploit productive synergies among water and energy systems*

U.S. Freshwater Withdrawal[1]



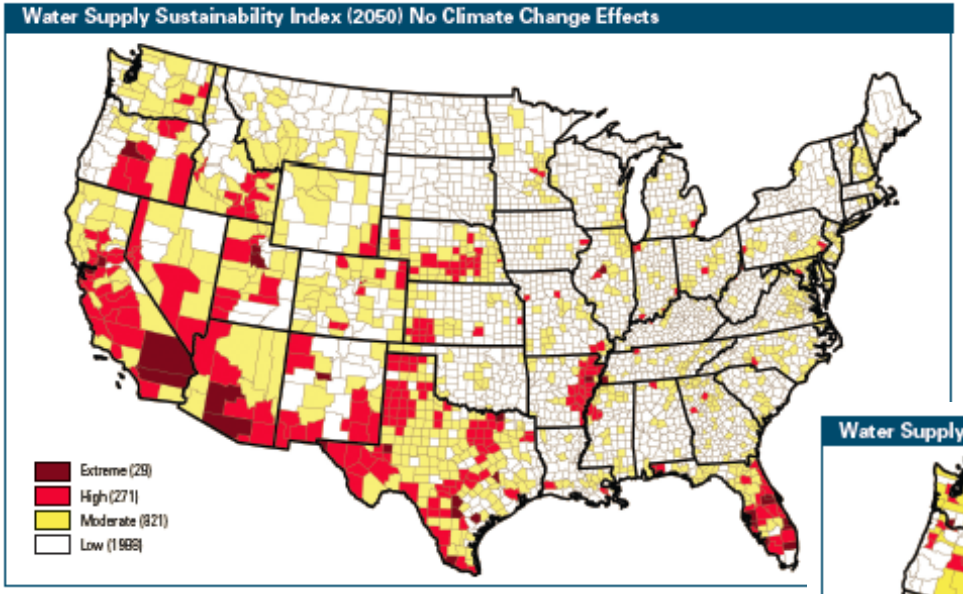
2010 Thermoelectric Freshwater Requirements:
Withdrawal: ~ 117 BGD
Consumption: ~ 4 BGD

U.S. Freshwater Consumption[2]

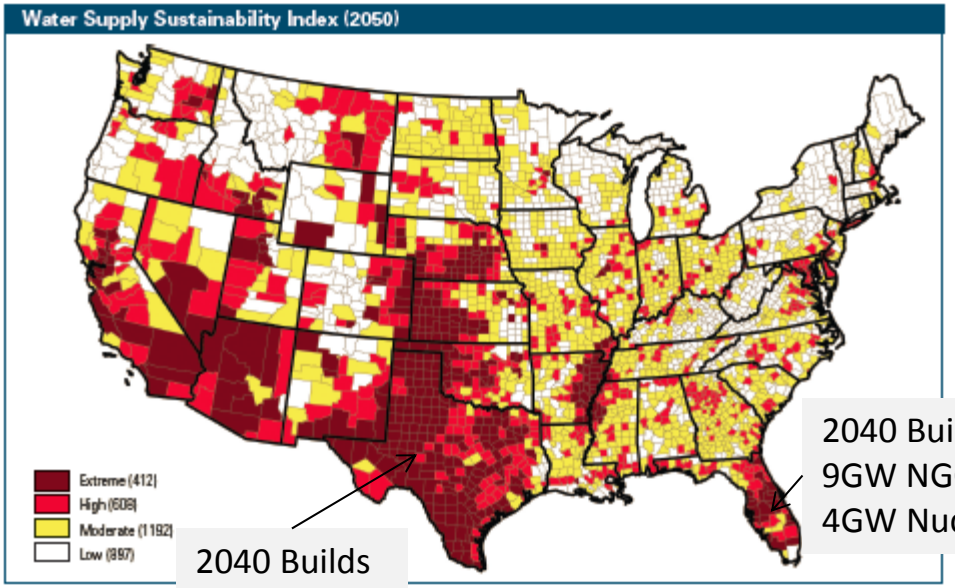


Sources: [1]USGS, Estimated Use of Water in the United States in 2010, USGS Circular 1405, 2014
[2]USGS, Estimated Use of Water in the United States in 1995, USGS Circular 1200, 1998

Current Water Demands Do Not Appear Sustainable in Many Parts of the U.S.



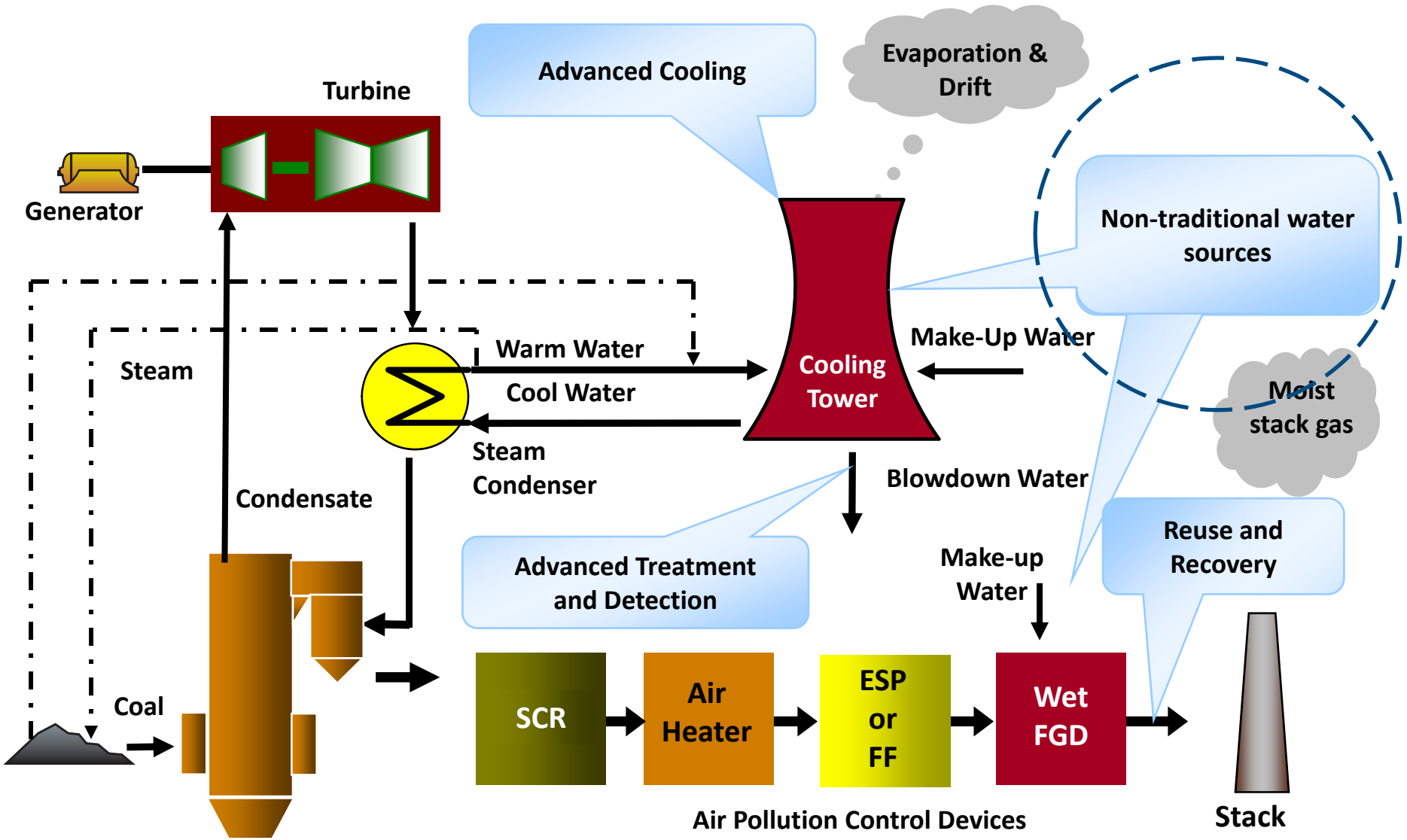
State	Percent of Counties At-Risk for Water Shortage	Value of Crops Produced in At-Risk Counties ($000s)
Florida	96%	4,803,297
Texas	98%	5,333,981



EIA's AEO 2014 shows that the most water constrained areas, FL and TX will see significant population growth and power plant builds by 2040

National Resources Defense Council: http://www.nrdc.org/globalWarming/watersustainability/

Areas for Water Use Reduction



Water Management Research Focus Areas

- **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*

University Training Research

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:

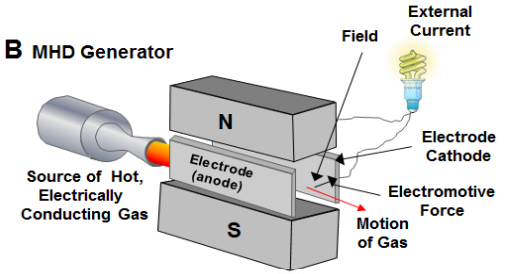
- ❑ 500+ Technical Papers
- ❑ 5+ Technical Awards
- ❑ 2 Patents Issued to Date

HBCU

NETL's Innovative Concepts Research

Target Concepts and Research:

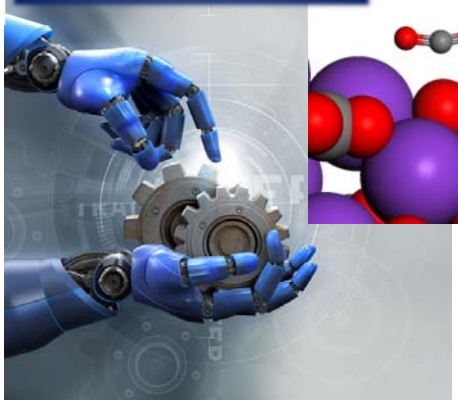
-That removes barriers to applying new technologies
- Has opportunity to transform a system
- Introduces step change improvements in a process
- Reduces cost associated with emerging technologies
- Removes/reduces environmental impacts

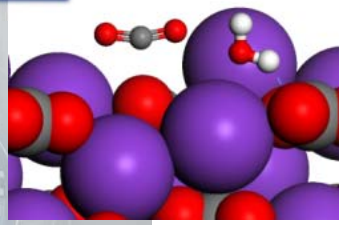


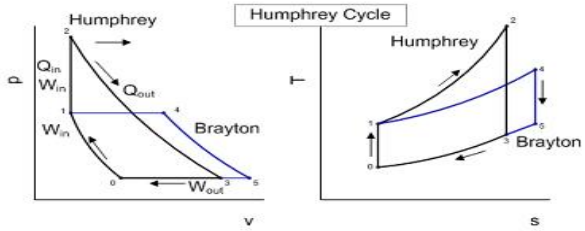
Magnetohydrodynamic (MHD) Power Generation

Nano materials

Advanced Manufacturing

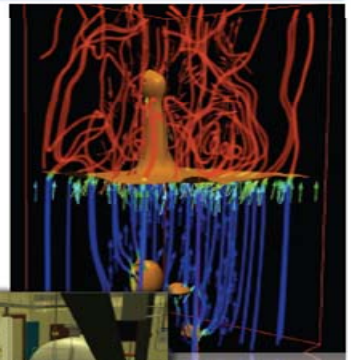






Thermal and Power Cycle Improvements

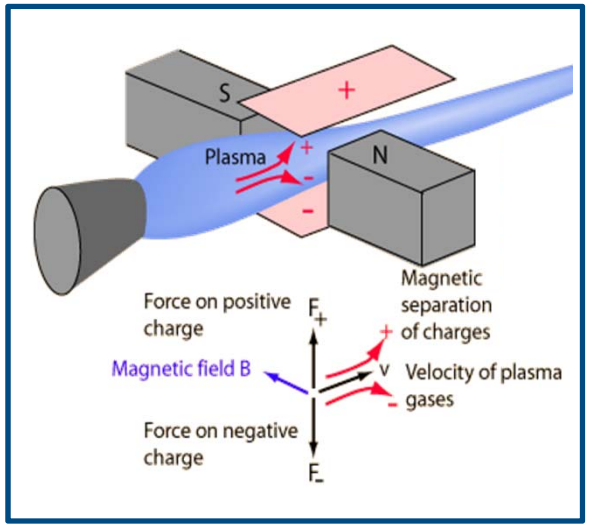
Water Use/ Reuse Novel Cooling & Heat Transfer



Virtual and Immersive Engineering

High Temperature Materials for Direct Power Extraction (DPE)

- By the Mid-21st Century deploy near-Zero Emission Power Generation to reduce GHG emissions
- Greater power output from same fuel input for the emission control and sequestration systems



- **Use strong magnets and convert kinetic energy of conductive gases directly to electric power**
- **Higher plant efficiency – at high temperature**
  - Synergy w/ oxy-fuel for CCUS
- **Power cycle has potential to turn air separation unit from efficiency disadvantage to efficiency advantage!**
- **Can use Oxy-firing with Natural Gas instead of Coal**
  - Eliminate material problems with products of combustion
  - Oxycombustion promotes simplified CCS technology
  - Can be coupled with advanced power cycle technologies
  - Higher electrical output powers ASU and CPU
  - Overall Energy Output and Efficiency comparable to existing NGCC
- **R&D Needed**
  - New Math Models
  - Model Validation
  - Systems Analysis
  - Seed Development (alternatives to K; better, no seed)
  - Bottoming Cycle Integration Research

DPE involves moving an electrically-conductive fluid through a magnetic field. An electromotive force (EMF) is induced between the channel wall electrodes, thus producing electric power

Crosscutting Technology Research Success Stories

- **Made a successful 6,000 lb casting of an AUSC steam valve body of Haynes 282 nickel superalloy. *This casting is believed to be the world's largest casting of H282 to date*.**
- **Achieved ASME Code approval for the use of Inconel 740 nickel superalloy in boilers, pressure piping and other pressure vessels in other non-nuclear power plant applications. *Inconel 740 was the first precipitation strengthened nickel alloy to be approved by ASME for use in boilers.***
- **Sponsored University and Training funding to provide students the opportunity to perform hands on fossil energy research critical to the National energy infrastructure. Program is estimated to have trained over 3000 students , with 1500+ technical papers generated, 15+ technical awards received, and 9 patents issued to date.**
- **Initiated, developed, and tested Single-Crystal Sapphire Optical Fiber Sensor Instrumentation at temperatures up to 1600 °C in a commercial gasification system, and is being commercialized.**

Crosscutting Technology Research
Success Stories

- **Successfully developed the Carbon Capture Simulation Initiative (CCSI) and is transitioning it into applied application in the Carbon Capture Program.**
- **National Risk Assessment Partnership (NRAP) was successfully developed and released risk assessment tools, and is transitioning the tools to the Carbon Storage Program for application to actual storage systems.**
- **Demonstrated 3-D, High-speed Tomography for understanding the multiphase flows encountered in fluidized beds to provide real-time monitoring of process dynamics and physical properties. The system is applicable to a variety of other systems, including being used as an observation and control tool for scientific experiments in space, and being integrated in combustion engines enabling design and control of combustion**

Conclusions

- **The U.S. power generation industry is at a critical juncture**
  - Demand, resources, workforce, reliability, regulation, grid integrity, transmission, etc.
- **Competing demands for reliable, low-cost energy and climate change mitigation appear incongruent**
- **Uncertainty of regulatory outcomes and rising costs impact industry's willingness to commit capital investment, endangering near-term production capacity**
- **The U.S. must foster new processes that address conflicting energy objectives simultaneously**
- **Sensors and Controls play an important role in economical and practical operation of an advanced power plant**

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