Brookhaven National Lab & New York Smart Grid Consortium: Observations and Opportunities

Jim Misewich

SIXTY YEARS
OF DISCOVERY
1947-2007

BROOKHAVEN
NATIONAL LABORATORY

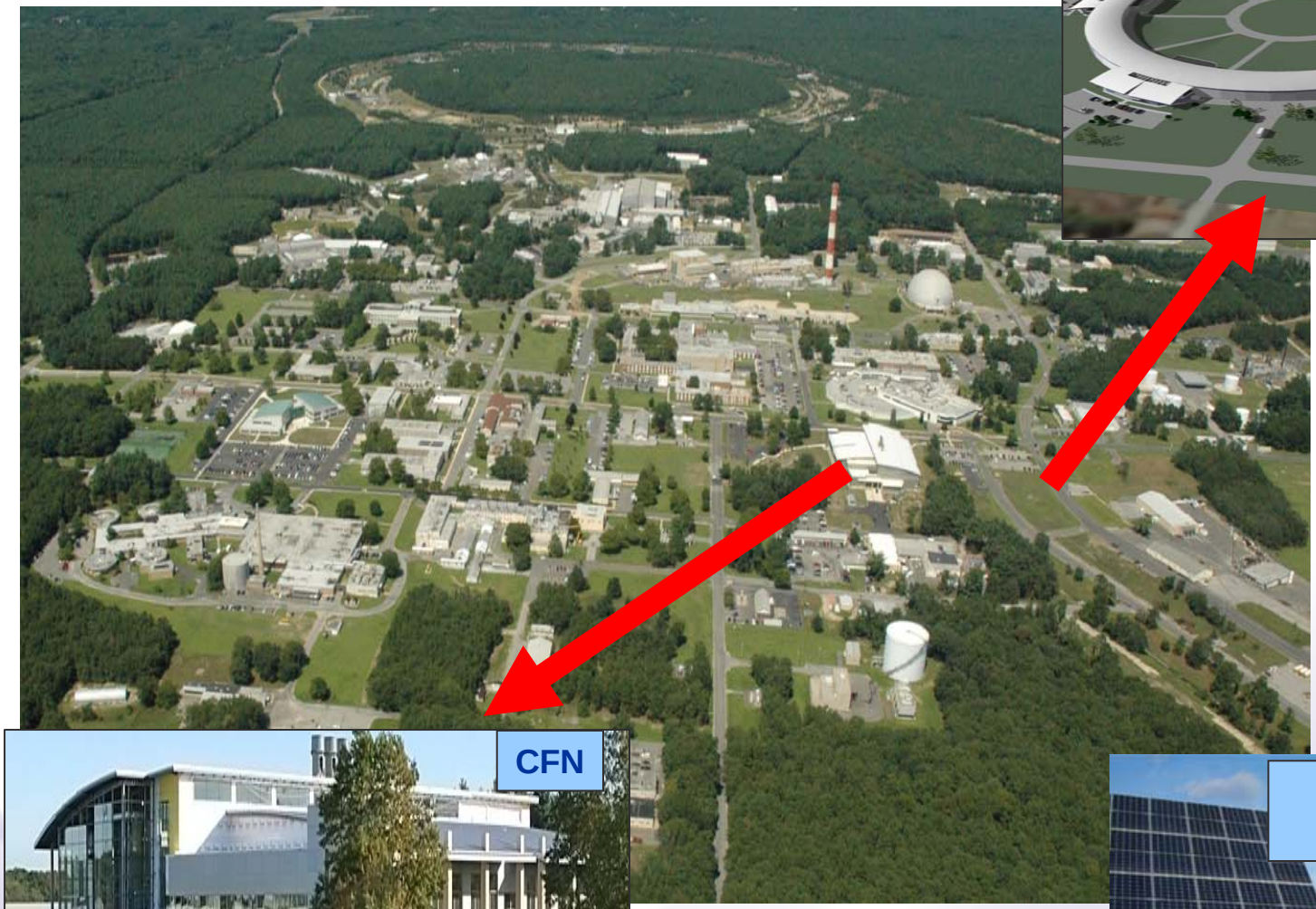
Office of Science
U.S. DEPARTMENT OF ENERGY

Outline

1. Brookhaven National Lab
2. Brookhaven's involvement with the Smart Grid Consortium
3. Overview of Brookhaven's grid related activities and plans

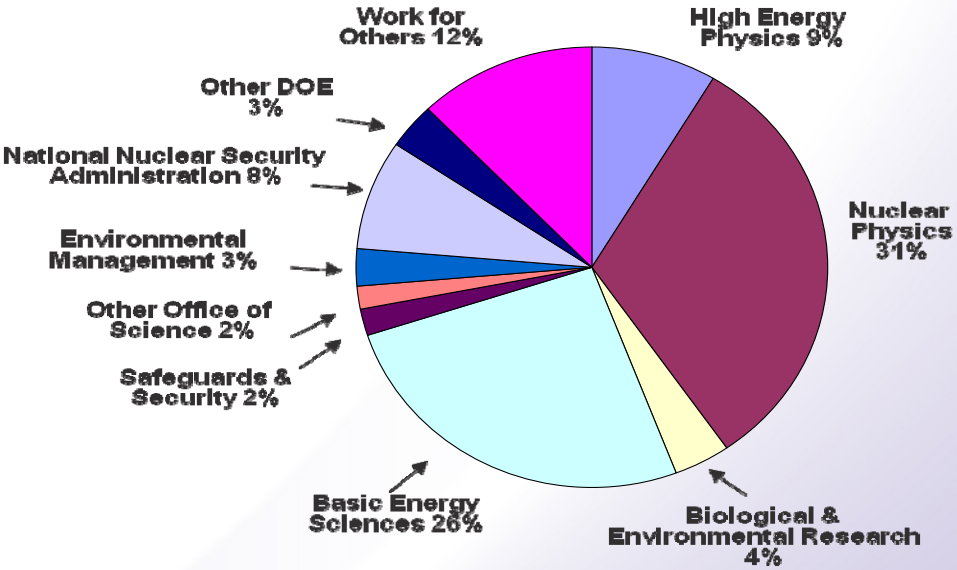
1. Brookhaven National Laboratory

- 5000 Acre Site



Brookhaven National Lab Snapshot

- Established 1947
- One of 10 National Labs owned by the DOE Office of Science
- Operated by Brookhaven Science Associates, a partnership of Battelle and Stony Brook University, with participation of Harvard, Yale, MIT, Cornell, Columbia, Princeton
- ~2750 employees & >4000 scientific facility users annually
- S&T Portfolio
  - Nuclear and Particle Physics
  - Energy Sciences
  - Life Sciences
  - Environmental Science
  - Energy Technologies
  - National Security
- 7 Nobel prizes for research at BNL; latest 2002, 2003, 2009
  - **Chemistry department's Ray Davis Jr. won Nobel prize for Physics (2002)**
  - **V. Ramakrishnan (2009 Chemistry Nobel Prize) began his work on ribosomes in the Biology department (1983-1997), and used NSLS facility**



FY09 New Funding
$610M (Ops & Constr.)
$231M (ARRA Ops & Constr.)
$841M (Total)
~3/4 from DOE Office of Science

Brookhaven Strategic/Business Plan

BNL Energy Vision: effective use of renewable energy through improved conversion, transmission, and storage

BNL Initiatives

CFN/Nanoscience

NSLS II

New York Blue

Core Programs BES EENS

Materials for Energy

- **Correlated Electron Materials**
- **Materials for Catalysis**
- **Solar Nano-materials**
- **Energy Storage Materials**

Collaborators/Joint Appointments

STONY BROOK STATE UNIVERSITY OF NEW YORK

GM

COLUMBIA UNIVERSITY

CORNELL UNIVERSITY FOUNDED A.D. 1865

Rensselaer FUTURE ENERGY SYSTEMS A NYSTAR Designated Center For Advanced Technology

GE Global Research

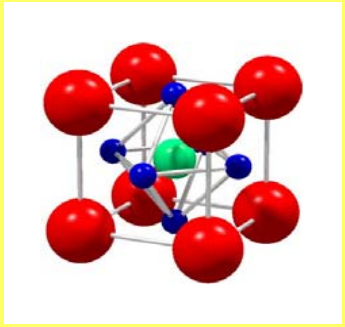
United States - India - China - Germany

IBM

COLLEGE OF NANOSCALE SCIENCE & ENGINEERING UNIVERSITY AT ALBANY

BROOKHAVEN NATIONAL LABORATORY

Correlated Electron Materials



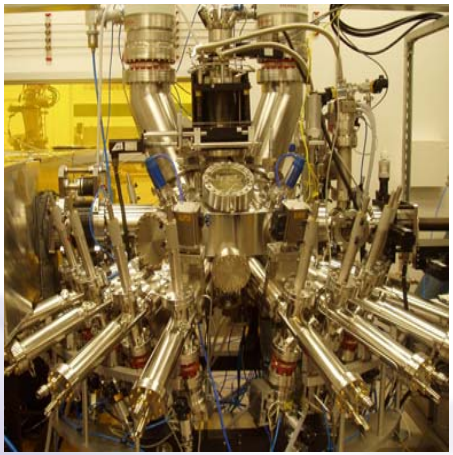
Extreme physical behavior

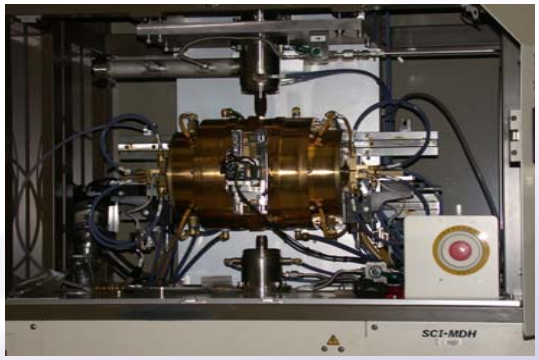
- Cu : High-T_c Superconductivity
- Mn: Colossal Magneto-Resistance
- Co: Giant Thermopower
- Ti: Giant K, Ferroelectrics

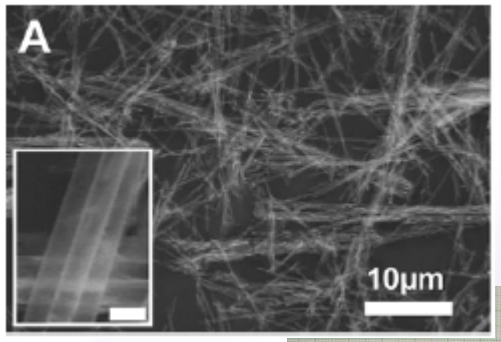
Fundamental Science Issues:

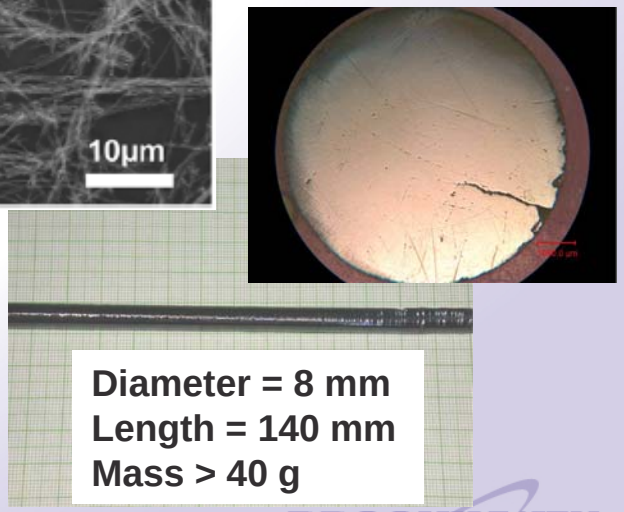
- Inhomogeneities and Competing Orders
- Low Dimensional Phenomena
- Pairing Mechanism in the HTS
- Quantum Criticality

Synthesis foundation: bulk, thin film, nano



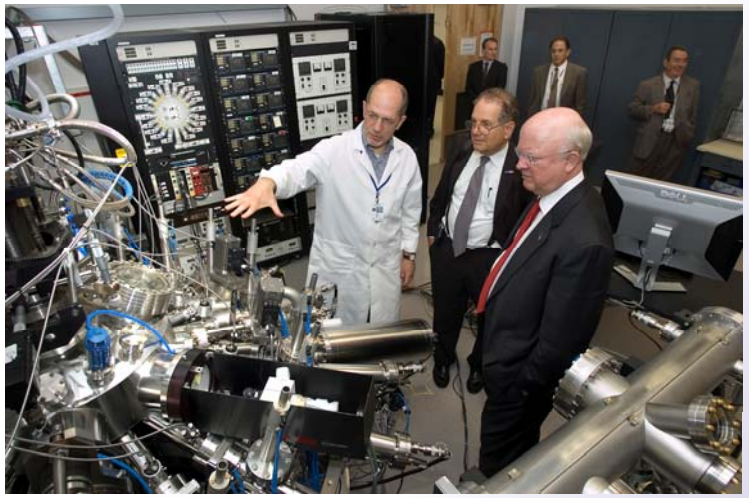






Condensed Matter Physics and Materials Science Department

Research Themes: Strongly Correlated/Complex Materials



Research Budget: In 2008 approx 17.5M

2009 EFRC in Superconductivity

DOE 2008 Performance Evaluation: BNL

"…research programs have demonstrated world leadership and sustained impact in superconductivity…"

Discoveries in Superconductivity:

- *Stripe phase (electronic inhomogeneity) via neutron scattering studies*
- *Interface superconductivity in a single interface layer*
- *Low dimensional nature of high temperature superconductivity*
- *Unusual behavior in phase diagram*
- *…*

Publications:

- *Last 12 months: 30 papers in Physical Review Letters, Nature, and Science*
- *High Tc Superconductivity Portfolio:*
  - *50 papers > 200 citations; 9 papers > 500 citations; 2 papers > 1500 citations*

Recent Honors:

- *2008 IEEE Award for Applied Superconductivity: Mas Suenaga*
- *2009 Kamerlingh Onnes Prize for Superconductivity: Seamus Davis and John Tranquada*

Center for Emergent Superconductivity

Brookhaven National Laboratory

Argonne National Laboratory

University of Illinois at Urbana-Champaign

American Superconductor Corporation

Superpower, Inc

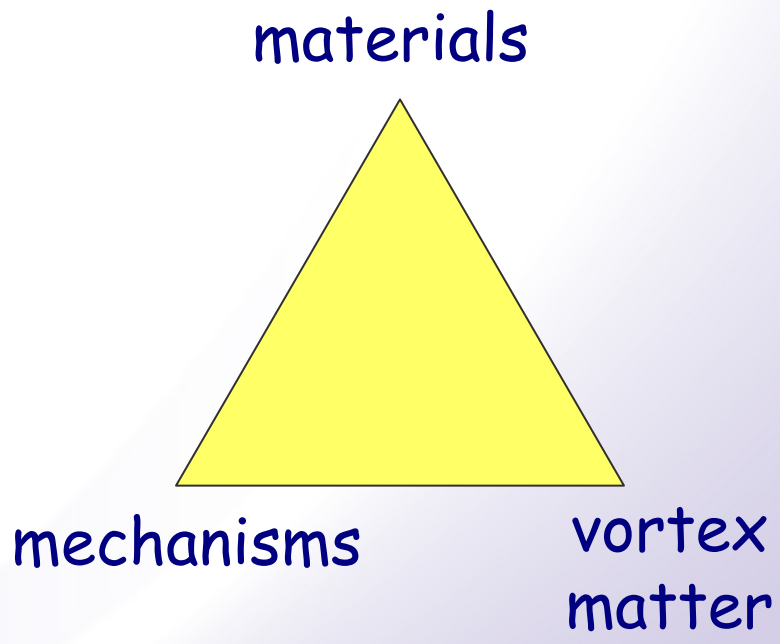
J.C. Seamus Davis
Director

Peter Johnson, John Tranquada, George Crabtree, Mike Norman, Dale Van Harlingen, Laura Greene
Program Committee

Ivan Bozovic, Cedomar Petrovic, Alexei Tsvelik, J.C. Campuzano, Wai-Kwong Kwok, Alexei Koshelev, Peter Abbamonte, Tony Leggett, Jim Eckstein
Principal Investigators

Aug 1, 2009

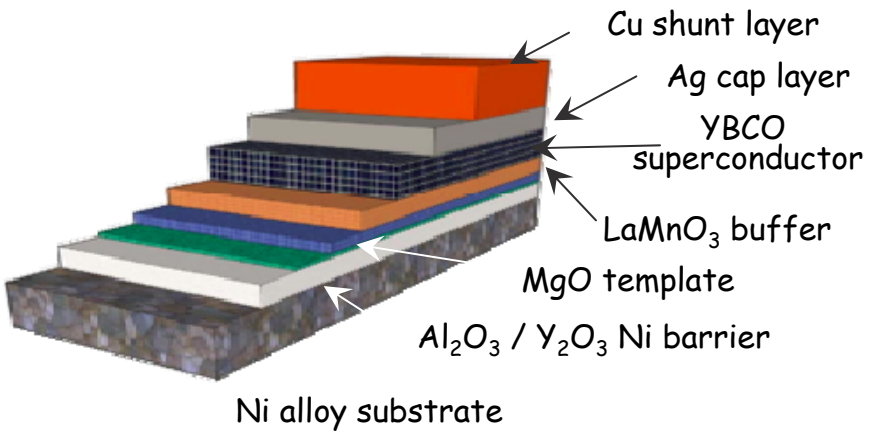
New materials with enhanced critical properties: Tc, Jc, Hc



$22.5M DOE
$2.5M NY State

Brookhaven Lab Materials Research: Superconducting Cable Fabrication Advances

Gen 2 Cables: Functional Multilayers



Brookhaven National Lab:

Sub-atmospheric reactor enables reel-to-reel Gen 2 High Temperature Superconductor fabrication used by American Superconductor

- High capacity
- Low use of carrier gas
- High conversion rates / high productivity

(12) **United States Patent**
Wiesmann et al.

(10) **Patent No.: US 6,794,339 B2**
(45) **Date of Patent: Sep. 21, 2004**

(54) **SYNTHESIS OF $YBA_2CU_3O_7$ USING SUB-ATMOSPHERIC PROCESSING**

Solovyoy, et al., "The Effects of HF Partial Pressure and Pressure Gradients of YBCO Growth in the BaF_2 Process",

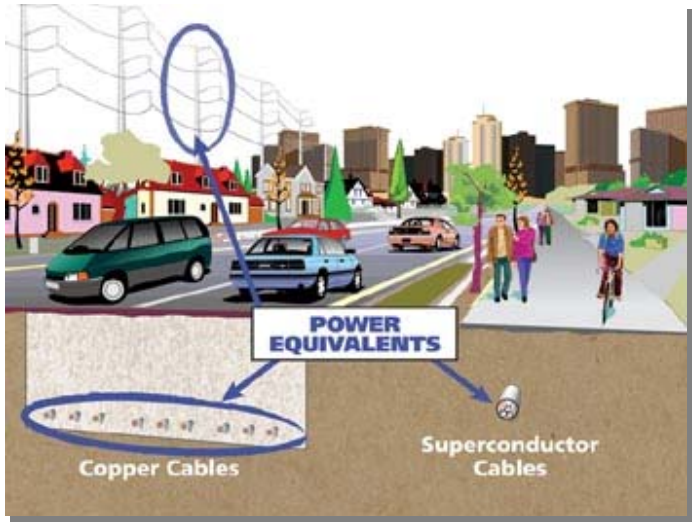
- Cooperative Research and Development Agreements

American Superconductor®

SuperPower Inc.

Superconducting Materials for the Grid

- TRANSMISSION: NY State testing



LIPA commissioned the first high temperature superconducting power transmission cable (138 kV) system on June 25, 2008 at Holbrook site, Long Island, NY, capable of carrying 574 megawatts of power.

Superconducting Cables

- Increasing the efficiency and capacity of the grid

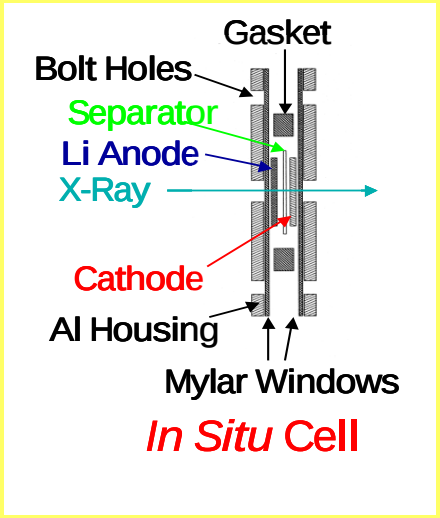
Long Island Power Authority

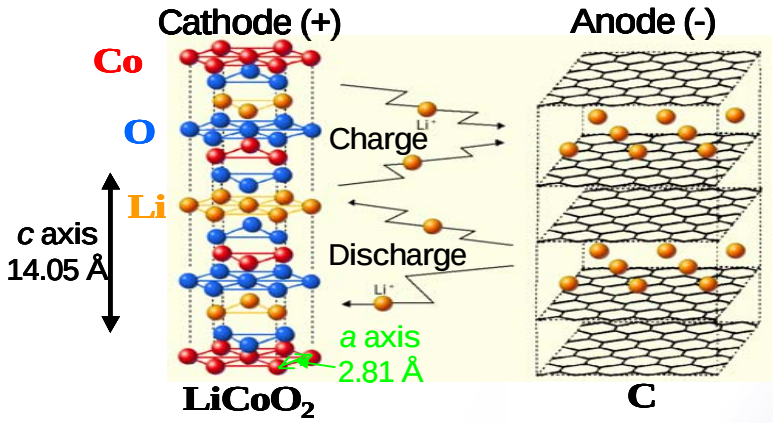
- Longest cable live on the grid

- DISTRIBUTION: Project Hydra (ConEd)—connecting Manhattan substations with current limiting superconducting cable

Energy Storage Materials

Key Issues: Brookhaven Focus
In-situ analysis
Novel materials synthesis

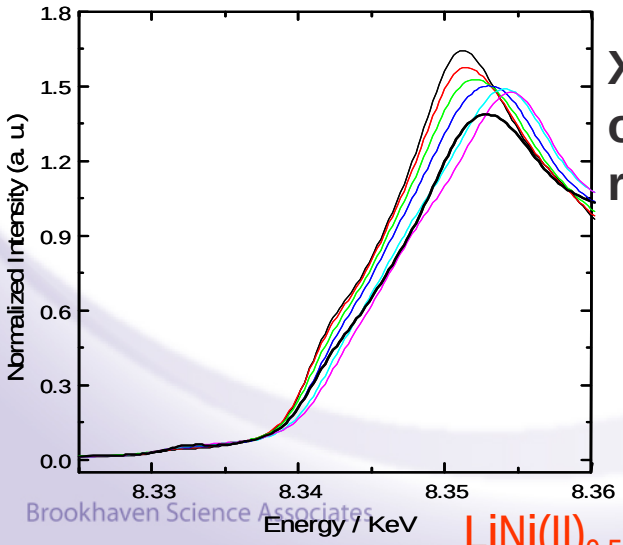




Layered structure of electrodes in lithium ion batteries

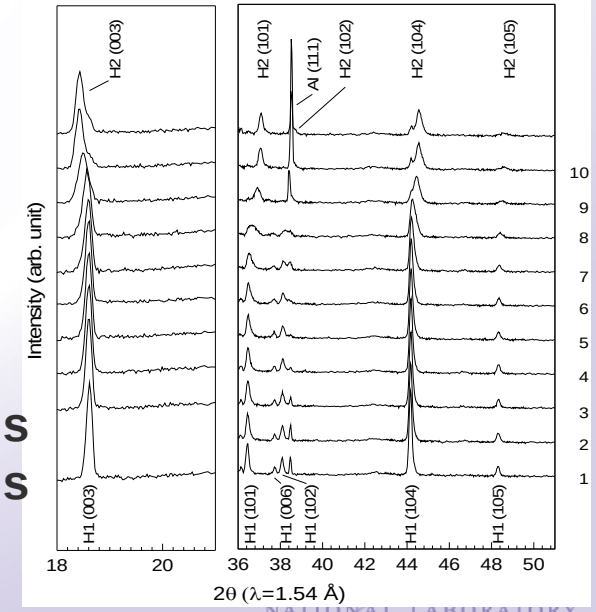
Photon Science Tools

Probe materials at work



XANES :conversion of Ni(II) to Ni(IV). Mn remains as Mn(IV).

XRD :expansion of *c* axis and a contraction of *a* axis

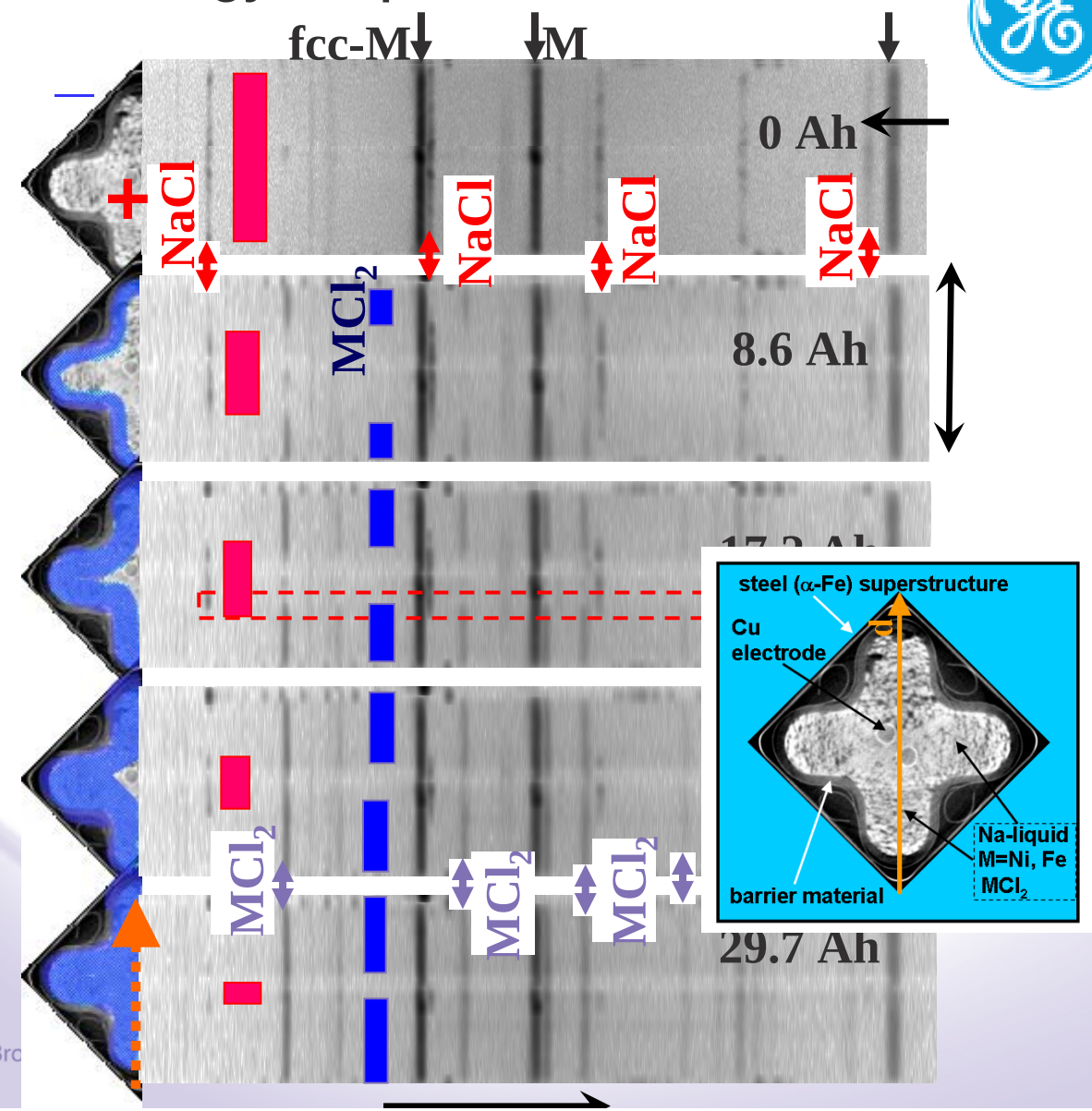


$LiNi(II)_{0.5}Mn(IV)_{0.5}O_2 + 6C \rightarrow Ni(IV)_{0.5}Mn(IV)_{0.5}O_2 + LiC_6$

ENERGY STORAGE MATRIX			Technology Issue							
			Electrochemical performance	Degradation mechanism during cycling and storage	New material for electrodes	Polymer/liquid electrolytes	Electrode-electrolyte Interface (SEI)	Defects	Safety	3D internal structure
Synchrotron Tool	Spectroscopy	EXAFS	Catalyst at interface	Local environment around specific element	Coordination and band length change		Element specific		Decrepitation of materials when hydrogenated	
		XANES	In-situ oxidation state	Range reduction of valence changes	Redox reaction in-situ	Element selective ion complexing	Charge transfer process		Thermal decomposition during heating	
		PES		Electronic energy-band structures			Bulk/surface electronic structure			
		IR Microspectroscopy	Reaction pathway			Identify species present	Identify species present			
	Scattering/ Diffraction	Single-crystal/ Powder XRD	Dynamic studies	Irreversible structural damages	Temperature dependent in-situ structure determination		Interface structure		In-situ phase transformation during cycling	
		High Energy XRD		Location specific structural changes in real battery					Commercial battery in situ	
		u-XRD			Phase transformations in micron region			Grain structure, orientation, stress, strain	In-situ cracking and stress	
		PDF					In-situ time-resolved formation of nanoparticles	Atomic structure		
		SAXS/WAXS		Particle shape and size change	Particles evolution during cycling	Evolution of structures in real time at nano to micro scales	Formation of nanoparticles/ breakage of larger particles			
		GISAXS/ GIXD	Surface structure			In-situ PEM structural changes	In-situ surface/ interface structure			
		RXS/RXD			Element, charge and orbital ordering phenomena					
	Imaging	Micro-XCT	In-situ particles formation	Breakage 3D imaging during cycling	Morphological changes during cycling		Non-equilibrium Li battery			Micro 3-D internal structure
		TXM	Change in near surface morphology	Evolution of surface or interface structure at nano scale	3D elemental distribution at nano scale	Interface structure by phase contrast	3D imaging in nano spatial resolution	Internal 3D structural imaging	Nanostructural and morphological changes during cycling	3-D internal structure at submicron to nano scale
		SXM	Chemical states and local structure in micron scale	Oxidation state in micron region	2D composition and oxidation mapping		Local oxidation state change			2D elemental imaging
		Topography	Strain distribution in near surface		Strain distribution			Strain induced by cycling		
		PEEM/LEEM	Surface element mapping		Surface 2D mapping					

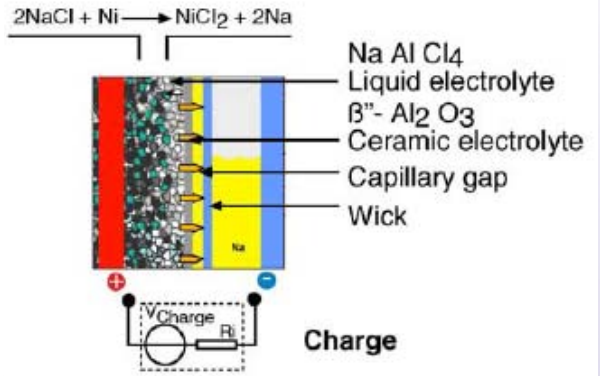
Electrical Energy Storage

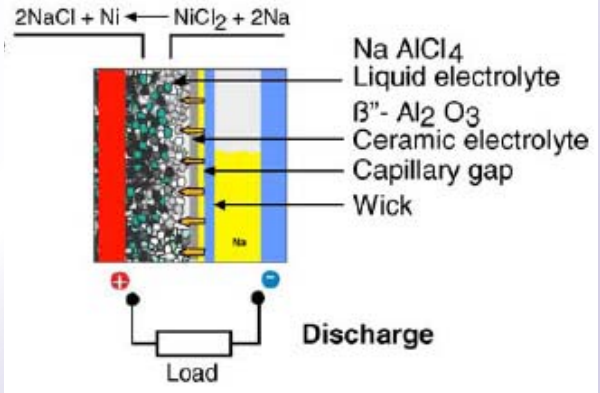
Energy Dispersive Diffraction



GE Global Research

United States - India - China - Germany





Croft, Rijssenbeek, Gao

BROOKHAVEN NATIONAL LABORATORY

NY-BEST: A NYSERDA Consortium

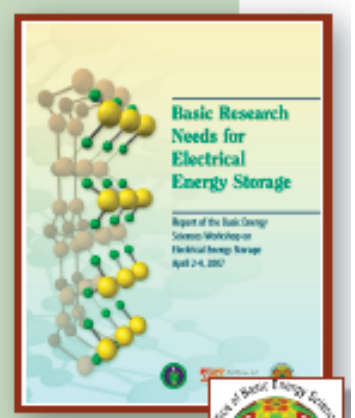
- $25M state funding

"the key … technology [needed] is a rechargeable electric battery that can run automobiles longer … and at lower cost" *—Gov. Paterson, 2009 State-of-the-State address*

NYS–ABC plans to answer this need by connecting NYS's assets in battery development in three coordinated teams:

1. a **research team** developing materials aimed to meet the industry's needs
2. an **engineering team** proving the feasibility of the new materials
3. both working with **prep. & industry teams** to establish manufacturability and integration into new platforms

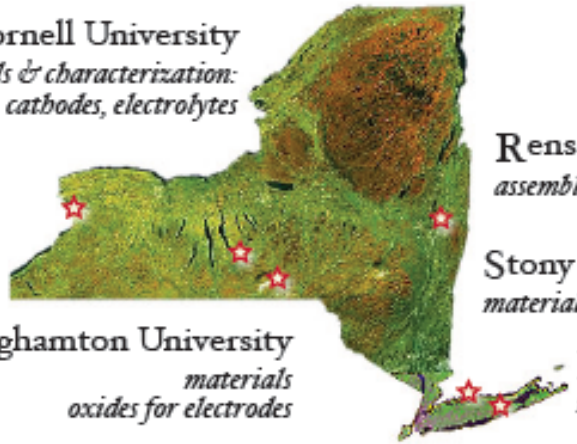
Research is already underway. Support for NYS–ABC today will position NYS to capitalize on the developing market for this necessary technology tomorrow.



April 2007 US DOE report defines the technology needs.

3 Teams

Research, Engineering & Industry



Cornell University
materials & characterization: anodes, cathodes, electrolytes

University at Buffalo
materials & devices: anodes, cathodes, electrolytes

Binghamton University
materials oxides for electrodes

Rensselaer Polytechnic Institute
assemblies & prototypes

Stony Brook University
materials characterization

Brookhaven National Lab
materials & device characterization

BROOKHAVEN NATIONAL LABORATORY

EFRC: Northeastern Chemical Energy Storage Center

Next Generation Batteries:

- new chemistries
- deeper fundamental understanding

(i) solid-solid conversion mechanisms
(ii) mechanisms and kinetics of phase transitions in electrode materials
(iii) surface structure and morphology effects on reaction mechanisms
(iv) size effects in controlling electrode mechanisms and performance

BNL Role:

- Advanced in-situ capabilities
- Multidimensional experimental tools, e.g. combine imaging with spectroscopy simultaneously.

NOCESC Team

Director: Clare P. Grey (Stony Brook University)

Glenn Amatucci (Rutgers University); Gerbrand Ceder (MIT), M. Stanley Whittingham, (Binghamton U.), Robert Kostecki (Lawrence Berkeley Laboratory); Anton Van der Ven (U. Michigan), Peter Chupas (Argonne National Laboratory), Jason Graetz, Xiao Qing Yang (Brookhaven National Laboratory) Steven Garofalini, Frederick Cosandey, Robert Bartvnski (Rutgers) Shirley Meng (U. Florida), Peter Khalifah (Stony Brook University/BNL)

2. The NY Smart Grid Consortium and the BNL Role

Electrical Grid

- Engineering marvel of 20th century
- World's most complicated machine

The 21st Century: Unprecedented Challenges for the Grid

capacity

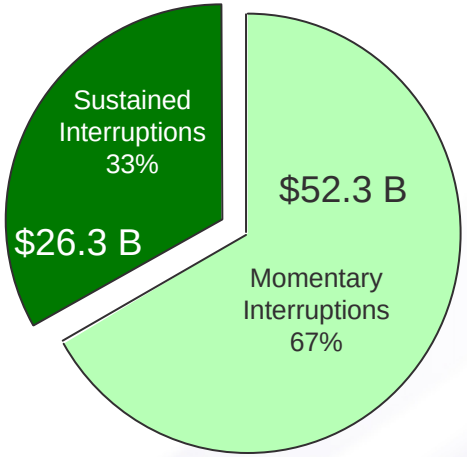
growing electricity uses growing cities and suburbs
high people / power density
urban power bottleneck

2030
50% demand growth (US)
100% demand growth (world)

reliability
power quality

average
power loss/customer
(min/yr)

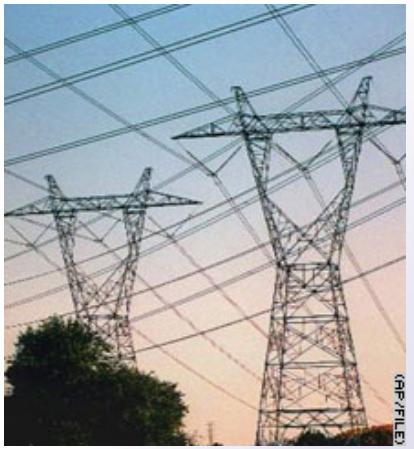
US	214
France	53
Japan	6



$79 B economic loss (US)

LaCommare & Eto, Energy 31, 1845 (2006)

efficiency
lost energy



62% energy lost in production / delivery

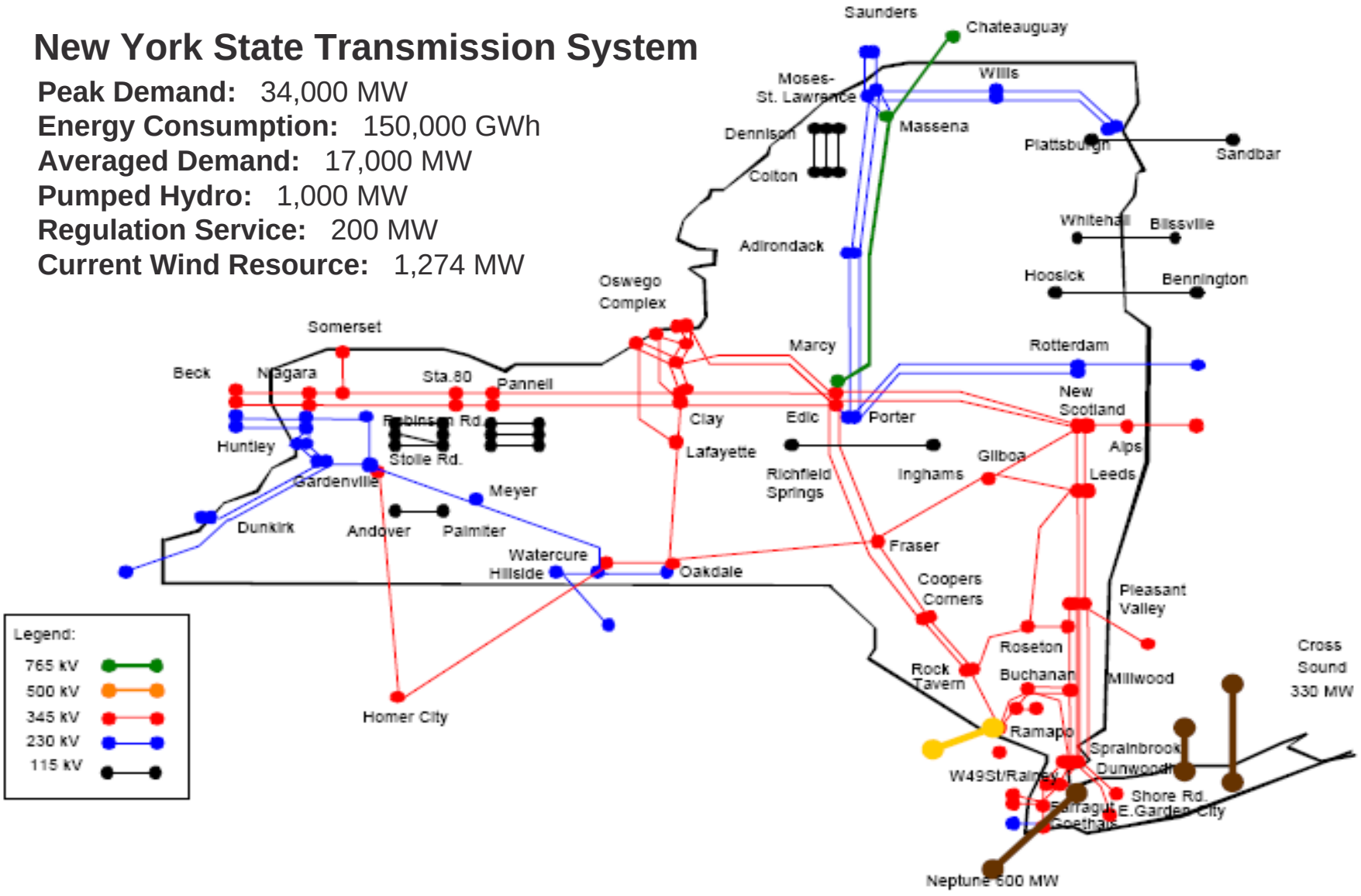
8-10% lost in grid

40 GW lost (US)
~ 40 power plants

2030: 60 GW lost
340 Mtons CO_2

New York State Transmission System

Peak Demand: 34,000 MW
Energy Consumption: 150,000 GWh
Averaged Demand: 17,000 MW
Pumped Hydro: 1,000 MW
Regulation Service: 200 MW
Current Wind Resource: 1,274 MW



New York State SmartGrid Consortium

- Founded in 2008
- Inclusion of all stakeholders to define and work toward a common vision
- A key public-private partnership to promote statewide implementation of the smart grid
- Only organization of its scale in the U.S. committed to representing all major contributors across the energy value chain including: utilities, markets, operators, industry, academia, government, and end-users

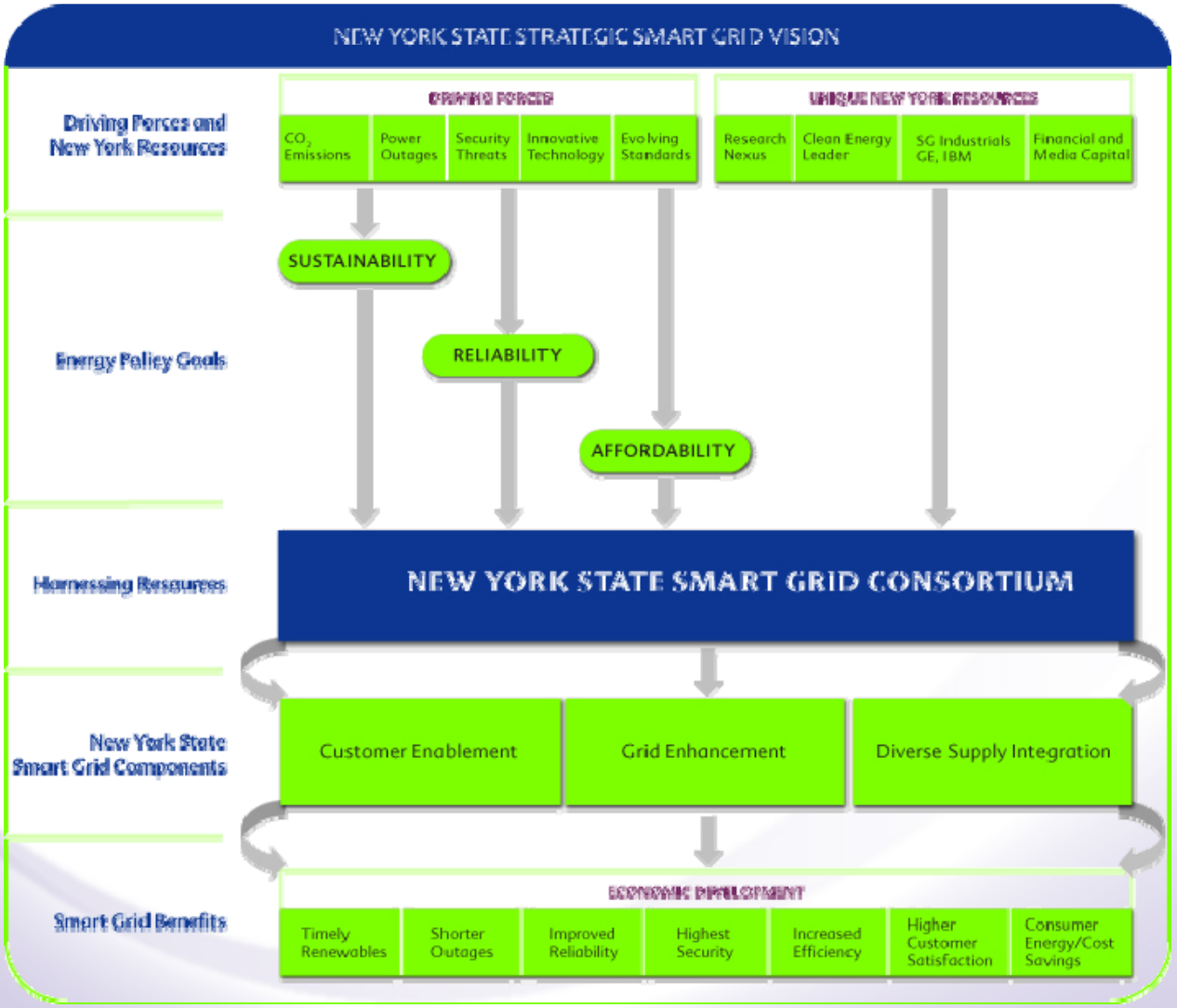
Brookhaven National Laboratory Leadership Role:

- Definition of vision for smart grid in NY State
  - Brookhaven Lab, IBM, Stony Brook University, and Battelle
- Research, Development, and Deployment support
  - Integration and coordination of the technical teams with the consortium
  - Advanced materials, energy storage, systems, sensors, security
- Neutral party in organization
  - BNL role to facilitate smart grid roll-out in NY State and region
  - Role in research oriented proposals for long-term issues

NY Smart Grid Vision

"…the holistic model for public-private partnerships that we need to secure our sustainable energy future."

David A. Paterson, Governor of New York



Utilities:
- NY Power Authority
- LI Power Authority
- Con Edison
- National Grid
- Central Hudson
- Energy East

Government:
- NY State Energy Research & Development Authority
- NY State Foundation for Science, Technology and Innovation

Industry:
- General Electric
- IBM

Research:
- State University of New York
- Advanced Energy Center
- Brookhaven Lab
- Syracuse University
- …

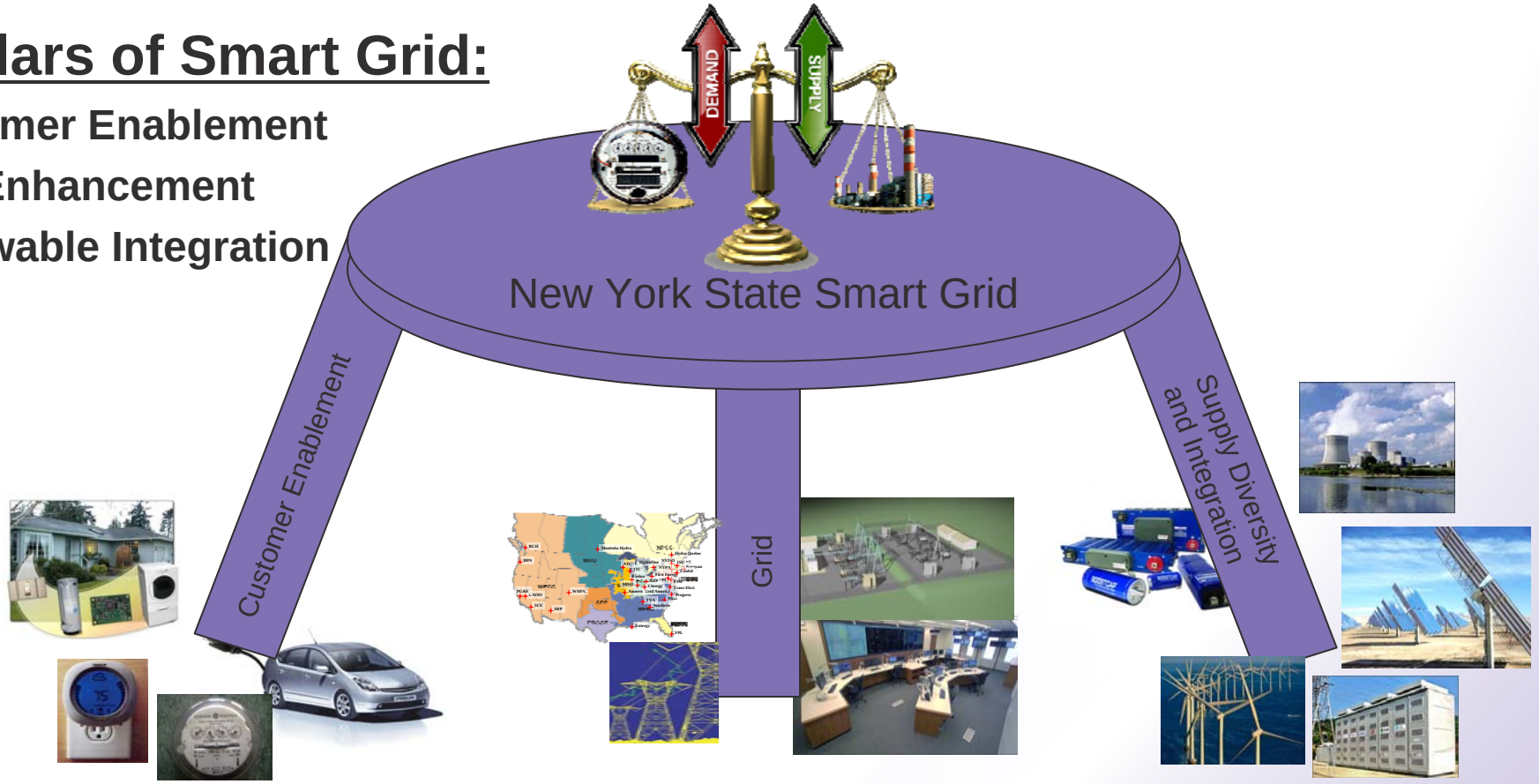
New York Smart Grid Vision

3 Pillars of Smart Grid:

Customer Enablement

Grid Enhancement

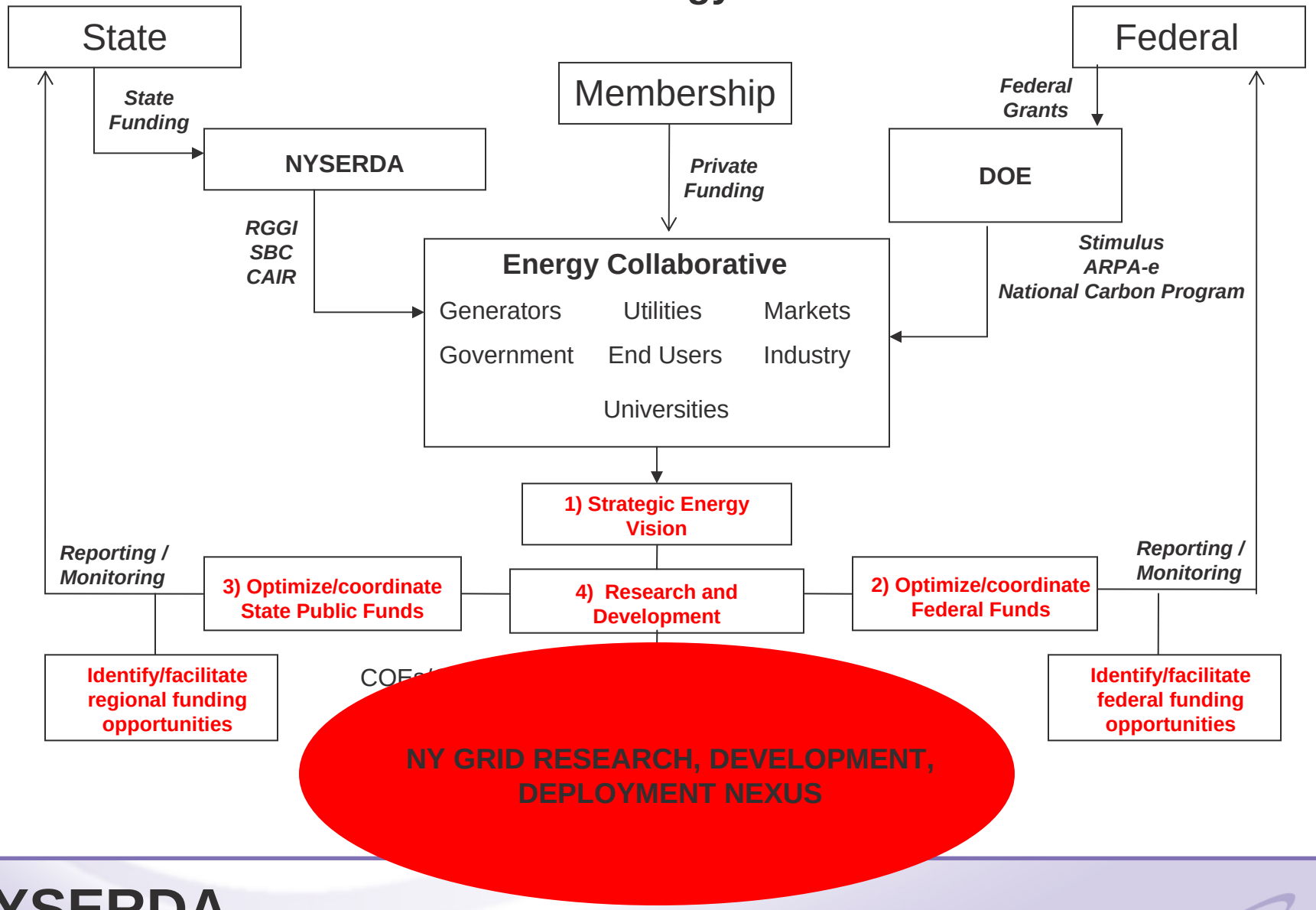
Renewable Integration



Ensuring both quantity and quality of NY power

- Standards and Protocols
- Interoperability
- Security

Collaborative Energy Framework



NY Grid Research, Development, Deployment Nexus

Proposed Key Functions

1. Roadmap/vision for NY State Smart Grid Implementation
2. Resource for Utility/ISO Implementation
   - Stimulus funding roll-out support
     - Smart Grid Investment Grants
     - Smart Grid Demonstration Projects
   - Technological/consulting resource
   - Catalog of state-of-the-art technologies
   - Interoperability/standards/security
3. Facilitate organization of teams to respond to further DOE short to medium term opportunities with compelling proposals consistent with vision/roadmap
4. Identification of medium to long range needs and technical challenges to be addressed (research opportunities)
   - Make the case to support a call for Energy Innovation Hub on the Grid

NY Grid Research, Development, Deployment Nexus

Proposed Key Functions

1. Roadmap/vision for NY State Smart Grid Implementation

- Current state and outlook
  - Only existing “roadmap” is vision created for NYSGC (Vadari, M. Valocchi (IBM), Misewich)—need to institutionalize a process to develop and continuously refine a SG roadmap to guide NY SGC
  - Coordinate with NIST/EPRI
  - Get buy-in from NY Stakeholders (utilities, ISO…)

NY Grid Research, Development, Deployment Nexus

Proposed Key Functions

2. Resource for Utility/ISO Implementation
   - Stimulus funding roll-out support
     - Smart Grid Investment Grants
     - Smart Grid Demonstration Projects
   - Technological/consulting resource
   - Catalog of state-of-the-art technologies
   - Interoperability/standards/security
- Current state and outlook
  - “Utility tech organizations are decimated due to deregulation...”
  - Opportunity to provide a support center to help coordinate activities

NY Grid Research, Development, Deployment Nexus

Proposed Key Functions

3. Facilitate organization of teams to respond to further DOE short to medium term opportunities with compelling proposals consistent with vision/roadmap

- Current state and outlook
  - Recognition that stimulus opportunities (SGIG, SGDP) are only a “down payment” on smart grid
  - Expect additional opportunities

NY Grid Research, Development, Deployment Nexus

Proposed Key Functions

4. Identification of medium to long range needs and technical challenges to be addressed (research opportunities)
   - Make the case to support a call for Energy Innovation Hub on the Grid
   - Aimed at medium to long term challenges that would truly enhance the grid, but are *beyond the capabilities of existing technologies* (Smart Grid 2.0)

- Current state and outlook
  - "Utility tech organizations are decimated due to deregulation..."
  - Opportunity to provide a support center to help coordinate activities
- Possible funding sources
  - DOE Energy Innovation Hubs
    - Although not likely to be in the mix of hubs on FY10, collectively we must support the case with DOE that an Energy Innovation Hub in Smart Grid is essential for Smart Grid 2.0

3. BNL Grid Related Activities and Plans

- Vision/organization for a potential Energy Innovation Hub on the Electric Grid
  - Strawman vision for grid hub technical areas
  - Organizing teams around grid technical area activities
- Support for Regional Grid Activities
  - With support of PNNL, develop Grid Support Center for East Coast inspired by PNNL Grid Center in West Coast
  - Work with George Smith, Bill Clagett on Controlled Separation Implementation Roadmap
- Support New York Smart Grid Consortium

Energy Innovation Hub Outline Vision (Smart Grid 2.0)

Four strawman technical areas for discussion/exploration

- Sensors, systems, security
- Grid scale energy storage
- Advanced materials (superconductors/thermoelectrics)
- Power electronics

Boundary Conditions

- Must be beyond existing technology for a DOE hub
- Must have Chu-recognized high level scientists participating (Bell Labs!)
- “under one roof”
  - This seems to be more relaxed than initial vision
- Must have clear vision for real-world impact

Energy Innovation Hub Outline Vision (Smart Grid 2.0)

APPROACH

- Forming teams to explore four straw man areas
- Identify technical grand challenges that would have impact
- “Best” scientists/engineers/companies/institutions working together
- Value proposition/economic analysis (possible Markal role)
- Validation by NYSGC “customers”
- Leverage Related NY State EFRCs
  - Storage (SBU led, BNL, NE battery community)
  - Storage (GE)
  - Superconductivity (BNL led, ANL, UIUC, American Superconductor, Superpower)

Strawman Vision for Grid Hub Structure

GOVERNANCE/MANAGEMENT/COORDINATION/ORGANIZATION:

Sensors, Systems, Security

- Leader: Misewich (interim)
- Partners: IBM,Columbia PNNL,BNL Battelle,SBU …

Grid Scale Energy Storage

- Leader: Kao
- Partners: GE, NE Battery Community, SBU…

Advanced Materials

- Leader: Crabtree
- Partners: BNL, ANL, UIUC, AMSC…

Power Electronics

- Leader: Haldar (CNSE)
- Partners: GE, AMSC, RPI, CNSE-Albany…

VALIDATION: NY Smart Grid Consortium (Utilities, ISO)
Value proposition, impact if successful, deployment commitment

Sensors, Systems, Security

- Team interest
  - IBM, SBU, BNL, Battelle, Columbia
  - PNNL (partner for PMUs/Grid support in NY State, perhaps partner or competitor on SG Hub)
- Leader – Misewich (interim)
- Preliminary work
  - Formed partnership with PNNL (Mike Davis)
    - Exploring support of NY PMU network
    - Sensor data handling
    - Grid analysis from PMU data
    - Support of NY ISO
  - Work with NY Defensive Strategies Council (Clagett, Smith, Vadari)
    - Focusing on Controlled separation implementation
    - Draft roadmap
  - Visit to PNNL with Clagett, Smith, Stokes, Misewich
    - Visit grid center
    - Discuss NY controlled separation roadmap
    - Set up East Coast Grid Center

NEW YORK DEFENSIVE STRATEGIES ROAD MAP

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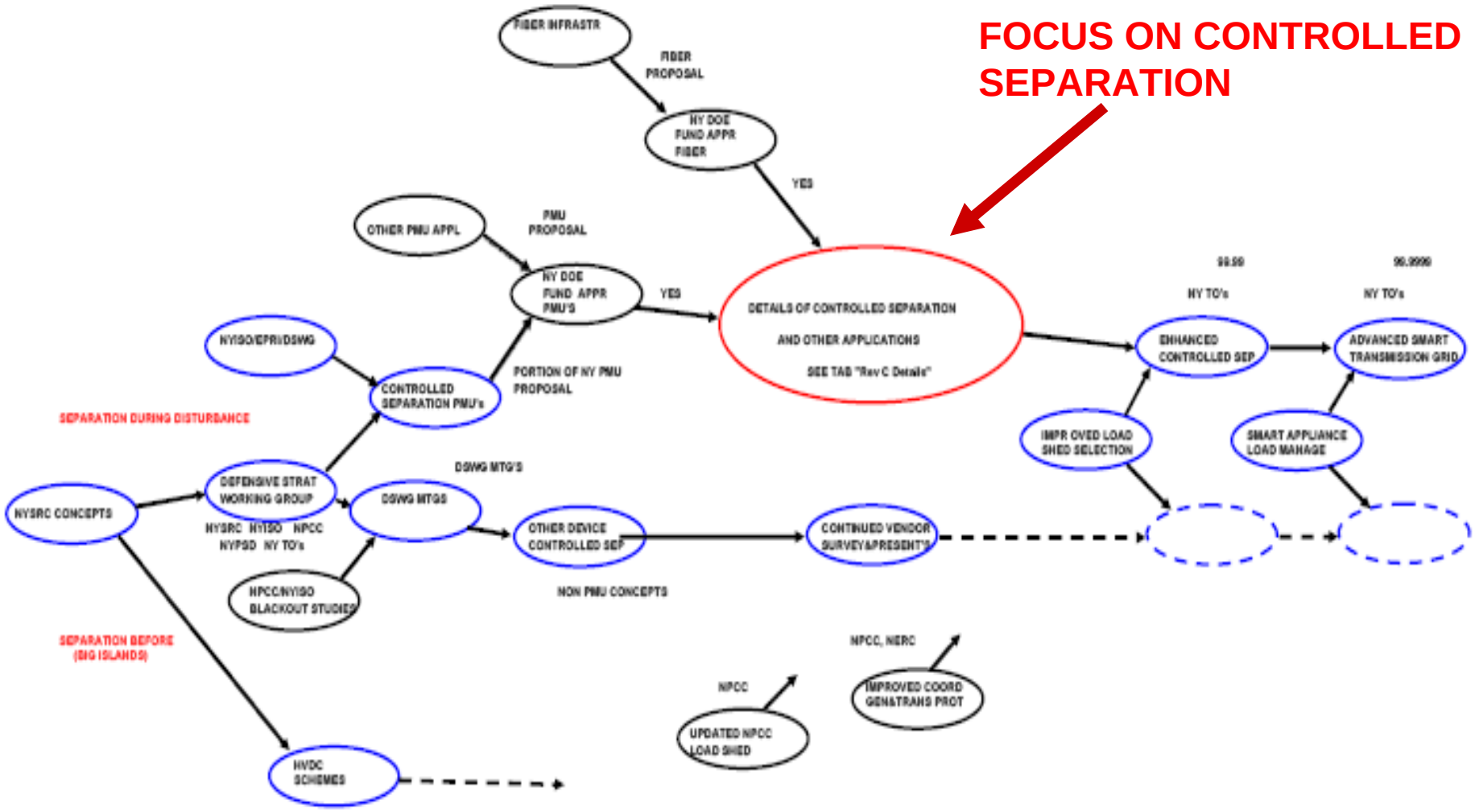

Grid Scale Energy Storage

- Team interest
  - GE, NE Battery Community (Whittingham, Chiang, Takeuchi, Grey, Amatucci…), PNNL (possibility)
- Leader – Chi-Chang Kao (Chairman, NSLS at BNL)
- Preliminary work
  - Working with GE on photon probes for electrical energy storage
  - EERE proposal for dry room
  - Chi-Chang Kao/ Jim Misewich organized Photon Science for Electrical Energy Storage Workshop
  - Working with NY-BEST (NYSERDA funded battery initiative)—convinced of need to focus on grid scale storage

Advanced Materials

- Team members
  - BNL, ANL, UIUC, American Superconductor (AMSC), Superpower
- Leader: George Crabtree (ANL)
- Preliminary work
  - Working with AMSC on superconducting materials with improved critical properties
  - EFRC: Center for Emergent Superconductivity
  - Misewich and Crabtree on APS committee to explore smart grid physics
  - Oxide materials for batteries
  - Thermoelectric materials for cooling superconductors (integrated self-cooling superconducting cable)

Power Electronics

- Team interest
  - GE, CNSE-Albany (Albany Nanotech—a $5B state-of-the-art semiconductor development lab in NY), RPI
- Leader: Pradeep Haldar (CNSE—head of Nanoengineering constellation)
- Preliminary work
  - Discussions with GE Schenectady (power electronics group)
  - Discussions with RPI power engineering school

BNL Advanced Energy Materials Group
BNL Global and Regional Solutions Directorate

Mission: *to bridge the gap from discovery to deployment*

Major Research Areas:

- Superconducting Materials ⇒ Grid Cables
- Thermoelectric Materials ⇒ Power Generation
- Nanomaterials Science ⇒ Power electronics
- Battery Materials ⇒ Grid Storage