Breakthroughs in Research and Development

What can we expect, and how can we expect more?

Robert C. Armstrong
Director, MIT Energy Initiative
Chevron Professor of Chemical Engineering
Outline

- Broad research portfolio
- Synergies with fossil energy
- Seed new ideas on a regular basis
- R&D aimed at the developing world
- Closing thoughts
Transformations

267 projects*
- Solar
- Hydrogen/fuel cells

Innovations

297 projects*
- Hydrocarbon products/processing
- CCS

*Projects may have more than one focus area; total projects by focus area exceed total projects supported
Global Systems

- **149 projects***
  - Carbon management
  - Transportation

Tools

- **153 projects***
  - Nanotechnology
  - Modeling/simulation

*Projects may have more than one focus area; total projects by focus area exceed total projects supported
Some Themes

- Energy-water-land
- Advanced manufacturing
- Gas monetization
- Storage
- Efficiency
  - Technologies
  - Behavior
- Solar – CSP
  - Hybrids, solar fuels
- Wind – ORES
- Conventional drilling – millimeter wave drilling
- Materials for energy
  - Earth abundant
  - Accelerate discovery
- Systems integration and behavior
Advanced Storage for the Grid

- Flow Batteries
- Liquid Metal Batteries
- Metal-Air Batteries
- Compressed Air
- Flywheels
  (frequency regulation)

Liquid Metal Battery
Donald Sadoway, MIT
Advanced Storage for Offshore Wind

- Game-Changer: Floating Turbines Moored with Storage Systems
  - Floating turbines located beyond coastal visual horizon
  - Using the ocean as a pumped hydro storage systems

Spar Buoy Floating Turbine Design; Sclavounos Lab, MIT
Mooring / Pumped Hydro Storage; Slocum Lab, MIT
Concentrated Solar Power on Demand: CSPonD

- Prof. Alex Slocum
- Prof. Alexander Mitsos
- Danny Codd
- Dept. of Mechanical Engineering
- Prof. J. Buongiorno
- Dr. Charles Forsberg
- Dr. T. McKrell
- Dept. of Nuclear Science and Engineering

A. Slocum et al., *Solar Energy* (2011)
Concentrated Solar Power on Demand: CSPonD

- Molten salt volumetric absorption
- Integrated thermal storage
- Beam-down hillside heliostat field

Idealized sketch of first few hillside heliostat rows of a CSPonD system

(Not to scale!)

Daytime

Nighttime
Multiple Power Cycle Options

Salt Temperature: 500°C, 700°C, and 700+ °C

- Steam power cycles--Today
- Supercritical carbon dioxide power cycle
  - High efficiency
  - Very compact and potentially low cost
  - Advanced technology
- Air Brayton power cycle
  - Existing technology
  - No cooling water requirements
  - Requires 700°C salt temperatures
Combined Open-Air Brayton Cycle

With NG Peaking Capability

- Use conventional, commercial compressor
  - (GE, Siemens, Mitsubishi have appropriate designs)

- Turbines modified to implement multiple reheat stages
  - Optimal expansion pressure ratio (1.9 to 2.2) is similar to single stage pressure ratio in conventional multi-stage combustion turbine
Novel Uses for Concentrated Solar Thermal

- Steam for EOR
  - Chevron – southern California (tower)
  - Shell – Oman (trough)
- Couple with desalination
- Process heat for chemical production and refining
- Solar fuels
  - Thermal energy for CO₂ reduction and fuel upgrading
MITEI Seed Fund Research Projects
118 early stage, innovative research projects funded
Improved Water Desalination

One of the Smithsonian’s top five surprising scientific milestones of 2012, alongside the Mars rover and the Higgs boson

- New method of desalinization uses one-atom-thick sheets of graphene (blue) to filter impurities (green and purple) from water molecules (red and white).
- Cheaper and less energy-intensive than existing systems.
Seed Fund Innovation Pathways

- **Route to start up**
  - FastCAP Systems – an MIT spinoff commercializing a nanotube-enhanced ultracapacitor for use in vehicles and grid-scale energy storage
    - Technology developed in the MIT lab of Joel Schindall
    - Received funding from an ARPA-E award and a MITEI seed grant (2008-2010)

- **Route to government funding**
  - Paul Woskov / Dan Cohn - millimeter wave drilling research
    - received DOE funding and a MITEI seed grant (2008-2010)
  - Jeffrey Grossman, et al. - solar thermal fuels research
    - received ARPA-E funding and a MITEI seed grant (2009-2011)

- **Route to Member funding, post seed fund award**
  - Kripa Varanasi - nanotextured surfaces
    - seed project lead to follow-on projects with Chevron, Shell, and Masdar

- **Route directly to member funding at seed fund proposal stage**
  - Peter Fisher - Seed proposal (2009) submitted, but not selected for funding by the group
    - Enel picked up the project and funded it as sponsored research.
Energy Startups from MIT: Partial List

- **Zome**: Abelson/Beal, residential/utility cooperative energy consumption management, MITEI seed fund.
- **FastCap**: Schindall, Ultra-capacitors, MITEI seed fund.
- **Ambri**: Sadoway, grid-scale batteries, TOTAL funding & investment.
- **Sun Catalytix**: Nocera, some early Eni funding.
- **GMZ**: Chen, Thermo-electric energy conversion.
- **24M Technologies**: Chiang/A123 spinout, lithium and flow batteries; ARPA-E award.
- **SunPoint Technologies**: Students, PV tracking.
- **WiTricity**: Joannopoulos, wireless charging, MITEI seed fund.
- **Novogy**: Stephanopoulos, bio-fuels startup, TOTAL investment
- **Ethanol Boosting Systems**: Cohn, Bromberg.
International Reach

- Russia: Skolkovo Institute of Science and Technology (Skoltech)/Energy Cluster
  - $25-35M over 5 years for two energy-related Centers for Research Education and Innovation
- India: Tata Center for Technology and Design in the Developing World
  - Projects: 47 active, 53 funded (each worth ~225k)
  - 4 new classes, 36 faculty ($5M Tata Chair), 12 Departments (all 5 schools)
  - MISTI Tata program =10 undergraduates to India
Closing Observations

- Success appears closer than it is (usually)
- Need to maintain a broad portfolio
  - Resist the urge to focus on winners too soon
  - Seed new ideas regularly
- Take advantages of synergies with fossil energy where possible
- R&D for constrained environments/developing world is critical
- R&D very unlikely to be enough
  - Remember that fossil fuel technologies improve with time as well
Will Rogers

“Even if you're on the right track, you'll get run over if you just sit there.”

*US humorist & showman (1879 - 1935)*
Questions?