Stakeholder Workshop for Advanced Sensing in Fossil Energy Applications
Summary of Poster Notes from Roundtable Discussions
May 8-9, 2010

Funding identified as need/barrier:

- Funding shortfall and advocate support during technology transition from proof of principle or scale-up demonstrations into commercialization or full-scale plant demonstrations
- Some funding and some testing; enough long-term & real environments to get industry support
- Leverage funding with industry to support transition
- More funding to provide value to industry – 53% of power make them better with better measurement
- Funding from small business perceptive
- Leverage funding with industry to support transition

1.1. What sensor technologies or measurement needs are missing from consideration for development?

Online Coal Analyzer

- Fuel Quality
- Missing from commercial needs
  - How to move information around plants consider North American Electric Reliability Corp. Critical Infrastructure Protection System (NERC CIPS) – wireless security
  - How operators will/can use advanced sensor data

Measurement Needs

- What is important to measurement
- What ranges of measurement spectrum
- Characteristics of sensor quality
- Sulfur
- H_2 quality
- Tunable lasers – Midwave Infrared (MWIR)
- Common method to measure plant efficiency
- Method to measure plant availability (up time)
- Prove the accuracy/reliability of sensor – what can be done to prevent plant shutdowns?
- Health – Status Monitoring
- High temperature sensors close to combustion environment

Technologies

- Packaging:
- Acoustic/Instability Measurement
- Real time particle imaging
- Hyper spectra imaging
- Ultraviolet (UV) flame dynamics

- Terahertz Imaging - Data Mining
- Reducing environment in both resistance and reductive to corrosive/oxidizing environment

Sensor Performance Issues

- Sensor performance =making sure we understand how sensors perform
- Response time
- Trending & rate of change - Data Mining
- SO_x and resistance / measurements – sensor handle contaminants
- Application specific testing

1.2 What should be considered in the basis for prioritizing (sensor) technology development?

- **Technical Vision of Sensor/Rational Plan for Getting From A → B**
- **Priority Based on Needs**
- **Research Versus Industry Specific Problem**
- **Collaboration/Partnerships**
  - Short term vs. long term
    - Focus on long term goal for technology prioritization
    - Too short time fluctuation with funding trend
    - DOE long term development plan
  - More industry small businesses universities partnerships - "technology pipeline"
    - How do we get industry involved?
  - Industry specific problems and needs should be researched
    - Avoid duplication of services/overlap with industry, i.e., cycle back to more innovative approaches if industry is already working on a priority area
    - General criteria input from needs and industry - some industries do not know what they need
    - Government requirement for 20% of Industry cost share is not good for fundamental work and serves as handicap promising concepts. Maybe appropriate to use a sliding cost share based on technology maturity.
  - Can the program benefit from international /DOE collaboration?
    - A stand-alone topic would address how to support this collaboration in enabling technologies.
  - What should the sensor vision look like, i.e., perform detailed analysis
  - Tie to energy efficiency and cost reduction
  - Communication of needs with prioritization to show results in 2-3 years
  - Sensor Survivability (use Integrated Gasification Combined Cycle (IGCC))
    - Interface and functionality standards
    - Adaptability to industry
  - Technology Transfer
    - DOE to help foster ideas through these processes into a working tech transfer scenario & communicate how we make those decisions
  - Enabling Technology
  - Early Adoption

- Foster success beyond prototypes
- Siemens - what to measure Propulsion Instrumentation Working Group (PIWG) prioritization

Other

- Legal – Intellectual Property (IP) issues
- Assessment of Market Opportunities
- Data risk information is a poor tie back to control for value and priority
  - Identify realistic Risks & Opportunities
  - Realistic assessment of negative impacts of funding timelines (i.e. administration change, funding)
  - Minimum risk reward portfolio of different risks
  - Spectrum over the risk rewards area with good selection of high risk/ high reward, spectrum of lower risk, and a spectrum of maturity timelines

Discussion

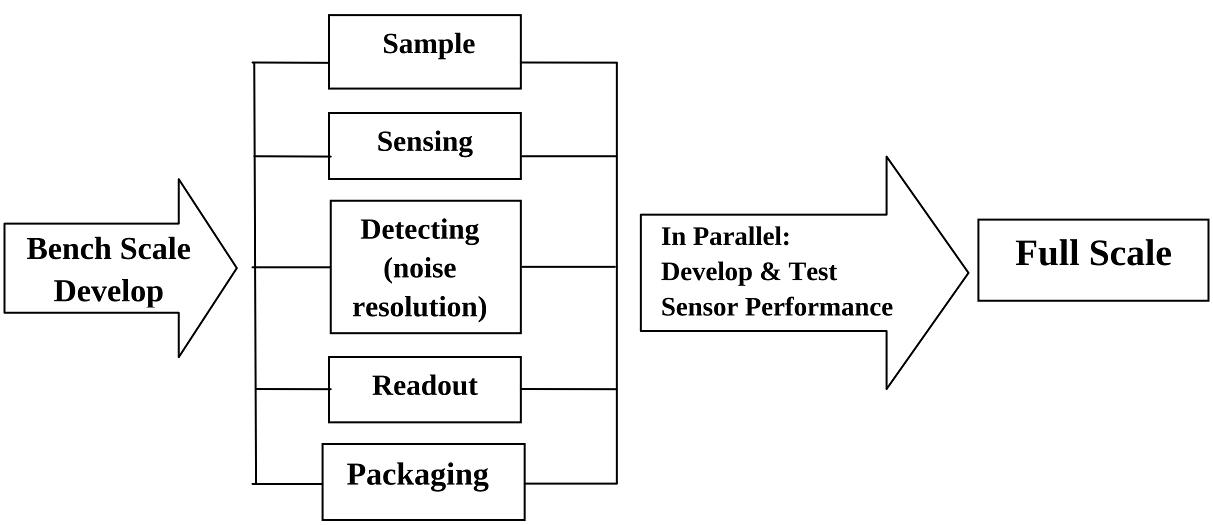
- New Funding Opportunity Announcement (FOA) from DOE collaboration and clean energy governments to establish collaboration center for carbon capture, clean vehicle, and nuclear topics (no sensor that is fundamental enabling).

1.3. What additions or adjustments can be made to technology development timelines considering NETL's development plans and work by others?

- Wireless and energy storage need longer term more consistent trends

2014 - Bench Scale or Above

- Integrate into Field Testing:



2018 – Full Scale Demonstration

- How do you get to full-scale demonstration by 2018?
  - Research versus applied need agendas

        - Development gap between research and commercialization
        - Assess how large is the gap and then prioritize
    - Educate applicants – universities need to support prototype
- Consortium-based Projects/Groupings
    - Assistance to identify and work with potential partners, which is often difficult to obtain
    - Continuity of players (industrial help is typically pro bono).
        - Can funding help keep this industrial involvement consistent?
- Identify assets that could be used in development
    - Test Facility as close to final application as possible
- Clearinghouse list of potential test facilities *(will require industrial involvement)
- Full scale sensor test, but conduct testing until sensor performance is more clearly understood
- "Technology Pipeline"
    - How to identify and work with potential partners

2.1. What <u>novel materials, technologies, or concepts</u> can the Advanced Research (AR) Sensors and Controls (S&C) program consider pursuing to establish feasibility and potential breakthrough technologies?

Feasibility of Coal-Derived Carbon Products
High Temperature Interconnecting Materials

- Novel Materials: need to understand goals: how high/ other conditions
- Interconnects high temperature support standards and cannot adversely affect signals
- Thermodynamic stability to start
- Metamaterials
    - How can it be used?
    - Can be doped heat transfer and other applications for materials
- Crystals – high temperature piezoelectric materials (up to 1600^{o}C)
- Optical fiber distributed sensor packaging & attachment materials & technologies

Sensors

- Change in the way we look at active sensor materials
    - Start with high temp materials
    - Modify
    - Stop working way up
- Stability of sensor materials – managing drift, layer structures, and composites are good approach to managing materials changes at high temperatures
- Best temperature sensors; listen to folks who make the equipment; see from Inventors; need help from DOE and equipment Original Equipment Manufacturer (OEMs)

High temperature

- Placing sensors onto parts – onto Thermal Barrier Coating (TBC) above 1000^{o}C it shorts not deposit dielectric contains that is compatible with TBC but doesn't effect it - Coefficient of Thermal Expansion (CTE), chemical compatibility – high dielectric
- Delineate breakthrough for what temperature range – stability with temperature cycling those ideal for mid range temperatures

- High temperature electrolyte materials – multi silicates
- Materials for fiber-optic to the interactive systems cables for high temperature environment – interconnect connectors
- Value of the control combustion control – high temperature O_2
- Porous ceramic for sensor packaging up to 1400^{o}C

Technologies

- Other wireless – acoustic and other approaches non-contact
- Reliable test beds for materials in syngas and coal systems
- User test facility to transition sensors, room for failure, to scale up and bring industry into fold at this level.
- Technology Transfer
  - Bench scale testing to transfer technology Gas Technology Institute (GTI) facility
- Enabling Technologies
  - Sensors – work end users gasification prioritized sensor needs near term needs of end users
- All this other technology lighting-solar
- High electrical resistance for this dielectric
- Rapid bench top screening
  - Combinatorial Chemistry

Concepts

- Goal to make highest possible impact, e.g., optical signal processing is expensive so whole system to support reduction in cost breakthrough in high cost technologies
- Pull sensors out of technologies so it can provide value to their areas beyond
  - Sensors are embodiment of other industries needs but every sector requires sensors
  - Sensors as enabling technology - what can't be done today? Research that gap
- Foster success beyond prototypes
- Open website for industry ideas to ensure real needs are captured
  - Needs OEM ideas
  - Needs researchers ideas
  - Input value capture continuously
- Defense Advanced Research Projects Agency (DARPA) Model – Shorter term, High Risk - High Reward (2-year) Go-No Go 1-year
  - If you're not failing – may not be adventurous enough
  - How does this burden AR in funding?
  - White paper (DARPA model)
  - Make connections then move to next stage so partnerships can grow
- Soft instrumentation (less invasive)
  - Physical instrumentation challenged in Harsh Environment
  - O_2 – 1500^{o}C in boilers
- Algorithms for sensor placement good
  - Go one more step - reconfigurable sensors systems algorithms
  - Make system or sensor system reconfigurable

Discussion

- Packaging (low costs)
- How to resolve potential conflict of low cost packaging– transition from one to the other
    - Success & failure
    - Low cost/high risk vs. durability at low cost
- Predict Failures
- Waterwall wastage measurements to improve / predict availability
    - Pipe steam / fireside erosion / corrosion
    - Sense slagging (different slag) be able to sense multiple slag types

2.2. What enabling technologies are missing or underdeveloped that are key for the employing emerging sensor technologies?

- Cross -germination with other industries (chemical, petro, metal, paper, pulp)
- Packaging
    - Novel Materials
    - Cyber security Requirements, i.e., security, integration, Data Encryption Standard (DES)
    - Development of Standard Packaging acceptable to various sensor technologies (avoid everyone developing their own)
    - Develop in parallel
    - Education on existing standards
- Standardized Packaging vs. Proprietary Developments
- National Testing Facility (Can one be made available?)
    - Common system for comparison
    - Retrofit vs. New Technology (Differences)
- Different types of sensors for same applications
- Thick film lick and stick materials
- High stability
- Die attach and film attach materials
- High survivability temperature, but low cure temperature
- Optical access
    - How to maintain optical access – maintain and materials
    - Free space and contained optical
    - Optical access tie back to systems
- Application oriented
- Sim Val project

2.3. What role does modeling and computational sciences have in sensor placement?

- Can sensor determine whether sensor could serve in specific location (harsh environment)
- Ability to Envision Full Design
- Model Verification
- Lehigh University Computational Fluid Dynamics (CFD) Modeling has proved beneficial for Laser-induced breakdown spectroscopy (LIBS)
    - Laser path clean

  - Ignition prevention (coal dust)
- (Assist in) Sensor Placement
  - Assists operators in control
- Very application specific for these modeling and sensor placement to get better results
- Model based controls virtual sensing using models
- Interconnection of sensors within a network / sensor systems within a facility
- Temp Dist / Flow Dist (Furnace)
- Shift from Physical Modeling to CFD
- Data Rich / Information Poor
  - Interpretation of Data → How you use it
  - Prioritize relevance of data
- Data Fusion (NASA/DOD)?
- Sensor input into control strategies
  - Minimum impact on current fleet
  - Major impact on Next Gen
- Sensor development /sensor placement
  - Boundary conditions available from both University and Industry
  - Computational models to answer sensor related issues
  - Sensor placement and sensor type for model validation versus sensor placement and type at full scale and scale up
  - Need clarification for sensor development to help where they can help
  - Sensors for performance but not much on sensor for reliability strain creep crack failure analysis
- Intelligent models; model growth by collecting sensor data
  - Model based on average conditions but also real degradation. Models need to account exception based and excursions to help with manning upsets and interpreting those process upsets
  - Propulsion – Safety & Affordable Readiness (PSAR) – Defense Advanced Research Projects Agency (DARPA) prognostic models temperature of inlet and outlet but not metal and TBC temperatures – first stage component temperatures will improve fidelity of prognostic models
  - Parallel development of enabling technologies need readout sensor circuit and read out circuit and how to decompose a sensors – develop these concurrently with simple models to allow you to hit development timelines faster. Low levels models to facilitate concurrent development
  - Air Force and Navy – clear line between for Coal Bed Methane (CBM) and control shows up in maturity process and timeline validation levels
- Feedback from existing plants
- Turbine modeling to measure exit exhaust temperature
- Self diagnostics and quick set up, shrink electronics, signal conditioning
  - Help foster realistic test beds for transition test beds automotive industry – test beds for certain technology

3.1. What enabling technologies are missing or underdeveloped for implementing advanced sensing in industrial power plant environments?

- Interconnection of sensors within a network/ sensor systems within a facility
- Secure wireless technology
- "Technology Pipeline" - More industry-small business-university partnerships
- Need for Advanced Control Systems for Advanced Sensors
- Designs for sensor integration
    - Spectroscopy state vibration tolerant systems that are low cost and rugged
    - How to put finalized package into play, for example:
        - In drilling, are additional widget needed?
        - In electronics, access to Distributed Control System (DCS) (Parallel System perhaps?)
- Cost-effective Manufacturing Technologies/Strategies
- IP agreements (Lehigh's example) Lay out intentions ahead of time
- Sensor Survivability (use IGCC)
    - Interface and functionality standards
    - Adaptability to industry
- Project support for enabling technology development to support productizing the technology
- Methodically evaluate enabling technology while system approach support
    - Concurrent develop of enabling technologies
    - Focused FOAs enabling technologies where needs are known
- Supporting easy systems for installation making more convenient for user
- Not be industrial to avoid conflicting with production priorities need testing stepping stone

Discussion

- Technology Roadmap (Government &Industry Needs
- Identify Technology Gaps
- Energy Harvesting
- Plug & Play

3.2. What efforts are needed to support early adoption of advanced sensor technology?

- Incentives to Power Companies
    - Tax credits
    - Regulatory incentive for early adoption
    - Fear of the rules changing
    - Royalty-free licenses to the technology
    - Central & LLC (individual operation facilities)
    - How to incentivize both?
- Development Stage [Including Industry in Advisory Boards]
    - Potential path to test bed
- Strong business case (developer-side)
    - Encourages industry pull
- Risk Adverse Industry – Demonstrate in others industrial apps that are less adverse
- Feedback from existing plants
- Connection of technologies developed in AR to implement in existing plants

- Economic drivers / regulations
- Industry development phase for projects
- Sensor adaptation to specific applications / systems
- Well-defined regulations to "bridge the gap" (from industry) → a checklist for companies to follow
- Identify companies that are willing to test at their facilities
- IP link between academia and industry

3.3. What is needed to foster success for sensor developers to move (sensors) beyond prototypes?

Ability to Envision Final Design

Proposal/Contracts

- Provide information related to work in proposals with basic value via initial demonstration
- Clear delineation in FOAs fundamental versus applied
- Navy Small Business Innovation Research (SBIR) and Army add options to contracts –similar to Phase II and beyond
- Similar setup to SBIR - Phase I option 70K and a second Phase I option of 50K; Phase II transfer requirement / or requirement to bring in partners
- Phase II transfer requirement or consider requirement to bring in partner
- Legal Stuff
  - Small business perceptive: everyone has a big, slow moving legal staff. Get agreement out of the way – legal stuff

Transition

- Set up workshops to facilitate technology transition to Coal Power Projects (CPP) program Contractors need to understand requirements and drive connection
- Place or delineate responsibility with recipient, funding agency and user
- DOE facilitation to support transition with industry

Partnerships

- Partnerships between Industry - Small Business - University employing technology
  - Industrial Champions to assist in communicating and connection
    - Sponsored interaction vs. random identification
    - Lab scale → Industry Risk Adverse
- Identify the customer sooner in the DOE projects
  - Link to customer or user
  - Customer base or someone to champion connection
- Partnerships may help eliminate ego
  - Encourage Commercialization Potential Assessment
  - Small Business Technology Transfer (STTR) requires path forward
  - Technology Transfer Offices may also be a hindrance (as opposed to ego)
- Present the challenges, delineate the accomplishments – system level perspective
  - Standardized model to ensure success(es**)**

Scaling of Appropriate Technology Demonstration

- Methodology/approach for achieving Technology Readiness Levels

- Advancing complexity and research system functionality

Technology

- Ability to advance through prototypes
- Whole system approach to make a prototype
- Implementation →(Product Engineering)
    - Market Information
- Developing Control Strategies as well as sensor
    - Access to existing plant control
- Bring in or have industry days to showcase new technology
- Make overlap of the push and pull to get thing to go
- Technical and enabling technologies for industrial sensing
- Ruggedized sensing and signal processing